Financial Intermediation in a New Keynesian DSGE Model: A Study on Consequences of Non-Systemic Bank Failure for Monetary Policy

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List of Abbreviations

AB	agent-based
BGG	Bernanke, Gertler and Gilchrist (1999)
BM	banking model
ch.	channel
dev.	deviation
DGP	data generating process
DIS	dynamic IS
DSGE	dynamic stochastic general equilibrium
EA	Euro area
ECB	European Central Bank
EinSiG	Einlagensicherungsgesetz
eq.	equation
eqs.	equations
equ.	equilibrium
FAM	financial accelerator model
FEVD	forecast error variance decomposition
fig.	figure
GDP	gross domestic product
GK	Gertler and Karadi (2011)
GMM	generalised method of moments
HT	Holmstrom and Tirole (1997)
HPD	highest posterior density
i.i.d.	identically and independently distributed
KM	Kiyotaki and Moore (1997)
MCMC	Markov chain Monte Carlo
MCS	macroprudential credit spread rule
MH	Metropolis Hastings
ML	maximum likelihood
MP	monetary policy
MTR	macroprudential Taylor rule
NK	New Keynesian
NNS	New Neoclassical Synthesis
PC	Phillips Curve
RBC	real business cycle
SFC	stock-flow consistent
VAR	vector autoregression

List of Symbols

Mathematical Operators and Functions

$\mathbf{A}$	parameter matrix (state-space form)
$\mathbf{B}$	parameter matrix (state-space form)
$corr$	correlation
Δ	difference operator
$\mathbf{E}$	expectation operator
$f(\cdot)$	density function
$\mathcal{L}$	Lagrangian function
Pr	probability
$p(\cdot)$	probability function
st.dev.	standard deviation
var	variance
$\mathbb{X}_t$	vector of predetermined endogenous variables (state-space form)
$\mathbb{Y}_t$	vector of non-predetermined endogenous variables (state-space form)
$\mathbb{Z}_t$	vector of exogenous variables (state-space form)

Variables and Parameters

B	bank loans
B_ψ	bank shock interval parameter
C_E	entrepreneurs' real consumption
C_W	workers' real consumption
c	retailers' marginal cost parameter
c_s	credit spread
D	bank deposits
DI	deposit insurance fees
DI^e	deposit insurance fees with endogenous deposit insurance factor
E_ψ	entrepreneurial shock interval parameter
e	bank equity
e_{to}	risky asset (Tobin mean variance model)
GAP	output gap

G^B	auxiliary bank function
G^E	auxiliary entrepreneurial function
G^M	auxiliary bank function
G^N	auxiliary bank function
H	labour
I	real private investment
J	auxiliary variable for inflation determination
JJ	auxiliary variable for inflation determination
K	real capital stock
L	leisure
MC	retailers' real marginal cost
MoC	aggregate monitoring costs
MR	minimum reserves
m_{cs}	macroprudential credit spread rule instrument
m_{tr}	macroprudential Taylor rule instrument
N^b	gross deposit insurance payouts
N^n	net deposit insurance payouts
N_E	entrepreneurs' net worth
nn_x	$x = \{b, e, r, w\}$ index for individual bank, entrepreneur, retailer (retail good variety), or worker
P	retail price index
P^*	optimal retail price
P^W	wholesale price index
PO	posterior odds ratio
$p(\psi^B)$	bank shock probability function
$p(\psi^E)$	entrepreneurial shock probability function
p_e	price of one bank equity share
Q	price of real capital
q_e	number of shares of bank equity
R/R_n	real/nominal risk-free return
R_b/R_{bn}	real/nominal loan return
R_d/R_{dn}	real/nominal deposit return
R_e/R_{en}	real/nominal return on bank equity
R_{ed}/R_{edn}	real/nominal effective deposit return
R_k	real return on physical capital
R_p/R_{pn}	real/nominal portfolio return

R_w/R_{wn}	real/nominal wholesale return
r/r_n	real/nominal risk-free interest rate
r_d/r_{dn}	real/nominal deposit interest rate
r_e/r_{en}	real/nominal interest rate on equity
r_p/r_{pn}	real/nominal portfolio interest rate
r_{rf}	safe rate of interest (Tobin mean variance model)
r_{to}	risky interest rate (Tobin mean variance model)
S	investment adjustment cost function
s	time index counter
T	tax income
t	time index counter
U	workers' period utility
U_C	workers' marginal utility of consumption
U_{CC}	second derivative of workers' utility function with respect to C_W
U_H	workers' marginal (dis-)utility of working
U_{HH}	second derivative of workers' utility function with respect to H
V	workers' wealth
V^e	share of equity in workers' wealth
V_{to}	portfolio volume (Tobin mean variance model)
W	nominal wage rate
X^B	aggregate retail goods demand less workers' consumption (banking model)
X^F	aggregate retail goods demand less workers' consumption (financial accelerator model)
Y	real output
Y^W	real wholesale output
Y_H^W	marginal product of labour
Y_K^W	marginal product of physical capital
z_c	NK DIS curve function of parameters
z_e	auxiliary variable in log-linear approximation of entrepreneurs' consumption
z_h	NK DIS curve function of parameters
z_m^x	$x = \{F, B\}$ auxiliary variable in log-linear approximation of aggregate monitoring costs
z_y	NK DIS curve function of parameters
α	partial output elasticity with respect to labour
β	workers' discount rate
Γ^B	auxiliary bank function
Γ^E	auxiliary entrepreneurial function

γ^p	price indexation rate
δ	depreciation rate
ϵ_A	technology shock
ϵ_B	bank risk shock
ϵ_E	entrepreneurial risk shock
ϵ_G	government consumption shock
ϵ_I	investment adjustment cost shock
ϵ_K	capital quality shock
ϵ_M	monetary policy shock
ϵ_{MS}	mark-up shock
ϵ_P	preference shock
ζ	elasticity of substitution between retail goods
η	utility function parameter (simple NK model)
η_E	probability of staying entrepreneur
η_l	weight of leisure in workers' utility function
θ_π	Taylor rule parameter
θ_m	macroprudential Taylor rule parameter
θ_y	Taylor rule parameter
κ	NK PC curve function of parameters (simple NK model)
κ_{ff}	NK PC curve function of parameters
$\tilde{\kappa}$	NK PC curve function of parameters (simple NK model)
Λ/Λ^N	real/nominal stochastic discount factor
λ^F	Lagrange multiplier of banks' optimisation problem
λ_x^{IS}	$x = \{1, 2, 3, 4, 5\}$, reduced-form NK DIS function parameter
λ^L	Lagrange multiplier of entrepreneurs' optimisation problem
λ_x^{PC}	$x = \{1, 2, 3, 4\}$, reduced-form NK PC function parameter
λ^W	Lagrange multiplier of workers' optimisation problem
μ^B	transaction cost parameter
μ^E	transaction cost parameter
μ^N	transaction cost parameter
ν^d	deposit insurance factor
ν^{de}	endogenous deposit insurance factor
ν_π	Taylor rule parameter (simple NK model)
ν_y	Taylor rule parameter (simple NK model)
Ξ^b	bank profits
Ξ^c	profits of capital investment funds

ξ^p	Calvo pricing parameter
ξ^r	minimum reserve ratio
ξ_E	entrepreneurial net worth parameter
ξ_{NE}	entrepreneurial net worth parameter
O^p	price dispersion
Π	inflation
$\tilde{\Pi}$	auxiliary variable for inflation determination
ρ_A	autocorrelation in exogenous technology process
ρ_B	autocorrelation in exogenous bank risk process
ρ_{EH}	equity habit parameter
ρ_E	autocorrelation in exogenous entrepreneurial risk process
ρ_G	autocorrelation in exogenous government consumption process
ρ_I	autocorrelation in exogenous investment adjustment cost process
ρ_K	autocorrelation in exogenous capital quality process
ρ_{MS}	autocorrelation in exogenous mark-up process
ρ_P	autocorrelation in exogenous preference process
ρ_R	persistence parameter in Taylor rule
ϱ^E	entrepreneurial risk premium
ϱ^B	bank risk premium
σ	degree of risk aversion (simple NK model)
σ_A	standard deviation of the technology shock
σ_B	standard deviation of the bank risk shock
σ_E	standard deviation of the entrepreneurial risk shock
σ_G	standard deviation of the government consumption shock
σ_I	standard deviation of the investment adjustment cost shock
σ_K	standard deviation of the capital quality shock
σ_M	standard deviation of the monetary policy shock
σ_{MS}	standard deviation of the mark-up shock
σ_P	standard deviation of the preference shock
σ_c	degree of non-separability between consumption and leisure
σ^2_{to}	variance of risky interest rate (Tobin mean variance model)
τ	income tax rate
τ_M	macroprudential credit spread rule parameter
Υ^A	technology process
Υ^B	bank risk shock process
Υ^E	entrepreneurial risk shock process

Υ^G	government consumption (process)
Υ^I	exogenous investment adjustment cost process
Υ^K	exogenous capital quality process
Υ^{MS}	exogenous mark-up process
Υ^P	exogenous preference process
Φ^B	loan-to-deposit ratio
ϕ^B	bank leverage ratio
ϕ^E	entrepreneurs' leverage ratio
ϕ_I	investment adjustment cost parameter
χ	consumption habit parameter
ψ^B	idiosyncratic bank shock
ψ^E	idiosyncratic entrepreneurial shock
ω_1	workers' portfolio function parameter
ω_2	workers' portfolio function parameter
ω_3	workers' portfolio function parameter
ω_{mpe}	endogenous deposit insurance factor parameter
ω_{mpp}	endogenous deposit insurance factor parameter
ω_{to}	utility function parameter (Tobin mean variance model)

Abstract

The recent financial crisis spurred the discussion about bank failures as a feature of reality both in popular and academic realms. Yet, not every defaulting bank is of systemic relevance and leads to a financial crisis. When a bank fails, the business is either dismantled or taken over by a different entity. In the sense that banks are private businesses, this may be considered an ordinary phenomenon. Yet, to the extent that banks play a special role in transmitting monetary policy impulses, the incidence of non-systemic bank failure can have extraordinary consequences for monetary policy.

These consequences are the central concern of this thesis. While there are various pieces of research in the literature on monetary policy and financial fragility, these pieces generally address only one aspect of monetary policy conduct. The objective of this thesis is to provide an integrated, (comparatively) comprehensive yet focused assessment of the impact of non-systemic bank failures on monetary policy conduct. For this purpose, this thesis studies monetary policy transmission as well as the trade-off between different monetary policy objectives with and without non-systemic bank default. These two aspects of monetary policy are analysed in a benchmark case and when there are additional macroprudential policies in place to counter financial fragility.

For analysing these topics, a standard New Keynesian dynamic stochastic general equilibrium (DSGE) model with financial accelerator is extended to incorporate non-systemic bank default. The banking model presented in this thesis features the endogenous determination of non-systemic bank default and bank leverage through workers' portfolio choice problem. A financial accelerator model without the additional bank-specific friction is used as a reference to discern the effects of non-systemic bank failures. For the analysis, both the banking and the financial accelerator models are log-linearised around their respective deterministic steady states. These log-linear approximations are estimated on German data using Bayesian techniques. The next and final step consists in simulating the log-linear banking and financial accelerator models for monetary policy analysis purposes.

The key findings of this thesis are the following. Firstly, the incidence of bank default affects the transmission of monetary policy. In particular, the introduction of the friction

on banks' liability side leading to non-systemic bank default gives rise to an additional bank balance sheet channel. This bank balance sheet channel works on top of the balance sheet channel associated with non-financial firms. Incidentally, the bank balance sheet channel mainly affects aggregate demand and only marginally inflation. The findings imply that the bank balance sheet channel has a fundamentally compounding nature. The results suggest that the bank balance sheet channel in the form studied in this thesis does not play a large role as an endogenous propagating mechanism of monetary policy by itself, but rather as an amplification and propagation mechanism to the balance sheet channel associated with non-financial firms.

Moreover, bank default affects the capabilities of the central bank to achieve different monetary policy objectives. If a central bank aims to minimise inflation volatility, the introduction of bank default yields a worse outcome than when banks do not default. Moreover, taking output gap stabilisation as an additional (secondary) monetary policy objective into account, banking model dynamics also imply a deterioration of the central bank's trade-off between inflation and output gap variance stabilisation. Thirdly and related, the results concerning the monetary policy trade-off depend on the parametrization. Comparing the banking model to the financial accelerator model when both models are evaluated at their respective (different) posterior means, the trade-off between monetary policy objectives is better in the banking model than in the financial accelerator model. These results imply that the introduction of non-systemic bank failures has non-trivial effects for the trade-off between different monetary policy objectives as well as estimation results.

Finally, the results concerning macroprudential policies highlight a variety of potential policy-spillovers. Concerning monetary policy transmission, the findings are clear-cut. Interest rate policy remains effective regarding the transmission to inflation since the response of inflation is not fundamentally affected. However, the transmission to GDP is different with macroprudential policies and in particular depends on the size and direction of the macroprudential trigger. With respect to the trade-off between inflation and output gap stabilisation, the results are not as clear-cut. In particular, depending on how financial imbalances are measured and with which macroprudential instrument the government responds to them, macroprudential policies can lead to an improvement in terms of the trade-off between policy objectives as well as to a deterioration.

In conclusion, this thesis corroborates and extends the existing literature in a variety of ways. On the theoretical side, this study proposes a model with a set of additions to a standard New Keynesian DSGE model with a loan market friction. Furthermore, the single focus on non-systemic bank default as the additional bank-specific distortion, abstracting from other influences such as tax advantages or capital requirements, and its explicit microfoundation provide a rigorous foundation for the analysis. On this count, this thesis contributes to the relevant literatures a comprehensive evaluation of the consequences of non-systemic bank failure for monetary policy, not only concerning transmission but also the central bank's capabilities with respect to its objectives. On the empirical side this thesis highlights the importance of sensitivity and robustness analyses as well as providing estimates for a New Keynesian DSGE model based on data for Germany. Finally, this thesis contributes on the issues of macroprudential policies and their interactions with monetary policy. The discussion of macroprudential policies in this thesis highlights the need for a rigorous and transparent modelling approach as well as implementation of any additional policy so as to adequately gauge its impact and usefulness and to communicate any changes duly.

Kurzzusammenfassung

Die jüngste Finanzkrise verstärkte die Diskussion um Bankinsolvenzen als Teil der ökonomischen Wirklichkeit sowohl in der Allgemeinheit als auch im wissenschaftlichen Diskurs. Jedoch ist nicht jede Bankinsolvenz von systemischer Relevanz und führt zu einer Finanzkrise. Im Falle einer Bankinsolvenz wird die Unternehmung entweder aufgelöst oder von einer anderen Institution übernommen. Betrachtet man Banken als private Unternehmen, so kann dieser Prozess als gewöhnliches Phänomen interpretiert werden. Insofern Banken jedoch eine besondere Rolle im geldpolitischen Übertragungsprozess spielen, könnten nicht-systemrelevante Bankinsolvenzen außergewöhnliche Konsequenzen für die Geldpolitik haben.

Die Untersuchung dieser Konsequenzen ist der zentrale Fokus der vorliegenden Dissertation. In der Literatur finden sich verschiedene Ansätze, die den Zusammenhang zwischen Geldpolitik und finanzieller Fragilität untersuchen. Allerdings betrachten diese im Allgemeinen nur einen Aspekt der Geldpolitik. Das Ziel dieser Dissertation ist eine verhältnismäßig umfassende und gleichzeitig fokussierte Untersuchung des Einflusses der Insolvenz nicht-systemrelevanter Banken auf die Durchführung der Geldpolitik. Zu diesem Zweck analysiert diese Dissertation den monetären Transmissionsmechanismus und die Zielmöglichkeiten-Kurve zwischen Inflationsraten- und Produktionslückenstabilisierung einer Zentralbank mit und ohne Insolvenz nicht-systemrelevanter Banken. Diese beiden Aspekte der Geldpolitik werden sowohl ohne als auch mit der Existenz makroprudenzieller Instrumente, die eingesetzt werden um finanzieller Fragilität entgegen zu wirken, evaluiert.

Dazu erweitert diese Dissertation ein Neu-Keynesianisches dynamisches, stochastisches, allgemeines Gleichgewichtsmodell (DSGE) mit finanziellem Akzelerator um eine zusätzliche finanzielle Friktion, die die Insolvenz nicht-systemrelevanter Banken abbildet. Das Banking Modell, das in dieser Dissertation präsentiert wird, beinhaltet die endogene Bestimmung von nicht-systemrelevanten Bankinsolvenzen und dem Fremdfinanzierungsgrad der Banken mithilfe des Portfolio-Optimierungsproblems privater Haushalte (Arbeitnehmer). Ein Modell mit finanziellem Akzelerator, jedoch ohne die zusätzliche bankbezogene finanzielle Friktion, wird als Referenz verwendet um die Veränderungen zu unterscheiden, die sich aus der Insolvenz nicht-systemrelevanter Banken ergeben. Die Banking und

Finanzieller-Akzelerator Modelle werden zunächst um ihren jeweiligen nicht-stochastischen Gleichgewichtspunkt log-linearisiert und dann mit Bayesianischen Methoden geschätzt. Schließlich werden beide Modelle zum Zweck der geldpolitischen Analyse simuliert.

Die wichtigsten Resultate dieser Dissertation sind die Folgenden. Die Insolvenz nicht-systemrelevanter Banken beeinflusst die geldpolitische Transmission insofern sie mit einem Bankbilanzkanal einhergeht. Dieser Bankbilanzkanal wirkt zusätzlich zu dem Bilanzkanal, der mit nicht-finanziellen Unternehmen zusammenhängt. Tatsächlich wirkt der Bankbilanzkanal vorrangig auf die aggregierte Nachfrage und nur geringfügig auf die Inflation. Die Ergebnisse implizieren, dass der Bankbilanzkanal, so wie er in dieser Dissertation modelliert ist, keine übermäßige Signifikanz als eigenständiger, endogener Propagierungsmechanismus der geldpolitischen Transmission besitzt, sondern vor allem als ein Verstärkungs- und Propagierungsmechanismus des Bilanzkanals nicht-finanzieller Firmen zu begreifen ist.

Des Weiteren hat die Insolvenz nicht-systemrelevanter Banken Einfluss auf die Möglichkeiten einer Zentralbank verschiedene geldpolitische Ziele zu erreichen. Falls sich eine Zentralbank darauf konzentriert die Inflationsratenvarianz zu minimieren, so führen nicht-systemrelevante Bankinsolvenzen im Modell zu einer Verringerung des Potenzials einer Zentralbank, da die minimale Inflationsratenvarianz höher ist als in einem Modell ohne Bankinsolvenzen. Wenn die Stabilisierung der Produktionslücke ein zusätzliches (sekundäres) geldpolitisches Ziel ist, dann führt die Dynamik des Banking Modells ebenfalls zu einer Verschlechterung des Zielkonfliktes zwischen Inflationsraten- und Produktionslückenstabilisierung in Bezug auf das Finanzielle-Akzelerator Modell bei gleicher Parametrisierung. Die spezifischen Ergebnisse bezüglich des geldpolitischen Zielkonflikts sind jedoch abhängig von der Parametrisierung. Wenn das Banking Modell mit dem Finanziellen-Akzelerator Modell unter der Verwendung des geschätzten Parametervektors des jeweiligen Modells verglichen wird, so zeigt sich, dass sich hier der Zielkonflikt im Banking Modell besser gestaltet als im Finanziellen-Akzelerator Modell. Somit implizieren diese Ergebnisse, dass die Einführung von Insolvenzen nicht-systemrelevanter Banken bedeutende Auswirkungen auf den Zielkonflikt der Zentralbank sowie auf die Schätzergebnisse der Modelle haben kann.

Abschließend zeigen die Ergebnisse bezüglich der Einführung makroprudenzieller Instrumente verschiedene Interaktionseffekte auf. Im Hinblick auf den geldpolitischen Transmissionsmechanismus sind die Resultate eindeutig. Die Zinspolitik bleibt unverändert wirkungsvoll wenn die Übertragung geldpolitischer Impulse auf die Inflation betrachtet wird. Allerdings wird die Übertragung auf das Bruttoinlandsprodukt von makroprudenzieller Politik beeinflusst und hängt besonders von der Größe und Richtung der makroprudenziellen Steuerungsvariable ab. In Bezug auf den geldpolitischen Zielkonflikt zwischen Inflationsraten- und Produktionslückenstabilisierung können die Ergebnisse nicht so eindeutig festgelegt werden, denn es zeigen sich Verbesserungen als auch Verschlechterungen. Dabei hängen die Veränderungen vorrangig davon ab, wie finanzielle Fragilität gemessen wird, sowie welches makroprudenzielles Instrument verwendet wird um dieser finanziellen Fragilität entgegen zu wirken.

Zusammenfassend lässt sich feststellen, dass diese Dissertation die bestehende Literatur an verschiedenen Punkten untermauert und erweitert. Auf der theoretischen Seite präsentiert diese Dissertation eine Erweiterung zu einem gängigen Neu-Keynesianischen DSGE Modell mit Kreditmarktfriktion. Des Weiteren bietet der Einzelfokus auf die Insolvenz nicht-systemrelevanter Banken als einzige zusätzliche Banken-spezifische Friktion sowie deren explizite Mikrofundierung eine systematische Grundlage für die Analyse der Auswirkungen auf die Geldpolitik, indem von anderen Einflüssen wie Steuervorteilen oder Kapitalvorschriften abstrahiert wird. In diesem Sinne trägt diese Dissertation eine erweiterte Evaluation der Folgen der Insolvenz nicht-systemrelevanter Banken für die Geldpolitik zur bestehenden Literatur bei, da sowohl die Transmission geldpolitischer Impulse als auch die Zielmöglichkeitenkurve der Zentralbank betrachtet werden. Auf der empirischen Seite stellt diese Dissertation die Bedeutung von Sensitivitätsanalysen hervor. Zudem werden Schätzergebnisse für ein DSGE Modell auf der Basis von Daten zu Deutschland präsentiert. Letztendlich trägt diese Dissertation zur Diskussion um makroprudenzielle Politik und deren Einflüsse auf die Geldpolitik bei. Insbesondere zeigen die Ergebnisse, dass transparente und fundierte Modellierungs- und Umsetzungsansätze nötig sind, um die Auswirkung und Nützlichkeit der Instrumente adäquat einzuschätzen und zu kommunizieren.

Chapter 1

Introduction

The recent financial crisis of 2007-08 led to serious disruptions in financial markets and a global recession. In turn, the banking panic fuelled by concerns about banking liquidity and solvency was not least accelerated by the failure of several financial intermediaries.[1] Yet, not every defaulting financial intermediary is of systemic relevance and leads to a financial crisis. In the US, considering all years since the 1960s, the years 2005 and 2006 have been the only ones where no bank covered under the Federal Deposit Insurance filed for bankruptcy.[2] Yet, the US banking system was not constantly in crisis during this time.[3] A similar argument can be made for the German banking system.[4]

Thus, banks fail in the real world, even though not yet as often in macroeconomic models. The banking business is then either dismantled or taken over by a different entity. In the sense that banks are private businesses, this may be considered an ordinary phenomenon. Yet, to the extent that banks play a special role in transmitting monetary policy impulses, the incidence of bank failure can have extraordinary consequences for monetary policy.

Financial fragility and its interactions with monetary policy have been an especially prominent research area since the onset of the financial crisis 2007-08. One reason is certainly that central banks responded to the financial crisis with unconventional measures to restore the functioning of interbank markets, connected markets of financial intermediation and to ensure the orderly transmission of monetary policy. However, the connection

[1] See Ivashina and Scharfstein (2010: 319)

[2] See Federal Deposit Insurance Corporation (2015), URL in list of references

[3] Building a cross-country crisis database, Laeven and Valencia (2013: 258f) only declare the years 1988 and 2007 onwards as crisis years. Their dataset covers the years 1970 to 2011. Considering only the time since the 1960s, Reinhart and Rogoff (2009: 346f, 390) find similarly that the US experienced banking crises in 1984-1988 and 2007. Their complete dataset covers 1800 to 2008.

[4] See Blank, Buch and Neugebauer (2009: 359, 361) and de Graeve, Kick and Koetter (2008: 209) for yearly bank distress frequencies and Laeven and Valencia (2013: 255) and Reinhart and Rogoff (2009: 365) for banking crisis incidence.

between banking sector fragility and monetary policy is not only relevant for systemic banks or for crisis times. As economies are entering 'post-' or 'non-financial-crisis' times, questions arise about whether, how and when monetary policy should return to 'normality' as well.[5] Then, a logical next step is to ask how monetary policy conduct is affected by non-systemic bank default, given that bank default is also a non-crisis phenomenon.

This next step is the central focus of this thesis. Given that bank default is not a new aspect, one may expect that this topic has already been examined thoroughly in macroeconomic studies. Somewhat surprisingly, bank default and financial fragility more generally have only recently played a more prominent role in the research agenda on monetary policy, particularly spurred by the latest financial crisis as noted above. There are various pieces of research on the role of banks and banking sector fragility in monetary policy transmission, as well as on governmental policies targeted at enhancing financial stability. As will be argued throughout this thesis, this thesis provides an extended and integrated assessment based on the following key characteristics: (i) a focus on discerning the consequences of non-systemic bank default for monetary policy, (ii) an analysis of these consequences both when there are measures to counter financial fragility in place and when they are not, and (iii) based on a model extension which is designed to concentrate on the incidence of non-systemic bank default as the only additional financial market imperfection. In this sense, this study can be seen as a corroboration and expansion of existing research.

As evidenced by the wide variety of literatures, the connections between monetary policy and financial intermediaries in general and financial fragility in particular allow for many research agendas. To focus the contribution, I pose the following research questions to summarise the objectives of this thesis. From the title it is clear that the principal research question focuses on how non-systemic bank failures impact the conduct of monetary policy. This first research question is approached from two distinct but linked perspectives. On the one hand, what are the consequences for monetary policy transmission to the real economy? This essentially queries whether a monetary policy impulse affects inflation and output in a different way when there are non-systemic bank failures. On the other hand, does bank default affect the capabilities of the central bank with regard to achieving its policy objective(s) more generally? This concerns both the primary objective of price stability as well as other policy objectives such as output gap stabilisation.

As a corollary, the incorporation of banking sector fragility into monetary policy analysis raises another research question. When default is possible both in the goods production and the financial sectors, which market imperfection implies more serious consequences for

[5] See, for example, Borio and Disyatat (2009: 22ff) for an early discussion.

monetary policy conduct? This research question aims to highlight potentially dissimilar effects of different financial frictions concerning monetary policy. For one, knowledge about differential impacts is crucial for monetary policy since it can benefit the analysis of macroeconomic developments on which monetary policy decisions are based. Furthermore, this knowledge also helps to evaluate how monetary policy decisions affect inflation and output when different economic environments imply that one of the frictions has grown more severe.

Thirdly, what if there are governmental measures to enhance banking sector stability and resilience? How does the existence of such macroprudential measures, for instance, affect the link between non-systemic bank default and monetary policy transmission as well as the trade-off between different monetary policy objectives? This third research question goes hand in hand with a more thorough evaluation of the link between monetary policy and financial fragility. Furthermore, assessing additional policies allows to discern the impact of potential spill-over or feedback effects on the conduct of monetary policy.

To answer these questions a New Keynesian dynamic stochastic general equilibrium (DSGE) model with financial accelerator is extended to incorporate non-systemic bank default. The DSGE model allows for the focus on 'normal' business cycles in that short-run fluctuations are reproduced instead of long-run growth. The New Keynesian modelling approach provides a specific rationale for monetary policy to have real effects in the short term. Moreover, the financial frictions concern both the asset as well as the liability sides of banks' balance sheet. In particular, the financial friction concerning banks' liabilities is the core modelling contribution of this study. This financial friction characterises the incidence of non-systemic bank default and provides the microfoundation for the evaluation of its impact on monetary policy. Furthermore, this banking model is log-linearised around its non-stochastic steady state and estimated using Bayesian methods. Based on this estimated model, the consequences of non-systemic bank default for monetary policy are analysed, both in terms of transmission and policy objectives. This analysis crucially revolves around the comparison of the banking model proposed in this study to a financial accelerator model which does not feature the additional bank-specific friction leading to bank default.

As well as limiting the focus to short- and medium-term developments, the particular modelling approach also draws boundaries to what this study can reasonably achieve. For one, the incidence of a financial crisis (or any other crisis) is not traced here. As a consequence of the log-linearisation, only small perturbations from the equilibrium are considered. With the focus on non-systemic bank failures and non-crisis times comes the abstraction from the unconventional measures taken by central banks in the aftermath of the latest financial crisis. Thus, this thesis only deals with 'conventional' (interest-rate-based) monetary policy. The main reason is that such a wider concept of monetary policy instruments necessitates some treatment of systemic bank failures which is in turn not the focus of this thesis. Thus, these two limitations are left to future research. Given the model's level of abstraction, there are many other, more specific restrictions placed on the analysis, which will be subsequently discussed as necessary. For the general research question, however, these two topics are considered the most important limits to be borne in mind.

Taking these limits into consideration, this thesis contributes to the existing literature in the following ways. On the theoretical side, this study proposes a model with a set of additions to a standard New Keynesian DSGE model with a loan market friction. These additions concern the endogenous determination of non-systemic bank default and bank leverage, and the specification of a portfolio choice problem on the part of households. This portfolio choice problem handles the choice between bank deposits, which are risk-free from the perspective of households due to a deposit insurance scheme, and bank equity which is risky because of the possibility of bank default. Undoubtedly, individual elements have been studied in the literature before. Yet, to the best of my knowledge, a model with the different features as presented in the following has not been proposed in a large-scale New Keynesian DSGE framework.

Furthermore, the single focus on non-systemic bank default as the additional bank-specific distortion, abstracting from other influences such as tax advantages or capital requirements, and its explicit microfoundation provide a rigorous foundation for the analysis. On this count, this thesis contributes to the relevant literatures a comprehensive evaluation of the consequences of non-systemic bank failure for monetary policy, not only concerning transmission but also the central bank's capabilities with respect to its objectives. This thesis will show that the particular modelling approach of non-systemic bank failures followed here produces a bank balance sheet channel in monetary policy transmission. Furthermore, the findings of this thesis suggest that this bank balance sheet channel primarily affects the response of aggregate demand of goods and services. In contrast, the response of inflation is not fundamentally affected by the introduction of bank default. Moreover, bank default affects the capabilities of the central bank to achieve different monetary policy objectives. If a central bank aims to minimise inflation volatility, the introduction of bank default yields a worse outcome than when banks do not default. Moreover, taking output gap stabilisation as an additional (secondary) monetary policy objective into account, banking model dynamics also imply a deterioration of the central bank's trade-off between inflation and output gap variance stabilisation.

However, the results on the trade-off between different monetary policy objectives depend on the parametrization. This sensitivity links to the empirical contributions of this thesis: highlighting the importance of sensitivity and robustness analyses as well as providing estimates for a New Keynesian DSGE model based on data for Germany. In terms of sensitivity, this study maintains that some results in comparing the effects of monetary policy with and without non-systemic bank failures are affected by the parametrization. In particular, parameter values are argued to be one of the crucial elements for evaluating central banks' capabilities with respect the trade-off between monetary policy objectives. Comparing the banking model to the financial accelerator model when both models are evaluated at their respective (different) posterior means, the trade-off between different objectives is better in the banking model than in the financial accelerator model. Thus, different model dynamics and parameter estimates have non-trivial effects for the trade-off between different monetary policy objectives.

Furthermore, this thesis contributes to the empirical literature in that it provides estimates concerning Germany. To begin with, there are few comparable existing estimates in the literature based on German data. Furthermore, the choice for using German data is not only based on their rarity in the literature, but rather on the particularities of the Euro area. While monetary policy is conducted considering the Euro area as a whole, financial systems are still disparate in Europe. Estimates based on aggregate Euro area data may blur potentially asymmetric effects of monetary policy. Thus, these estimates, as well as the analysis based on these estimates, can be interpreted as one piece of a larger puzzle to analyse how monetary policy in the Euro area is affected by fragile banks.

Finally, this thesis contributes on the issues of macroprudential policies and their interactions with monetary policy. This study argues that both the choice of macroprudential instrument and the measure of financial imbalances have non-trivial consequences for monetary policy conduct. While there appear general patterns in terms of monetary policy transmission, the results on the trade-off between monetary policy objectives do not fit a particular pattern in that some combinations of macroprudential instrument and financial measure enhance and others constrain a central bank's capabilities. Thus, the discussion of macroprudential policies in this thesis highlights the need for a rigorous and transparent modelling approach as well as implementation of any additional policy so as to adequately gauge its impact and usefulness and to communicate any changes duly.

To accomplish the research objectives and make aforementioned contributions, this thesis is structured in the following way. Chapter 2 establishes the theoretical framework by reviewing the relevant literatures. The chapter starts with the general macroeconomic research paradigm, and continues to the areas of financial intermediation and financial market imperfections and their links to monetary policy. Based on the outline of theoretical approaches, the review of the empirical results on this link corroborates the usefulness and exigency of this thesis' research agenda. Chapter 2 concludes with a review of closely-related research which underscores the theoretical contributions of this thesis.

Chapter 3 describes the banking model which is used in this study for analysing the research questions. The primary objective of chapter 3 is to explain the decision-making problems of the various agents which make up the model economy. The optimum conditions are presented and the modelling choices are justified.

Chapters 4 to 6 use the banking model to examine the research questions. Chapter 4 should be taken as an intermediate step which elaborates on some key features of the model. The chapter discusses the concept of the non-stochastic steady state and its stability and determinacy realms for the banking model. Furthermore, more details are provided on how the banking model's specificities affect the canonical DSGE model representation in terms of the New Keynesian Dynamic IS-Phillips Curve-Monetary Policy framework. Furthermore, chapter 4 compares the asymmetric roles of financial capital in the decision problems of non-financial firms and banks. This difference is argued to be crucial for understanding the specific consequences of bank failure as laid out in chapter 6.

Next, chapter 5 discusses the estimation of the banking model. Beginning with a short discussion of the estimation method, chapter 5 presents the estimation results of the banking model. In order to gauge the empirical fit of the banking model, it is compared to the financial accelerator model which does not include the friction leading to bank default. The final section of chapter 5 reports the results of the sensitivity analyses of the estimation procedure.

Chapter 6 presents the simulation results to evaluate the consequences of non-systemic bank failure for monetary policy. It thus builds on the intermediate results from the preceding chapters in terms of steady-state and estimation analyses. Chapter 6 starts with the analysis of monetary policy transmission and the consequences for the trade-off between different monetary policy objectives assuming that the government has not introduced any instruments to enhance financial stability. Then, the experiments are repeated under the assumption that there are macroprudential instruments in place in order to answer the last research question. In sum, chapter 6 is an integrated presentation and discussion of the results relating them to the relevant literatures.

Finally, chapter 7 summarises and concludes. The results of the previous chapters are combined to state the answers to the research questions succinctly. The conclusions to be drawn are considered and avenues of future research are pointed out.

Chapter 2

Financial Intermediaries and Monetary Policy in Macroeconomic Modelling

The connection between financial intermediation and monetary policy is an active field of (macroeconomic) research. In particular, the financial crisis of 2007-08 has been a catalyst for research discerning the functioning of the different parts of the financial intermediation process. Thus, it is clear that this study is based on a large repertory of research which is the focus of this chapter. There are a number of objectives this chapter aims to reach. To begin with, this chapter addresses various methodological choices. For one, this concerns the New Neoclassical Synthesis (NNS) as the overarching theoretical framework. Also, it relates to the particular approach to describing the relationship between the financial sector and monetary policy. Furthermore, the review of the literature on theoretical and empirical aspects of this link aims to establish the warrant for the way monetary policy interactions with the financial sector are modelled in this study. Overall, the core objective of this chapter is to place this study within the related literature and discern the gap this study aims to fill.

This chapter is structured as follows. In section 2.1 the dynamic stochastic general equilibrium (DSGE) modelling approach is justified by considering the role of monetary policy in the NNS as compared to other approaches. Section 2.2 discusses monetary policy conduct in Germany. The next two sections 2.3 and 2.4 deal with theoretical and empirical studies on monetary policy transmission justifying a non-trivial role for the financial sector. Finally, section 2.5 positions the present research within the relevant literature on banking sector fragility and monetary policy.

2.1 Monetary Policy in the New Neoclassical Synthesis

This study's research question presupposes a departure from monetary neutrality.[6] For if the classical dichotomy held, monetary policy would not affect real variables. In turn, the financial sector and the real economy are connected, since banking sector developments impact the financing available to private agents in the economy. So, with monetary policy targeting the price level (or inflation rate), if the price level and aggregate demand of goods and services[7] are not linked to each other, and financial sector developments are linked to aggregate demand, then the price level is not dependent on the financial sector. In this case, monetary policy targeting a stable price level will not be affected by the financial sector, that is also bank default. Thus, this study would be rather short.

Apart from this practical justification, what is the warrant for monetary non-neutrality? For one, the practice and communication of monetary policy in central banks supports the view that monetary policy affects the real economy. For instance, the Federal Reserve is mandated to aim for maximum employment in addition to price stability.[8] Furthermore, in a recent press statement explaining the decision to keep the target range for the federal funds rate fixed, the Federal Reserve explicitly stated that the loose monetary policy is intended to help improve labour market conditions.[9] Moreover, there is a large theoretical literature evaluating the effects of monetary policy, as well as its optimal design and interdependencies with other kinds of policy. As will become clear from the fraction of the literature cited in the following sections, there are clear indications that monetary policy has real effects. Besides, the accumulated body of empirical research covering the last decades shows that monetary developments do not only affect inflation, but also the real economy.[10]

To be more specific about the kind of monetary non-neutrality, the banking model used to answer this study's research questions belongs to the class of New Keynesian (NK) DSGE models. DSGE models embody the view that macroeconomic developments are the result of the coordination of individual agents' actions through markets based on rational decision-making.[11] Furthermore, equilibrium is a defining feature of DSGE models: while the model economy may be disturbed from its long-run equilibrium due to exogenous

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6 Monetary neutrality signifies that nominal and real variables develop independently of each other, see Walsh (2003: 213) and Woodford (2003: 6).

7 Unless stated otherwise, the term 'aggregate demand' will be used to denote 'aggregate demand of goods and services' in this thesis.

8 See Board of Governors of the Federal Reserve System (2016b: 1), URL in list of references

9 See Board of Governors of the Federal Reserve System (2016a), URL in list of references

10 A very prominent narrative study is M. Friedman and Schwartz (1963), and subsequently, time-series methods have become popular as exemplified in the work of Christiano, Eichenbaum and Evans (1999), see Galí (2008: 4). The empirical literature pertaining to this study is reviewed in section 2.4.

11 See Wickens (2008: 1)

shocks, it always rests in a short-run equilibrium.[12] This kind of model is associated with the paradigm of the New Neoclassical Synthesis (NNS). Monetary non-neutrality is one of the key features of the NNS, in contrast to the classical paradigm, for example. Put in a nutshell, the central features of the NNS about monetary policy are: Monetary policy has short-term effects on real variables due to nominal rigidities, but little long-term effects.[13] Reducing inflation yields gains due to lower relative price distortions and transaction inefficiencies.[14] Then, monetary policy does not only impact the economy, but the research paradigm creates a justification for a prominent role of monetary policy in managing aggregate demand.[15] Finally, central bank credibility plays a crucial role.[16]

The impact of monetary policy on the real economy is a direct consequence of one of the main tenets of the NNS: price and nominal wage rigidities. This means that non-financial firms[17] as price-setters, for example, face some form of constraint which limits the frequency of price and/or wage adjustments.[18] If prices cannot respond instantaneously and completely, then a central bank' ability to manipulate the nominal risk-free interest rate transfers into (imperfect) manipulation of the real risk-free interest rate.[19] Since the real risk-free interest rate affects real investment and real consumption decisions, monetary policy has an impact on real variables. As long as there is no absolute impediment to changing prices and nominal wages, the effects of monetary policy will dissipate over the long term.[20] This is referred to as short-term monetary non-neutrality.[21]

While the principal objective of monetary policy is generally considered to be price stability, output (gap) stabilisation can be deemed an additional target. Aiming to avert excessive business cycle swings and thus volatility in the real economy due to mechanically fulfilling the objective of price stability can be one justification.[22] In fact, in simple NK DSGE models, price stability and output gap stability go hand in hand. There, monetary policy has the potential to stabilise output at its potential level through stabilising prices by managing average marginal cost over time.[23] As a consequence, non-financial firms do

[12] See Wickens (2008: 1)
[13] See Goodfriend and King (1997: 232)
[14] See Goodfriend and King (1997: 232)
[15] See Goodfriend and King (1997: 256)
[16] See Goodfriend and King (1997: 232)
[17] The term non-financial firm is used to distinguish these firms from financial intermediaries.
[18] See Galí (2008: 5). This necessarily implies that the respective markets are not perfectly competitive.
[19] See Galí (2008: 5)
[20] See Galí (2008: 5)
[21] See Galí (2008: 5)
[22] See Galí (2008: 95)
[23] See Goodfriend and King (1997: 256, 262ff). However, monetary policy cannot change the steady-state average mark-up, and consequently the level of potential output, since this is determined by non-financial firms' market power, see Goodfriend and King (1997: 262).

not have an incentive to change their prices.[24] This implies that there is no trade-off for monetary policy between inflation and output stabilisation.[25] However, in more elaborate models this accordance of objectives does not necessarily hold. Various possibilities for a trade-off between output gap and inflation stabilisation to arise have been considered. A widely used concept to create such a trade-off is the introduction of exogenous randomness in the mark-up process, often called cost-push or mark-up shocks.[26] Also, the presence of nominal wage stickiness in addition to price stickiness can result in a short-term trade-off.[27]

NK DSGE models are not the only kind of macroeconomic model which allows for monetary non-neutrality. Stock-flow consistent (SFC) modelling, for example, is one alternative approach to monetary policy analysis. SFC models are made up of interlinked balance sheets of the agents in the model paying particular attention that each financial asset is matched by a corresponding financial liability of another agent.[28] The advantages of the SFC approach include the 'natural' match to national accounts data as well as the ability to check the logical consistency of the model.[29] Given that SFC models are based on accounting principles, no agent can accumulate financial assets which have no counterpart liability of another agent.[30] The models are thus internally consistent.[31] Godley and Lavoie (2012), for example, provide a text-book style monograph building an increasingly complex SFC model. They show that monetary policy has real effects.[32] However, SFC models also present a major drawback: by focusing on the aggregate balance sheet of aggregate sectors, intra-sector and heterogeneous behaviour cannot be traced.[33]

To counter this last point, consider the other extreme: agent-based (AB) models.[34] The central tenets of AB models are heterogeneous agents, and agents being bounded-rational

[24] As Galí (2008: 47) shows using a simple NK model, inflation is a function of expected marginal costs, defined as deviations from the steady state.
[25] See Goodfriend and King (1997: 276)
[26] See Clarida, Gali and Gertler (1999: 1672)
[27] See Goodfriend (2004: 39). As will be discussed in chapter 6, the models considered in this thesis feature such a trade-off. Furthermore, parametrization as well as model structure impact the trade-off.
[28] See Caiani et al. (2016: 378) and Caiani, Godin and Lucarelli (2014: 425). These accounting rules are based on the quadruple entry principle, see Godley and Lavoie (2012: 47).
[29] See Caiani et al. (2016: 378). Also, Caiani et al. (2014: 426) argue that SFC models are prime candidates for studying endogenous money because of their focus on keeping track of stocks and flows in the economy. As will be outlined in the next section, this study abstracts from the debate of loanable funds vs. endogenous money. Thus, this issue will not be discussed further at this point.
[30] See Caiani et al. (2016: 378)
[31] See Caiani et al. (2016: 378)
[32] Incidentally, the real effects produced by the model by Godley and Lavoie (2012) are conflicting with conventional accounts: While contractionary monetary policy has negative short-term effects on real output, over the medium and long terms real output is actually higher than at the outset. The authors attribute this behaviour to higher government expenditures due to higher interest rates. See Godley and Lavoie (2012: 116f, 122f, 151, 415)
[33] See Caiani et al. (2016: 378)
[34] See Tesfatsion (2006) for a comprehensive introduction to AB models.

and behaving in an adaptive manner.[35] AB models are advocated on the basis that macroeconomic developments are the outcome of an evolving system of individual agents directly interacting with each other, not necessarily or rather seldom in equilibrium.[36] Thus, there is no artificial representative agent. Furthermore, proponents argue that their ability to create crises endogenously and to study the dynamics of the economy even outside equilibrium are advantages of AB models.[37] The EURACE project is one of the most prominent examples of this approach. The collaborative project aims to build a complex AB model of the European Union.[38] In a related effort to build a comprehensive AB model, Dosi et al. (2015) study the interaction between monetary and fiscal policies. Their simulations reveal that the dynamics of the economy crucially depend on the combination of fiscal and monetary policies.[39] In particular, monetary policy which reacts to both unemployment and inflation performs better than one which is only concerned with inflation.[40]

Nevertheless, despite their alleged appeal of being more ‘realistic’, AB models have weaknesses. Most importantly, Caiani et al. (2016) state that most AB models found in the literature do not obey stock-flow consistency.[41] This is critical since the simulation-based approach of AB models means that small discrepancies can build up over the simulation span, potentially rendering the simulated paths of stocks and flows inconsistent.[42] As a remedy to this problem, Caiani et al. (2014) and Caiani et al. (2016) have proposed to merge the AB and SFC modelling paradigms.[43] This combination would not only make AB models stock-flow consistent but would also enrich SFC models by disaggregating the amplification effects due to a whole sector behaving in a homogeneous way.[44]

Yet, only considering stock-flow consistent AB models, there are still unresolved issues and other drawbacks. For one, the treatment of expectations in AB models is a contentious issue. AB models aim to incorporate scientific results from psychology, among others,

[35] See Fagiolo and Roventini (2012: 88)
[36] See Fagiolo and Roventini (2016: 3), URL in list of references
[37] See Tesfatsion (2006: 843) and Dosi, Fagiolo, Napoletano, Roventini and Treibich (2015: 167)
[38] See Deissenberg, van der Hoog and Dawid (2008) and Dawid, Harting, van der Hoog and Neugart (2016) as well as the references therein for more information.
[39] See Dosi et al. (2015: 182)
[40] See Dosi et al. (2015: 178). More specifically, Dosi et al. (2015: 176) find that there are merits to monetary policy targeting both the unemployment rate and inflation even though this leads to an increase in average inflation.
[41] See Caiani et al. (2016: 379)
[42] See Caiani et al. (2016: 379). The issue of stock-flow consistency is important for any kind of model. Note that given this criticism, care was taken in specifying the model. Also, the methodological approach chosen here for the DSGE model, that is local stability and small perturbations from the steady state, ensures that stocks cannot build up indefinitely. See section 4.4 for more details on the stability of the model.
[43] See Caiani et al. (2014: 444) and Caiani et al. (2016: 377)
[44] See Caiani et al. (2014: 444)

in modelling agents as boundedly rational.[45] Proponents of AB models emphasise the importance of incorporating learning in agents' decision rules.[46] However, it has been criticised that often the underlying assumptions and characteristics of heterogeneity and learning are not explained thoroughly.[47] Furthermore, learning can also be incorporated into DSGE models. De Grauwe (2010), for instance, also aims to include the results of limited cognitive abilities from psychology and neural science into macroeconomic models.[48] Similar to proponents of AB models, he argues that in reality, agents do not understand the world entirely, and thus rely on rules-of-thumb in their decision-making process.[49] To this end, de Grauwe (2010) includes additional forecasting equations in a simple NK model.[50] The author argues that endogenous waves of optimism and pessimism create endogenous business cycles, as well output and inflation inertia and differential effects of monetary policy.[51]

What is more, the treatment of agents' cognitive abilities and expectations in AB models poses problems when it comes to policy evaluation and regime changes. In contrast, the rational expectations paradigm incorporated into DSGE models is well equipped to analyse the consequences of policy changes since the evolution of the economy is derived from structural optimisation problems. Due to the explicit microfoundation, consequences of monetary policy can be analysed avoiding the Lucas critique.[52] Rational expectations and agents' optimisation problems as the basis of the model provide a way to address the issue of changing expectations, caused by an altered underlying model economy structure, as for example when new governmental policies are adopted.[53] This is of particular importance in the present context since the research question revolves around a non-trivial change in the economic structure. In each of the economic environments studied here, agents are fully informed and behave rationally, thus act optimally. Different consequences for monetary policy between models with and without bank failure are due to different constraints placed on rational economic agents. Therefore, the results are not blurred by mingling effects of agents not incorporating some features of the economic structure into their decision-making. Such additional effects are certainly an interesting topic for future research.

Moreover, there are particular difficulties surrounding the calibration of AB (and

[45] See Fagiolo and Roventini (2012: 88)
[46] See Fagiolo and Roventini (2012: 90)
[47] See Wäckerle (2013: 14)
[48] See de Grauwe (2010: 414)
[49] See de Grauwe (2010: 414)
[50] See de Grauwe (2010: 418f)
[51] See de Grauwe (2010: 438f)
[52] See Woodford (2003: 10f). Lucas (1976: 40ff) argues that predictable policy changes affect behavioural parameters, therefore impacting the forecasting performance of models.
[53] See Woodford (2009: 272)

SFC) models. Firstly, AB models are generally over-parametrised.[54] As such, this leads to difficult choices when it comes to choosing the parameters and testing robustness.[55] Secondly, the calibration of initial values for stocks and flows is critical since AB models produce path-dependent dynamics.[56] For this reason, a burn-in period of the simulation is usually discarded to remove the effects of initial values.[57] At the same time, Caiani et al. (2016) argue that initial stock values have to be sufficiently high for the agents to accommodate possible very large swings in the first periods of the simulation.[58] Similarly, Tesfatsion (2006) argues that an extensive specification effort is necessary to avoid a situation in which the modeller would have to adjust the processes during the simulation.[59] So, given that calibration is a very sensitive issue in AB models, it is rather disconcerting that Caiani et al. (2016) state that the majority of the corresponding literature does not discuss the choice of calibration for initial stocks and flows adequately.[60] While parameter identification is a critical topic for DSGE models as well, the routines developed so far help in conducting efficient sensitivity and robustness analyses.

Finally and related, the modelling and evaluation approaches within the AB(-SFC) paradigm are still very disparate.[61] Furthermore, AB models are generally very complex leading authors to present only the main intuition and assumptions without being able to clearly delineate different mechanisms.[62] Given their dissimilar, specific foci and different solution methods, it is rather difficult to compare the results of different AB models.[63] In contrast, there exists a set of solution routines, evaluation and estimation tools for more or less standard DSGE models.[64]

Furthermore, recent research on DSGE models has turned to addressing various criticisms which have been used as arguments in favour of alternative approaches. For one, the suggested advantage of AB models in modelling heterogeneous agents looses much of its strength in the presence of the current efforts to build heterogeneous agent DSGE

[54] See Fagiolo and Roventini (2012: 105f) and Dawid et al. (2016: 2)
[55] See Fagiolo and Roventini (2012: 105f)
[56] See Fagiolo and Roventini (2012: 90, 106)
[57] See Caiani et al. (2016: 390) and Fagiolo and Roventini (2012: 106)
[58] See Caiani et al. (2016: 380)
[59] See Tesfatsion (2006: 845)
[60] See Caiani et al. (2016: 380, 388)
[61] See Caiani et al. (2016: 379)
[62] See Dawid et al. (2016: 2f). This count may be equally true for large-scale DSGE models. However, given that the core of most DSGE models tends to be made up of a known set of elements, only the new or amended elements need to be explained. In contrast, AB models tend to be more heterogeneous, see Dawid et al. (2016: 2). Notable contributions to streamline AB models include Caiani et al. (2016) and Dawid et al. (2016).
[63] See Caiani et al. (2016: 379)
[64] Obviously, there are also issues which require more sophisticated solution and/or estimation techniques, such as the modelling of non-linearities or heterogeneous agents, see section 3.1.2.

models.[65] While the model presented here does not feature heterogeneous agents for reasons discussed in section 3.1.2, the fact that dynamic general equilibrium and heterogeneity among agents can be linked in a single model shows that this research area is also not limited to AB models. Fagiolo and Roventini (2012) elaborate on another argument against DSGE models by arguing that the reliance on external shock processes to create business cycles in DSGE models implies that such models cannot explain how business cycles or crises arise endogenously.[66] Admittedly, the start of the business cycle or crisis may not arise endogenously in DSGE models. Yet, the evolution of the economy through a business cycle can still be traced. Moreover, recent research has also turned to global solution methods as an alternative to log-linearisation. Thus, issues such as modelling non-linearities, for instance the zero-lower bound, become feasible in the realm of DSGE models. The possibility to incorporate such features into DSGE models, even though they are not used here, is still an argument for the use of a DSGE model in the present context: As will be argued many times more, the focus is on a comparative exercise.[67] The objective is not only to show how the presented model is different, but also to build a reference point for future research potentially incorporating heterogeneous agents and non-linearities.

It is due to the incorporation of rational expectations, and the comparability as well as practicability in terms of parametrization, sensitivity and robustness analyses that this study uses a DSGE model. Nevertheless, it is important to keep in mind the limits and criticisms of DSGE models which also spurred the research in AB and SFC models. These concern more technical issues such as the inclusion of ad-hoc assumptions about price indexation to introduce persistence, as well as whether shocks in DSGE models should be interpreted as structural.[68] More fundamental criticisms relate, among others, to the use of rational expectations and the ‘representative agent’ as noted above. These issues are certainly important and indicate that much work needs to be done. Yet, the same applies to addressing the weaknesses of other approaches. To the extent that these criticisms are deemed relevant for this study, they will be addressed to enhance transparency. For instance, section 3.1.2 deals at length with the assumption of the representative agent, and more generally chapter 3 extensively discusses the particular modelling choices.

Furthermore, this discussion for the choice for a DSGE model should not be interpreted as discarding AB modelling and other approaches. The central concern of this study may be equally studied in an AB model. As is true for many realms of methodology, there are advantages and disadvantages to using a specific approach. Whether or not the results

65 For references to the literature, see section 3.1.2.
66 See Fagiolo and Roventini (2012: 86)
67 The comparison concerns both the characteristics of each model’s steady state and the models’ behaviour when disturbed from their respective steady states.
68 See Chari, Kehoe and McGrattan (2009: 244f)

presented in this study hold in a different context is an interesting study for future research. In the end, any model can only be an abstraction from reality and is bound to be an incomplete representation. Then, the question is for which purpose the model is used. In particular, this study is primarily concerned with an additional feature of the economy, not a fundamental paradigm-shifting change in assumptions. Thus, it is imperative to be able to compare the results of this research with the literature. This concerns both the parallels with established results in the literature and the use of this study as a building block and reference for future research. To this end, the body of work on NK DSGE models is sufficiently rich to clearly delineate the consequences of the additional feature. In conclusion, for the purposes of this study, in my view the advantages of DSGE models outweigh the disadvantages.

2.2 Characterisation of Monetary Policy in Germany

After characterising the overarching paradigm under which monetary policy affects the economy, the next step is to characterise monetary policy itself. In particular, this concerns the principal objective(s) of monetary policy. While this is generally deemed to be price stability, the exact definition and possible inclusion of further objectives vary across countries. To this end, this section provides a short overview of the monetary policy arrangements of the Deutsche Bundesbank[69] and the European Central Bank (ECB). Discussing both is necessary since the data used in the estimation spans the time between 1994 and 2015.[70] This section argues that monetary policy in Germany can be represented by a common monetary policy rule in the banking model despite different entities being in charge of its conduct. Furthermore, the rationale for the focus on a particular implementation of the monetary policy rule as well as the inflation target are discussed.

The policy objective of the Bundesbank had been long-term[71] price stability since the 1970s.[72] To this end, the conduct of the Bundesbank centred on money supply control.[73] The reasoning follows from money demand and quantity theoretic considerations. In particular, it was argued that money supply outgrowing the productive capacity of the

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69 Henceforth, the term ‘Bundesbank’ will be used.

70 See chapter 5 for a discussion of the choice of time period.

71 The distinction between short, medium and long term is not clear-cut in general. For the purposes of this study, the short term is defined as a period of up to two years, the long term is a period of 8 years and more, and the medium term is a period of length in between these two. The justification is loosely based on the business cycle literature as well as considerations that in the short term prices are rigid, and in the long term prices are flexible. As outlined later in this study, estimates of price frequency changes in Germany roughly correspond to this definition.

72 See Buchheim (2007: 1024). Also, the Bundesbank was to support the general economic policy insofar this was permitted by the primary objective being fulfilled, see Deutsche Bundesbank (1995: 18). The conduct prior to the 1980s is not reviewed here. See Deutsche Bundesbank (1995: 14ff) and Buchheim (2007) for more details.

73 See Deutsche Bundesbank (2006: 28)

economy would lead to inflation over the long term.[74] Then, the central bank should target a money supply growth rate equalling the productivity growth rate of the economy.[75] Overall, the Bundesbank conduct concurred with the monetarist approach.[76]

Similarly to the Bundesbank, the principal objective of the ECB is price stability.[77] Yet, in contrast to the Bundesbank, the ECB does not consider money supply to be the single most important factor on which monetary policy decisions are based. Rather, it has been argued that the ECB, at least partially, conducts flexible inflation targeting.[78] In particular, monetary aggregates are only one part of the two-pillar strategy of the ECB to discern long-term risks to price stability and to cross-check the results from the economic analysis.[79] An economic analysis forms the second pillar and concerns the analysis of the real economy and financing conditions.[80]

Since both the Bundesbank and the ECB consider monetary aggregates in their decision-making, a case could be made for representing monetary policy by a money supply rule. Nevertheless, in this study as in much of the literature, monetary policy will be represented by a Taylor-type interest rate rule.[81] The use of an interest rate rule provides a representation of both the money supply control era of the Bundesbank and the two-pillar strategy of the ECB. For one, even though the Bundesbank targeted a certain money growth rate, various authors have argued that Bundesbank policy may be better represented by an interest rate rule than a monetary targeting regime.[82] D. Romer (2000), for instance, argues that the Bundesbank formulated an explicit inflation target, while also taking account of output and exchange rate movements.[83] Secondly, the majority of observations falls into the ECB policy period. Characterizing ECB monetary policy with

74 See Deutsche Bundesbank (1995: 81f). Also, a stable relationship between monetary aggregates and prices, and the capability of the Bundesbank to steer the target variable are mentioned as justifications for the money supply control policy, see Deutsche Bundesbank (1995: 67ff).
75 See Deutsche Bundesbank (2006: 28f)
76 See Buchheim (2007: 1024)
77 See The Member States (2012: Art. 127(1)). Also similar to the Bundesbank, the ECB is mandated to support the general economic policy under the condition that it does not prejudice its primary task, see European Central Bank (2002: 4).
78 See Svensson (1999, 2011) for a thorough discussion of (flexible) inflation targeting. Svensson (2000: 98) argues that ECB policy resembled flexible inflation targeting in the early stages of the monetary union, as well as that there are further issues to be resolved or improved.
79 See European Central Bank (2016d), URL in list of references
80 See European Central Bank (2016b), URL in list of references
81 For more details on the discussion around interest rate vs. money supply rules, see for example Woodford (2003: 44ff).
82 See Clarida and Gertler (1997: 367, 404f) and D. Romer (2000: 154f). Also, Rohde (1995: 253, 263) argues that the flexible money market control regime the Bundesbank had conducted since 1985 only allows for a control of the interest rate while monetary aggregates are only indirectly controllable by the central bank.
83 See D. Romer (2000: 155). Deutsche Bundesbank (1995: 80), for example, states that while the monetary aggregate is the main subordinate target, other indicators and the economic situation play a role in setting monetary policy.

a money supply rule would be inadequate since monetary targeting is only one pillar of the ECB policy. Finally, monetary aggregates are regarded to be particular important in characterising the long-run risks to price stability. By the very nature of DSGE models this study is concerned with short-run fluctuations which are more clearly related to the second pillar of ECB policy.[84]

Another advantage of the use of an interest rate rule is the possibility to abstract from the process of money creation.[85] Disyatat (2011), for instance, argues that the money multiplier becomes inconsequential with interest rates at the centre of monetary policy conduct.[86] This is a result of central bank reserves being held for structural reasons and thus being interest-insensitive as well as independent of the monetary policy stance.[87] Therefore, monetary policy can be characterised by the policy interest rate and the debate between loanable funds and endogenous money can be disregarded.[88] Furthermore, there are other features of the present model which agree with the delegation of the discussion of what is created first to a secondary topic. As will be shown, the process of financial intermediation is principally characterised by weighing different returns. Financial volumes play a role insofar as they affect returns. Thus, the primary question does not concern the order of loans and deposits. In fact, there is a great degree of simultaneity. This does not mean that the issue as such is secondary. Rather, it means that the particular approach of this thesis allows to abstract from this distinction. The central concern is how banks' financing costs affect the financing costs of non-financial firms and in turn the real economy. In conclusion, the choice of interest rate rule supports the modelling approach.

Abstraction from the money market and the specific implementation of the interest rate policy in terms of the quantity of money means that the recent practice of unconventional monetary policies cannot be adequately traced in this study. On the one hand, this is another simplification to contain the focus. On the other hand, it is a consequence of the particular modelling approach which emphasises the links between various returns instead of financial volumes. There are certainly possibilities to amend the model to incorporate unconventional monetary policies. However, since the focus of this study is on the consequences of non-systemic bank default, and not on the extraordinary situation since the start of the financial crisis, an adequate treatment of unconventional monetary policies is simply

84 A sensitivity analysis is conducted to discern the appropriateness of estimating the model using combined data from the Bundesbank and ECB periods, see section 5.5.

85 See D. Romer (2000: 162)

86 See Disyatat (2011: 5)

87 See Disyatat (2011: 5)

88 Proponents of endogenous money argue that banks create deposits in the process of loan-granting, see Howells (2006: 59), Dow (2006: 35) and Hannsgen (2006: 205). The loanable funds approach instead assumes that saving precedes loans, see Lindner (2013: 8). On this distinction see also Werner (2005), especially pages 174ff.

out of the bounds of this study. Thus, the issue is left to other ongoing and future research.[89]

Irrespective of the specific formulation of monetary policy measures taken by the Bundesbank and the ECB, the primary and ultimate aim is price stability. Specifically, price stability is operationalised as targeting a 2% inflation rate per year.[90] The Bundesbank justified the 2% target instead of 0% inflation with reference to measurement errors due to insufficient recording of substitution effects and quality changes.[91] For the monetary policy target of the ECB, a recent speech gives further reasons. Firstly, a positive inflation target enables real adjustments in the presence of nominal rigidities, both in terms of wages and external competitiveness. Secondly, this inflation target decreases the risk of hitting the zero lower bound of interest rates.[92]

To the contrary, this study assumes a central bank inflation target of 0%.[93] There are several reasons for this. For one, there is no measurement error in the steady state of the model, thus agents' expectations and the realisation of the inflation rate coincide in the steady state and inflation behaves according to the model otherwise. Thus, there is no need for a buffer to accommodate unspecified features. Even in the presence of unspecified influences the 0% target can be justified. Consider, for example, exogenous monetary policy shocks as measurement errors. Monetary policy shocks in the model are symmetrically distributed around 0. As a consequence, measurements are not biased in one direction. In contrast, the Bundesbank cites statistical measurement problems which overstate the changes in the price index.[94]

Furthermore, averting deflation is mentioned by Draghi (2016) as a justification for slightly positive target inflation.[95] Yet, this does not need to be a priority for monetary policy in the banking model presented here. The reason is that financial contracts are written in real terms in the banking model. This study purposefully abstracts from the debt-deflation channel for focus and simplicity.[96] Thus, a buffer is not needed since positive and negative shocks have symmetric consequences. Besides, the zero lower bound of the interest rate is not relevant for the analysis and simulations considered in subsequent

[89] Gertler and Karadi (2011) and Gertler, Kiyotaki and Queralto (2012), for example, analyse unconventional monetary policies in an NK DSGE model with the possibility of bank default. See also chapter 6 on this issue.
[90] This is true of the Bundesbank period as well as the ECB period, see Deutsche Bundesbank (1995: 83) and European Central Bank (2015a), URL in list of references.
[91] See Deutsche Bundesbank (1995: 83)
[92] See Draghi (2016), URL in list of references
[93] To be precise, the model as such can incorporate any target inflation rate, but the simulations were run under the assumption of a 0% inflation rate target.
[94] See Deutsche Bundesbank (1995: 83)
[95] See Draghi (2016), URL in list of references
[96] For example, Bailliu, Meh and Zhang (2015: 151) study a model with nominal loan contracts where unexpected changes in inflation affect the real debt burden.

chapters. Thus, a buffer is also not needed in this case to accommodate manoeuvre space with very low interest rates.[97] Finally, from a modelling perspective, an inflation rate of 0% minimises the distortions from nominal rigidities.[98] Thus, a 0% inflation target can be justified in the present context.

In conclusion, for the purposes of this study, monetary policy is characterised by the following features: the primary objective of price stability, the conduct according to an interest rate rule, and a target inflation rate of 0%. The next step is to deal with the question of how monetary policy is transmitted through the financial system. Beforehand, one further qualification is necessary concerning the structure of the banking system. The German banking system is usually characterised by a three-pillar structure: commercial banks, and the systems of savings banks and cooperative banks. The distinctive features of each group concern the ownership structure, the principle of profit-maximisation and inter-group vs. intra-group competition.[99] With respect to the empirical findings in section 2.4, some reference is made to this institutional structure. However, the macroeconomic model in this study is too abstract to be able to reflect these structural issues. The question of different effects of bank default in different parts of the banking system is left to future research. Heterogeneous agent models should provide the necessary tools to adequately study such a three (or more) part structure. To this end, this study can be seen as a step to unveil the consequences of non-systemic bank default for monetary policy (in Germany) more generally.

2.3 Channels of Monetary Policy Transmission

The knowledge about how monetary impulses are transmitted through the economy is instrumental for the conduct and evaluation of monetary policy.[100] This is the focus of monetary policy transmission analyses which aim to discern the relationship between the monetary policy instrument(s) on the one hand and real economic activity and prices on the other hand.[101] Research in this field has postulated a variety of so-called transmission channels each of which describes a particular chain of economic agents' reactions triggered

[97] Furthermore, given the closed economy framework, the external competitiveness argument does not apply here either. Another issue which is abstracted from is that ECB conducts monetary policy which is targeted at the whole Euro area and not Germany only. This is warranted because this study aims to discern potential effects of bank default, and not to describe how monetary policy has been or should optimally be conducted in the Euro area.

[98] On this point, see also Goodfriend and King (1997: 263).

[99] See R. H. Schmidt and Tyrell (2004: 31ff). See Hackethal (2004: 73ff) for an overview of the banking sector in Germany.

[100] See Mishkin (1995: 4)

[101] See Belke, Eppendorfer and Heine (2002: 435)

by a monetary policy impulse.[102] The channels are neither exclusive nor do they appear in isolation, that is a monetary policy impulse is transmitted through multiple channels simultaneously and any (combination of) channel(s) may reinforce or counterbalance other channel(s).

Of particular use for this study is the fact that the variety of monetary transmission channels can be divided into two groups depending on whether financial intermediation is regarded as a veil or not. Boivin et al. (2011), for instance, group the channels of monetary transmission into two categories: neoclassical and non-neoclassical channels.[103] Neoclassical channels[104] transmit the monetary policy impulse assuming perfect financial markets, that is financial intermediation is portrayed as a veil.[105] In contrast, non-neoclassical channels arise in imperfect financial markets.[106] Non-neoclassical channels assume that asymmetric information (or government intervention) in financial markets can generate new channels of monetary policy transmission.[107] The most prominent examples of non-neoclassical channels are the balance and bank lending channels as well as the risk-taking channel. Given this thesis' focus on an additional bank-specific friction, this discussion concentrates on these non-neoclassical channels.

As a starting point, fig. 2.1 presents a highly stylised representation of monetary policy transmission. The figure traces a monetary policy action from the left to the economic variables output and inflation on the right. Initially, a monetary policy action induces changes in money market rates and/or private sector inflation expectations. On the one hand, inflation expectations of the private sector are an important factor in monetary policy transmission, not least through their impact on real interest rates according to the Fisher equation.[108] On the other hand, the various channels emphasise the relevance of controlling a risk-free interest rate or the money supply to different extents. Accordingly, the impact of monetary policy on money market or other short-term rates is the starting point of many neoclassical channels, for instance the interest rate channel.[109] In contrast, the evolution of central bank reserves as a consequence of monetary policy actions is crucial

[102] For general summaries, see, for instance, Mishkin (1995), Worms (2004) and Boivin, Kiley and Mishkin (2011).
[103] See Boivin et al. (2011: 374f.). Note that this classification overlaps nicely with the one proposed by Worms (2004: 167ff) of traditional channels and channels which arise when there is imperfect information in financial markets.
[104] These include, for instance, the interest rate or exchange rate channels, see Boivin et al. (2011: 375). Mishkin (1995) provides an early summary of the various channels.
[105] See Boivin et al. (2011: 374)
[106] See Boivin et al. (2011: 374)
[107] See Boivin et al. (2011: 380). A good example of government intervention based effects is so-called 'Regulation Q' in the US up to 1986 which produced a credit rationing channel, see Boivin et al. (2011: 381). See McCarthy and Peach (2002) for more details on this regulation.
[108] See Worms (2004: 168)
[109] See Boivin et al. (2011: 374ff)

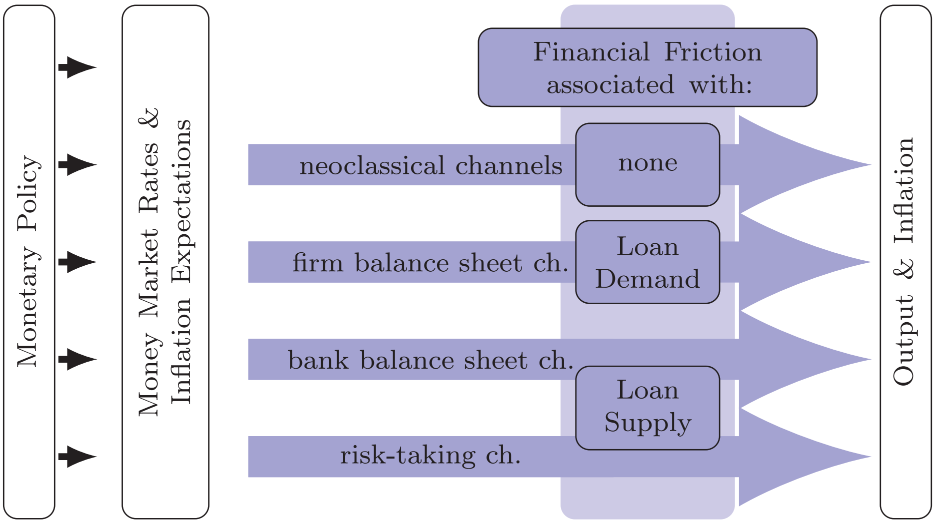

Figure 2.1: Channels of Monetary Policy Transmission; highly stylised and not necessarily exhaustive representation, in particular there are certainly feedback and spill-over effects between different channels which are not presented here for simplicity; ch. denotes channel; own representation based on fig. 6.2 in Worms (2004: 167).

for understanding the bank lending channel (summarised under the bank balance sheet channel in fig. 2.1), as will be explained below. Based on the exposition in section 2.2, this distinction already indicates which channels are not traced in this study.[110] Yet, the interactions between monetary policy instruments and operating targets such money market rates need not be discussed here any further. This thesis does not deal with frictions between monetary policy instruments and operating targets, but rather concentrates on frictions which arise subsequently as indicated by the arrows.

Thus, the discussion of monetary policy transmission channels starts after the monetary policy impulse has affected money market rates and inflation expectations. Neoclassical channels relate these changes in money market rates and inflation expectations to aggregate demand components as well as price- and wage-setting decisions under the assumption that financial intermediation is frictionless. Subsequently, the responses of output and inflation depend on these induced changes in aggregate demand, prices and wages.[111] In contrast to neoclassical channels, the non-financial firm balance sheet, bank balance sheet and risk-taking channels take an intermediate step and focus on financial intermediation in relating monetary impulses to aggregate demand and price-setting. Changes induced by monetary policy in the severity of asymmetric information problems lead in all three cases to differential outcomes in terms of loan interest rates and loan volumes which in

[110] This is the reason central bank reserves are not explicitly depicted in fig. 2.1 for simplicity. See below for the discussion of which channels are important for this study.
[111] See Worms (2004: 167)

turn affect aggregate demand and price-setting.[112] The non-financial firm balance sheet channel mainly works through changes in loan demand, while both the bank balance sheet and risk-taking channels affect loan supply.

Consider first the (non-financial firm) balance sheet channel. In contrast to the Modigliani-Miller Theorem[113], this balance sheet channel starts from the premise that external financing is more expensive than internal financing. Imperfect information and its associated problems of moral hazard, costly monitoring and enforcement are prime causes of this spread, also called the external finance premium.[114] In this view, a borrowers' net worth is crucial in alleviating these problems because it aligns, to some extent, the interests of borrowers and lenders.[115] Monetary policy in turn impacts borrowers' balance sheets in a number of ways. Consider contractionary monetary policy: This leads to rising interest expenses on existing, flexible-rate debt as well as indirectly to potentially declining revenues through lower aggregate demand generated by monetary policy.[116] Both of these mechanisms reduce non-financial firms' cash flow.[117] Furthermore, as rising interest rates tend to be linked to lower asset prices, the value of collateral for credit contracts declines.[118] Thus, the external finance premium increases, and capital demand and investment decrease.[119] Since this mechanism has further feedback effects over subsequent periods, this amplification and propagation mechanism through balance sheets has been termed 'financial accelerator'.[120]

Next, turn to bank-based channels.[121] The early literature on the balance sheet channel focused on non-financial firms as borrowers. Even so, banks also played a role in the early credit channel literature in terms of a bank lending channel.[122] The bank lending channel is uniquely identified with financial intermediaries and is primarily associated with the loanable funds paradigm mentioned above. At the core of the bank lending channel is the availability of loanable funds which determine loan supply.[123] The crucial

[112] These channels have been related to aspects of financial intermediation other than the loan market. The fundamental mechanisms are most naturally explained with respect to the loan market, which is the approach followed here for simplicity.
[113] Under a specific set of assumptions Modigliani and Miller (1958: 268) find the capital structure to be irrelevant for a non-financial firm's market value.
[114] See Bernanke and Gertler (1995: 29)
[115] See Bernanke and Gertler (1995: 35)
[116] See Bernanke and Gertler (1995: 36). The latter effect presumes that in the short run, non-financial firms' costs do not adjust appropriately, see Bernanke and Gertler (1995: 36).
[117] See Bernanke and Gertler (1995: 36)
[118] See Bernanke and Gertler (1995: 36)
[119] See Bernanke and Gertler (1995: 35) and Bernanke et al. (1999: 1370)
[120] See Bernanke and Gertler (1995: 35)
[121] Henceforth, this study will be concerned with banks as defined as financial intermediaries granting loans and deposits to the non-financial sector, unless specified otherwise.
[122] See Bernanke and Gertler (1995: 29, 40ff)
[123] See Bernanke and Gertler (1995: 40)

assumption of this channel is that banks as financial intermediaries and suppliers of credit to non-financial firms cannot easily substitute bank deposits with other forms of financial liabilities. The designation 'easily' is chosen purposefully. In the model by Bernanke and Blinder (1988), the key assumption is that banks do not issue any form of liability other than bank deposits.[124] Subsequently, this strong assumption was moderated. As Kashyap and Stein (1994) emphasise, the relevant assumption for the lending channel to be at work is that there is no complete substitutability between bank deposits and other forms of bank financing in the aggregate.[125] In the case of contractionary monetary policy, bank deposits fall due to a decline in central bank reserves.[126] Thus, loanable funds and as a consequence bank loan supply decrease. As non-financial firms potentially incur costs in establishing new credit relationships when banks tighten loan supply, this can also lead to an increase in the external finance premium.[127]

The bank lending channel and its loanable funds basis have come under intense criticism. Especially the assumption that banks cannot easily accommodate a shortfall in bank deposits by other liquid funding options has been criticised.[128] Furthermore, there is a debate about whether central bank reserves play a crucial role for loan-granting decisions.[129] In response to these criticisms, Disyatat (2011), for instance, argues for a new bank lending channel as the theoretical equivalent of the balance sheet channel described above for non-financial firms.[130] Thus, there may exist a similar balance sheet channel for banks.[131] Elaborating on such a bank balance sheet channel, the balance sheet structure can be further disaggregated to relate to other aspects such as bank liquidity or bank capital. In this vein, Boivin et al. (2011) identify a bank capital channel as a separate bank-related channel.[132] The negative effect of loan losses on bank capital may lead to a deleveraging process restricting credit availability and reducing aggregate demand.[133]

Finally, the risk-taking channel has come to prominence since the financial crisis 2007-8. This channel traces the effects of monetary policy on different risk perceptions and risk pricing by agents.[134] The focus of the risk-taking channel is generally on expansionary monetary policy to discern the effects of prolonged low interest rates on (bank) behaviour.

[124] See Bernanke and Blinder (1988: 435f)
[125] See Kashyap and Stein (1994: 226)
[126] See Kashyap and Stein (1994: 221) and Disyatat (2011: 4)
[127] See Bernanke and Gertler (1995: 40f)
[128] See Disyatat (2011: 7)
[129] This is demonstrated by the discussion between loanable funds and endogenous money, see above. See also Disyatat (2011)
[130] See Disyatat (2011: 8)
[131] This possibility had already been noted by Bernanke et al. (1999: 1379).
[132] See Boivin et al. (2011: 382)
[133] See Boivin et al. (2011: 382f)
[134] See Borio and Zhu (2012: 237)

According to this channel, expansionary monetary policy can increase bank risk-taking.[135] This may increase the impact of monetary policy on the real economy and may also exacerbate boom-bust cycles.[136] Furthermore, the risk-taking channel can be disaggregated into different sub-mechanisms which link asset prices, target rates of return and central bank communications to the perception of and tolerance to risk.[137] As Dell'Ariccia, Laeven and Marquez (2014) show, these sub-mechanisms do not necessarily work in the same direction. In particular, with a fixed capital structure (as in the case of binding capital requirements, for instance), expansionary monetary policy induces banks with low leverage to lower their monitoring effort, while the reverse is true for banks with high leverage ratios.[138] Overall, the risk-taking channel appears to be a fertile ground for future research.

Importantly, none of the non-neoclassical channels of monetary policy works in isolation and independently of other channels. In particular, for any of the financial intermediation channels to have real effects, some form of nominal rigidity is still necessary.[139] Otherwise, nominal interest rate changes would only affect prices.[140] Furthermore, expectations concerning the future path of monetary policy are important determinants of transmission, as indicated in fig. 2.1 through the term inflation expectations. Indeed, Woodford (2003) argues that monetary policy is successful if it can form expectations about the policy rate and the implied path of economic activity and prices.[141] With policy interest rates at the zero lower bound, the issue of longer-term expectations has gained even more prominence. The shaping of these expectations by central bank communications has become known as forward guidance.[142] When policy rates are at the zero lower bound, there is no more potential to cut interest rates to stimulate demand. The intention of forward guidance is then to induce an increase in aggregate demand now by committing to keep policy rates low even after economic conditions would suggest a monetary tightening.[143]

More generally, how does this discussion inform the particular characterisation of monetary policy transmission as used in this study? First of all, the use of an NK DSGE model ensures that expectations play a crucial role and nominal rigidities allow for monetary non-neutrality. Furthermore, monetary policy is not passed through the financial sector as if it were a veil. Financial market imperfections such as asymmetric information incorporate the findings of the credit channel literature. To be specific, the model features

[135] See Borio and Zhu (2012: 242)
[136] See Borio and Zhu (2012: 248)
[137] See Borio and Zhu (2012: 242ff)
[138] See Dell'Ariccia et al. (2014: 66)
[139] See Kashyap and Stein (1994: 226)
[140] See Kashyap and Stein (1994: 226)
[141] See Woodford (2003: 15)
[142] See J. R. Campbell, Evans, Fisher and Justiniano (2012: 2f)
[143] See J. R. Campbell et al. (2012: 2)

the balance sheet channel, with respect to both non-financial firms and banks. This double balance sheet channel is the only non-neoclassical channel incorporated into the model. This is not to say that other channels are not or even less important, but they are abstracted from in order to keep the model and its analysis tractable.

The reasons for concentrating on this double balance sheet channel are manifold. Separating the effects of various channels is not only of analytical convenience but also helps in uncovering which channels are important in specific contexts and times. This study should thus be taken as a piece of a larger puzzle. Furthermore, as more and more channels are included, the contributions of the individual channels become more difficult to separate. The singular attention to the balance sheet channel as it works through non-financial firms' and banks' balance sheets helps to distinguish the impact of bank default.[144] The symmetric approach to modelling the financial friction associated with non-financial firms and banks facilitates the accomplishment of one of the research questions, namely discerning the relative importance of these two financial frictions. This would be more difficult using, for example, the bank lending channel approach. Admittedly, bank default may also affect monetary policy through other channels. Yet, in this regard, this study can be seen as a baseline: as will be shown, even in the absence of potentially higher bank fragility arising from a risk-taking channel, bank default and monetary policy are tightly interlinked. Therefore, for the purposes of this study, modelling the risk-taking channel is not necessary and its complications are abstracted from for simplicity. The additional layer of risk-taking is an interesting topic to be analysed in future research.

Touching on the issue of bank default, the possibility that a bank may not generate sufficient revenues to pay its creditors raises the question of the rationale for banks' existence. According to standard banking theory, banks have the functions of providing liquidity services and a payment system, asset transformation, risk management, information administration and monitoring.[145] Concerning non-neoclassical channels of the monetary transmission mechanism in general, information asymmetries justify the existence of financial intermediaries as separate economic entities. In this line of argument, banks are explained by referring to their ability to ameliorate asymmetric information problems or their consequences. Non-bank borrowers may have more information on their financial position, but banks' ability to collect information and monitor can moderate the moral hazard problem, for instance. In this sense, banks possess (superior) monitoring

[144] A similar reasoning applies to not incorporating all possible neoclassical transmission channels. For example, given the closed economy set-up, there is no space for an exchange rate channel. The most important neoclassical channel included in the banking model is the interest rate channel.

[145] See Freixas and Rochet (2008: 2)

capabilities which other agents have not.[146] Also, banks can be interpreted as specialised information processing agents, such that banks can extract a higher value than other agents in case projects (loans) are liquidated.[147]

Yet, if banks' liabilities are also subject to asymmetric information, these arguments are weaker. When banks have more information on their financial position, banks' creditors must also collect information and monitor banks. In this study, the existence of banks is still justified by their specific skill-set. Banks possess superior knowledge and monitoring skills than non-financial creditors with respect to lending to non-financial firms.[148] Accordingly, the financial friction associated with non-financial firms is more severe than the one of banks in the sense that non-bank investors still find it optimal to delegate the monitoring of non-financial firms to banks. Non-bank investors save entirely through banks. The explicit reasons for these superior abilities are left unspecified. As a result, banks are the only financial intermediaries and all financial funds are intermediated by banks.

In conclusion, various channels have been proposed for characterising monetary policy transmission through the banking sector. This study will concentrate on one particular channel, namely the balance sheet channel applied to non-financial firms and banks to discern the consequences of bank default. Some reasons for this choice have already been proposed in this section, with the following sections providing more. Before elaborating on the references to the theoretical literature, the next section will provide a short overview of the empirical literature on the link between monetary policy transmission and financial intermediation.

2.4 Empirical Literature on Financial Intermediation and the Monetary Policy Transmission Mechanism

From a theoretical perspective, financial intermediation has the potential to impact monetary policy. Yet, is this reflected in empirical results? This is the focus of this section. There are two layers to this question. Firstly, there is the question of whether the financial sector can be represented as a veil. Is the monetary policy impulse transmitted by the financial system one-to-one? This is addressed in numerous studies of interest

146 Holmstrom and Tirole (1997: 670), for instance, argue that financial intermediaries are the only agents that can monitor borrowers, since they can commit sufficient own capital and/or have an informational advantage.

147 See Angeloni and Faia (2009: 8) for a model where banks have superior extraction skills in the case of non-financial firm default due to an information advantage.

148 As will be shown in chapter 5, the absolute size of monitoring costs in percent of the collected assets is smaller in case of bank default than a non-financial firm's default for a given risk premium.

rate pass-through. As it turns out, pass-through is far from perfect, especially in the short run. So if the financial sector transforms the monetary policy impulse, the second layer concerns the determinants of this transformation. Studies in this group concern empirical analyses of the channels discussed above, as well as other potential features of the financial system which are only loosely related to the channels, such as banking sector competition. The following paragraphs will show that the empirical results are somewhat mixed concerning how features of the financial system affect monetary policy.

Pass-through of monetary policy impulses concerns the extent to which changes in the policy interest rate are reflected in retail loan and deposit interest rates at financial institutions. The empirical literature on this topic is vast, the interested reader is referred to de Bondt, Mojon and Valla (2005) and Kopecky and van Hoose (2012) as a starting point to the relevant literature.[149] The general result of this literature is that pass-through is incomplete both over the short and the long run.[150] For Germany, the studies by Weth (2002), Mueller-Spahn (2008) and Al-Eyd and Berkmen (2013) show that pass-through is incomplete and varying across bank products.[151]

One approach to explaining slow adjustment of retail interest rates is to consider the degree of competition in the banking sector. Many studies have found banking systems in various countries to be monopolistically competitive markets. For instance, Bikker and Haaf (2002) and Claessens and Laeven (2004) show that the banking sector in Germany as well as in many other countries is a monopolistically competitive market.[152] The recent cross-country study by Weill (2013) also finds that the German banking sector is a monopolistically competitive market.[153] As to the reasons for why banks should possess market power, switching costs as well as market concentration can be cited, for example.[154] The link between banking sector competition and monetary policy has also

[149] See de Bondt et al. (2005: 25f) and Kopecky and van Hoose (2012: 1186) and the references therein.
[150] This applies to various countries and time spans, see Kopecky and van Hoose (2012: 1186).
[151] See Weth (2002: 18f), Mueller-Spahn (2008: 9f), and Al-Eyd and Berkmen (2013: 15). Weth (2002: 18) finds that almost complete pass-through is achieved for mortgage lending rates in a few months; the author estimates the model over the period 1993-2000. Mueller-Spahn (2008) uses data between 2003 and 2006. The estimates of Al-Eyd and Berkmen (2013) are based on the time period 2003-2013.
[152] Both Bikker and Haaf (2002) and Claessens and Laeven (2004) study cross-country panel datasets on banks over the years 1988-1998 and 1994-2001, respectively. Both studies indicate monopolistic competition in the German banking sector, see Bikker and Haaf (2002: 2202) and Claessens and Laeven (2004: 572f). Bikker and Haaf (2002) also analyse subsamples of the banking sector. In Germany, restricting the focus to small and medium-sized banks supports the finding of monopolistic competition, while including only large banks yields the finding of a perfectly competitive market, see Bikker and Haaf (2002: 2201f).
[153] See Weill (2013: 106ff). Weill (2013) considers the time period between 2002 and 2010.
[154] See Gerali, Neri, Sessa and Signoretti (2010: 111). According to the structure-conduct-performance paradigm, market power can be a result of market concentration; menu costs such as fees for using specific bank services as well as asymmetric information problems can give rise to switching costs which make it costly for bank customers to switch banks, resulting in bank market power, see Gerali et al. (2010: 111).

been studied. In an early study, Cottarelli and Kourelis (1994) present empirical evidence that, among others, regulatory impediments to competition in the banking sector inhibit pass-through by making loan rates stickier.[155] Also, Mojon (2000) finds that competition increases monetary pass-through.[156] From this perspective, the issue of limited interest rate pass-through can be treated in a similar way as prices and nominal wages in assuming a departure from perfect competition and some form of rigidities in the price-setting behaviour of banks.[157]

In addition to this explanation in terms of market structure, various other factors have been studied in the literature. Given the vastness of the literature and the space limits here, the following examples are collected from studies about German banks. For one, Schlüter, Busch, Hartmann-Wendels and Sievers (2012) argue that cost efficiency affects the interest rate setting behaviour of banks and thus interest rate pass-through.[158] Mueller-Spahn (2008) reports different pass-through estimates for different German banking groups.[159] Also, bank size has been found to impact interest rate pass-through.[160] Concerning other balance sheet characteristics, bank leverage, liquidity and the shares of saving deposits in banks' liabilities and of long-term non-bank loans in banks' balance sheets have been reported as determinants of interest rate pass-through to lending rates.[161] However, the results on these different determinants are not unambiguous: For the shares of deposits and loans in banks' balance sheet considered by Weth (2002), the higher the respective share, the lower is the interest rate pass-through.[162] In contrast, Mueller-Spahn (2008) reports that a lower diversification of banks' balance sheet leads to increased pass-through.[163] In conclusion, empirical studies suggest that the interest rate pass-through is not complete at least in the short run, but the factors impacting the pass-through are manifold.

Nevertheless, analysing the pass-through from policy or money market rates to lending and deposit rates and its potential determinants reflects only one part of the financial intermediation process. Another important part is the evolution of the credit volume. Based on the bank lending channel view, Kashyap and Stein (2000) argue, for example,

155 See Cottarelli and Kourelis (1994: 32). Cottarelli and Kourelis (1994) use a cross-country dataset for the time between 1980 and 1993.

156 See Mojon (2000: 8). Mojon (2000) studies a subset of Euro area countries for the time period 1979-1998.

157 Theoretical models on this issue have been proposed by Kopecky and van Hoose (2012) in a partial equilibrium setting, and Gerali et al. (2010) in a DSGE model framework.

158 See Schlüter et al. (2012: 47), URL in list of references, their dataset comprises the time between 2003 and 2008.

159 See Mueller-Spahn (2008: 14, 18)

160 See Weth (2002: 22) and Mueller-Spahn (2008: 14, 20)

161 See Weth (2002: 22f), Mueller-Spahn (2008: 14) and Al-Eyd and Berkmen (2013: 15)

162 See Weth (2002: 22f)

163 See Mueller-Spahn (2008: 14). Diversification is defined as the degree to which total income originates from interest income, see Mueller-Spahn (2008: 12).

that banks with a more liquid asset portfolio do not have to cut lending (as much) when deposits are withdrawn, but can instead also reduce their liquid assets.[164] Using bank-level data Kashyap and Stein (2000) provide empirical support for the existence of the bank lending channel in the US.[165] In particular, small banks with less liquid balance sheets contract lending comparatively more after a monetary policy tightening.[166] Furthermore, Kishan and Opiela (2006) found a similar result using bank capital as the determining feature of the bank lending channel.[167] Concerning the Euro area (EA), studies conducted within the context of the Monetary Transmission Network at the turn of the century report results that are in line with both the balance sheet and the bank lending channels at a disaggregated level.[168] Here, balance sheet liquidity appears to be a determinant of the bank lending channel, and not the level of bank capital.[169]

Concerning Germany, the empirical results on this topic are mixed. In early studies, Ehrmann et al. (2001), Hülsewig (2003) and Worms (2003) provide support for a credit channel[170] based on bank loan supply changes.[171] Furthermore, in line with other EA countries Ehrmann et al. (2001) and Worms (2003) show that liquidity is a determinant of how a bank's loan volume changes after a monetary policy shock, while size is not.[172] In contrast, the results by Favero, Giavazzi and Flabbi (1999) and Küppers (2001) do not support the bank lending channel.[173]

What is more, not only do results differ concerning the existence of bank-specific influences, but also on the direction of the effects. Küppers (2001) and Kakes and Sturm (2002) find that responses to monetary policy vary for different banking groups.[174] In line with Kashyap and Stein (2000), Kakes and Sturm (2002) find that lending by the largest banks

[164] See Kashyap and Stein (2000: 409)
[165] See Kashyap and Stein (2000: 425), they use data ranging from 1976 to 1993.
[166] See Kashyap and Stein (2000: 424f)
[167] See Kishan and Opiela (2006: 282), the study uses US data for the time 1980 to 1999. The argument for bank capital as a distinguishing feature is that banks with a lower capital base encounter more problems when trying to shift from insured to non-insured deposits following contractionary monetary policy, see Kishan and Opiela (2006: 262f).
[168] See European Central Bank (2010: 86)
[169] See European Central Bank (2010: 86) and Ehrmann, Gambacorta, Martínez-Pagés, Sevestre and Worms (2001: 29ff)
[170] In general, the credit channel is an umbrella term for both non-financial firms' balance sheet channel and the bank lending channel, see Bernanke and Gertler (1995: 34f).
[171] See Ehrmann et al. (2001: 29ff), Hülsewig (2003: 24), and Worms (2003: 192). The dataset of Ehrmann et al. (2001) covers the years 1988 to 2000 for different European countries, 1994 to 1998 for Germany. Hülsewig (2003) covers the time between 1975 and 1998. Worms (2003) uses the data range 1992–1998.
[172] See Worms (2003: 187) and Ehrmann et al. (2001: 29ff)
[173] See Favero et al. (1999: 12) and Küppers (2001: 1922ff). The study by Favero et al. (1999) uses a case-study approach for the year 1992 where monetary tightening took place in Europe. Küppers (2001) uses data for the time 1969–1996.
[174] See Küppers (2001: 1922ff) and Kakes and Sturm (2002: 2086f). Kakes and Sturm (2002) cover the time between 1975 and 1997.

does not change much after a monetary policy shock while generally smaller credit cooperatives decrease both their lending and liquid assets.[175] To the contrary, Küppers (2001) finds that the largest banks in Germany experience a drop in their loan volume following contractionary monetary policy, while this is not true for generally smaller savings banks and credit-cooperatives.[176] These conflicting results may be partially aligned by the results by Worms (2003) who emphasises that the structure of the banking sector is important and interbank deposits are crucial for explaining the insignificance of bank size.[177] Through their integration into a large network, small savings and cooperative banks can reduce their interbank deposits in the respective network in order to protect their loan portfolio.[178]

A similar conflicting picture arises from more recent studies. Eickmeier, Hofman and Worms (2009) do not find conclusive evidence in favour of a bank lending channel but point to the difficulties in disentangling loan supply and demand effects.[179] In contrast, de Santis and Surico (2013) find evidence in favour of the bank lending channel.[180] Also, the findings by Puri, Rocholl and Steffen (2011) support the existence of a bank lending channel during the financial crisis 2007-8. German savings banks affected by the crisis in the US subprime market accepted fewer loan applications than non-affected banks.[181] Furthermore, they identify bank size and liquidity as further determinants of this effect.[182] Somewhere in between, Arnold, Kool and Raabe (2011) find bank size and liquidity to be indicators of the bank lending channel, but not capitalisation.[183] However, Arnold et al. (2011) emphasise that their results are dependent on the specific sector to which loans are granted.[184] Conceding the caveat that different results may be due to differing econometric methodologies and datasets, these diverging results point to the difficulties in disentangling loan demand and supply effects.

To summarise the previous discussion, empirical studies indicate that banks' balance sheets play a role in monetary policy transmission. Similar to the literature on pass-through, the determinants vary. The difficulties in separating demand and supply effects which

[175] See Kakes and Sturm (2002: 2086). Yet lending by savings banks increases after a monetary policy shock, see Kakes and Sturm (2002: 2086f).
[176] See Küppers (2001: 1922)
[177] See Worms (2003: 188f)
[178] See Worms (2003: 191)
[179] See Eickmeier et al. (2009: 216f), their data ranges from 1985 to 2005.
[180] See de Santis and Surico (2013: 440), they use a dataset for different European countries, among them Germany, from 1999 to 2011. They find different variables (size, liquidity, capitalisation) to be significant in different regressions, especially when the dataset is disaggregated to study bank heterogeneity, see de Santis and Surico (2013: 440ff).
[181] See Puri et al. (2011: 566), they use data on German savings banks from July 2006 to June 2008. 'Affected' banks are those whose corresponding Landesbank announced losses due to the financial crisis, see Puri et al. (2011: 562).
[182] See Puri et al. (2011: 578)
[183] See Arnold et al. (2011: 15f). They use data on Germany covering the years 1992 to 2002.
[184] See Arnold et al. (2011: 16)

come with the focus on volumes constitute a further reason for not explicitly modelling the bank lending channel but to concentrate on the broader balance sheet channel.

However, how important is the effect of banks' balance sheets vis-à-vis non-financial firms' balance sheets?[185] Some studies have aimed to compare these two channels. Meisenzahl (2014) compares the non-financial firm and bank balance sheet channels.[186] Meisenzahl (2014) concludes that the non-financial firm balance sheet channel plays a large role while the bank balance sheet channel does not.[187] In contrast, in a DSGE model-based exercise, Villa (2013) finds that the model in which imperfections arise from the interactions of financial intermediaries with their stakeholders fits better to EA data than the model where distortions arise from information asymmetries between non-financial firms and banks.[188]

These contradictory findings suggest that the significance of either channel is context-dependent. In particular, Jimenéz, Ongena, Peydró and Saurina (2012) find that banks' balance sheets primarily play a role in crisis times, but not during normal times.[189] In contrast, non-financial firms' balance sheets affect loan-granting both in normal and even more in crisis times.[190] Ciccarelli, Maddaloni and Peydró (2013) analyse monetary policy transmission in 'stressed' and 'non-stressed' EA countries beginning with the recent financial crisis. They find the non-financial firm balance sheet channel to be important over the whole period for stressed countries, while the bank balance sheet channel is only important during crisis times.[191] The authors argue that the insignificance of bank-related characteristics after 2009 is due to the full allotment policy of the ECB.[192] Finally, Ciccarelli, Maddaloni and Peydró (2010) find evidence in support of both parts of the credit channel.[193] Furthermore, the relative impact of the two sub-mechanisms of the credit channel varies for different loan products.[194] Taking these results together, there is an indication for a more prominent role of the non-financial firm balance sheet channel while banks' balance sheets become especially important in financial crises.

[185] In the spirit of a streamlined and focused exposition, the vast empirical literature on the non-financial firm balance sheet channel is not reviewed here. The interested reader is referred to Beck, Colciago and Pfajfar (2014: 3) as a starting point.

[186] The non-financial firm balance sheet channel is based on a costly state verification problem, while the bank balance sheet channel is derived from a moral hazard problem along the lines of Holmstrom and Tirole (1997), see Meisenzahl (2014: 60ff).

[187] See Meisenzahl (2014: 75). The study is based on US data between 1998 and 2003.

[188] See Villa (2013: 5). Villa (2013: 5) compares a Bernanke et al. (1999) model to a Gertler and Karadi (2011) model and estimates them on EA data from 1980 to 2008.

[189] See Jimenéz et al. (2012: 2). They use data on banks in Spain between 2002 and 2010.

[190] See Jimenéz et al. (2012: 3)

[191] See Ciccarelli et al. (2013: 23f), their study analyses EA countries over the time 2002-2011.

[192] See Ciccarelli et al. (2013: 24)

[193] See Ciccarelli et al. (2010: 11), their data span the years 2002 to 2009 for the EA and 1992 to 2009 for the US.

[194] See Ciccarelli et al. (2010: 12)

Given that only recently attention was directed to the risk-taking channel, the empirical literature is still developing. Maddaloni and Peydró (2011) find evidence that low policy rates induce softer lending standards in the US and European countries.[195] Using US data from 1997 to 2008, Buch, Eickmeier and Prieto (2014) find that the banking system as a whole does not engage in additional risk-taking in response to looser monetary policy.[196] However, when looking at different groups of banks, there are significant differences. In contrast to large banks and foreign banks, small banks engage in additional risk-taking.[197] Thus, while they do not find a risk-taking channel working in the aggregate, the risk-taking channel appears to be active for small banks.[198] Similarly, the studies by Dell'Ariccia, Laeven and Suarez (2013) and Jiménez, Ongena, Peydró and Saurina (2014) both provide support for a risk-taking channel of expansionary monetary policy, yet again with conflicting results.[199] Dell'Ariccia et al. (2013) show that the risk-taking channel is less strong for banks with a comparatively low capital base.[200] This is in contrast to the findings of Jiménez et al. (2014) which indicate that it is poorly capitalised banks to whom the risk-taking channel appears to apply.[201] Thus, research on the risk-taking channel so far has shown that banks' balance sheet position is not only relevant in terms of the credit channel, but can also be a factor in other aspects of bank behaviour. These results show that there is space for a risk-taking channel, but more research is needed on its determinants and specific characteristics.

Turning to the issue of banking sector fragility, Blank et al. (2009) study the interrelatedness in the German banking system as a factor in a banks' distress frequency.[202] The authors find that adverse shocks to large banks lead to an increase in the probability of distress of small banks.[203] Furthermore, de Graeve et al. (2008) find significant effects of monetary policy on banks' distress frequency.[204] In particular, the authors find that contractionary monetary policy leads to an increase in banks' distress probability.[205] Besides, de Graeve et al. (2008) also find that the degree of bank capitalisation has an

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195 See Maddaloni and Peydró (2011: 2150), they use bank lending surveys between 2002 and 2008.
196 See Buch et al. (2014: 23)
197 See Buch et al. (2014: 24)
198 See Buch et al. (2014: 27). The authors also find that new riskier loans are shorter in maturity and tend to be backed by collateral more frequently. Thus, the risk appears to be taken into account by these small banks. See Buch et al. (2014: 27)
199 See Dell'Ariccia et al. (2013: 18), who use US loan rating data for the period 1997 to 2011, and Jiménez et al. (2014: 499), who use data on banks in Spain from 2002 to 2008.
200 See Dell'Ariccia et al. (2013: 18)
201 See Jiménez et al. (2014: 493, 499)
202 Blank et al. (2009: 354) use data on individual German banks from 1994 to 2004. The term 'distress' covers a variety of situations not restricted to explicit default, from mandatory announcements to closure, see Blank et al. (2009: 359).
203 See Blank et al. (2009: 354)
204 de Graeve et al. (2008) use data on individual German banks for the time 1995–2004.
205 See de Graeve et al. (2008: 207f)

impact on this effect.[206] Thus, again banks liability structure is a significant feature. Therefore, there appears to be a link between monetary policy and banking sector fragility.

Taken together, these empirical studies suggest that banks play an important role in the monetary transmission process. As is clear from sometimes contradictory results, the involved processes are highly complex. While there are indications for specific important factors, the exact details remain elusive, as well as time- and context-dependent. Aiming for an even slightly exhaustive representation in this study would not only be presumptuous but would also miss the point. On the one hand, banks' balance sheets have appeared to be an influential factor in many studies. On the other hand, the results are inconclusive as to the explanatory power of volume effects. This informs the focus on the broader balance sheet channel instead of the bank lending channel.

Particular aspects are also abstracted from to keep the analysis tractable, as has been argued before. Apart from the focus on one non-neoclassical channel, this study will also not deal with explicit interest rigidities as evidenced by interest rate pass-through studies.[207] Consequently, the model also abstracts from imperfect banking sector competition. The reasoning is similar to the exclusion of the risk-taking channel: interest rate rigidities introduce a further layer of effects which are not essential to the research question.

Moreover, the fact that the financial friction on each side of banks' balance sheet is modelled in a similar fashion helps contribute to another question raised above: the relative impact of information asymmetries in the loan market vis-à-vis the markets for bank liabilities. Therefore, as a corollary of the research question, this study can provide model-based statements about the importance of the two financial frictions along the lines of Meisenzahl (2014), applied to German data. The fact that crisis times are not studied here does not preclude such an analysis. The links between financial crises and macroeconomic developments have been examined extensively before.[208] The interesting question for this study is the relative importance of bank-related to non-financial firm-related information asymmetries for macroeconomic developments in 'normal' business cycles. Financial crises have occurred relatively infrequently in the past. The start and end points of business cycles tend to have a higher frequency, which means that it is equally important to discern the effects of banking sector fragility in normal times.

Overall, the previous sections discussed the link between monetary policy and financial

206 See de Graeve et al. (2008: 208)

207 A model with monopolistic competition in banking with sticky interest rates has been proposed by Gerali et al. (2010) and is used frequently in the literature as a building block, see Angelini, Neri and Panetta (2012) and Hollander and Liu (2016), for instance.

208 See, for example, Reinhart and Rogoff (2009)

intermediation on a general basis. Also, various reasons have been presented for the methodological approach and features of the model used in this study. The justification for the more specific aspects implemented in the model is delegated to chapter 3 along with a detailed presentation. Beforehand, the next section will conclude with the discussion about various strands of the literature which are more closely-related to this study. The presentation will progress along the aspects of modelling financial sector frictions in macroeconomic models, from general issues to specificities of the nature of bank default.

2.5 Locate the Research: on Banking Sector Fragility in the Literature

This section surveys the literature on frictions associated with financial intermediaries' liabilities to show how the present study relates to various approaches in the literature. Since this study principally concerns the financial friction on banks' liability side, the interested reader is referred to Beck et al. (2014) and Gerke et al. (2013) for a guide to the literature on financial frictions between non-financial firms and financial intermediaries.[209] As is clear from previous discussions, this study is related to the literature on the interconnections between monetary policy and financial intermediaries at a general level. However, at this level, comparisons are quite blunt.[210] To this end, the following paragraphs will relate several aspects of this study to similar or diverging approaches in the literature. The section starts with a short overview of the approaches to modelling financial frictions. Then, key aspects are dealt with, concerning the question of endogenous or exogenous bank leverage, the nature of bank capital, possibilities for modelling bank default, and more specific issues of deposit insurance and the relationship between the returns on different bank liabilities. This section closes by distinguishing the particular modelling contribution of this thesis.

The literature on financial frictions in macroeconomic models is vast. There are four prominent approaches to modelling financial frictions: Bernanke et al. (1999) (BGG), Kiyotaki and Moore (1997) (KM), Holmstrom and Tirole (1997) (HT) and Gertler and Karadi (2011) (GK).[211] BGG postulate an agency problem between non-financial firms and banks to derive a spread, the external finance premium, between internal and external

[209] See Beck et al. (2014: 5f) and Gerke et al. (2013: 254)

[210] General overviews of the field are provided by Beck et al. (2014) and Gerke et al. (2013). Furthermore, Borio and Zhu (2012) present a meta-analysis of the literature related to the study of bank capital.

[211] Both BGG and KM deal with the financial situation of non-financial firms. In the following years, these approaches have been used and developed extensively. Nonetheless, both approaches are equally applicable to the financing situation of other agents such as banks.

financing costs of non-financial firms.[212] Endogenous changes in borrowers' leverage affect the external finance premium and amplify the economy's reaction to monetary policy.[213] In contrast, the approach by KM is based on an explicit collateral constraint.[214] Then, the value of the collateral asset determines the available loan volume and through this the level of investment.[215] As a consequence, the economy's response to exogenous shocks is both more persistent and amplified.[216]

HT and GK propose models in which financial intermediaries play a key role. HT postulate a double moral hazard problem affecting both non-financial firms and financial intermediaries.[217] The HT model works as follows: non-financial firms (borrowers) can choose projects with different risk profiles, with riskier projects being better from the point of view of non-financial firms, while lenders prefer safer projects.[218] To moderate the moral hazard problem, banks monitor non-financial firms so they cannot choose the worse of the risky projects.[219] However, monitoring involves private costs for banks, thus creating another moral hazard problem.[220] In the end, this set-up leads to both non-financial firms and banks being capital-constrained.[221] Then, the amount of capital of non-financial firms and banks as well as their relative sizes affect real investment.[222] Finally, GK postulate a model of non-financial firm equity financing with a moral hazard problem between financial intermediaries and their investors. The possibility that bank managers can abscond part of their borrowed funds leads to an endogenous leverage constraint on banks.[223] GK use the model to analyse unconventional monetary policy and find benefits to direct central bank intermediation in a financial crisis.[224]

This study uses the modelling approach of BGG for both sides of banks' balance sheet. In addition to the reasons presented before, this choice is governed by the analytical ease

212 See Bernanke et al. (1999: 1345, 1348). See also the discussion about the balance sheet channel above. The work of Bernanke et al. (1999) itself draws, among others, on the previous work of Carlstrom and Fuerst (1997) in a real business cycle model context, see Bernanke et al. (1999: 1378).
213 See Bernanke et al. (1999: 1345, 1371)
214 See Kiyotaki and Moore (1997: 212)
215 See Kiyotaki and Moore (1997: 212)
216 See Kiyotaki and Moore (1997: 212)
217 See Holmstrom and Tirole (1997: 663ff). The model by HT is essentially a partial equilibrium model, but has been applied to a dynamic (stochastic) general equilibrium context, see for instance Chen (2001) and Meh and Moran (2010).
218 Non-financial firms enjoy private benefits by choosing projects with a low success probability, see Holmstrom and Tirole (1997: 667f). Yet, only projects with higher success probabilities produce a positive pay-off when investment costs are taken into account, see Holmstrom and Tirole (1997: 668).
219 See Holmstrom and Tirole (1997: 667ff)
220 See Holmstrom and Tirole (1997: 669)
221 See Holmstrom and Tirole (1997: 663)
222 See Holmstrom and Tirole (1997: 686)
223 See Gertler and Karadi (2011: 21, 32)
224 See Gertler and Karadi (2011: 32f)

of incorporating default.[225] For instance, default of non-financial firms and bank default are not treated explicitly in GK and KM.[226] In HT, the main model mechanism revolves around the respective volumes of bank (and non-financial firm) capital which determine the degree to which banks can attract loanable funds.[227] While projects and thus loans can fail in HT, this loanable funds basis runs counter the intention to model the balance sheet channel for both non-financial firms and banks in this study. What is more, the resulting symmetry of financial frictions on both banks' asset and liability sides using the BGG approach is well-suited to study the additional effect of bank default as well as to compare the relative impact of each financial friction. Thus, the choice in favour of the BGG modelling approach is based on the specific research question of this study.[228]

Having presented general approaches to modelling financial frictions, the next paragraphs will turn to the more specific strands this study is related to. For one, this study concerns the literature on the determination of bank leverage. A popular approach is to assume explicit capital constraints. Exogenous capital constraints simplify the model solution when leverage is indeterminate in the steady state.[229] Furthermore, in analysing macroprudential policy an exogenous capital constraint allows for a simple mapping from (binding) banking regulation. Examples of this approach are Kollmann (2013) and Benes, Kumhof and Laxton (2014). In Kollmann (2013), banks face a capital constraint and have to pay penalty fees if they fail to hold the required level of capital.[230] They find that adverse shocks to bank capitalisation lead to sizeable reductions in real activity.[231] In Benes et al. (2014) banks also pay penalty fees if their capital is below a certain threshold.[232] Furthermore, Benes et al. (2014) argue that mistakenly optimistic banks in combination with negative shocks can result in a financial crisis in their model with adverse consequences for the real economy.[233]

Yet, in the banking model presented in the next chapter, bank leverage is determined endogenously. This can be rationalised by arguing that exogenous capital constraints imply that capital adequacy ratios are always binding which may not be an adequate

[225] For more details on the specific model design, see chapter 3.
[226] See Gertler and Karadi (2011: 27f) and Kiyotaki and Moore (1997: 212f). In Gertler and Karadi (2011: 21), the threat of bank resolution is part of the approach in rationalising the endogenous leverage constraint, but does not occur as such. Clerc et al. (2014: 6) argue that banks can possibly fail in papers using the KM approach, but this possibility is excluded by equilibrium conditions.
[227] See Holmstrom and Tirole (1997: 675f, 690) and Meh and Moran (2010: 555f)
[228] In contrast, a study on the risk-taking channel may be more adequately conducted using the HT approach, for instance.
[229] See the discussion in section 4.1.
[230] See Kollmann (2013: 164f), they use an open-economy layout and estimate their model using US and EA data.
[231] See Kollmann (2013: 182)
[232] See Benes et al. (2014: 22, 26f).
[233] See Benes et al. (2014: 47)

representation of reality. Furthermore, the primary focus here is on monetary policy, not macroprudential policies. It is illustrative to examine the consequences of bank default without any bank capital regulation in place, and then extend and compare with the case when macroprudential policies are introduced.[234] The analysis under the assumption that bank leverage is unconstrained in the benchmark model allows to focus on the consequences of the financial friction under scrutiny. Moreover, various authors have proposed endogenous bank leverage models. As already mentioned above, models using the GK framework generate an endogenous leverage constraint as a result of the moral hazard problem. Van der Kwaak and van Wijnbergen (2014), for example, extend the GK moral hazard problem to evaluate the link between sovereign risk and financial fragility.[235] In their model, endogenous bank leverage, sovereign risk and financial fragility are tightly linked and a deterioration in one or more of these factors has adverse consequences for the real economy.[236] Thus, the choice for endogenous bank leverage can additionally be justified by the prominent role it plays in these models. Related, Nuño and Thomas (2012) build a model where one part of the banking sector faces a capital constraint while the other does not.[237] On the basis of their results, Nuño and Thomas (2012) provide an argument for leverage to be determined endogenously in macroeconomic models.[238]

A second question relates to the nature of bank capital. The majority of papers assumes inside capital, that is bank capital accumulated from retained earnings of the banking business, such as in Benes et al. (2014) and Meh and Moran (2010). In applying the HT approach to a DSGE model, Meh and Moran (2010) show that negative shocks to bank capital have adverse effects for the economy.[239] Moreover, van der Kwaak and van Wijnbergen (2014) use this definition of bank capital to study the effects of bank bail-outs.[240] While this definition of bank capital lends itself naturally to research questions about bail-outs, the concept of bank capital used in this study is better suited to analyse the choice of liability structure as a result of supply and demand. Hence, this study is more closely related to papers modelling bank capital as outside or marketable equity held by households.

In particular, this study is similar to Abbate and Thaler (2014) in its concept of bank

[234] The analysis of macroprudential policies in chapter 6 aims to gauge how the benchmark results are affected by potential macroprudential policies on an ad-hoc basis.
[235] See van der Kwaak and van Wijnbergen (2014: 223, 236)
[236] See van der Kwaak and van Wijnbergen (2014: 236)
[237] See Nuño and Thomas (2012: 19), they calibrate their model to US data.
[238] See Nuño and Thomas (2012: 27). Nuño and Thomas (2012: 27) find that when leverage is exogenously imposed, it moves acyclically with bank assets while an endogenous leverage specification leads leverage to move pro-cyclically with assets. As Nuño and Thomas (2012: 12) argue, only the latter observation is in line with the reported positive correlation of assets and leverage of financial intermediaries in the data.
[239] See Meh and Moran (2010: 574)
[240] See van der Kwaak and van Wijnbergen (2014: 233f)

equity in that equity holders enjoy limited liability and receive any profits from the banking business after deposit holders have been paid out.[241] However, in contrast to this study, Abbate and Thaler (2014) posit an agency problem in that equity holders choose a more or less risky project in order to study the risk-taking channel of monetary policy.[242] The authors find that low policy rates lead to a higher bank leverage ratio and a riskier bank asset profile.[243] The model presented in the next chapter will instead allow for a complete diversification of individual loan risk. Banks are themselves subject to idiosyncratic shocks leading some banks to default. This assumption is in line with Kiley and Sim (2014), for example.[244] Kiley and Sim (2014) study the impact of bank capitalisation on asset prices and the real economy and show that increasing costs associated with raising new equity lead to adverse consequences for the real economy.[245] Yet, while Kiley and Sim (2014) assume marketable bank equity similar to this study, they include the possibility of additional equity issuance.[246] In contrast, this study assumes limited liability for bank shareholders.[247] Recent research has also aimed at combining these two concepts of bank capital in a single model, as in Gertler et al. (2012).[248]

Furthermore, this study is not only concerned with different bank liabilities but more specifically with banking sector fragility. There are a number of papers which address bank default. Two of the approaches differ in their assumption about banks' ability to diversify loan risk. The first approach assumes that bank default is a direct consequence of non-financial firms' default while the second approach uses idiosyncratic bank shocks to generate bank default. As an example of the former approach, Dell'Ariccia et al. (2014) propose a partial equilibrium model in which banks choose the level of monitoring to reduce loan risk.[249] The authors analyse the risk-taking channel and find that expansionary monetary policy results in higher bank leverage and lower monitoring effort.[250]

241 See Abbate and Thaler (2014: 13)
242 See Abbate and Thaler (2014: 2, 13)
243 See Abbate and Thaler (2014: 16)
244 See Kiley and Sim (2014: 179)
245 See Kiley and Sim (2014: 175, 186, 197)
246 See Kiley and Sim (2014: 177f). In Kiley and Sim (2014: 180) banks face a binding capital constraint.
247 Furthermore, this thesis does not deal with bank re-capitalisation. As will be explained in chapter 3, if bank revenues plus bank equity are insufficient to cover a bank's borrowing costs, then it defaults and ceases to exist. Further governmental intervention, such as bank bailouts mentioned above, are not considered here. This is consistent with the focus on non-systemic bank failures.
248 Gertler et al. (2012) provide an extended model of Gertler and Karadi (2011) which includes both inside and outside bank equity. While a higher level of internal net worth allows for higher credit creation (ceteris paribus), higher outside equity allows the bank to divert funds more easily and thus tightens banks' leverage constraint, see Gertler and Karadi (2011: 21) and Gertler et al. (2012: S22f). They argue that outside equity can act as a buffer when inside equity (due to lower accumulated profits or asset prices) declines, see Gertler et al. (2012: S23, S27). However, this depends on the larger disciplinary power of deposits than outside equity which runs counter the modelling approach of risk-free deposits followed here, see Gertler et al. (2012: S22).
249 See Dell'Ariccia et al. (2014: 66)
250 See Dell'Ariccia et al. (2014: 86f)

Several papers have used the second approach in applying the BGG framework, that is idiosyncratic bank shocks. Darracq Pariès, Jacquinot and Papadopoulou (2016), for example, propose a large scale, multi-country DSGE model with various layers of default including bank default along the lines of BGG.[251] Darracq Pariès et al. (2016) use the model to trace the financial crisis in the EA and argue that sovereign stress, fragile banks and capital requirements were important factors contributing to the economic developments.[252] Also, Clerc et al. (2014) propose a model incorporating default for multiple agents in this way.[253] Clerc et al. (2014) show that high bank leverage leads to more volatility in the real economy and that capital regulation reduces leverage and bank fragility.[254]

Furthermore, these two approaches to modelling bank default are not mutually exclusive. In Badarau and Popescu (2015) bank default arises as a direct consequence of non-financial firms' default and more generally if a bank's revenues are insufficient to cover its liabilities.[255] The authors examine how monetary policy can enhance financial stability. To this end, they study the monetary policy response to a financial bubble and find that a standard monetary policy rule cannot counter financial instability.[256] Furthermore, even in the cases when the central bank acted against financial imbalances, it had to forego price stability to some extent for the improvement in financial stability.[257] In chapter 6, this study will also touch on these issues. Concerning the modelling approach, there is a crucial difference between this study and Clerc et al. (2014), Darracq Pariès et al. (2016) and Badarau and Popescu (2015): these authors use the concept of inside bank capital.[258] Thus, the agency problem is more properly described as existing between deposit-holders and the bank (even though there may be deposit insurance), whereas in the model proposed here the agency problem à la BGG exists between the bank and equity-holders. This assumption will turn out to have a decisive impact on the role of bank equity.

251 See Darracq Pariès et al. (2016: 10ff)
252 See Darracq Pariès et al. (2016: 38f)
253 See Clerc et al. (2014: 6). The layout in Clerc et al. (2014) is similar to the model proposed in this study in that there also exists a deposit insurance scheme. Yet, in Clerc et al. (2014: 13), the deposit insurance scheme is funded by lump-sum taxes and the return on bank deposits is subject to a risk premium. In the model proposed in this study deposit insurance enters the optimisation problem of banks and bank deposits earn the risk-free return. Moreover, this study derives an incentive compatibility constraint on the part of households which together with the asset demand equations determines bank leverage. In contrast, Clerc et al. (2014: 13, 27) study capital regulation and to this end determine leverage by (binding) regulation and introduce a separate agent who supplies bank equity.
254 See Clerc et al. (2014: 8)
255 See Badarau and Popescu (2015: 362f)
256 See Badarau and Popescu (2015: 372)
257 See Badarau and Popescu (2015: 372). On this basis the authors argue for a separate (macroprudential) instrument to counter financial instability.
258 The framework with a separate agent who supplies bank equity in Clerc et al. (2014) can be deemed more similar to the concept of internal bank capital, that is accumulated from retained earnings, than to the one used in this study, see also footnote 253.

This relates to the matter of bank deposits being risk-free or not. The possibility of bank deposits being subject to cuts connects to the third modelling approach to bank default: bank runs. In contrast to above approaches, default due to bank runs does not necessarily need to be grounded in insufficient bank assets but rather in their illiquidity. For example, Angeloni and Faia (2013) use a model with bank runs to argue that the risk-taking channel is active following expansionary monetary policy.[259] Meanwhile, bank runs are explicitly ruled out here due to a deposit insurance scheme. As Diamond and Dybvig (1983) show in a multiple-equilibria model, deposit insurance can eliminate the risk of bank runs and thus improve on an undesirable equilibrium.[260] Thus, in modelling the liability structure of banks, deposit insurance is a means to generate a view among households that bank deposits are risk-free even though banks are fragile.[261]

In this vein, Collard, Dellas, Diba and Loisel (2012) and Gornicka and van Wijnbergen (2013), for instance, propose models where households hold both bank deposits and bank equity, and deposit insurance ensures that bank deposits pay the risk-free policy return.[262] While the deposit insurance scheme as such is not the most important feature in these models, it constitutes a similarity with the study presented here. However, in contrast to this study, Collard et al. (2012) and Gornicka and van Wijnbergen (2013) assume that the outlays of the deposit insurance fund are financed by the general government budget or by lump-sum taxes.[263] In contrast, as is practised in Germany, this study assumes that deposit insurance fees are levied on banks' to cover outlays in case of bank default.[264] Only any additional shortfall is borne by the government budget. Thus, deposit insurance is explicitly incorporated in the optimisation problem of banks.[265]

[259] See Angeloni and Faia (2013: 313, 317)

[260] See Diamond and Dybvig (1983: 402, 404)

[261] As argued by Clerc et al. (2014: 6f), deposit insurance may also create an incentive distortion for banks to take on too much risk. Clerc et al. (2014: 27) approach this issue by imposing binding bank capital regulation to offset this distortion. In contrast, in the model proposed here, deposit insurance fees aim to internalise part of the costs of bank default.

[262] See Collard et al. (2012: 4, 9f) and Gornicka and van Wijnbergen (2013: 8). While the study by Collard et al. (2012) shares some characteristics with the present study (see below), there are some notable differences. Firstly, Collard et al. (2012: 8, 10) impose a binding leverage constraint on banks. Secondly, the financial friction Collard et al. (2012: 6ff) impose on bank lending is different to the BGG approach in that the authors model loans with different risk profiles and constant monitoring of safe loan projects.

[263] See Collard et al. (2012: 9f). Gornicka and van Wijnbergen (2013) do not specify the financing structure of the deposit insurance fund in their partial equilibrium model.

[264] See chapter 3 for more details on the particular implementation.

[265] Related, the model also features minimum reserves. However these are merely an auxiliary modelling device. In general, the functioning and role of minimum reserves is a debated topic. One may argue in favour that they increase the resilience of the payments system. Yet, the recourse to this explicit justification is not necessary. For example, Roger and Vlcek (2011: 6) assume a liquidity requirement which mandates banks to hold a certain percentage of their balance sheet volume as liquid (government) securities. These government securities simply finance government spending, see Roger and Vlcek (2011: 6).

The assumption about bank deposits being risk-free is tightly linked to the distribution of returns on bank liabilities. In the papers considered, bank equity is generally assumed to be more expensive than bank deposits. There are various motivations for this spread. Firstly, in a partial equilibrium framework, Repullo and Suarez (2008) simply assume an ad-hoc premium on equity financing.[266] Secondly, Collard et al. (2012) assume that there is an ad-hoc tax distortion which favours debt.[267] Thirdly, Abbate and Thaler (2014) produce an equity premium as in Dell'Ariccia et al. (2014) due to an exogenous constant cost of holding equity.[268] Fourthly, Covas and Fujita (2010) assume that equity issuance costs lead to more expensive equity.[269] Fifthly, Dib (2010) derive the equity premium as a function of capital adjustment costs and the possibility of diverting part of the bank capital for personal gain.[270] Sixthly, Aguiar and Drumond (2007) and Agénor, Alper and Pereira da Silva (2011) use a deposits-in-utility function approach to derive asset demand equations from households' optimisation problem to create a spread.[271]

In contrast to these, I explicitly derive the different required returns on bank deposits and bank equity from the optimisation problems of banks and workers. In particular, differential returns on bank equity and risk-free bank deposits arise due the incidence of non-systemic bank default. The modelling approach which resembles the one presented here most closely is the partial equilibrium framework of Gornicka and van Wijnbergen (2013) who derive a no-arbitrage condition between risk-free insured bank deposits and risky subordinate debt.[272] There, holders of subordinate debt demand a risk-adjusted return which compensates them for the risk of default and in case funds are insufficient to pay them in full.[273] However, Gornicka and van Wijnbergen (2013) follow the GK framework in a partial equilibrium setting, while this study uses the BGG approach. Furthermore, the focus of Gornicka and van Wijnbergen (2013) is to study the effects of

266 See Repullo and Suarez (2008: 7). Repullo and Suarez (2008: 1f) postulate a friction in that banks cannot recapitalise when they have an ongoing lending relationship.

267 See Collard et al. (2012: 9)

268 See Abbate and Thaler (2014: 11)

269 See Covas and Fujita (2010: 144). Covas and Fujita (2010) use a model without bank default and with a binding capital constraint determining the bank leverage ratio.

270 See Dib (2010: 7f)

271 See Aguiar and Drumond (2007: 14f) as well as Agénor, Alper and Pereira da Silva (2009: 7ff) for the description of this part of the model by Agénor et al. (2011). The models by Aguiar and Drumond (2007: 12ff) and Agénor et al. (2011: 9) do not feature bank default and determine banks' leverage ratio through regulation. A further contrast to this study is that in Aguiar and Drumond (2007: 15f) the expected real return on bank equity is set equal to the expected real return on real capital. In Agénor et al. (2011: 8) adjustment costs contribute to the spread between bank equity and bank deposits.

272 See Gornicka and van Wijnbergen (2013: 10). Kiley and Sim (2012) also derive a no arbitrage condition for bank liabilities, but this concerns bank debt and not bank equity. Furthermore, this no-arbitrage condition is not the cause of the spread between return on equity and the return on deposits. In Kiley and Sim (2012) debt is cheaper due to a tax advantage and equity dilution costs. See Kiley and Sim (2012: 5ff)

273 See Gornicka and van Wijnbergen (2013: 10)

minimum capital requirements and regulatory penalties on banks' capital structure.[274]

Finally, due to the focus on financial fragility, this study will also deal with macroprudential policies in chapter 6. The literature on this topic has grown enormously especially since the financial crisis 2007-8. Since this study concentrates on monetary policy, there will be no comprehensive modelling exercise concerning macroprudential policy. Rather, approaches from the literature will be incorporated to show some of the possible consequences for monetary policy of countering financial instability. The approaches proposed in the literature are taken as illustrative means, and this study does not aim for a thorough evaluation of macroprudential policies themselves. Given the focus on monetary policy, the macroprudential policies are introduced as is, and coordination issues are not treated explicitly.[275] For an overview of the literature on macroprudential policies see Loisel (2014), for instance.

In sum, this study is closely related to the papers by Clerc et al. (2014) and Collard et al. (2012) even though in different aspects. Both papers address the implications of financial fragility. Similarities to the approach of Clerc et al. (2014) include bank default along the lines of BGG and the existence of a deposit insurance scheme. The model presented in this study is similar to Collard et al. (2012) concerning the concept of bank equity and risk-free bank deposits. Yet, there are some noteworthy differences to these two papers some of which have already been outlined in footnotes 253 and 262, centred on the modelling approach. Additionally, the focus in this study is specifically on the consequences for monetary policy while Clerc et al. (2014) study capital regulation and Collard et al. (2012) focus on optimal policy and the interplay with prudential policies.[276] As a final difference, the model proposed here is estimated using German data while these two other models are calibrated.

In terms of the research question, this study is closely related to Markovic (2006). There, households hold risk-free bank deposits and bank equity with the possibility of bank default.[277] Markovic (2006) examines the bank balance sheet channel and finds that the effects of monetary policy are stronger when banks are fragile.[278] Yet, there are some important differences: Bank default and the spread between the returns on bank equity and bank deposits are introduced in a relatively ad-hoc fashion in Markovic (2006). For one, Markovic (2006) defines banks' default probability as a linear function of output

[274] See Gornicka and van Wijnbergen (2013: 2f)
[275] On the issue of coordination of macroprudential and monetary policies, see for example Angelini et al. (2012).
[276] Further, neither Clerc et al. (2014) nor Collard et al. (2012) study monetary policy shocks.
[277] See Markovic (2006: 16f)
[278] See Markovic (2006: 30)

instead of providing explicit microfoundations.[279] Moreover, bank default is simply an add-on in the arbitrage condition between bank deposits and bank equity.[280]

What is more, Markovic (2006) uses a reduced-form representation of the BGG approach in that the elasticity of the credit spread to non-financial firms' leverage is a time-invariant function.[281] In contrast, the model presented in the following chapter derives the risk premium on bank equity as well as the external finance premium of non-financial firms as functions of default risk using the BGG approach.[282] Contrary to a reduced-form representation, default probabilities and premiums are time-varying and specifically depend on the financial positions of the actors. They are thus explicitly derived from microfoundations. In order to study the impact of bank default, the endogeneity and microfoundation of these variables is crucial. Furthermore, while Markovic (2006) concentrates on impulse response analysis, this study will additionally consider policy trade-offs and the question of how results change when macroprudential policies are introduced. Thus, this study provides a more encompassing analysis. As a final point, the model by Markovic (2006) is calibrated, while the model presented here is estimated on German data.

Overall, this section has shown that the banking sector features which are added to an NK DSGE model with financial accelerator as presented in this study (that is bank default, deposit insurance and bank liability structure) have parallels in the literature.[283] Nevertheless, to the best of my knowledge, these elements have not been modelled as presented in the next chapter to study the interaction between financial intermediation and monetary policy. The model is built to focus entirely on the effects of non-systemic bank default for monetary policy. To this end, the microfoundation for a pecking order of bank liabilities in an NK DSGE model context is based on the incidence of non-systemic bank default in combination with a portfolio choice problem of workers who view bank deposits as risk-free due to deposit insurance. This is a crucial difference to the literature cited above who mostly use ad-hoc or utility based elements to justify a wedge between the return on equity and deposits. Furthermore, this particular approach to modelling the financial friction is deliberately chosen and well-suited to answer the research question of this study, namely the consequences of non-systemic bank default. A rigorous microfoundation specifically designed to the research question is indispensable in the context of

[279] See Markovic (2006: 24). Bank equity is separated into the volume of bank equity shares and the price of these shares, see Markovic (2006: 17). There is no deposit insurance scheme in Markovic (2006).
[280] See Markovic (2006: 17)
[281] See Markovic (2006: 20ff). Also, the impact of banks' liability structure on the credit spread is ad-hoc in Markovic (2006: 20).
[282] Also, the risk premium on bank equity does not only change when banks' default probability changes, but also depends on other developments as will be explained in the next chapter.
[283] The features of this NK DSGE model are standard and thus not discussed here. The modelling choices concerning the NK core are explained in chapter 3.

DSGE modelling. As Darracq Pariès et al. (2016) argue in the context of their model, the particular implementation of financial frictions has important consequences for the model's steady state and dynamics.[284] In conjunction with the extensive analysis of the impact on monetary policy, this constitutes the main theoretical contribution of this research.

[284] See Darracq Pariès et al. (2016: 38)

Chapter 3

The Banking Model: A New Keynesian DSGE Model with Financial Frictions and Portfolio Choice

The previous chapter introduced a wide variety of theoretical approaches on monetary policy and financial intermediation. One of the important functions of chapter 2 was the explanation and justification of the particular modelling approach followed here, starting from the New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) framework and the representation of monetary policy, to the precise notion of the interactions of the financial sector with monetary policy and non-financial agents. The core objective of this chapter is to present the banking model in detail, and thus to lay the foundation for the analyses in subsequent chapters. Apart from presentation, the other main goal of this chapter is to justify the various modelling choices and explain the underlying assumptions.

This chapter starts with a discussion of the more general modelling assumptions within the realm of NK DSGE models which are made in this study in section 3.1. Section 3.2 provides an overview of the model layout concerning the markets and actors that are included and indicates where the various frictions[285] are located. Each actor's decision problem(s) are treated individually in subsequent sections 3.3 to 3.8. The chapter will close with the definition of equilibrium and the specification of functional forms in section 3.9.

[285] Frictions are understood as impediments to a complete and immediate adjustment of actors' control variables to unexpected events.

3.1 General Modelling Assumptions

3.1.1 On Discrete- and Continuous-Time Modelling

There is an ongoing debate among economists whether to use discrete- or continuous-time in modelling economic phenomena. DSGE models as the successors of the discrete-time real business cycle (RBC) framework pioneered by Kydland and Prescott (1982) still have this RBC model at their core and generally follow this timing structure. More recently, some DSGE models have been set in continuous time as potential analytical advantages have been put forward. In the following I will start with a short summary of some proposed advantages of continuous-time modelling and then present arguments for why I will use discrete time in the model presented here.

The use of continuous time can be motivated by several factors. Assuming that decisions are made continuously instead of synchronised at a discrete point in time can be argued to be more realistic. Secondly, due to the extensive mathematical elaboration of systems of continuous-time equations, the modeller can access a wide variety of methods.[286] In a similar vein, a further proposed analytical advantage is due to Ito's Lemma, which enables the researcher to find closed-form solutions for a broader set of economic models than is possible with difference equations.[287] Finally, Parra-Alvarez (2013) argues that the computational cost in terms of time needed to solve the model, which is the more important the more complex the model gets, is less for continuous-time than for discrete-time DSGE models when using popular perturbation methods.[288]

On the other hand, it should be clear that the decision to build a model in discrete or continuous time is eventually dictated by the economic problem at hand and the aim of the modelling exercise as there are several reasons in favour of the use of difference equations.

Firstly, the criticism against discrete-time modelling of having all decisions synchronised at one point in time loses much of its strength when one wishes to take the model to macroeconomic data. Some data such as on financial assets traded on stock exchanges is available at a daily frequency. Yet, this is not true for macroeconomic data in general and of national accounts data more specifically which are assembled at a quarterly or even yearly frequency. Hence for this kind of data all information about the transactions within a given time period is aggregated into a number at the end of the period. A second category of data does not represent an aggregated representation of decisions taken during the period but simply the state of affairs as the average or at the end of the period. This

[286] See Cochrane (2005: 26)
[287] See Parra-Alvarez (2013: 2)
[288] See Parra-Alvarez (2013: 28). Further details on this study are given below.

is true, for instance, for the interest rate statistics published by the European Central Bank (ECB).[289] Thus, there is no information on how the interest rates moved within the month. All the researcher has at his disposal are the states at discrete points in time. Thus, setting up a model in discrete time where each period corresponds to, say, a quarter, allows for a seamless mapping of coefficients and decision rules from the model to the data.[290]

Secondly, a first-order difference equation allows for a more diverse set of mathematical movements than a first-order differential equation.[291] Thirdly, another argument for discrete-time modelling is the use of numerical methods. Cochrane (2005) maintains that in practice, a theoretical continuous-time model is frequently transformed into a discrete-time model for simulation purposes. There, the use of a discrete-time model may be more transparent.[292] Complexity is a serious issue concerning large DSGE models which are intentionally constructed to replicate a large variety of real-world economic phenomena. Thus, there is no certainty a priori that a specific continuous-time model has a closed-form solution. Also, developing an existing model through adding additional features might make the closed-form solution analytically unattainable even though it was in the simpler model.

Furthermore, assuming that a continuous-time version of a discrete-time DSGE model has a closed-form solution while the discrete-time version has not, there is no reason why the researcher should not be able to analyse various subsystems of the discrete-time model analytically. Stability analyses of subsystems or single equations is just as expedient with discrete time as within the framework of continuous time. The probably best-known example is the Taylor principle: if monetary policy in a discrete-time NK DSGE model is modelled with a Taylor rule, the parameter governing the response of the policy interest rate to changes in current inflation need be larger than 1 for the economic equilibrium to be unique.[293]

This result links to another important difference between discrete- and continuous-time models: determinacy regions for certain parameters may be diametrically opposed. Take again the Taylor rule: Dupor (2001) has shown by introducing capital investment into a continuous-time NK framework that the monetary authority has to react passively to changes in inflation to ensure determinacy.[294] In contrast, using a similar NK model

[289] See European Central Bank (2003: 47-48)
[290] See Fernández-Villaverde, Posch and Rubio-Ramírez (2013: 2)
[291] See Gandolfo (2010: 173)
[292] See Cochrane (2005: 26)
[293] See Galí (2008: 50). Galí (2008: 50) shows that this condition is necessary and sufficient. Note that the exact parameter value for this uniqueness is model-dependent and also depends among others on other parameters in the Taylor rule, see Galí (2008: 50).
[294] See Dupor (2001: 93ff)

in discrete time, Carlstrom and Fuerst (2005) show that only active monetary policy leads to a determinate unique equilibrium.[295] I do not wish to comment on which values seem more plausible in reality; rather, I would like to point out that this difference of determinacy conditions is not trivial for comparing results of various DSGE models. Since one of the purposes of this modelling exercise is to show the consequences of allowing for non-systemic bank default in DSGE models, I believe it to be important to stay in reasonable comparative distance. Given that the pioneering papers developing financial frictions as well as their successors are largely set in discrete-time, this is another reason to follow this approach.

Furthermore, once the switch is made from first-order to second-order perturbation the computational advantage of continuous-time modelling decreases significantly. The aforementioned study by Parra-Alvarez (2013) compares various solution methods for continuous-time models (perturbation and projection methods) in terms of their accuracy and speed.[296] In terms of speed he also compares his computations with the corresponding results of a discrete-time version of the model from a paper by Aruoba, Fernández-Villaverde and Rubio-Ramírez (2006). He shows that the time advantage of the continuous-time model decreases from being 40 times faster to 5 times for first-order and second-order perturbation methods respectively.[297] Though this is still significant, the absolute time is only 0.03 and 0.08 seconds for the continuous-time version.[298] Moreover, conducting a similar study with a more complicated discrete-time model, Caldara, Fernández-Villaverde, Rubio-Ramírez and Yao (2012) show using a faster computer that a second-order perturbation needs only 0.02 seconds.[299] Hence, technological advances should make this tentative advantage less significant.

Related to this is the computational cost in terms of programming itself. Efficient coding can lead to faster computations. Appropriate vectorisation in Matlab for example can lead to fewer cache misses and thus a significant reduction of computing time.[300] Secondly, and analogous to the argument that there is a plethora of mathematical resources for continuous-time methods, DSGE modelling is predominantly done in discrete time.

[295] See Carlstrom and Fuerst (2005: 10f, 16). Carlstrom and Fuerst (2005: 14) find that these opposing parameter conditions depend on the different timing of the arbitrage condition linking the real interest rate to the marginal productivity of capital.

[296] See Parra-Alvarez (2013: 3)

[297] See Parra-Alvarez (2013: 28)

[298] See Parra-Alvarez (2013: 28). The results on time advantages are mixed for projection methods, see Parra-Alvarez (2013: 28).

[299] See Caldara et al. (2012: 204). Parra-Alvarez (2013) used a 2.53 GHz Intel R Core TM2 Duo running Windows 7 while Caldara et al. (2012) used a 3.3 GHz Intel computer with Windows 7. Admittedly there is a myriad of factors influencing the speed of computations, but based on this information one could tentatively argue that the latter computer is faster.

[300] See McGarrity (2007), URL in list of references. Obviously, this applies to both discrete- and continuous-time modelling.

Given that this DSGE modelling has led to an established diverse set of routines, codes and programmes, the researcher does not need to reinvent the wheel when it comes to (computational) solution and estimation procedures. This can certainly be considered an advantage in terms of computing costs.

Moreover, even though continuous-time modelling is more popular in finance, macroeconomic modelling is still overwhelmingly set in discrete time.[301] Hence, when introducing new methods to advance the solution, estimation and testing procedures of DSGE models authors have referenced this fact to justify the use of discrete time.[302] Hence, if new methods are first developed for discrete-time models this may equally function as an argument for introducing new theoretical elaborations in discrete-time to facilitate comparisons.

As a final remark, note that in the majority of cases authors do not mention or explain their decision to use discrete or continuous time at all.[303] In the end, the choice is a judgement call which should be tailored to the particular task.[304] As already noted by Tobin (1982), neither discrete time nor continuous time provide a completely accurate characterisation of reality.[305] Some aspects of economies and decision-making processes are more adequately represented by changes at discrete points at time, while for others continuous time is a better characterisation.[306] Hence, for the purposes of my model and the reasons outlined above I consider the use of discrete time more advantageous.

3.1.2 On Representative and Heterogeneous Agents

Despite the widespread and profound criticism which is regularly directed at the representative agent assumption in economic modelling it remains *the* most widely used technique for combining a microfounded model with a tractable mechanism for aggregation especially in medium- to large-scale models. The most basic representation of a DSGE model is its RBC core: although there is a continuum of households, they all behave identically. This result is due to the fact that they all have the same utility function and budget constraint and have access to a complete set of Arrow-Debreu securities. Thus they can be represented by one infinitely lived household who maximises lifetime utility from consumption, works to produce a homogeneous consumption good and decides on investment to refurbish his depreciated capital stock. This is the *single representative agent model*.[307]

[301] See Fernández-Villaverde, Guerrón-Quintana and Rubio-Ramírez (2015: 222)
[302] See Fernández-Villaverde et al. (2015: 222)
[303] This is probably more applicable to the former than the latter.
[304] See Cochrane (2005: 26)
[305] See Tobin (1982: 189)
[306] See Tobin (1982: 189)
[307] For textbook derivations see Galí (2008: 16ff, 41ff) for examples of basic RBC and NK models without capital, and for instance Wickens (2008: 30ff) with capital as a production input.

This is in stark contrast to so-called *heterogeneous agent models* where individual agents are allowed to differ in terms of preferences, beliefs, income or wealth. Heterogeneity among agents may arise due to heterogeneity in terms of the preference structure or idiosyncratic risk, for instance.[308] The key is that agents in heterogeneous agent models cannot completely insure against idiosyncratic shocks and thus, income and wealth of household 1 is different from the wealth of household 2 at the end of a period (that is, after all shocks have realised).[309] This difference is crucial, as once agents have access to a complete set of state-contingent contracts such that all idiosyncratic risk may be traded away, there is no need to solve for the whole wealth distribution but agents can be represented by a composite agent.[310] This is valid even if preferences are heterogeneous as well.[311] In contrast, in heterogeneous agents models this full insurance assumption is purposely dropped. Then the wealth distribution becomes an additional state variable which affects aggregate real variables and prices.[312]

There is a third kind of modelling strategy which lies somewhere in between a single representative agent and heterogeneous agent models. I denote this intermediate framework *representative agents of multiple types model*. It is a modification of the basic representative agent in that it features different types of (representative) agents. The model economy may be populated by a representative household, a representative consumption goods producing firm, a representative capital goods producing firm, a government and others. However, in contrast to a heterogeneous agent model, this heterogeneity is introduced at a more restricted level. Seen from this perspective, the multiple types model aggregates individuals into different types and characterises these types by a representative agent. This kind of model might also involve differentiating one of those said types. Iacoviello (2005), for example, assumed that there are two types of households, each of which modelled as a representative household, which differ in their time discount rates β such that one of those types will always borrow and the other will always lend.[313]

The question is now: which modelling strategy to follow? As noted above the representative agent framework has been criticised on many grounds. One of them is the neglect of inequality in the economy, and indeed the early heterogeneous agent model literature sought to describe and explain the unequal distributions of wealth and income.[314] The distribution of wealth among the population of households becomes a crucial variable in

[308] See Guvenen (2011: 257)
[309] See Krusell and Smith (1998: 868)
[310] This result is due to Constantinides (1982: 253ff). Note that this composite agent does not necessarily lead to an expression for aggregate demand, see Guvenen (2011: 262ff).
[311] See Guvenen (2011: 264)
[312] See Guvenen (2011: 258)
[313] See Iacoviello (2005: 742)
[314] See Heer and Maussner (2005: 275)

those models, which affects aggregate variables and prices. Despite this more realistic appeal, heterogeneous agent models, or rather the implementation in terms of model design and computational limits, does have serious drawbacks which will be discussed in the following paragraphs. As will be explained below, for a DSGE model the size of the one presented here, modelling heterogeneous agents is simply not (yet) feasible.

Satisfactorily modelling heterogeneity in one dimension most often necessitates simplifying assumptions in other parts of the model sphere so as to keep the number of state variables to a reasonable limit. Heterogeneous agent models with a high-dimensional wealth distribution may be more attractive from a real world view and it might also explain the puzzles surrounding some incompatibilities between microeconomic evidence and representative-agent DSGE model requirements for certain parameters, for example the equity premium puzzle and the risk aversion parameter.[315] However, this richness in detail is also one of the most damaging disadvantages: An additional state variable per se is not a problem in terms of the analytical and computational burden. The problem results from the fact that with a high or infinite number of heterogeneous agents the set of state variables becomes extremely high-dimensional or even infinite-dimensional.[316] Analytical solutions are generally unattainable except for a small number of problems.[317]

Moreover, the very popular algorithm developed by Krusell and Smith (1998) for solving heterogeneous agent models yields an approximate solution for the equilibrium where aggregate variables depend almost exclusively on the average wealth level and the aggregate shock process.[318] While the formulation of this approximate solution was certainly a huge step forward in terms of computing heterogeneous agent models with incomplete markets and aggregate uncertainty, it presents also a tremendous drawback: The consequences for aggregate variables of ex-post heterogeneity do not seem very different from the representative agent framework if there is a possibility to describe the approximation of the equilibrium solution with the mean of the wealth distribution only and not any further distribution moments.[319]

The approximate solution in the model of Krusell and Smith (1998) depends on the marginal propensity of saving out of current wealth of the various agents to be similar.[320] The realm of and departures from the approximate solution are areas of ongoing research

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[315] See section 3.7 for a short discussion.
[316] See Algan, Allais, Den Haan and Rendahl (2014: 278)
[317] See Heer and Maussner (2005: 247f). See Guvenen (2011: 305) for a list of models with an analytical solution.
[318] See Krusell and Smith (1998: 869). Krusell and Smith (1998: 869) also argue that this result is not overly sensitive to modifications in parameter values or model layout.
[319] See Guvenen (2011: 258)
[320] See Krusell and Smith (1998: 870) and Algan et al. (2014: 278)

with several new algorithms having been proposed more recently.[321] However, the accuracy of the various methods is a serious concern.[322] Moreover, there is no consensus on the specific accuracy test to be used, since one test may detect inaccuracies when there are none or vice versa.[323] The accuracy of a given method vis-à-vis other methods appears to be model-dependent.[324] Having found one method to be accurate in a simple model does not necessarily imply that the same method is as accurate when the model is extended.[325]

Another point to consider is the modelling of idiosyncratic uncertainty. Heterogeneous agent models need an exogenous shock to model idiosyncratic uncertainty which is the ultimate source of the heterogeneity. As noted above, the crucial difference to representative agent models is that agents cannot insure completely against adverse idiosyncratic shocks which leads to differing income and wealth levels. In the model considered here, there are also idiosyncratic shocks to agents, but instead of solving for the whole wealth distribution of those agents, this study uses a shortcut: using first and second distribution moments and the additional assumption that decision problems are linear functions of business volumes, the optimisation problems can be described as functions of probability density functions. To see why linear functions avoid the need to solve for the whole distribution note that with, for example, a linear propensity to consume out of wealth, aggregate consumption does not depend on wealth heterogeneity.[326] While this approach necessarily precludes any discussion of distributional issues, it allows nevertheless for the analysis of aggregate quantities which are of interest here.

To sum up, while fully-fledged heterogeneous agent models appear attractive from a real-world perspective, they face various computational and analytical difficulties. One of the main goals of the research presented here is to evaluate the consequences of introducing non-systemic bank default and portfolio choice into an otherwise standard NK model with financial accelerator. The exploration of potential differences between the approach of using linear functions for aggregation instead of a heterogeneous agent solution method would be interesting in its own right; however, it is beyond the scope of this research and given the size of the model and the number of frictions, probably not yet feasible. Technological and methodological advances in the years to come will presumably open up the opportunity for such an exercise. In sum, these reasons justify the use of the representative agents of multiple types approach in this study, specified in the following sections.

[321] For an overview see Algan et al. (2014).
[322] See Algan et al. (2014: 306f)
[323] See Algan et al. (2014: 307f)
[324] See Kollmann, Maliar, Malin and Pichler (2011: 194)
[325] See Den Haan, Judd and Juillard (2010: 2)
[326] See Guvenen (2011: 303)

3.2 General Overview: Markets and Actors

At the core of the banking model is a state-of-the-art New Keynesian DSGE model.[327] The derivation of the NK model core follows Cantore, Gabriel, Levine, Pearlman and Yang (2013).[328] Thus, the model features a more or less standard model layout with various nominal and real frictions to which a second financial friction and portfolio choice are added. This section will provide an overview of the various agents that populate the model economy and interact on different markets. It is a closed economy so as to focus on the interactions between real and financial sectors. There is no explicit role for cash money, thus the implicit assumption is that the economy is at the cashless limit, as in Woodford (2003) and Gertler and Karadi (2011).[329] The explicit derivation of the optimisation problems and the optimality conditions will be explained in subsequent sections for each actor and decision problem separately.

The Market(s) for Retail Goods Retail goods are produced by non-financial wholesale goods producing firms, each run by an entrepreneur, in a perfectly competitive market and are sold on the final retail goods market by retailers with a price mark-up.[330] In the first phase of retail goods production, entrepreneurs combine labour and capital as production inputs. These wholesale goods are then sold on the wholesale market to a continuum of retailers who diversify the homogeneous good into heterogeneous final retail goods for sale on the final goods market. The final retail goods market is monopolistically competitive and final retail prices exhibit nominal rigidities. Retail goods are demanded by workers and entrepreneurs who ex- or implicitly derive utility from consumption, the government for consumption and by capital investment funds as investment goods (See "the Market for Capital Goods").

The Market for Capital Goods Capital goods are an input in the production of wholesale goods, thus demand for capital goods is determined by entrepreneurs' profit maximisation objective. Entrepreneurs combine their own net worth with bank loans to purchase capital goods. As in Bernanke et al. (1999) (BGG), the banking model features a financial accelerator. Entrepreneurs may become insolvent due to an idiosyncratic shock which in turn makes bank loans risky.[331] This results in a spread between the

[327] A textbook derivation of a stereotypical NK model can be found in, for example, Galí (2008: 41-70).

[328] Specifically, this concerns workers' utility function, the production function, the labour market, and the optimisation problems of retailers and capital investment funds. See Cantore et al. (2013: 415-417, 421-427)

[329] See Woodford (2003: 31f) and Gertler and Karadi (2011: 19)

[330] Henceforth, the terms (non-financial) wholesale goods producing firm and entrepreneur will be used interchangeably to refer to wholesale goods production.

[331] In this context, there is no distinction between insolvency and illiquidity. Since all contracts last one period, there are no long-term assets the entrepreneur can invest in, which have a longer commitment period than the liability side of the entrepreneur's balance sheet.

rate of interest on real capital and the risk-free rate (See "Financial Markets and Bank Intermediation"). On the other hand, the supply of capital goods is determined by capital investment funds' profit maximisation objective. Capital investment funds buy period $t-1$ depreciated capital from entrepreneurs and period t investment goods from retailers, and combine these to build the period t capital stock subject to investment adjustment costs. They then sell the period t capital stock to entrepreneurs. The stock and price of physical capital are determined by equating capital demand and supply.

The Labour Market There are no frictions associated with this market.[332] Workers are the only suppliers of labour in the economy. Workers supply their labour endowment as a function of the real wage to earn wage income. The demand for labour is determined by the profit maximisation objective of entrepreneurs. There are no other agents in this economy which demand labour, since entrepreneurs (and by extension) retailers are the only agents which feature a production function. Demand and supply on the labour market determine the wage rate and the amount of labour used in the production process.

Financial Markets and Bank Intermediation There are two financial markets incorporated into the banking model which are both subject to frictions: the market for bank loans and the market for bank liabilities. Concerning the former, the interaction between entrepreneurs demanding loans and banks supplying them constitutes the loan market. As noted above, entrepreneurs finance the purchase of capital goods with a combination of internal and external finance. The only source of external finance for an entrepreneur is a bank loan. The financial friction introduced in the loan market is a financial accelerator in the spirit of BGG which leads to a spread between the risk-free real return and the real return on real capital.

In turn, banks balance their assets on the liability side with bank deposits and external bank equity collected from workers. The second financial friction of the model concerns the relationship between banks and bank equity-holders: Banks may become insolvent in a similar fashion to entrepreneurs. As any losses are absorbed by bank equity, bank equity as an asset becomes risky. A governmental deposit insurance scheme ensures that bank deposits are viewed as risk-free by workers. The model thus features an endogenous portfolio decision on the part of workers between risk-free bank deposits and risky bank equity. The result of this model design is an even wider spread between the real risk-free return and the real return on real capital.

Eventually, all interest rates are related to the risk-free interest rate. The risk-free

[332] This assumption is for simplicity and tractability. However, it would be straightforward to include frictions such as wage rigidities into the decision problems concerning this market.

interest rate is the rate of interest that would be paid on hypothetical open market operations between the central bank and banks. However, the banking model abstracts from central bank money supply and open market operations, and only considers the central bank as setting the nominal policy rate which is equal to the nominal risk-free interest rate. Thus, a crucial assumption is that bank are indifferent between open market operations and bank deposits.[333] This is only the case if the effective deposit rate is equal to the policy rate. Thus, the abstraction from open market operations implies that these two interest rates are equal.

Equilibrium The sequence of events is as follows: at the beginning of any period agents form expectations, and decide on the optimal quantities to supply and demand. Then, retail goods production starts. After wholesale goods have been produced, entrepreneurs sell the wholesale output to retailers, pay wages and sell the part of the capital stock which remains after depreciation to capital investment funds. Then, retailers differentiate the homogeneous wholesale good and sell the heterogeneous final retail goods on the final goods market. Subsequently, capital investment funds start refurbishing the real capital stock.[334] At the end of the period, banks collect equity and deposits to grant loans to entrepreneurs for them to buy the real capital stock from capital investment funds.

Looking at the economy from the perspective of national account statistics, the production account only includes retail goods production performed by entrepreneurs and, by extension, retailers. In line with standard practice in the literature neither the government nor banks feature a production function which adds to the production account, and neither does the transformation of the old capital stock into the new one feature in the production account. While admittedly this is an immense abstraction from reality, this simplification helps to keep the model tractable.

Economy-wide equilibrium is attained when all markets are simultaneously in equilibrium, that is supply equals demand in the retail goods and capital goods markets, the labour and financial markets. The analysis will focus on the model economy's behaviour in the vicinity of the non-stochastic steady state. There is no economic growth and thus in the deterministic steady state, all variables are constant, and all shocks are zero and are expected to stay zero in subsequent periods.[335] Hence, the analysis presumes

[333] Otherwise, the abstraction from open market operations would be harder to defend.

[334] For simplicity capital investment funds and retailers are assumed to be completely self-financing. They keep the revenue from selling capital and final retail goods, respectively, as reserve funds, which again for simplicity are not subject to interest income, and which they then use to buy capital and wholesale goods from entrepreneurs and final retail goods from retailers in the next period. Thus, the financing situation of these two types of economic agents does not feature in the banking model. They are owned by workers, and thus any supernormal profits are distributed lump-sum to workers.

[335] See chapter 4 for more details on the equilibrium concept used in this thesis.

that the economy rests in its deterministic steady state absent any disturbances.[336] The evolution of the economy to this steady state from, say, the beginning of time cannot be traced in this framework. While this issue and the study of economic growth are certainly important economic questions in their own right, the current study focuses on business cycle developments.[337] As noted in the introduction, a key motivation of this study concerns the interaction of financial fragility and monetary policy in 'normal', that is non-crisis, times. Therefore, this thesis can be seen as examining one dimension of potential interactions, that is the business cycle. The steady-state capital stock and all other variables are taken as given at this point in time and it is left to future research to explore the links between banking sector fragility and monetary policy concerning the other dimension, namely economic growth, as well as the consequences of bank failures which are of systemic relevance.

3.3 Entrepreneurs

Final retail goods production consists of two phases: wholesale goods production by entrepreneurs, and differentiation into final retail goods by retailers. Entrepreneurs are the key actor on the retail goods production side of the economy. Entrepreneurs run non-financial wholesale goods producing firms, and thus, decide on the wholesale production volume and optimal capital and labour demand. However, as will be explained in section 3.3.3, entrepreneurs are financially constrained in the sense that they cannot fully finance their real capital purchases and have to take out bank loans to this end. The complexity of this financial friction is the motivation for introducing a separate agent, the retailer, to model nominal price stickiness in the production sector. The description of the production side of the banking model economy proceeds as follows: this section deals with the optimisation problems of entrepreneurs, starting with a discussion of price rigidities and their specific incorporation into this model framework. The next section presents the optimisation problem of retailers.

3.3.1 Price Rigidities

The key ingredient which separates NK DSGE models from RBC models is some sort of nominal friction. As mentioned in chapter 2 these nominal rigidities usually come in the form of either sticky prices or wages.[338] Fundamentally, this means that some or all price-setters (wage-setters) are not able to change their price (wage) in a given period. As

[336] The support for this assumption in terms of stability and determinacy of the steady state is provided in chapter 4. Note that part of the model design presupposes the equilibrium to be locally stable and determinate, as will be pointed out as necessary.
[337] This focus on business cycle movements also justifies the methodological approach of using a log-linear approximation of the model for estimation and simulation.
[338] See D. Romer (2012: 238)

a result, monetary policy is no longer neutral in the short run, as incomplete adjustment of prices after a change in the nominal policy interest rate leads to shifts in the real interest rate.[339] Various explanations have been proposed in the literature for why producers may choose not to change prices every period, such as menu costs or incomplete information about the aggregate price level.[340] For the setting considered here, rigidity may also be explained by costs of collecting the relevant information. While one might argue that information on, for instance, aggregate inflation is costlessly available today, finding and processing information relevant for determining the optimal price is not as simple.

Price rigidities are only meaningful if there actually are producers who are able to set a price to maximise profits. In a perfectly competitive market, all producers are price-takers, hence there is one market price. Thus, some form of departure from perfect competition to make producers price-setters is a modelling prerequisite for stickiness in price-setting as a form of nominal friction. Moreover, monopolistic competition and staggered price setting in the retail sector introduce inefficiencies in the allocation of resources in the economy.[341] For one, monopolistic competition with completely flexible prices introduces a wedge between the marginal cost and the price eventually charged for the final retail good.[342] Thus, employment and output will be lower than with marginal cost pricing.[343]

Staggered price setting on the other hand introduces the rationale for monetary policy aimed at price level stability.[344] Staggered price setting leads to relative price dispersion (if there is non-zero inflation in long-run equilibrium, or if the economy is reacting to exogenous shocks and is thus not in long-run equilibrium), meaning that the efficient allocation is not attained due to deviations of relative prices from their optimal levels.[345] Furthermore, relative price dispersion reduces final output because production inputs are not allocated efficiently between producers with low and high prices.[346] However, if marginal costs are constant, producers do not have an incentive to change their prices (assuming a uniform and constant mark-up) and thus there is no relative price dispersion.[347]

[339] See Galí (2008: 5). The concept of monetary policy neutrality is slightly different from the concept of neutral monetary policy used by Goodfriend and King (1997) which concerns the outcome of monetary policy, even though they are connected. Goodfriend and King (1997: 232) define neutral monetary policy as a policy whereby stable prices and output equalling potential output can be attained. In a simple NK model monetary policy needs to stabilise the average mark-up between prices and marginal costs, see Goodfriend and King (1997: 232). Here, monetary policy non-neutrality concerns monetary non-neutrality and that monetary policy has non-negligible effects on the real economy.

[340] See D. Romer (2012: 267f)

[341] See Galí (2008: 73)

[342] See Galí (2008: 71-75) and Wickens (2008: 207-215) for a mathematical derivation.

[343] See Galí (2008: 73)

[344] See Galí (2008: 75)

[345] See Galí (2008: 74)

[346] See Christiano, Trabandt and Walentin (2011: 294)

[347] See the derivation of retailers' decision-making problem below.

There are various approaches to modelling price rigidities employed in the literature.[348] However, the probably most common one is Calvo-style price staggering which is also employed here.[349] The procedure works in the following way: final retail goods producers in a monopolistically competitive market will set their price to the profit-maximizing level. However, assuming Calvo-style price staggering, not all producers are able to set their price to the profit-maximizing level in each period.[350] In fact, each producer faces a probability of ξ^p that he will not be able to optimise. If a producer cannot optimise in period t, the producer will set the price in period t equal to the price in period $t-1$.[351] Thus, the inverse of $(1-\xi^p)$ is the average length a price stays in effect. While using a purely time-dependent pricing framework with an exogenously given frequency of price adjustment may not seem particularly realistic, state-dependent pricing models do not fare much better when taken to the data.[352] Moreover, this approach is analytically tractable and offers the advantage that the key parameter has a straightforward economic interpretation.

One final note about the implementation in terms of actors: Modelling monopolistic competition along with a financial accelerator complicates aggregation severely.[353] This is due to the non-linearity which arises from the financial friction.[354] Thus, it is computationally and analytically much more tractable to introduce another agent, called retailer, who buys the homogeneous good from the financially constrained entrepreneur. Therefore, the price friction is modelled separately from the financial friction. The point of the former friction is to introduce a wedge between the perfectly competitive price and the price eventually paid for the finished retail good, while the latter introduces a wedge between the real rate of interest on real capital and the real risk-free rate of interest.

From an empirical point of view, price stickiness appears pervasive. Numerous studies have been published describing the extent and sources of infrequent price adjustments. In a meta study based on microeconomic data underlying producer price indices in various Euro area (EA) countries, Vermeulen et al. (2012) report a frequency of price changes of 20.8% as the monthly average.[355] For the US, this frequency was reported to be roughly equal to 25%.[356] The corresponding frequency for Germany of 21.2% is only slightly higher

[348] See D. Romer (2012: 319-337) for a survey.
[349] See Calvo (1983)
[350] See Calvo (1983: 383ff)
[351] See Calvo (1983: 385). The fact that those retailers who can optimise are chosen randomly is an important assumption which enables the use of the law of large numbers in deriving aggregate dynamics, see Calvo (1983: 386).
[352] See D. Romer (2012: 339)
[353] See Bernanke et al. (1999: 1348)
[354] See Bernanke et al. (1999: 1348)
[355] See Vermeulen et al. (2012: 1632)
[356] See Nakamura and Steinsson (2008: Table 11, Supplement), who report a frequency of 25.2% between 1988 and 1997 and of 24.7% between 1998 and 2005.

than the EA average.[357] Other survey-based evidence for Germany suggests an average quarterly frequency of price changes of 31.56%.[358] While the former study implies an average duration of fixed prices of just under 5 months, the latter implies an average duration of over 3 quarters. These distinct statistics may be due to differing periods under study, and the underlying data collection methodology (producer price index versus survey data). Nevertheless, these numbers show that price changes are infrequent. As a further note, Vermeulen et al. (2012) also state that consumer prices are changed less frequently than producer prices.[359] Apart from the analytical convenience mentioned above, this fact provides an empirically-based reason for separating entrepreneurs and retailers in the model presented here, and having the nominal friction reside within the latter's optimisation problem.

The model design with Calvo-style sticky prices produces a representation of the supply side in terms of the New Keynesian Phillips Curve. However, the results from econometric analyses on the correct specification are contradictory.[360] Moreover, the specification so far cannot reproduce the phenomenon of inflation inertia, namely that inflation will tend to stay at high levels unless output is reduced.[361] To the contrary, it implies the opposite, which is considered as a major limitation.[362] However, inflation inertia can be introduced with only a minor modification of the previous framework: instead of non-optimised prices staying fixed, assume that they are indexed to past inflation.[363] While this is an ad-hoc assumption, it does fit with the aforementioned reasoning that producers' choice not to change prices is a reaction to search costs whereas a mechanical adjustment of a producer's price to lagged inflation does not involve major costs in terms of gathering relevant information.

3.3.2 Wholesale Goods Production

There is a continuum of mass 1 of entrepreneurs indexed by nn_e. Each of them runs a perfectly competitive wholesale goods producing firm. Each produces a homogeneous wholesale good using physical capital goods[364] $K_t(nn_e)$ and labour $H_t(nn_e)$ with a given common technology Υ_t^A. In line with the majority of the literature, capital goods are

[357] See Vermeulen et al. (2012: 1636)
[358] See Bachmann, Born, Elstner and Grimme (2013: 17)
[359] See Vermeulen et al. (2012: 1632)
[360] See D. Romer (2012: 343)
[361] See D. Romer (2012: 341)
[362] See D. Romer (2012: 343f)
[363] See D. Romer (2012: 344f)
[364] The terms capital (goods), physical capital (goods) and real capital (goods) are used interchangeably in this study, concerning volume, prices and returns of real, physical capital. When denoting financial volumes, the term 'financial capital' is used explicitly to avoid confusion.

homogeneous and can move freely between wholesale goods producing firms.[365] Technology follows a first-order autoregressive process with expectation equal to 1, perturbed by the shock ϵ_A.[366] Each entrepreneur faces the same decision problem: choosing labour and capital input to minimise costs subject to the production function. Given that all entrepreneurs are identical and act in a perfectly competitive market, and given that the decision problem is linear in balance sheet quantities, the problem can be solved in aggregate quantities. Thus, entrepreneur-specific indices are dropped. The aggregate output from entrepreneurs is the real wholesale output Y_t^W. The production function is given by the following constant-returns-to-scale function:[367]

$$Y_t^W = (\Upsilon_t^A H_t)^\alpha K_{t-1}^{1-\alpha} \tag{3.1}$$

where $0 \leq \alpha \leq 1$ and α is the labour share and equals the partial elasticity of output with respect to labour input.

Capital goods are bought from capital investment funds at the end of period $t-1$ for use in the production process of period t. Labour services are bought from workers in period t for use in production in period t. Entrepreneurs are price-takers on factor and wholesale markets. The derivation of labour demand is then straightforward and given by:

$$Y_{H,t}^W = \frac{W_t}{P_t^W} \tag{3.2}$$

$Y_{H,t}^W$ is the partial derivative of the production function with respect to labour, that is the marginal product of labour. W_t is the nominal wage rate and P_t^W is the wholesale price level at which entrepreneurs sell their homogeneous output to retailers. The optimality condition states that the nominal wage rate adjusted by the wholesale price is equal to the marginal product of labour.[368]

Similarly, optimal capital input is determined by equating marginal cost to marginal revenue. Marginal revenue is the ex-post real return of holding one unit of physical capital

365 See, for example, Goodfriend and King (1997: 257). While this is still a gross simplification, there are no capital reallocation problems omitted due to price stickiness since entrepreneurs produce a homogeneous good and price distortions only arise in the final retail goods sector. See Woodford (2003: 353) on allocation problems with firm-specific capital.

366 See section 3.9 for details.

367 See, for example, Cantore et al. (2013: 416), eq. 18.11, my notation.

368 Note that in general it is not true that the marginal product of labour is equal to the real wage rate even though P^W enters the first-order conditions. P^W is not the adequate price level to turn nominal variables into real variables since the aggregate price level is a composite index of retailers' prices, which are a constant mark-up over wholesale prices. Even in the absence of inflation and thus price dispersion, the real wage will differ from the wholesale price-adjusted wage in eq. (3.2) by the mark-up of retailers.

$R_{k,t}$, given by:[369]

$$R_{k,t} = \frac{\Upsilon_t^K Y_{K,t}^W \frac{P_t^W}{P_t} + (1-\delta)Q_t}{Q_{t-1}} \tag{3.3}$$

The first term in the numerator is the partial derivative of entrepreneurial revenues from selling output, $P_t^W Y_t^W$, with respect to capital, divided by the retail price index P_t to turn it into real terms.[370] $Y_{K,t}^W$ is the partial derivative of the production function with respect to capital, that is the marginal product of capital. Υ_t^K is a first-order autoregressive process with expectation equal to 1 which is perturbed by an aggregate capital quality shock.[371] δ is the depreciation rate and Q_t is the price of physical capital. The second term in the numerator is thus the (marginal) revenue the entrepreneur receives from selling his capital stock net of depreciation in period t to capital investment funds. Since the capital stock used for production in period t was bought by the entrepreneur in period $t-1$, the price of physical capital enters the denominator with a different time subscript.[372]

The appropriate marginal cost to consider for optimal capital holdings is the marginal financing cost of an additional unit of capital. In the absence of financial frictions, entrepreneurs would demand capital until the expected ex-post real return on real capital equalled the marginal financing cost of capital, which would be the real risk-free return.[373] In the standard NK model without imperfections in the financial sector, workers receive the expected real risk-free return on their savings due to the availability of a full set of state-contingent securities.[374] In such a perfect financial market, there is no role for financial intermediaries because funds will flow to the most profitable projects and given the assumption of no default, savers will receive their funds and the required return.[375] However, as discussed in chapter 2, there are strong indications for distortions in financial markets, arising from limited commitment and asymmetric information. These are implemented into the banking model using the financial accelerator framework of BGG. These financial frictions introduce a wedge between the marginal external financing cost of entrepreneurs and the risk-free rate.[376] The optimal loan contract in this setting is derived in the next

369 See Cantore et al. (2013: 417), eq. (18.19), my notation. Note that eq. (18.19) in Cantore et al. (2013) is already an arbitrage condition, thus eq. (3.3) here is equivalent to the right-hand side of eq. (18.19) in Cantore et al. (2013).

370 See again footnote 368.

371 See section 3.9 for details. See also eq. (3.37) for the evolution of the capital stock in section 3.5.

372 Note that the price of capital Q_t is uniform over the whole range of capital bought, that is while the price varies with variations in the total capital stock, the price for the first unit of capital is equal to the last unit of capital bought in a given period.

373 This is due to the fact that without financial frictions entrepreneurs may issue bonds (or other financial liabilities) which are not risky. Without risk, the interest rate on these bonds equals the risk-free rate.

374 See Brzoza-Brzezina, Kolasa and Makarski (2013: 36)

375 See Brunnermeier, Eisenbach and Sannikov (2012: 1)

376 As will be discussed further below, the banking model is generally expressed in terms of 'returns' on financial assets. Along the lines of Cochrane (2005: 8), I define the return on a financial asset as 1 plus the interest rate on that financial asset.

section. The second financial friction affecting this arbitrage condition is discussed in section 3.6.

3.3.3 The Optimal Loan Contract

The description of the optimal loan contract follows the financial accelerator proposed by Bernanke et al. (1999) whose derivation will be presented in the following paragraphs.[377] The intuition of the financial accelerator is as follows: entrepreneurs have to take out loans to finance part of their production costs, but the terms under which external finance is available depend on their net worth.[378] Net worth works as an informational proxy on the probability of default of the entrepreneur and thus the expected return on the loan. The higher the net worth, ceteris paribus, the lower is the probability of default and thus the quantity of real capital demanded by an entrepreneur increases.[379]

An individual entrepreneur buys new capital $K_t(nn_e)$ from capital producing firms at price Q_t for production purposes.[380] However, entrepreneurs are financially constrained in the sense that they cannot fully finance the purchase of the capital with their own internal funds (real net worth, $N_{E,t}(nn_e)$) themselves, but instead need additional external financing in the form of bank loans (real loan volume, $B_t(nn_e)$):[381]

$$Q_t K_t(nn_e) = B_t(nn_e) + N_{E,t}(nn_e) \tag{3.4}$$

The amount of external financing required by entrepreneurs thus depends on the value of the capital stock to be purchased as well as the level of entrepreneurial net worth. In turn, an individual entrepreneur's net worth is given by the difference between revenues and loan repayments:[382]

$$N_{E,t}(nn_e) = R_{k,t} Q_{t-1} K_{t-1}(nn_e) - R_{b,t} B_{t-1}(nn_e) \tag{3.5}$$

The first term on the right-hand side of eq. (3.5) is the real revenue of end-of-period $t-1$ physical capital and the second term denotes repayments of $t-1$ loans where $R_{b,t}$ is the

[377] See Bernanke et al. (1999: 1349-1355, 1380-1387). Note that in Bernanke et al. (1999: 1358), entrepreneurs also supply labour. In contrast, entrepreneurs solely manage the production process and do not earn wage income in the banking model presented here. As Bernanke et al. (1999: 1358) note, entrepreneurial labour income is generally not the main driver of variations in entrepreneurs' net worth, such that this is not a crucial difference.
[378] See Bernanke et al. (1999: 1353f)
[379] See Bernanke et al. (1999: 1355)
[380] The fact that entrepreneurs buy (and do not rent) the capital stock allows for a neat calculation of their net worth as the difference between assets, that is the capital stock, and liabilities, that is loans. Furthermore, to guarantee that financing conditions depend on an entrepreneur's aggregate financial position, the whole capital stock is purchased each period. See Bernanke et al. (1999: 1349)
[381] See Bernanke et al. (1999: 1349), eq. (3.2), my notation.
[382] See Bernanke et al. (1999: 1357f), eq. (4.8), my notation.

loan return.[383]

To generate the financial friction, two modifications are introduced. For one, each period, entrepreneurs experience idiosyncratic shocks $\psi_t^E(nn_e)$ which affect the return on their installed capital stock.[384] Note that this shock ψ_t^E is independent of and unrelated to the aggregate capital quality shock process Υ_t^K. The latter affects all entrepreneurs equally, while the former realisation is specific to each entrepreneur. The entrepreneur-specific shock is uniformly distributed over the interval $[\psi_{\min}^E; \psi_{\max}^E]$ with expectation equal to 1.[385] The after-shock real return on real capital is then given by:

$$\psi_t^E(nn_e) R_{k,t} Q_{t-1} K_{t-1}(nn_e) \tag{3.6}$$

A few remarks on terminology for the entrepreneur-specific shock should be made. Such a shock is termed 'low' if the realisation falls below the expected value, that is $\psi_t^E < 1$. This means the after-shock return on real capital is lower than its expectation. A shock is termed 'high' if the realisation of the shock is higher than its expected value, namely $\psi_t^E > 1$. In this case, the after-shock return on real capital is higher than expected in the previous period.

The second modification is the costly-state-verification framework as developed by Townsend (1979). The entrepreneur receives the information about the value of the entrepreneur-specific shock $\psi_t^E(nn_e)$ without incurring costs. In contrast, the bank must pay monitoring costs to verify the actual value of entrepreneurs' revenues.[386] For simplicity, monitoring costs are assumed to be proportional to these revenues.[387] The optimal loan contract and thus the loan return $R_{b,t}$ are then determined by the following equality:[388]

$$\overline{\psi}_{t+1}^E(nn_e) R_{k,t+1} Q_t K_t(nn_e) = R_{b,t+1} B_t(nn_e) \tag{3.7}$$

where $\overline{\psi}_{t+1}^E(nn_e)$ denotes the level of the idiosyncratic shock for values below which the entrepreneur does not have sufficient revenues to pay back the loan, that is he defaults.[389] If the shock lies in the interval $[\overline{\psi}_{t+1}^E; \psi_{\max}^E]$, the entrepreneur pays back his loan including interest.[390] Otherwise, if the shock lies between $[\psi_{\min}^E; \overline{\psi}_{t+1}^E]$, the entrepreneur defaults and

383 Note that in eq. (4.8) in Bernanke et al. (1999: 1358) the loan return is expressed as the sum of the risk-free rate and the entrepreneurial risk premium.
384 See Bernanke et al. (1999: 1349)
385 See section 3.9 for details.
386 See Bernanke et al. (1999: 1350)
387 See Bernanke et al. (1999: 1350)
388 See Bernanke et al. (1999: 1350), eq. (3.3), my notation.
389 See Bernanke et al. (1999: 1350)
390 See Bernanke et al. (1999: 1350)

the bank collects his remaining assets.[391] Rearranging for the default threshold yields:

$$\overline{\psi}^{E}_{t+1}(nn_e) = \frac{R_{b,t+1}B_t(nn_e)}{R_{k,t+1}Q_tK_t(nn_e)} \tag{3.8}$$

Comparing eq. (3.8) with eq. (3.5) shows that default occurs if an entrepreneur's net worth becomes negative. This is the case when the after-shock real return on real capital (eq. (3.6)) is so low that it cannot cover the loan liabilities including interest. Note that there is no incentive compatibility problem of an entrepreneur declaring default even if he has positive net worth: in case of declaring default, the entrepreneur receives nothing and exits, whereas in the case of zero profits he stays in the market and has the chance of receiving positive profits in the next period. Also, there is no need for monitoring in case the entrepreneur does not default since in this case the contract is fulfilled by paying the specified loan volume including interest.

With the risk of default, the repayment of the loan including interest is not a certain outcome. Thus, for a bank to be willing to grant a loan, the expected return the bank receives must be equal to its opportunity cost of granting the loan.[392] The loan contract is thus specified subject to an incentive compatibility constraint of the bank, namely a zero profit condition.[393] More specifically, for ease of exposition, it will be assumed that a specialised loan branch of the bank is responsible for the loan business as in Gerali et al. (2010).[394] The loan branch receives B_t from its parent bank which it will in turn grant as loans to entrepreneurs.[395] In period $t+1$, when these loans come due, the loan branch pays back the whole amount including interest accruing at the wholesale return $R_{w,t+1}$.[396] The zero profit condition for the loan branch is defined by the equality between the expected revenue from the loan business and the repayment obligation of the specified loan volume multiplied by the wholesale return:[397]

$$\begin{aligned} &\mathbf{E}_t\left[(1-\mu^E)R_{k,t+1}Q_tK_t\int_{\psi^E_{\min}}^{\overline{\psi}^E_{t+1}}\psi^E f(\psi^E)\mathrm{d}\psi^E + \Big(1-p(\overline{\psi}^E_{t+1})\Big)R_{b,t+1}B_t\right] \\ &\quad = \mathbf{E}_t\Big[R_{w,t+1}B_t\Big] \end{aligned} \tag{3.9a}$$

391 See Bernanke et al. (1999: 1350)
392 See Bernanke et al. (1999: 1351)
393 See Bernanke et al. (1999: 1351). Note that due to the additional bank-specific friction here, the relevant opportunity cost of the loan here is different from BGG, see footnote 396. Also, the zero profit condition implies that banks interact on a perfectly competitive loan market.
394 See Gerali et al. (2010: 117f)
395 See Gerali et al. (2010: 119)
396 Note that the use of the wholesale return is different from BGG. In BGG, the loan contract is defined with reference to the risk-free return because there is no financial friction associated with financial intermediaries' liability side.
397 See Bernanke et al. (1999: 1351), eq. (3.4), my notation. $\mathbf{E}_t$ denotes the expectation of a variable/function dependent on the information set at the beginning of time t.

The first term on the first line of eq. (3.9a) is the share of capital revenues the loan branch receives in case of entrepreneurial default, net of monitoring costs.[398] The parameter μ^E measures the share of revenues spent on monitoring. The second term on the first line specifies the income from non-defaulting entrepreneurs paying back their loans including interest. Here, $p(\overline{\psi}_{t+1}^E)$ is the probability of entrepreneurial default.[399] The second line is the repayment obligation of the loan branch vis-à-vis the wholesale bank branch. Using the definition of the shock threshold, eq. (3.8), and the balance sheet identity of entrepreneurs, eq. (3.4), this equation can equivalently be expressed as:[400]

$$\begin{aligned}\mathbf{E}_t\Bigg[R_{k,t+1}Q_tK_t\Bigg((1-\mu^E)\int_{\psi^E_{\min}}^{\overline{\psi}^E_{t+1}}\psi^E f(\psi^E)\mathrm{d}\psi^E+\overline{\psi}^E_{t+1}\Big(1-p(\overline{\psi}^E_{t+1})\Big)\Bigg)\Bigg]\\ =\mathbf{E}_t\Big[R_{w,t+1}(Q_tK_t-N_{E,t})\Big]\end{aligned} \tag{3.9b}$$

To simplify this expression, define:[401]

$$\Gamma^E(\overline{\psi}^E_{t+1})\equiv\int_{\psi^E_{\min}}^{\overline{\psi}^E_{t+1}}\psi^E f(\psi^E)\mathrm{d}\psi^E+\overline{\psi}^E_{t+1}\Big(1-p(\overline{\psi}^E_{t+1})\Big) \tag{3.10}$$

$$G^E(\overline{\psi}^E_{t+1})\equiv\int_{\psi^E_{\min}}^{\overline{\psi}^E_{t+1}}\psi^E f(\psi^E)\mathrm{d}\psi^E \tag{3.11}$$

where eq. (3.10) defines the share of the total return on capital received by the loan branch, and eq. (3.11) is the share which is deducted from the former due to monitoring.[402] Hence, the entrepreneur receives $1-\Gamma^E(\psi^E_{t+1})$ of the gross capital return.[403] Thus, given $N_{E,t}$ the entrepreneur maximises:[404]

$$\max\mathbf{E}_t\left[\Big(1-\Gamma^E(\overline{\psi}^E_{t+1})\Big)R_{k,t+1}Q_tK_t\right] \tag{3.12}$$

subject to the zero profit condition of the loan branch:[405]

$$\mathbf{E}_t\Big[R_{k,t+1}Q_tK_t\Big(\Gamma^E(\overline{\psi}^E_{t+1})-\mu^E G^E(\overline{\psi}^E_{t+1})\Big)\Big]=\mathbf{E}_t\Big[R_{w,t+1}(Q_tK_t-N_{E,t})\Big] \tag{3.13}$$

398 Due to the separation of the financial and price friction, the decision problem developed in this section is linear in balance sheet quantities. Thus, the entrepreneurial sector can be completely described by a representative entrepreneur. Thus, for simplicity, entrepreneur-specific indices are dropped and the optimal loan contract is derived for the representative entrepreneur. Aggregation is dealt with below.

399 The entrepreneurial default probability is given by $p(\overline{\psi}^E)=\Pr\left[\psi^E<\overline{\psi}^E\right]=\int_{\psi^E_{\min}}^{\overline{\psi}^E_t}f(\psi^E)\mathrm{d}\psi^E$ where $p(\cdot)$ denotes the probability function, see Bernanke et al. (1999: 1380). See section 3.9 for details on the distribution of the entrepreneur-specific shock.

400 See Bernanke et al. (1999: 1351), eq. (3.5), and Bernanke et al. (1999: 1381), unnumbered equation, my notation.

401 See Bernanke et al. (1999: 1381), unnumbered equations, my notation.

402 See Bernanke et al. (1999: 1381)

403 See Bernanke et al. (1999: 1381)

404 See Bernanke et al. (1999: 1382), unnumbered equation, my notation.

405 See Bernanke et al. (1999: 1382), unnumbered equation, my notation.

Again, the left-hand side of eq. (3.13) is the expected return from granting loans, that is the share of capital revenues the bank receives net of monitoring costs. The right-hand side are wholesale interest expenses.

The relevant first-order conditions of this problem are:[406]

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial K_t} &= \mathbf{E}_t\Big[\Big(1-\Gamma^E(\overline{\psi}^E_{t+1})\Big)R_{k,t+1} + \lambda^L_t\Big(\Big(\Gamma^E(\overline{\psi}^E_{t+1}) \\
&\quad - \mu^E G^E(\overline{\psi}^E_{t+1})\Big)R_{k,t+1} - R_{w,t+1}\Big)\Big] && = 0 \qquad (3.14)\\
\frac{\partial \mathcal{L}}{\partial \overline{\psi}^E_{t+1}} &= \mathbf{E}_t\Big[-\Gamma^{E\prime}(\overline{\psi}^E_{t+1}) + \lambda^L_t\Big(\Gamma^{E\prime}(\overline{\psi}^E_{t+1}) - \mu^E G^{E\prime}(\overline{\psi}^E_{t+1})\Big)\Big] && = 0 \qquad (3.15)
\end{aligned}$$

where λ^L_t is the Lagrange multiplier on the zero profit condition (eq. (3.13)). A dash (') in eq. (3.15) indicates the first derivative of the function with respect to the entrepreneur-specific shock. By combining eqs. (3.14) and (3.15), an expression for the premium on external finance is derived which relates the expected real return on real capital to the wholesale return:[407]

$$\mathbf{E}_t\Big[R_{k,t+1}\Big] = \mathbf{E}_t\Big[\varrho^E(\overline{\psi}^E_{t+1})R_{w,t+1}\Big] \qquad (3.16)$$

where $\varrho^E(\overline{\psi}^E_{t+1})$ is the risk premium of external finance:[408]

$$\begin{aligned}
\varrho^E(\overline{\psi}^E_{t+1}) = \Gamma^{E\prime}(\overline{\psi}^E_{t+1})\Big(&\Big(1-\Gamma^E(\overline{\psi}^E_{t+1})\Big)\Big(\Gamma^{E\prime}(\overline{\psi}^E_{t+1}) - \mu^E G^{E\prime}(\overline{\psi}^E_{t+1})\Big) \\
&+ \Gamma^{E\prime}(\overline{\psi}^E_{t+1})\Big(\Gamma^E(\overline{\psi}^E_{t+1}) - \mu^E G^E(\overline{\psi}^E_{t+1})\Big)\Big)^{-1} \qquad (3.17)
\end{aligned}$$

Thus, loan volume and loan rate are determined by demand and supply such that condition eq. (3.16) is satisfied.

Having derived the optimal contract for a given level of entrepreneurial net worth, it is this (aggregate) entrepreneurial net worth which remains to be determined. First of all, note that above derivation applies to the representative entrepreneur. Due to the linearity of the optimisation problems discussed above in loans, capital and entrepreneurial net worth, the derivation is valid for any entrepreneur in the banking model. Aggregation is achieved by simple addition of individual entrepreneurs' balance sheet quantities, or equivalently, multiplication of the balance sheet quantities of the representative entrepreneur derived above by the number of entrepreneurs. Since the assumption is that there is a

406 See Bernanke et al. (1999: 1383), unnumbered equations, my notation. $\mathcal{L}$ denotes the Lagrangian function.

407 This corresponds to eqs. (3.9) or (4.5) in Bernanke et al. (1999: 1354, 1357)

408 See Bernanke et al. (1999: 1354, 1383), unnumbered equations (insert the equation for $\lambda(\overline{\omega})$ into the equation for $\rho(\overline{\omega})$), my notation.

continuum of mass 1, above derivations can be similarly interpreted as being solved for in aggregate quantities. This is the interpretation used in this study.

As in BGG, to prevent any entrepreneur from accumulating enough net worth so as to be able to cover his whole capital purchases without bank loans, each period entrepreneurs exit and become workers with probability $1 - \eta_E$.[409] Thus, the incentive-compatibility constraint of the loan branch always binds in equilibrium. In the aggregate this transforms into the assumption that each period a fraction $1 - \eta_E$ of entrepreneurs exits.[410] These entrepreneurs simply consume their remaining net worth.[411] To keep the proportions of workers and entrepreneurs constant over time, an equal number of workers become entrepreneurs and start a new business.[412] New entrepreneurs receive net worth equal to a fraction $\xi_E/(1-\eta_E)$ of exiting entrepreneurs' net worth.[413] From eq. (3.5), entrepreneurs' net worth is given by the difference between after-shock revenues and loan repayments, which can be expressed more simply using the definition of the share of the after-shock capital return entrepreneurs receive $(1 - \Gamma^E)$.[414] Then, aggregate net worth of entrepreneurs at the end of the period $N_{E,t}$ and aggregate entrepreneurial consumption (of exiting entrepreneurs) $C_{E,t}$ are given by:

$$N_{E,t} = (\eta_E + \xi_E)\left(1 - \Gamma^E(\overline{\psi}_t^E)\right) R_{k,t}Q_{t-1}K_{t-1} \tag{3.18}$$

$$C_{E,t} = (1 - \eta_E)(1 - \xi_E)\left(1 - \Gamma^E(\overline{\psi}_t^E)\right) R_{k,t}Q_{t-1}K_{t-1} \tag{3.19}$$

3.4 Retailers

There is a continuum of retailers with mass 1 indexed by nn_r. Retailers purchase homogeneous wholesale goods from entrepreneurs on the wholesale market and diversify them into heterogeneous final retail goods subject to constant marginal and average costs c. Total

409 See Bernanke et al. (1999: 1347)
410 See Gertler and Karadi (2011: 19)
411 See Bernanke et al. (1999: 1358). Since entrepreneurs' consumption is only a small share of aggregate demand, adding a further optimisation problem at this stage would make the derivations unnecessarily complicated.
412 This mechanism follows Gertler and Karadi (2011: 19) applied to entrepreneurs and workers.
413 See Gertler and Karadi (2011: 22). New entrepreneurs need some net worth because otherwise they would not be able to purchase any capital goods. One interpretation is that start-up funds are collected partially from exiting entrepreneurs by reducing their consumption with the remainder coming lump-sum from workers' budget. Note that this is different to Bernanke et al. (1999: 1358) who assume that net worth of entrepreneurs who do not exit is supplemented by wage income.
414 Compare eq. (3.6) in Bernanke et al. (1999: 1353) with the definition of the auxiliary function Γ^E in eq. (3.10) above.

output Y_t is defined as the sum of final goods from the retail sector:[415]

$$Y_t = \frac{(1-c)Y_t^W}{O_t^p} \tag{3.20}$$

where O_t^p measures the loss in output as a result of price dispersion, defined as:[416]

$$O_t^p = \int_0^1 \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta} \tag{3.21}$$

where P_t is the retail price index and $P_t(nn_r)$ is the price charged by a single retailer. As noted above, price dispersion lowers output because input factors are distributed inefficiently to retailers as a result of some retailers being unable to set the optimal price.[417]

Final retail goods are sold on the final goods market to workers, entrepreneurs, the government and capital investment funds. The former three explicitly or implicitly derive utility from consumption, the latter use final retail goods as investment goods. Before specifying the decision problem of retailers more explicitly, the demand function(s) for retailers' output need to be explained. This will be done using workers' consumption demand as an example. The demand functions for the other three agents and aggregate demand can be derived analogously. Since each retailer produces a slightly different variety, every worker has to decide how much to consume of each.[418] Assume that workers' total consumption $C_{W,t}$ can be represented by a Dixit-Stiglitz index of retail goods with ζ specifying the elasticity of substitution between the varieties:[419]

$$C_{W,t} = \left(\int_0^1 C_{W,t}(nn_r)^{\frac{\zeta-1}{\zeta}} \mathrm{dnn_r}\right)^{\frac{\zeta}{\zeta-1}} \tag{3.22}$$

The optimal behaviour of the worker solves choosing the quantity of each variety of the retail good $C_t(nn_r)$ to maximise the consumption index, namely total consumption, subject to total consumption expenditures $\int_0^1 P_t(nn_r)C_t(nn_r)\mathrm{dnn_r}$.[420] The optimal allocation of a worker's consumption between the different varieties is thus characterised by the following

415 See, for example, Cantore et al. (2013: 422), eq. (18.36), my notation. See also appendix section A.1 for details.
416 See Christiano et al. (2011: 295), eqs. (21) and (22), my notation.
417 See Christiano et al. (2011: 294). Note, however, that the loss in output as a result of price dispersion only affects the dynamics in second-order or higher-order approximations. Dynamics derived from first-order approximations do not depend on price dispersion, see Christiano et al. (2011: 297).
418 As will be shown later, all workers behave identically, thus the demand schedules can be derived in aggregate terms.
419 See Dixit and Stiglitz (1977: 298f), especially eq. (4), my notation.
420 See Galí (2008: 42)

set of demand functions:[421]

$$C_{W,t}(nn_r) = \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta} C_{W,t} \tag{3.23}$$

with the aggregate retail price index given by a Dixit-Stiglitz Index:[422]

$$P_t = \left(\int_0^1 P_t(nn_r)^{1-\zeta} \mathrm{dnn_r}\right)^{\frac{1}{1-\zeta}} \tag{3.24}$$

Thus, the demand function faced by a particular retailer nn_r is given by:[423]

$$Y_t(nn_r) = \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta} Y_t \tag{3.25}$$

Equation (3.25) states that the demand for a specific variety depends positively on the aggregate level of demand Y_t, and negatively on the ratio of its price $P_t(nn_r)$ to the general price level P_t.

Retailers set their price to maximise profits subject to above demand schedule. This is not a one-period problem since the crucial NK model friction enters here: sticky prices. Thus, not all retailers are able to change their price in every period. More specifically, Calvo-style sticky prices mean that with probability ξ^p a retailer cannot adjust its price in period t to the (new) optimal level.[424] With probability $1 - \xi^p$ he sets the price to the optimal level P_t^*.[425] As in Christiano, Eichenbaum and Evans (2005a), there is some degree of inflation indexation, that means retailers who cannot optimise their prices index their prices to the lagged inflation rate.[426] The degree of this indexation is measured by γ^p.[427] This allows for a flexible implementation of indexation: if γ^p is equal to 1, prices are fully indexed, that is change 1 for 1 with observed last period's inflation. In contrast, if $\gamma^p = 0$, there is no indexation which is equivalent to the original Calvo framework when prices are kept completely constant.

Therefore, the decision problem of the representative retailer is to set the price P_t^* to maximise the stream of profits for the periods for which this price is expected to stay

421 See Dixit and Stiglitz (1977: 299), eq. (14), my notation. See Galí (2008: 61f) as well as Dixit and Stiglitz (1977: 298ff) for a detailed mathematical derivation.
422 See Dixit and Stiglitz (1977: 298), eq. (4), my notation.
423 See Cantore et al. (2013: 421), eq. (18.24), my notation.
424 See Calvo (1983: 383)
425 Note that in the case of zero inflation and in the absence of shocks, P_t^* is equal to P_{t-1}^* and thus price staggering does not have any consequences.
426 See Christiano et al. (2005a: 10f)
427 γ^p may take on any value between 0 and 1.

fixed given the probability ξ^p.[428] Since retailers are owned by workers, all profits are redistributed as dividends to workers at the end of the period.[429] Moreover, this ownership assumption necessitates the inclusion of the nominal stochastic discount factor $\Lambda^N_{t,t+s}$ in the objective function.[430] Thus, retailers' objective function can be written as:[431]

$$\mathbf{E}_t\left[\sum_{s=0}^{\infty}(\xi^p)^s\Lambda^N_{t,t+s}Y_{t+s}(nn_r)\Big(P^*_t(nn_r)\Big(\frac{P_{t+s}}{P_t}\Big)^{\gamma^p}-P_{t+s}MC_{t+s}\Upsilon^{MS}_{t+s}\Big)\right] \tag{3.26}$$

which is maximised subject to the demand function for the output of retailer nn_r:[432]

$$Y_{t+s}(nn_r)=\left(\frac{P^*_t(nn_r)}{P_{t+s}}\right)^{-\zeta}Y_{t+s} \tag{3.27}$$

Υ^{MS}_t is a first-order autoregressive process with expectation equal to 1 which is perturbed by a mark-up shock ϵ_{MS}.[433] This mark-up process Υ^{MS}_t affects the steady-state mark-up. $\Lambda^N_{t,t+s}$ is the nominal stochastic discount factor given by:[434]

$$\Lambda^N_{t,t+s}=\beta\frac{U_{C,t+s}/P_{t+s}}{U_{C,t}/P_t} \tag{3.28}$$

where β is workers' discount rate and $U_{C,t}$ is workers' marginal utility of consumption (see section 3.7). MC_t is retailers' real marginal cost which is equal to the wholesale price P^W_t divided by the aggregate final retail good price index P_t.[435] The first-order condition is, noting that $\Pi_{t+s}={P_{t+s}}/{P_t}$:[436]

$$\mathbf{E}_t\left[\sum_{s=0}^{\infty}(\xi^p)^s\Lambda^N_{t,t+s}Y_{t+s}(nn_r)\Big(P^*_t(nn_r)\Pi^{\gamma^p}_{t+s}-\frac{\zeta}{\zeta-1}MC_{t+s}P_{t+s}\Upsilon^{MS}_{t+s}\Big)\right]=0 \tag{3.29}$$

If we abstract from Calvo-style sticky prices, that is set $s=0$, the first-order condition reduces to (excluding the mark-up shock for simplicity):

$$P^*_t(nn_r)=\frac{\zeta}{\zeta-1}MC_t(nn_r)P_{t+s} \tag{3.30}$$

428 See Galí (2008: 44)
429 See footnote 334 for more details on this assumption.
430 The subscript $t, t+s$ denotes that the stochastic discount factor is defined over the interval t to $t+s$.
431 See Cantore et al. (2013: 421), eq. (18.25), my notation. Note that the objective function in Cantore et al. (2013) does not include price indexation. See Christiano et al. (2005a: 11), eqs. (9) and (10) for how indexation enters retailers' objective function.
432 See Galí (2008: 44)
433 See section 3.9 for details.
434 See Cantore et al. (2013: 421), unnumbered equation, my notation.
435 See Cantore et al. (2013: 422), eq. (18.32)
436 See Cantore et al. (2013: 426), unnumbered equation, my notation. See Christiano, Eichenbaum and Evans (2005b: 10f) for more details on the relationship between this condition and the standard NK Phillips Curve representation.

This means the optimal price is a mark-up over retailers' nominal marginal cost. Notice that the optimal mark-up $\zeta/(\zeta-1)$ is constant over time since the elasticity of substitution between the different varieties of the final retail good ζ is a constant.

The infinite sum of eq. (3.29) may be represented as a set of difference equations, and the approach of Cantore et al. (2013) and Gabriel, Levine, Pearlman and Yang (2010) is used to derive it. To this end it is convenient to introduce the auxiliary variables J_t, JJ_t and $\tilde{\Pi}_t$. Inflation dynamics are then described by:[437]

$$\frac{P_t^*}{P_t} = \frac{J_t}{JJ_t} \tag{3.31}$$

$$JJ_t - \xi^p \beta \mathbf{E}_t\Big[\tilde{\Pi}_{t+1}^{\zeta-1} JJ_{t+1}\Big] = Y_t U_{C,t} \tag{3.32}$$

$$J_t - \xi^p \beta \mathbf{E}_t\Big[\tilde{\Pi}_{t+1}^{\zeta} J_{t+1}\Big] = \frac{\zeta}{\zeta-1} MC_t \Upsilon_t^{MS} Y_t U_{C,t} \tag{3.33}$$

$$\tilde{\Pi}_t = \frac{\Pi_t}{\Pi_{t-1}^{\gamma^p}} \tag{3.34}$$

Note that this representation in terms of the ratio of the optimal price to the current price level is not arbitrary. In the steady state with for example zero inflation, this ratio has a defined value of 1, while the price level may not.[438]

The dynamics of the price index can be highlighted by decomposing the aggregate price index given in eq. (3.24) into a share of those retailers that can and those that cannot optimise in a given period. Note that the former set the new optimal price, and that the latter set their price equal to the previous' period price times the inflation indexation rate.[439] The new optimal price is also equal across all optimising retailers due to the fact that they all buy the same homogeneous input at the same price and have the same cost function. The aggregate price index can then be expressed as:[440]

$$P_t^{1-\zeta} = \xi^p \Big(P_{t-1}\Pi_{t-1}^{\gamma^p}\Big)^{1-\zeta} + (1-\xi^p)\Big(P_t^*\Big)^{1-\zeta} \tag{3.35}$$

dividing by $P_{t-1}^{1-\zeta}$ and rearranging yields for the inflation rate Π_t:

$$\Pi_t = \left(\xi^p\Big(\Pi_{t-1}^{\gamma^p}\Big)^{1-\zeta} + (1-\xi^p)\left(\frac{P_t^*}{P_{t-1}}\right)^{1-\zeta}\right)^{\frac{1}{1-\zeta}} \tag{3.36}$$

437 See Cantore et al. (2013: 426), unnumbered equations, and Gabriel et al. (2010: 7), eqs. (25) to (27), my notation.

438 See Galí (2008: 44-45)

439 See Christiano et al. (2011: 333). Invoking the law of large numbers and that retailers who can optimise are drawn randomly, price index dynamics due to non-optimizing retailers' prices reduce to the lagged aggregate price index times the inflation indexing rate, see Christiano et al. (2011: 293) and Cantore et al. (2013: 421). See also footnote 351.

440 See Christiano et al. (2005b: 11), eq. (3.13), my notation.

3.5 Capital Investment Funds

The supply of capital is determined by specialised capital investment funds. After the retail goods production phase in period t, capital investment funds buy the period t stock of real capital net of depreciation from entrepreneurs. Capital investment funds buy final retail goods as investment goods I_t and combine these cost-freely with the old capital stock to generate the new period $t+1$ capital stock. The new capital stock is then sold to entrepreneurs.[441] Capital investment funds manage investment without incurring resource costs in the long-run equilibrium; however, adjusting the level of investment in the short run is costly: if period $t+1$ investment is different from period t investment then only a fraction of investment expenditures is added as new capital.[442] Thus, the law of motion for the capital stock is given by:[443]

$$K_t = \Upsilon_t^K \Big((1-\delta)K_{t-1} + \Big(1 - S(I_t/I_{t-1})\Big) I_t \Big) \tag{3.37}$$

where $S(\centerdot)$ is the investment adjustment cost function. As outlined in the next paragraph, the function S satisfies $S(1) = 0$ and $S'(1) = 0$, where S' denotes the first derivative of the investment adjustment cost function.[444]

Investment adjustment costs affect the optimal choice of investment. In a similar way as habits work within the utility function (see below), investment adjustment costs are included to improve the empirical fit of the model. Admittedly, investment adjustment costs as introduced here are an ad-hoc feature of NK DSGE models not explicitly derived from any maximisation problem. Intuitively, it might be argued that investment involves installation costs in terms of setting up the machinery, which could yield an immediate complete adjustment to shocks to be suboptimal.[445] Also, among others, Christiano et al. (2011) cite Matsuyama (1984) as an example for microfounding investment adjustment costs.[446] Matsuyama (1984) argues that investment adjustment arise due to planning costs involved; if non-financial firms want to increase investment, real resources need to be spent in the planning and management processes.[447] On the other hand, there is an offsetting learning effect on the part of managers such that at constant investment levels, adjustment costs are zero.[448] Hence, the argument is that adjustment costs matter in the short but not in the long run.

[441] Note that transaction costs for buying and selling capital are neglected for simplicity.
[442] See for example Christiano et al. (2005a: 15) and Gertler et al. (2012: S21)
[443] See also, for example, Cantore et al. (2013: 416), unnumbered equation, my notation.
[444] See section 3.9 for the specific functional form.
[445] See Wickens (2008: 33)
[446] See Christiano et al. (2011: 343)
[447] See Matsuyama (1984: 4)
[448] See Matsuyama (1984: 4)

More specifically, including investment adjustment costs has been shown to improve the responses of investment, consumption and interest rates especially to a monetary policy shock in DSGE models.[449] As Villa (2013) shows using Bayesian estimation techniques, including investment adjustment costs significantly improves the empirical fit in terms of the log data density.[450] Moreover, Christiano et al. (2011) argue that an investment adjustment cost function which depends on the rate of change of investment is in line with vector autoregression (VAR)-based evidence of a hump-shaped response of investment.[451] In contrast, a specification of the investment adjustment cost function which depends on differences between the investment to capital ratio and the depreciation rate has been argued to imply a large immediate response followed by small subsequent responses which is not borne out by VAR-analyses.[452] These considerations justify the particular form of eq. (3.37).

The stream of expected discounted profits of capital investment funds Ξ_t^c is then given by:[453]

$$\mathbf{E}_t\left[\sum_{s=0}^{\infty}\Xi_t^c\right] = \mathbf{E}_t\left[\sum_{s=0}^{\infty}\Lambda_{t,t+s}Q_{t+s}\Big(1 - S({}^{I_{t+s}}/{}_{I_{t+s-1}})\Big)I_{t+s} - I_{t+s}\right] \tag{3.38}$$

Capital investment funds choose the level of investment to maximise profits (eq. (3.38)). The first order condition is given by:[454]

$$Q_t\left(1 - S({}^{I_t}/{}_{I_{t-1}}) - \frac{I_t}{I_{t-1}}S'({}^{I_t}/{}_{I_{t-1}})\right) + \mathbf{E}_t\left[\Lambda_{t,t+1}Q_{t+1}S'({}^{I_{t+1}}/{}_{I_t})\left(\frac{I_{t+1}}{I_t}\right)^2\right] = 1 \tag{3.39}$$

As noted above, in the deterministic steady-state investment is constant, thus $I_t = I_{t-1}$ and investment adjustment costs are zero. Outside the long-run equilibrium, the price of capital varies inversely with investment adjustment costs, according to eq. (3.39).

3.6 Banks

Banks grant loans to entrepreneurs and balance these assets by issuing bank deposits and bank equity, which are held by workers. The optimal loan contract was presented in section 3.3.3, which follows the standard financial accelerator developed by Bernanke et al. (1999) between entrepreneurs and banks. This section deals with the overall financial position of the bank, focusing in particular on the liability management of the bank. As

449 See Christiano et al. (2005a: 40)
450 See Villa (2013: 28)
451 See Christiano et al. (2011: 342f)
452 See Christiano et al. (2011: 341ff)
453 See Gertler et al. (2012: S21), unnumbered equation, and Cantore et al. (2013: 417), unnumbered equation, my notation.
454 See Gertler et al. (2012: S21), eq. (12), and Cantore et al. (2013: 417), unnumbered equation, my notation.

Bank Transaction in Order of Settlement		Internal Net Worth (Cum)
	Period $t-1$	
Deposits and Equity collected	$-(D_t + e_t)$	
Minimum Reserves	$+MR_t$	
Loans granted	$+B_t$	0
	Period t	
Loans paid back including interest	$-R_{w,t+1}B_t$	$+R_{w,t+1}B_t$
Deposits paid out including interest	$+R_{ed,t+1}D_t$	$R_{w,t+1}B_t - R_{ed,t+1}D_t$
Equity paid out including dividends	$+R_{e,t+1}e_t$	0
Deposits and Equity collected	$-(D_{t+1} + e_{t+1})$	
⋮		

Table 3.1: Transactions Matrix of a Representative Non-Defaulting Bank; transactions in order of settlement. Assets are indicated by a + sign and liabilities by a − sign. The column 'Internal Net Worth (Cum)' shows the level of internal net worth that is accumulated after the respective transaction on the same row has been settled.

laid out in chapter 2, assuming that only loan markets are prone to imperfections does not seem to be a realistic modelling strategy. In this section, the financial friction between banks and workers is introduced, which mirrors the framework of the financial accelerator of Bernanke et al. (1999) as an application to the liability side of banks. However, as will be shown in section 4.2, they have differing consequences for the role of net worth.

There is a continuum of banks with mass 1 indexed by nn_b. As indicated before, a bank consists of two branches: a loan and a wholesale branch. While the loan branch of the bank manages the loan contract, the wholesale branch of the bank is in charge of the management of the bank's overall financial position. Banks are one-period entities which operate over the same period as the financial contracts they participate in: After all contracts have been settled, banks are closed. Then, a new continuum of banks is set up. These new banks collect bank equity e_t and bank deposits D_t from workers. A fraction of the deposit volume is mandated to be placed at the central bank as minimum reserves MR_t, while the remaining fraction of banks' balance sheet volume is made up of loans to entrepreneurs via the loan branch.[455] In the next period, the loan branch pays back the loan volume including wholesale interest expenses. Subsequently, bank deposits are paid out including interest, and any remaining revenues are paid out to equity-holders. This timing structure is visualised in table 3.1, representing the financial position of a bank in

[455] This timing representation indicates a loanable funds nature of the model. As has been emphasised before, this study abstracts from the debate between loanable funds and endogenous money. The key assumption for the banking model is that banks' balance sheet identity holds at all times.

a flow of funds table.

3.6.1 The Financial Position of the Bank

The bank's balance sheet constraint is given by:[456]

$$B_t + MR_t = D_t + e_t \tag{3.40}$$

where MR_t are minimum reserves[457] held at the central bank, D_t is the bank deposit volume and e_t the bank equity volume. Given banking sector fragility, the government established a deposit insurance scheme which covers bank deposits in case a bank defaults. To alleviate the government budget at least partially from these costs, banks have to pay deposit insurance fees DI_t. Also, minimum reserves are introduced on an ad-hoc basis without any explicit reference to enhancing payment system stability. Minimum reserves mainly serve as a modelling device to ensure that the real deposit return does not necessarily have to be smaller than the real risk-free return due to deposit insurance fees, as will become clearer below.

Then, the bank's profit Ξ_t^b is given by:

$$\Xi_t^b = R_{w,t}B_{t-1} + R_t MR_{t-1} - R_{d,t}D_{t-1} - DI_t - R_{e,t}e_{t-1} \tag{3.41}$$

R_t is the real risk-free return[458] which is paid on minimum reserves, $R_{d,t}$ is the real deposit return and $R_{e,t}$ is the real equity return. Minimum reserves and deposit insurance fees are simple linear functions of the (lagged) deposit volume:[459]

$$MR_t = \xi^r D_t \tag{3.42}$$

$$DI_t = \nu^d D_{t-1} \tag{3.43}$$

456 As in the case of entrepreneurs, the linearity of the decision problem in balance sheet quantities allows for the wholesale banking sector to be characterised by a representative bank. Therefore, the decision problem is solved in aggregate quantities in the following.

457 There are no excess reserves held, for instance due to a precautionary motive.

458 The real risk-free return is given by the nominal policy return set by the central bank divided by inflation, see section 3.8.2. The relationship between real and nominal returns is standard and specified further below.

459 This is in line with the practice in, for example, the EA where minimum reserves generally depend on a specified set of bank liabilities of the previous month(s), see European Central Bank (2002: 53). Yet, in order to simplify the derivations, the volume of period t minimum reserves is a function of period t, and thus not lagged, deposit liabilities in the banking model. In Germany, according to §26 (1) Einlagensicherungsgesetz (EinSiG) financial institutions pay deposit insurance fees on a yearly basis, which according to §19 (2) EinSiG are calculated on the basis of deposit liabilities and risk considerations. Given that all banks have access to the same one asset the latter factor is omitted in the benchmark model.

where ξ^r and ν^d are parameters to be determined. Using eqs. (3.42) and (3.43), bank profits (eq. (3.41)) can alternatively be written as:

$$\Xi_t^b = R_{w,t}B_{t-1} - (R_{d,t} + \nu^d - R_t\xi^r)D_{t-1} - R_{e,t}e_{t-1} \tag{3.44}$$

One can assume that theoretically, the bank has the ability to balance its assets with central bank financing, even though this is not explicitly incorporated into the banking model (see below). This implies that there is an upper limit to the deposit return. If the effective rate of return on bank deposits were higher than the rate of return on central bank financing, banks would switch from deposit to central bank financing. This upper limit is given by setting the effective deposits return $R_{ed,t}$, which takes into account deposit insurance fees and income from minimum reserves, equal to the risk-free return (in real terms):

$$R_{ed,t} = R_{d,t} - R_t\xi^r + \nu^d = R_t \tag{3.45a}$$

with some simple manipulation this yields:

$$R_{d,t} = (1 + \xi^r)R_t - \nu^d \tag{3.45b}$$

So depending on the parameters ξ^r and ν^d, the deposit return will be higher or lower than the real risk-free return. For simplicity, assume that the real effective deposit return is always set equal to the real policy return such that the bank is indifferent between deposit or central bank financing at the margin.[460]

3.6.2 The Derivation of the Bank Risk Premium

There exists an agency problem between equity-holders and banks along the lines of the financial friction used in section 3.3.3.[461] While bank deposits are completely insured by the governmental deposit insurance scheme, it is bank equity which absorbs any unexpected losses.[462] Note that bank equity is introduced here as a composite value variable, that is price and volume effects are not treated separately. Hence, bank equity e_t is then equal to

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[460] Also, for simplicity, banks do not use central bank financing in this model. While this does not capture the dynamics of the events following the recent financial crisis, this assumption helps keeping the model tractable and focus on the portfolio choice of workers.

[461] It is workers who hold both bank deposits and bank equity, no other agent has access to either of those two assets. However, to distinctly specify the source of the friction, the term equity-holders is used as a way of referring to workers in terms of their choice to hold bank equity.

[462] The absorbing function of bank equity is similar to entrepreneurial net worth. In contrast to entrepreneurial net worth, bank equity is not accumulated from retained earnings. This allows to postulate a demand for bank equity by workers, as will become clearer below. Conversely, entrepreneurial net worth is modelled as inside financial capital in order to focus on the markets for bank liabilities.

the product of the price of equity $p_{e,t}$ times the quantity of equity shares $q_{e,t}$:

$$e_t = p_{e,t} q_{e,t} \tag{3.46}$$

As any business, the bank seeks to maximise profits. Furthermore, each bank is subject to an idiosyncratic shock ψ_t^B which affects its wholesale loan revenue. This shock is analogous to the entrepreneur-specific shock ψ^E used for deriving the optimal loan contract above. The bank-specific shock is uniformly distributed over the interval $[\psi_{\min}^B; \psi_{\max}^B]$ with expectation equal to 1. The interpretation of 'low' and 'high' values of this shock are the same as for the entrepreneur-specific shock.[463]

This idiosyncratic bank shock might be thought of as a bank-specific ability to process loans with $\mathbf{E}_t[\psi_{t+1}^B]$ being average (or expected) productivity. As the intermediation process is not modelled explicitly with a production function using real resources, it can also be argued that the shock represents bank-specific efficiency in terms of how loans (or loan revenue) are created. Another interpretation would be that the shock represents non-interest income business, that is credit default swaps and other financial derivatives. The neat feature of this interpretation is its symmetric nature: some banks may be 'lucky' on financial markets, while others did bad bets.

The difference between loan revenue and deposit liabilities (both including effective interest) after all shocks have been settled is paid out to equity-holders. Thus, the expected return on equity $R_{e,t+1}e_t$ is given by:[464]

$$\mathbf{E}_t\Big[R_{e,t+1}e_t\Big] = \mathbf{E}_t\Big[\overline{\psi}_{Z,t+1}^B R_{w,t+1} B_t - R_{ed,t+1} D_t\Big] \tag{3.47}$$

where $\overline{\psi}_{Z,t+1}^B$ is the threshold level of the shock which equalises the expected returns on bank equity and bank deposits. As will become clearer subsequently, a worker will only hold bank equity if the return (including monitoring costs) is at least as high as the return on bank deposits. Ex-post, that is in $t+1$, values of ψ_{t+1}^B which are above $\overline{\psi}_{Z,t+1}^B$ lead to a higher $R_{e,t+1}$. Conversely, values of ψ_{t+1}^B below this threshold lead to a return on equity which is lower than expected, and thus lower than the expected return on bank deposits. A bank defaults if the shock realisation falls below $\overline{\psi}_t^B$ which is the value which renders loan revenues insufficient to cover banks' deposit liabilities. These two thresholds are defined as:

$$\overline{\psi}_t^B = \frac{R_{ed,t} D_{t-1}}{R_{w,t} B_{t-1}} \tag{3.48a}$$

463 See section 3.3.3 for details.

464 Given that all profits are distributed as dividends, this equation holds true regardless of the level of the shock, except for values below the bank default threshold where $R_{e,t}e_{t-1} = 0$.

$$\overline{\psi}^B_{Z,t} = \frac{R_{e,t}e_{t-1} + R_{ed,t}D_{t-1}}{R_{w,t}B_{t-1}} \tag{3.48b}$$

and their respective probabilities as:

$$p(\overline{\psi}^B_t) = \Pr\left[\psi^B < \overline{\psi}^B\right] = \int_{\psi^B_{\min}}^{\overline{\psi}^B_t} f(\psi^B)\mathrm{d}\psi^B \tag{3.49a}$$

$$p(\overline{\psi}^B_{Z,t}) = \Pr\left[\psi^B < \overline{\psi}^B_Z\right] = \int_{\psi^B_{\min}}^{\overline{\psi}^B_{Z,t}} f(\psi^B)\mathrm{d}\psi^B \tag{3.49b}$$

where again $p(\cdot)$ denotes the probability function. To summarise: if ψ^B_{t+1} lies in the interval $[\psi^B_{\min}; \overline{\psi}^B_{t+1}]$ the bank defaults. Equity-holders will receive nothing, that is they lose their initial equity investment. Yet, they are also protected by limited liability as they do not have to save the bank from failing. The deposit insurance fund takes over the remaining assets of the bank and pays out deposit liabilities in full (see below). If the shock realisation lies in the interval $[\overline{\psi}^B_{t+1}; \overline{\psi}^B_{Z,t+1}]$ the bank does not default but the return on equity is lower than expected. Finally, if the shock realisation lies in the interval $[\overline{\psi}^B_{Z,t+1}; \psi^B_{\max}]$ the bank will make supernormal profits and the return on bank equity is higher than expected. Except for the case of bank default, the return on equity times the volume of equity is equal to total bank profits less monitoring costs, if applicable.

The bank seeks to maximise total supernormal dividends Ξ^b_{t+1}, defined as:

$$\begin{aligned}\mathbf{E}_t\left[\Xi^b_{t+1}\right] = \mathbf{E}_t\Bigg[&\int_{\overline{\psi}^B_{Z,t+1}}^{\psi^B_{\max}} \psi^B f(\psi^B)\mathrm{d}\psi^B R_{w,t+1}B_t \\ &- \left(1 - p(\overline{\psi}^B_{Z,t+1})\right) R_{ed,t+1}D_t\Bigg]\end{aligned} \tag{3.50}$$

subject to an incentive compatibility constraint. The choice of having banks maximise supernormal profits instead of total profits is motivated by the following reasoning. Due to legal regulations of operating financial businesses, banks cannot operate without equity. The size of this implicit regulatory leverage ratio is left indeterminate as it does not affect the derivations here. Since equity holders are risk-averse, banks know that bank equity has to be remunerated at a higher rate than deposits in order to attract equity-holders. Thus, banks here have the objective to maximise the benefits of equity holding, which leads them to maximise supernormal dividends instead of total profits.

As noted above, workers are only willing to hold bank equity if the revenue from holding a unit of bank equity, that is including default and monitoring costs, is at least equal to the revenue from holding a unit of bank deposits. Therefore, the incentive compatibility constraint of equity-holders is:

$$\begin{aligned}
\mathbf{E}_t\Bigg[& R_{w,t+1}B_t \int_{\overline{\psi}^B_{Z,t+1}}^{\overline{\psi}^B_{\max}} \psi^B f(\psi^B)\mathrm{d}\psi^B - \int_{\overline{\psi}^B_{Z,t+1}}^{\overline{\psi}^B_{\max}} f(\psi^B)\mathrm{d}\psi^B R_{ed,t+1}D_t \\
& + (1-\mu^B)\Big(R_{w,t+1}B_t \int_{\overline{\psi}^B_{t+1}}^{\overline{\psi}^B_{Z,t+1}} \psi^B f(\psi^B)\mathrm{d}\psi^B \\
& - \int_{\overline{\psi}^B_{t+1}}^{\overline{\psi}^B_{Z,t+1}} f(\psi^B)\mathrm{d}\psi^B R_{ed,t+1}D_t\Big)\Bigg] \geq \mathbf{E}_t\Big[R_{d,t+1}e_t\Big]
\end{aligned} \tag{3.51}$$

As banks in the case of defaulting entrepreneurs, equity-holders have to pay proportional monitoring costs on the funds they receive if the realisation of the shock leads to a return on equity lower than expected. The reasoning for monitoring is the same as for entrepreneurs: the bank-specific shock is private information and equity-holders have to verify the exact value if they receive a lower equity return than they had expected.[465] This is the case when the shock falls in the interval between the default threshold $\overline{\psi}^B_t$ and the zero profit threshold $\overline{\psi}^B_{Z,t}$. This explains the separation into two terms in eq. (3.51). The first line of eq. (3.51) is the return on equity for shocks falling above the zero profit threshold, while the second and third line show the return on equity net of monitoring costs for shocks below the zero profit threshold but above the default threshold. The term on the right-hand side is the opportunity cost of holding bank equity.

Define the supernormal dividend function as G^M, the share of the loan revenue received by equity-holders as Γ^B, and monitoring costs as the product of the scaling parameter μ^B and the auxiliary function G^B:

$$\Gamma^B(\psi^B) = \int_{\overline{\psi}^B_t}^{\overline{\psi}^B_{\max}} \psi^B f(\psi^B)\mathrm{d}\psi^B - \overline{\psi}^B_t\Big(1 - p(\overline{\psi}^B_t)\Big) \tag{3.52}$$

$$G^B(\psi^B) = \int_{\overline{\psi}^B_t}^{\overline{\psi}^B_{Z,t}} \psi^B f(\psi^B)\mathrm{d}\psi^B - \overline{\psi}^B_t\Big(p(\overline{\psi}^B_{Z,t}) - p(\overline{\psi}^B_t)\Big) \tag{3.53}$$

$$G^M(\psi^B) = \int_{\overline{\psi}^B_{Z,t}}^{\overline{\psi}^B_{\max}} \psi^B f(\psi^B)\mathrm{d}\psi^B - \overline{\psi}^B_t\Big(1 - p(\overline{\psi}^B_{Z,t})\Big) \tag{3.54}$$

Combining eqs. (3.50) and (3.51) with the bank's balance sheet constraint eq. (3.40) and eqs. (3.48a), (3.48b) and (3.52) to (3.54), the maximisation problem can be written as:

$$\max \mathbf{E}_t\Big[\Xi^b_{t+1}\Big] = \mathbf{E}_t\Big[G^M(\psi^B_{t+1})R_{w,t+1}B_t\Big] \tag{3.55}$$

[465] Note that in contrast to entrepreneurial default, lenders to banks receive nothing in case of bank default since in this case the funds are insufficient to even pay out bank depositors.

subject to the incentive compatibility constraint:

$$\mathbf{E}_t\Big[\Big(\Gamma^B(\psi^B_{t+1}) - \mu^B G^B(\psi^B_{t+1})\Big) R_{w,t+1} B_t\Big] \geq \mathbf{E}_t\Big[R_{d,t+1}\Big(B_t - (1-\xi^r) D_t\Big)\Big] \tag{3.56}$$

The first-order conditions of this optimisation problem are:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial B_t} &= \mathbf{E}_t\Big[G^M(\psi^B_{t+1}) R_{w,t+1} \\ &\quad + \lambda^F_t \Big(\Big(\Gamma^B(\psi^B_{t+1}) - \mu^B G^B(\psi^B_{t+1})\Big) R_{w,t+1} - R_{d,t+1}\Big)\Big] &= 0 \qquad (3.57)\\ \frac{\partial \mathcal{L}}{\partial \psi^B_{t+1}} &= \mathbf{E}_t\Big[G^{M\prime}(\psi^B_{t+1}) + \lambda^F_t \Big(\Gamma^{B\prime}(\psi^B_{t+1}) - \mu^B G^{B\prime}(\psi^B_{t+1})\Big)\Big] &= 0 \qquad (3.58)\end{aligned}$$

where λ^F_t is the Lagrange multiplier associated with the incentive compatibility constraint of equity-holders. In eq. (3.58), a dash (') denotes the first derivative of the function with respect to the bank-specific shock. Combining eqs. (3.57) and (3.58) yields the relationship linking the real wholesale return to the real deposit return:

$$\mathbf{E}_t\Big[R_{w,t+1}\Big] = \mathbf{E}_t\Big[\varrho^B_{t+1} R_{d,t+1}\Big] \tag{3.59}$$

with the bank risk premium ϱ^B_{t+1} given by:

$$\begin{aligned}\varrho^B_{t+1} = -G^{M\prime}(\psi^B)\Big(& - G^{M\prime}(\psi^B)\Big(\Gamma^B(\psi^B) - \mu^B G^B(\psi^B)\Big) \\ & + G^M(\psi^B)\Big(\Gamma^{B\prime}(\psi^B) - \mu^B G^{B\prime}(\psi^B)\Big)\Big)^{-1}\end{aligned} \tag{3.60}$$

Hence, the financial friction between banks and workers increases the wedge between the real return on real capital and the real risk-free return further. Without this friction, the wholesale return would be equal to the risk-free return. Finally, note that in contrast to the net worth of entrepreneurs, banks do not accumulate net worth but have to collect bank equity from workers each period. Thus, the liability structure of banks is not only determined by banks' optimisation problem, but also by the asset demand equations which will be derived in the next section together with the other decision problems workers face.

3.7 Workers

There is a continuum of workers with mass 1, indexed by nn_w. Workers are agents who offer labour services in exchange for wage income. They choose between consuming and saving for later consumption. Workers may save their unconsumed income/wealth in two forms: bank deposits and bank equity. The sum of workers' wealth, that is the sum of bank equity and bank deposits, forms the financial capital of the economy. Deposits at banks are risk-free from the perspective of workers. Even though banks may default, depositors are insured against any deposit losses through the governmental deposit insurance scheme. On the other hand, bank equity may offer a higher return due to the fact that equity-holders receive the profit of the bank as dividends. If a bank has above-average profits, then equity-holders will receive an above-average return on equity higher than the expected return on bank deposits. However, bank equity is risky; not only in the case of bank default where all of the equity value is lost, but also if the bank is not very profitable and interest income is not sufficient to cover the deposit liabilities and pay for the promised higher rate of return of equity. This section first deals with the utility maximisation of the representative worker and subsequently discusses the portfolio choice problem.

3.7.1 Workers' Utility Function

The utility function of the representative worker is well-behaved, concave and twice non-separable: in consumption over time and in consumption and labour. There are several reasons for choosing this representation. Firstly, Basu and Kimball (2002) test separable and non-separable utility functions against data and find that the former are clearly rejected while the latter are not.[466] The non-separability over time helps moderate the equity premium puzzle, and non-separability between consumption and labour may be argued to be the more general representation in which the separable case is nested.

Standard time-separable utility functions have been criticised for their failure to solve the equity premium puzzle described by Mehra and Prescott (1985): with the standard representative agent representation it is difficult to explain the large difference between the return on equity and the risk-free return.[467] In models with a representative agent who derives utility directly from consumption, the risk-aversion parameter would need to be extremely large (too large to be plausible) to account for the empirically observed equity premium.[468] With time-inseparabilities, for example in the form of habits, workers do not directly derive utility from consumption per se, but rather from 'extra' consumption, that is consumption levels that are higher than usual. This feature makes the argument of the utility function more variable, and breaks the link between the coefficients of relative risk aversion and the elasticity of intertemporal substitution.[469] Furthermore, a utility specification with habits has been shown to be congruent with data on consumption and interest rates.[470]

[466] See Basu and Kimball (2002: 25) and Guerrón-Quintana (2008: 3613)
[467] See Mehra and Prescott (1985: 158) and Deaton (1992: 69)
[468] See Deaton (1992: 66, 68f)
[469] See R. E. Hall (1988: 343f) and J. Y. Campbell and Cochrane (1999: 238)
[470] See Cochrane (2005: 472)

In contrast, the significance of non-separability between leisure and consumption is still a debated issue. As noted above, Basu and Kimball (2002) have shown it to be important empirically.[471] In contrast, Kiley (2010) presents evidence that this non-separability may be of lesser importance when time non-separability in the form of habits is taken into account.[472] Yet again, Christiano et al. (2011) argue that this non-separability helps matching the hump-shaped response of consumption following shocks.[473] Also, Guerrón-Quintana (2008) provides evidence that smaller values for habits and investment adjustment costs are necessary to match the responses to a monetary policy shock.[474] Given that for the specific utility function considered here, the separable case is nested in the non-separable case the latter may be argued to be a more general approach.[475] Therefore the utility function features non-separability in both dimensions.

More specifically, the functional form of utility is a variant of King-Plosser-Rebelo preferences with habits.[476] Utility of a worker $U(nn_w)$ is increasing in real consumption $(C_{W,t})$, relative to external habits, and in leisure L_t. For simplicity, habits are modelled as lagged aggregate per capita consumption $C_{W,t-1}$ as in much of the literature.[477] In addition to the budget constraint discussed in the next subsection, workers are constrained in maximizing their utility by their time endowment. Without loss of generality this time endowment is normalised to 1. Workers can allocate their time endowment between leisure and labour, which can be expressed as: $1 = H_t + L_t$. Incorporating this time endowment constraint, a worker's utility function is given by:[478]

$$U(nn_w) = \frac{\Upsilon_t^P\Big((C_{W,t}(nn_w) - \chi C_{W,t-1})^{1-\eta_l}(1 - H_t(nn_w))^{\eta_l}\Big)^{1-\sigma_c} - 1}{1 - \sigma_c} \tag{3.61}$$

with the usual assumptions:[479]

$$U_C > 0; \quad U_{CC} < 0; \quad U_H < 0; \quad U_{HH} < 0 \tag{3.62}$$

that is, utility is increasing in consumption, but at a declining rate and utility is decreasing

471 See Basu and Kimball (2002: 25). Also, Cochrane (2005: 482) cites various studies which present evidence in favour of goods non-separability.
472 See Kiley (2010: 683)
473 See Christiano et al. (2011: 336f) and references therein.
474 See Guerrón-Quintana (2008: 3628)
475 For $\sigma_c = 1$ (see below), the utility function is separable in labour and consumption, see King, Plosser and Rebelo (1988: 202).
476 See King et al. (1988: 202)
477 Note that in eq. (3.61), habits are modelled as external for analytical convenience, that is habits are based on average consumption and not on an individual worker's consumption history. See Cochrane (2005: 467ff) for the distinction between external and internal habits.
478 See Cantore et al. (2013: 425), eq. (18.42), my notation.
479 See Barro and Sala-i Martin (2004: 427f) and Galí (2008: 16)

in hours worked at an increasing rate. A single-letter subscript denotes the first derivative of the utility function with respect to the variable, and a double-letter subscript denotes the second derivative. χ governs the degree of habit persistence, and σ_c the degree of non-separability between leisure and consumption.[480] A higher degree of non-separability is represented by a higher value of σ_c.[481] If σ_c is equal to one, the utility function above transforms into a logarithmic utility function separable in consumption and leisure.[482] Finally, η_l represents the share of leisure vis-à-vis consumption in the utility function. Υ_t^P is a first-order autoregressive process with expectation equal to 1 perturbed by a preference shock.[483]

All workers have the same utility function and budget constraint (see below) and have access to a complete set of Arrow-Debreu securities to insure against *idiosyncratic* shocks to labour and equity income.[484] Thus, all workers behave identically; the worker-specific index nn_w can be dropped in the following derivations. Note that workers in the aggregate cannot insure against negative shocks or developments. The marginal utility of consumption U_C and marginal disutility of labour U_H are:

$$U_C = \Upsilon_t^P(1-\eta_l)\Big((C_{W,t}-\chi C_{W,t-1})^{(1-\eta_l)(1-\sigma_c)-1}(1-H_t)^{\eta_l(1-\sigma_c)}\Big) \tag{3.63}$$

$$U_H = -\Upsilon_t^P\eta_l\Big((C_{W,t}-\chi C_{W,t-1})^{(1-\eta_l)(1-\sigma_c)}(1-H_t)^{\eta_l(1-\sigma_c)-1}\Big) \tag{3.64}$$

3.7.2 The Budget Constraint

The maximisation of a worker's utility is constrained by his time endowment and his budget.[485] The time endowment constraint was already integrated in the utility function eq. (3.61) above. The nominal budget constraint of the representative worker in period t is defined as:

$$(1-\tau)W_tH_t + r_{dn,t}D_{t-1} + r_{en,t}e_{t-1} = \int_0^1 P_t(nn_r)C_{W,t}(nn_r)\mathrm{dnn_r} + \Delta e_t + \Delta D_t \tag{3.65}$$

The worker receives nominal labour income W_tH_t net of income taxes and interest income from past saving and uses these funds to consume and save. $\int_0^1 P_t(n)C_{W,t}(n)\mathrm{dn}$ is total consumption expenditure. Income taxes are levied at an exogenous tax rate τ. e_t is the value of bank equity the worker holds, while the rest of his income and wealth which is not consumed is held as bank deposits D_t. As discussed before, interest income from deposits accrues at the nominal deposit interest rate $r_{dn,t}$, while $r_{en,t}$ is the nominal rate of interest

480 See Guerrón-Quintana (2008: 3617)
481 See Guerrón-Quintana (2008: 3617)
482 See Guerrón-Quintana (2008: 3617)
483 See section 3.9 for details.
484 See section 3.1.2 for details.
485 Additionally, the usual transversality condition applies, which rules out Ponzi games, see Galí (2008: 16) and Wickens (2008: 56f).

on equity. Note that the following convention is used here:[486]

$$R_{x,t} = 1 + r_{x,t} \tag{3.66}$$

where $r_{x,t}$ is the net return applied from period t to period $t+1$ and $R_{x,t}$ is the gross return from period t to period $t+1$, and $x = \{n, b, d, ed, e, k, p, w\}$. In the following, $r_{x,t}$ denotes an interest rate and $R_{x,t}$ denotes a return for simplicity.

The optimal allocation of consumption expenditures between the different retail good varieties was already described in section 3.4. The optimal allocation is characterised by a set of demand functions:[487]

$$C_{W,t}(nn_r) = \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta} C_{W,t} \tag{3.67}$$

Given this optimal allocation, total consumption expenditures equal the product of the price index eq. (3.24) and the consumption index:[488]

$$\int_0^1 P_t(nn_r)C_{W,t}(nn_r)\mathrm{dnn_r} = P_t C_{W,t} \tag{3.68}$$

which allows the budget constraint to be written more simply as:

$$(1-\tau)W_t H_t + r_{dn,t}D_{t-1} + r_{en,t}e_{t-1} = P_t C_{W,t} + \Delta e_t + \Delta D_t \tag{3.69a}$$

Concerning the wealth management of the worker, using the definitions of total worker wealth $V_t = D_t + e_t$ and of the equity share in wealth $V_t^e = e_t/V_t$ one may equally write eq. (3.69a) as:

$$(1-\tau)W_t H_t + r_{pn,t}V_{t-1} = P_t C_{W,t} + \Delta V_t \tag{3.69b}$$

with $r_{pn,t}$ as the nominal portfolio interest rate, defined as:

$$r_{pn,t} = r_{dn,t} + V_{t-1}^e(r_{en,t} - r_{dn,t}) \tag{3.70}$$

3.7.3 First-Order Conditions

The Lagrangian of the workers' optimisation problem is given by eq. (3.71). Note that it is simpler to use a slightly different notation with the nominal portfolio return $R_{pn,t}$ instead of the portfolio interest rate $r_{pn,t}$, such that the difference operator Δ can be dropped:

[486] This notation follows Cochrane (2005: 8).
[487] See Dixit and Stiglitz (1977: 299), eq. (14), my notation. See section 3.4 for more details.
[488] See Galí (2008: 42)

$$\mathcal{L} = \mathbf{E}_t \Bigg[\sum_{s=0}^{\infty} \beta^s U(C_{W,t+s}, H_{t+s}) + \lambda^W_{t+s}\Big((1-\tau)W_t H_t + R_{pn,t+s}V_{t+s-1} - P_{t+s}C_{W,t+s} - V_{t+s}\Big)\Bigg] \tag{3.71}$$

where λ^W_{t+s} is the Lagrangian multiplier associated with workers' budget constraint. The first-order conditions for this problem are then:

$$\frac{\partial \mathcal{L}}{\partial C_{W,t+s}} = U_{C,t+s} - \lambda^W_{t+s} P_{t+s} = 0 \tag{3.72}$$

$$\frac{\partial \mathcal{L}}{\partial H_{t+s}} = U_{H,t+s} + \lambda^W_{t+s}(1-\tau)W_{t+s} = 0 \tag{3.73}$$

$$\frac{\partial \mathcal{L}}{\partial V_{t+s}} = \beta^s \lambda^W_{t+s+1} R_{pn,t+s+1} - \beta^{s-1}\lambda^W_{t+s} = 0 \tag{3.74}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda^W_{t+s}} = (1-\tau)W_{t+s}H_{t+s} + R_{pn,t+s}V_{t+s-1} - P_{t+s}C_{W,t+s} - V_{t+s} = 0 \tag{3.75}$$

Without loss of generality, the time indexing parameter s is set to 0 in the following derivations. Combining eqs. (3.72) and (3.73) yields the standard labour supply equation including income taxes:

$$\frac{W_t}{P_t} = -\frac{U_{H,t}}{(1-\tau)U_{C,t}} \tag{3.76}$$

Hence, optimal labour supply is determined by the equality of the real wage and the marginal rate of substitution between consumption and leisure.

Combining eqs. (3.72) and (3.74) yields the Euler equation of the banking model:

$$\frac{U_{C,t}}{P_t} = \beta \mathbf{E}_t \left[R_{pn,t+1} \frac{U_{C,t+1}}{P_{t+1}} \right] \tag{3.77}$$

Using the real stochastic discount factor defined as:

$$\mathbf{E}_t \Big[\Lambda_{t,t+1}\Big] = \beta \mathbf{E}_t \left[\frac{U_{C,t+1}}{U_{C,t}} \right] \tag{3.78}$$

and the definition of real returns, the Euler equation can be written simply as:

$$1 = \mathbf{E}_t \Big[\Lambda_{t,t+1} R_{p,t+1}\Big] \tag{3.79}$$

where $R_{p,t}$ is the real portfolio return. Nominal returns are related to real returns by the inflation rate:[489]

$$R_{pn,t} = \frac{R_{p,t-1}}{\Pi_t} \tag{3.80a}$$

[489] See Cantore et al. (2013: 422), eq. (18.33), my notation.

$$R_{dn,t} = \frac{R_{d,t-1}}{\Pi_t} \tag{3.80b}$$

$$R_{en,t} = \frac{R_{e,t-1}}{\Pi_t} \tag{3.80c}$$

The difference of this Euler equation to conventional specifications is the type of return: in the banking model, the portfolio return enters the decision problem of the representative household, whereas usually the Euler equation is derived in terms of the risk-free return. This difference will be explored further below.

3.7.4 Asset Demand Functions

In most DSGE models in which more than one type of asset is modelled, one asset is assumed to enter the utility function of the respective agent. Probably the most common example is the money-in-utility model to derive some form of liquidity preference, but there are other possibilities such as housing or housing services.[490] This approach may be motivated by theoretical reasons, but it is also necessary due to analytical needs. DSGE models are generally approximated to first order around the deterministic steady state. This steady state is characterised by current and expected future shocks being set to zero. Hence, without risk in the deterministic steady state, all expected returns are equal.[491] Thus, investors (in this case workers) are indifferent between the different types of assets and portfolio shares are indeterminate.[492] Hence, including money or another asset in the utility function determines a preference for one asset on the demand side.

Related, consider the choice between money and bonds. For workers to be indifferent between holding money or interest-bearing bonds, the real return of holding money must be equal to the real return of holding a bond. If these returns were different in equilibrium, then the worker would only hold the asset with the higher return, and none of the other. If nominal bonds are remunerated at a positive nominal interest rate, no worker wants to hold money - even in the absence of inflation - since it does not pay interest.[493] On the other hand, if money enters the utility function of workers, workers have a preference for holding money, motivated by, for instance, liquidity preference. In this case the first-order conditions of workers' optimisation problem determine the optimal amount of money holdings.[494]

Since the approach of approximating the banking model around its non-stochastic

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[490] See for example Iacoviello (2005)
[491] See Coeurdacier and Rey (2013: 69)
[492] See Coeurdacier and Rey (2013: 69)
[493] Note that this reasoning abstracts from other determinants of money demand such as transactions demand or liquidity preference. These are theoretical justifications for including money in the utility function in a DSGE framework.
[494] For a textbook derivation of a money-in-utility model see Walsh (2003: 43ff).

steady state is also employed in this study, the problem of portfolio indeterminacy arises here as well.[495] However, while including money in the utility function may be justified by liquidity preference, including either bank deposits or bank equity in the utility function does not seem appropriate for the model presented here. Since all financial contracts last one period, there is no distinguishing feature between assets in terms of liquidity. From the point of view of workers, deposits are risk-free given that the government established a deposit insurance scheme. As workers are risk-averse, it might be argued that they prefer deposits. However, this approach would lead workers to only hold bank deposits in the steady state.[496] The reason is due to the formulation of the financial friction in section 3.6 which results in the returns on bank equity and bank deposits being equal in the steady state. If, furthermore, a preference for bank deposits was introduced through the utility function, then the rational worker would not hold bank equity. Yielding the same return, he would choose the asset which increases his utility more.

Instead of including bank deposits directly in the utility function, a different approach is followed here: asset demand functions in the spirit of Tobin (1958). Tobin (1958) originally derived this approach to explain why money was held as a non-interest-bearing asset when there are interest-bearing assets available.[497] Therefore, assume that the demand for bank equity evolves according to:

$$e_t = V_t\left(\omega_1 + \omega_2\left(\frac{R_{e,t+1}}{R_e} - 1\right) - \omega_3\left(\frac{R_{d,t+1}}{R_d} - 1\right)\right) \tag{3.81}$$

where ω_1, ω_2 and ω_3 are parameters to be determined and variables without time subscripts denote the steady state of the respective variable.[498] Equation (3.81) implies that bank equity demand increases with increases in workers' total wealth and the expected return on bank equity, and decreases with an increase in the expected return on bank deposits. Since there are only two assets the worker can choose, the corresponding demand for bank deposits is given by:

$$D_t = V_t\left((1 - \omega_1) - \omega_2\left(\frac{R_{e,t+1}}{R_e} - 1\right) + \omega_3\left(\frac{R_{d,t+1}}{R_d} - 1\right)\right) \tag{3.82}$$

An increase in the quantity demanded of bank equity as a reaction to a change in one of the returns must be accompanied by a reduction in the quantity demanded of bank deposits of equal size. This is the first accounting principle Tobin (1969) noted.[499] Hence,

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495 See chapter 4 on the computation of the equilibrium and its stability - determinacy realms.

496 In the following, the existence and stability of the deterministic steady state are already presumed, while the corresponding analysis is presented in chapter 4.

497 See Tobin (1958: 66)

498 See footnote 496

499 See Tobin (1969: 18)

the parameters ω_2 and ω_3 appear in both demand equations, although with opposite signs. The second accounting principle concerns the equilibrium portfolio shares: the sum of all asset demand changes after a change in total wealth must add up to 1.[500] Hence, the equilibrium portfolio share of bank equity is ω_1 and the one of bank deposits is $(1-\omega_1)$.

Although these accounting principles apply here, there are some differences to the demand equations originally proposed by Tobin: in his seminal paper of 1958, he derived the optimal portfolio shares as a function of the volatilities of the portfolio and the risky asset, as well as the interest rate spread.[501] This was not an ad-hoc proposition but he derived this relationship from investors' preferences.[502] However, there is a need to adjust the original demand equations to a DSGE model framework, since in the deterministic steady state all spreads are equal to zero.

To see this, the simple version of Tobin's mean-variance model given in Serletis (2007) is used for the comparison here:[503]

$$\frac{e_{to,t}}{V_{to,t}} = \frac{r_{to,t} - r_{rf,t}}{\omega_{to}\sigma_{to}^2} \tag{3.83a}$$

where $V_{to,t}$ is the total portfolio volume, $r_{to,t}$ is the risky interest rate associated with the risky asset $e_{to,t}$, $r_{rf,t}$ is the safe interest rate, σ_{to}^2 is the variance of the risky interest rate and ω_{to} is a utility function parameter.[504] The log-linear approximation to this equation is:

$$\hat{e}_{to,t} - \hat{v}_{to,t} = \left(\frac{r_{to}}{r_{to} - r_{rf}}\right)\hat{r}_{to,t} - \frac{r_{rf}}{r_{to} - r_{rf}}\hat{r}_{rf,t} - 2\hat{\sigma}_{to} \tag{3.83b}$$

From eq. (3.83b) it is clear why the demand equations have to be adjusted: the model would not be solvable due to the steady-state spread appearing in the denominator of eq. (3.83b), which is zero in the banking model presented here.

One point of departure is the presence of ω_1 in eqs. (3.81) and (3.82). The parameter ω_1 has a very natural interpretation: it is the steady-state equity to wealth ratio.[505] This also implies that the portfolio shares are determined (partially) exogenously. The justification for this is threefold: firstly, deriving those portfolio shares by a utility maximisation exercise would necessitate assumptions about the functional form of utility in terms of wealth and risk which would eventually also result in choosing parameters more or less

500 See Tobin (1958: 18)
501 See Tobin (1958: 71ff)
502 See Tobin (1958: 71ff)
503 See Serletis (2007: 115), eq. (9.4), my notation.
504 The underlying utility function is $U = r_{to} - (\omega_{to}/2)\sigma_{to}^2$. Serletis (2007: 115), unnumbered equation, my notation.
505 This can easily be seen by setting all returns equal to their steady-state values.

dependent on targeting steady-state portfolio shares. Instead, the assumption structure is made very transparent and a steady-state ratio imposed similar to the parameters determining the share between entrepreneurial consumption and net worth (see above, section 3.3). Secondly, while the parameter is calibrated, it is not fixed to a specific value. Rather, it is calibrated as a function of other parameters and endogenous variables and thus, can be determined in conformity with credit spreads.[506]

The other point of departure is the absence of the variance of the risky interest rate in eqs. (3.81) and (3.82). Despite this, it can be shown that considering log-linear approximations, the parameters in eqs. (3.81) and (3.82) are related to the structural parameters in the original Tobin demand equations. The log-linear approximations to eqs. (3.81) and (3.82) are:[507]

$$\hat{e}_t = \hat{v}_t + \frac{\omega_2}{\omega_1}\mathbf{E}_t\Big[\hat{r}_{e,t+1}\Big] - \frac{\omega_3}{\omega_1}\mathbf{E}_t\Big[\hat{r}_{d,t+1}\Big] \tag{3.84}$$

$$\hat{d}_t = \hat{v}_t - \frac{\omega_2}{1-\omega_1}\mathbf{E}_t\Big[\hat{r}_{e,t+1}\Big] + \frac{\omega_3}{1-\omega_1}\mathbf{E}_t\Big[\hat{r}_{d,t+1}\Big] \tag{3.85}$$

Equation (3.83b) gives some intuition about the parameters ω_1, ω_2 and ω_3. In comparison to eq. (3.84), it is easy to see that the ratios ω_2/ω_1 and ω_3/ω_1 roughly correspond to the terms multiplying the deviation of the risky and risk-free interest rates in eq. (3.83b) with the deviation of the variance of the risky asset from its steady state being small. Alternatively, for $\omega_1 = 0$ and $\omega_2 = \omega_3$, the non-linear asset demand equations of the banking model, eqs. (3.81) and (3.82) correspond to eq. (3.83a) where ω_2 is equal to the inverse of the variance of the risky asset's return times the utility function parameter. Thus, for the purposes of the present model, the asset demand equations relate sufficiently to the concept of Tobin (1958).

In general, it is not clear how ω_2 and ω_3 are related. Several restrictions on the parameters ω_2 and ω_3 have been put forward: Godley (1996) argued for a horizontal constraint on all parameters: in this two asset case, this corresponds to $\omega_2 = \omega_3$.[508] Alternatively, B. M. Friedman (1978) proposed symmetric constraints: the reaction of asset 1 to the interest rate of asset 2 should be equal to the reaction of asset 2 to the interest rate of asset 1.[509] Hence, in the two asset case, this would also yield $\omega_2 = \omega_3$. However, both of these additional restrictions imply that bank equity and bank deposits

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506 See section 5.2

507 Note that the returns entering these equations are still gross, not net, returns, even though lower-case letters are used in line with the other variables to denote the deviation from the steady state. Thus, $\hat{r}_{x,t+1}$ is defined as $log(R_{x,t+1}) - log(R_x)$ for $x = \{d, e\}$. For more details on the log-linear approximation see chapter 4.

508 See Godley (1996: 18)

509 See B. M. Friedman (1978: 613)

are perfect substitutes even when the economy does not rest in its steady state. This may be contentious concerning the banking model on the grounds that bank deposits are risk-free while bank equity is risky from the perspective of workers. In sum, the relative as well as the absolute sizes of the ω's are not determined by these derivations, since the volatility of the risky asset cannot be determined analytically in the banking model. Thus, this issue will be taken up again in chapter 5 when the model parameters are estimated.

Intuitively, eqs. (3.81) and (3.82) imply that workers will only change the portfolio weights if either one real return falls below or above its long-run value to take advantage of short-run fluctuations. With rational expectations and complete information, workers know the underlying model and the underlying long-run equilibrium to which the economy will tend if all shocks were zero. So, if they observe an increase in returns, they will still expect that returns are anchored at their equilibrium values in the long run. This reasoning contributes to the functional of form of eqs. (3.81) and (3.82). Furthermore, the specification is similar to the reaction function of the central bank which is explained in the next section.

3.8 The Government

3.8.1 Fiscal Policy

The last agent to be considered is the government which is in charge of fiscal and monetary policy. The specification of the governmental decision problem with respect to fiscal policy is kept to a minimum. The government is constrained to a balanced budget in every period. More specifically, fiscal policy is passive and taxes are non-distortionary.[510]

This is without doubt a gross abstraction from reality. However, within the context of this model, it is a reasonable and necessary simplification. For example, assume, for example, that there were government bonds which are by assumption risk-free. How would the representative worker choose between risk-free government bonds and insured bank deposits which are risk-free as well from the perspective of workers? There would be a need for a set of new assumptions, for instance determining the amount of government bonds from the supply sides since bank deposits and government bonds would in effect be perfect substitutes. In a similar vein, there would have to be some decision rule with respect to the choice between tax and debt financing which necessitates a thorough treatment of its

[510] More specifically, taxes are non-distortionary in the first-order log-linear approximation to the banking model used for estimation and simulation in the following chapters. The assumption of non-distortionary taxes is not unusual for the standard NK model and for models focusing on monetary policy, see for instance Christiano, Motto and Rostagno (2003: 1120) and Herbst and Schorfheide (2016: 7f).

own. This is beyond the scope of this model.

Hence, the assumption is simply that there is no government debt. If the government chooses or is forced to increase its expenditures then taxes T_t must be raised in order to balance the budget. Moreover, taxes are levied on wage income of workers at an exogenous tax rate τ. Government expenditures include government consumption of the retail good Υ_t^G, net deposit insurance payouts N_t^n and interest on minimum reserves.[511] On the income side the government also raises deposit insurance fees from banks DI_t. So the governmental budget constraint can be expressed as:

$$\Upsilon_t^G + N_t^n + (R_t - 1)MR_{t-1} = T_t + DI_t \tag{3.86}$$

where total taxes are:

$$T_t = \tau W_t H_t \tag{3.87}$$

Government consumption Υ_t^G follows an exogenous first-order autoregressive process perturbed by a government consumption shock.[512] Note that only net deposit payouts enter the governmental budget constraint. Gross deposit payouts N_t^b are equal to the deposit liabilities of failed banks including interest (eq. (3.88)). Net deposit payouts are gross deposit payouts less the remaining assets of failed banks (eq. (3.89)):

$$N_t^b = G^N(\psi_t^B)R_{d,t}D_{t-1} \tag{3.88}$$

$$N_t^n = N_t^b - (1 - \mu^N)G^N(\psi_t^B)R_{w,t}B_{t-1} \tag{3.89}$$

The auxiliary function G^N measuring the share of failing banks is defined as:

$$G^N = \int_{\psi_{\min}^B}^{\overline{\psi}^B} \psi^B f(\psi^B) d\psi^B \tag{3.90}$$

In the case of bank default, the government gains control over all remaining assets of the bank, and uses those funds to pay out depositors.[513] Any additional bank deposit liabilities which remain after these assets have been used up will be paid from the governmental budget. Note that the government also pays monitoring costs proportional to the loan

[511] It is only interest which enters the government budget constraint because minimum reserves are not a form of income or expense for the government. Thus, there is no volume effect of changing minimum reserves over time. Minimum reserves are kept in a separate vault, and simply handed back to banks at the end of the reserve period.

[512] On the specification see section 3.9.

[513] From the point of view of equity-holders, it is better to receive nothing in the case of default than to gain access to the assets themselves and pay out depositors since bank default occurs only when bank assets are insufficient to pay out deposit liabilities.

revenue of insolvent banks.[514] The share of bank assets used up in monitoring is scaled by the parameter μ^N.

3.8.2 Monetary Policy

As observed in reality, there is a separate governmental entity, the central bank, which is in charge of monetary policy. In line with the mandate of, for instance, the ECB, its primary objective is price stabilisation.[515] While the central bank is not independent concerning the definition of its policy goal, it is independent in its choice of policy instruments and conduct. As in most of the literature, the central bank sets the nominal risk-free return, defined as 1 plus the nominal policy rate, using a monetary policy rule. The specific form considered here is a Taylor-type rule with interest rate persistence:[516]

$$R_{n,t} = R_n^{(1-\rho_R)} R_{n,t-1}^{\rho_R} \left(\frac{\Pi_t}{\Pi}\right)^{(1-\rho_R)\theta_\pi} \left(\frac{GAP_t}{GAP}\right)^{(1-\rho_R)\theta_y} e^{\epsilon_{M,t}} \tag{3.91}$$

where θ_π and θ_y are parameters governing the responsiveness of the nominal risk-free return to inflation and the output gap. $\epsilon_{M,t}$ is the monetary policy shock, which is discussed further below.[517]

The rule stipulates that the policy return will be adjusted for deviations of inflation Π_t and the output gap GAP_t from their respective steady-state values Π and GAP.[518] Moreover, the monetary policy rule features interest rate inertia as long as the persistence parameter is strictly positive, that is $\rho_R > 0$.[519] Interest rate inertia can be motivated by various factors. This includes firstly, a larger impact of a change in the policy rate due to agents realizing that the change will last for several periods and secondly, lower interest rate volatility.[520] Moreover, if inflation and the output gap are equal to their long-run equilibrium values, given that the nominal policy return was equal to its steady-state value in the last period, then the central bank sets the policy return equal to the steady-state

[514] Note that the government pays monitoring costs on the funds it gains control over in the process of winding-up, that is loan revenue. Equity-holders pay monitoring costs on the funds they receive as well, in their case loan revenue less deposit liabilities. The parameters governing the size of monitoring costs, μ^B and μ^N are allowed to differ, see chapter 5 for details.

[515] See the Treaty on the Functioning of the European Union, Article 127 (1), The Member States (2012: 102)

[516] See, for example, Cantore et al. (2013: 422), eq. (18.34), my notation. Note that in contrast to Cantore et al. (2013: 422), the central bank in the banking model responds to deviations of the output gap, not actual output.

[517] The dimension of nominal returns and inflation is per cent per annum, the output gap is measured in terms of monetary units per quarter and the monetary shock is non-dimensional.

[518] Similar to the workers' asset demand functions, this specification presumes that the non-stochastic steady state exists and is stable and determinate. Chapter 4 will present the results on steady-state computation and analysis.

[519] By definition, ρ_R cannot be negative.

[520] See D. Romer (2012: 546)

nominal risk-free return R_n. Note that this specification is more flexible compared to an interest rate rule which responds to any absolute level of inflation, for instance. While the analysis in subsequent chapters deals with the zero-inflation steady state, in eq. (3.91), the steady-state level of inflation could as well be 2%. A key assumption in this respect is that the central bank has gained credibility for maintaining low inflation so that inflation expectations are well-anchored. In the following, I will assume that the central bank's inflation target is a 0% inflation rate, so that private agents' expectation of the inflation rate in the absence of any shocks is also 0%.[521]

So what is the long-run equilibrium value of the nominal risk-free return R_n. First, note that nominal and real returns are related to the inflation rate by the Fisher equation:

$$R_t = \frac{R_{n,t-1}}{\Pi_t} \tag{3.92}$$

The real risk-free return is determined by the decision problem of workers, and given by the inverse of the time preference rate of workers (see eq. (3.77)).[522] When the (target) inflation rate in the steady state is zero, then the central bank sets the nominal policy return equal to the real equilibrium risk-free return. Given the long-term neutrality of monetary policy in the model, this is the optimal decision of the central bank for the zero inflation rate target.[523] The central bank is free to set the policy interest return to a different level; this will lead to temporary movements of the economy around the steady state, but the economy will eventually, gradually move back to its steady state.[524] Hence, instead of permanently boosting the economy, the central bank risks losing its credibility for price stability if it were to use this latter strategy. In any event, setting the nominal policy return equal to the real risk-free return in the steady state is in accordance with price stability, which is the primary objective of monetary policy.

The output gap in NK DSGE models is defined as the difference between actual output and potential - or natural - output.[525] The German Council of Economic Experts, for instance, defines potential output as the output of the production process when the factors

[521] See section 2.2 for a discussion of this point.

[522] Strictly speaking, workers choose consumption such that the real stochastic discount factor is equal to the inverse of the real portfolio return. In the steady state, all real returns are equal, and consumption (and prices) are constant, such that eq. (3.79) reduces to $1 = \beta R$, which leads to the result cited in the text.

[523] See Wickens (2008: 386). Long-term neutrality of monetary policy is due to the stationary nature of the model and the focus on the vicinity of the steady state in subsequent analyses, see also chapter 2 on this issue.

[524] This discussion presupposes that the steady state is a stable and determinate equilibrium. See section 4.4 for a discussion of stability and determinacy in NK DSGE models in general and the banking model in particular.

[525] See for example Galí (2008: 48)

of production are engaged at their normal capacity.[526] Defining potential output in terms of an NK DSGE model with frictions is, however, not a trivial task. As Woodford (2003) points out, if nominal price rigidities are the only source of inefficiency, then optimal monetary policy characterised by price stability achieves the optimal resource allocation.[527] Although this result does not carry over to more complicated models with more frictions, output can be used as an instrumental variable for the efficient allocation if it is measured by a model which does not incorporate such frictions which lead to a time-varying difference between the flexible price equilibrium and the efficient equilibrium.[528] Thus, measuring potential output by a non-distortionary small-scale NK model which achieves an efficient allocation allows monetary policy to respond to deviations of output from the efficient allocation.[529]

Another possibility for defining potential output in terms of a model measure would be the long-run steady-state value of output. Remember that absent any shocks the economy will return to this equilibrium.[530] So, the central bank would adjust the policy return if actual output deviated from its equilibrium value. However, note that in case of, for instance, a positive transitory technology shock, the reaction of monetary policy would ceteris paribus be stronger using the steady-state value of output than using flexible price output. The reason is that flexible price output increases whereas the long-run equilibrium does not change due to the stationarity of the model. Hence, the change in the output gap and by extension of the policy return is lower in the former than in the latter case. In sum, the mechanism is not fundamentally different.[531] Thus, the output gap definition with respect to potential output is used. Details on the derivation of this output gap measure for the banking model are given in appendix section A.2.

As a final note on monetary policy implementation in the banking model, the transmission process of the policy rate to the relevant rates of private agents in the model works as follows: The policy rate is taken into account by banks who use the policy rate as a reference to determine wholesale and loan interest rates. Moreover, the deposit rate is assumed to adjust immediately to the policy rate according to eq. (3.45b). The portfolio rate of workers, however, is a composite of the deposit and equity rates; hence, the direct

526 See Sachverständigenrat zur Begutachtung der Gesamtwirtschaftlichen Entwicklung (2014: 114)

527 See Woodford (2003: 410)

528 See Woodford (2003: 418)

529 See also Galí (2008: 186) on this issue. Furthermore, another reason to exclude financial frictions is that when comparing the banking model to a standard financial accelerator model, the latter's definition of natural output would be different if financial frictions are included, which could potentially distort the analysis.

530 Again, this presupposes that the long-run steady state is stable and determinate, see footnote 524.

531 This does not imply that different definitions lead to the exact same results, especially concerning the magnitude of effects. This issue is considered in chapter 6 in describing objective trade-offs for monetary policy.

pass-through from the policy rate to the intertemporal decision problem of workers is not necessarily complete nor immediate. The transmission of monetary policy impulses to investment decisions works through various channels of monetary transmission, which are mainly the interest rate, credit and expectations channels as specified before.

3.9 Equilibrium and Functional Forms

Market Clearing Equilibrium is characterised by simultaneous market clearing, namely when total supply equals total demand in the labour, retail goods, capital goods and financial markets. The final retail goods market is cleared when output by retailers equals the sum of workers', entrepreneurs' and governmental consumption demand, investment demand by capital investment funds and monitoring resource costs MoC:

$$Y_t = C_{W,t} + C_{E,t} + \Upsilon_t^G + I_t + MoC_t \tag{3.93}$$

MoC_t is the sum of real resources banks, equity-holders and the government spend on monitoring entrepreneurs and banks. An analytical expression can be found in appendix section B.2.

The wholesale goods market is cleared if retailers' demand equals entrepreneurs' supply. The labour market is in equilibrium when entrepreneurs' demand for labour is equal to workers' supply of labour services. The market for capital goods is cleared when entrepreneurs' demand for capital is equal to capital investment funds' supply of capital. Financial markets are in equilibrium if entrepreneurs' demand for loans equals banks' supply, and banks' supply of equity and deposits respectively equals the corresponding demands of workers. Finally, the model closes with the monetary policy rule.

Functional Forms The functional form of the investment adjustment cost function $S(\boldsymbol{.})$ is:[532]

$$S\left(\frac{I_t}{I_{t-1}}\right) = \phi_I \left(\Upsilon_t^I \frac{I_t}{I_{t-1}} - 1\right)^2 \tag{3.94}$$

Given that in the deterministic steady state adjustment costs are zero and only the second derivative of $S(\boldsymbol{.})$ impacts dynamics, this specification is in line with many specifications in the literature.[533] The crucial parameter affecting dynamics is ϕ_I which scales the size of the adjustment costs. Υ_t^I is an exogenous first-order autoregressive process with expectation equal to 1, perturbed by a shock.

[532] The functional form is based on Cantore et al. (2013: 417), unnumbered equation, my notation.
[533] See for example Christiano et al. (2005a: 15)

The idiosyncratic financial shocks to entrepreneur's capital return ψ_t^E and banks' loan income ψ_t^B are identically and independently distributed (i.i.d.) with mean 1, and are uniformly distributed over the intervals $\left[1 - E_\psi \Upsilon_t^E, 1 + E_\psi \Upsilon_t^E\right]$ and $\left[1 - B_\psi \Upsilon_t^B, 1 + B_\psi \Upsilon_t^B\right]$, respectively. E_ψ and B_ψ are parameters and Υ_t^E and Υ_t^B are exogenous first-order autoregressive processes, affecting the interval size of the idiosyncratic shocks of entrepreneurs and banks, with expectation equal to 1 and perturbed by process-specific shocks.

The monetary policy shock $\epsilon_{M,t}$ is i.i.d. with mean zero and standard deviation σ_M. The aforementioned autoregressive processes Υ_t^A, Υ_t^B, Υ_t^E, Υ_t^G, Υ_t^I, Υ_t^K, Υ_t^{MS}, Υ_t^P take the following form:

$$\Upsilon_t^x = \left(\Upsilon^x\right)^{(1-\rho_x)} \left(\Upsilon_{t-1}^x\right)^{\rho_x} e^{\epsilon_{x,t}} \tag{3.95}$$

where $x = \{A, B, E, G, I, K, MS, P\}$. The variable without time subscript denotes the equilibrium value, ρ_x determines the degree of persistence and $\epsilon_{x,t}$ is the shock to the process. $\epsilon_{x,t}$ is i.i.d. with mean zero and standard deviation σ_x. While both positive and negative shocks hit the economy, the remainder of this text only reports the standard deviation as the positive root of the variance.

Chapter 4

Model Solution and Equilibrium Analysis

The previous chapter presented the banking model and justified the particular modelling choices. It showed how non-systemic bank default extends a New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model with a financial accelerator to the banking model. Furthermore, the previous chapter established that the friction on banks' liability side, which gives rise to bank failures, affects the total credit spread and thus has the potential to impact aggregate demand via the loan market. This chapter provides some economic intuition behind the banking model and explores some important aspects in more detail. The objectives are firstly, to discuss the equilibrium concept and its stability, without which chapters 5 and 6 would lack the foundation. The second objective is to elucidate selected key relationships of the banking model both in a partial and a general equilibrium setting.

For the essentially comparative purposes of this study it is convenient to separate the complexities due to the financial friction between banks and (bank) equity-holders and portfolio choice, which are specific to the banking model, from the complexities due to other frictions. Henceforth, the *banking model* presented in the previous chapter will be compared to a *financial accelerator model*. The financial accelerator model features the same nominal and real frictions except for the friction between banks and their equity-holders. Thus, in the financial accelerator model banks do not default and only the loan market is subject to a financial friction. Also, there is no portfolio choice problem on the part of workers. The separation between those two models will be a recurrent feature of the following chapters and is intended to isolate the effects of the introduction of non-systemic bank default.

This chapter proceeds as follows. The concept of the non-stochastic steady state, as well as its definition and computation for the non-linear banking model are discussed in section 4.1. The relationship between bank and entrepreneurial leverage and the respective credit spread is dealt with in a partial equilibrium setting in section 4.2. Next, section 4.3 focuses on general equilibrium, evaluating the changes due to various frictions on the system of difference equations in terms of the canonical NK dynamic IS-Phillips Curve-Monetary Policy (DIS-PC-MP) representation. Finally, section 4.4 evaluates the stability consequences of certain parameter settings. In contrast to the preceding sections, the results of section 4.4 are derived by numerical simulations, the reasons for which will become clear in sections 4.1 and 4.3.

4.1 The Non-Stochastic Steady State

For the estimation and simulation in chapters 5 and 6, the non-linear banking model presented in chapter 3 is log-linearly approximated around its zero-inflation non-stochastic steady state in line with common practice in the literature. The non-stochastic (or deterministic) steady state is equivalent to the perfect foresight solution in which agents do not foresee future shocks.[534] That is, all shocks and their expected future values are equal to 0.[535] Since there is no economic growth in the banking model, all endogenous variables are constant in the non-stochastic steady state of the non-linear banking model.[536]

The portfolio choice problem of workers raises a difficulty for the computation of the deterministic steady-state if returns are equal in equilibrium. As noted above, the portfolio choice of households is indeterminate in the deterministic steady state. Several authors have proposed different solution algorithms to overcome this difficulty.[537] The typical procedure is to append risk adjustments to the deterministic steady state and/or the linear approximations of the dynamic equations.[538] The result is, just as for the standard procedure, a system of linear decision rules for adjusting the control variables to deviations from the steady state. Depending on the solution procedure and model layout, monetary policy may or may not affect portfolio decisions, and first-order dynamics of the portfolio can be described reasonably accurately. However, note that the procedure of, for instance, Devereux and Sutherland (2011) uses a low-order approximation around the deterministic steady state for all equations, and higher-order approximations to solve for

[534] See Coeurdacier, Rey and Winant (2011: 398)
[535] To be specific, the innovations to the exogenous autoregressive processes are 0, namely $\epsilon_{x,t} = 0$, not the exogenous processes Υ^x.
[536] Steady-state values of selected endogenous variables are discussed in chapter 5.
[537] An indicative list includes Coeurdacier and Rey (2013), Devereux and Sutherland (2011), Evans and Hnatkovska (2012), and de Groot (2014).
[538] Coeurdacier et al. (2011) propose the concept of the risky steady state which is characterised by current shocks being zero but agents anticipating future shocks. The procedure developed by Devereux and Sutherland (2011) and Tille and van Wincoop (2010) appends risk adjustments to the portfolio problem only, while the procedure proposed by de Groot (2014) adjusts all forward-looking equations for risk.

the portfolio weights.[539] However, with local perturbation methods as used by Devereux and Sutherland (2011), the approximated dynamics are only valid for small deviations from the approximation point; this means that for medium to large risk adjustments this procedure may become inaccurate.[540] In contrast, the approach followed here is to model explicit demand functions and estimate the parameters pertaining to portfolio choice to facilitate the approximation around the deterministic steady state. Thus, instead of redefining the approximation point for the dynamic description of the model I let the data determine the portfolio shares and dynamic adjustment parameters.[541]

Moreover, de Groot (2014) argues that the incorporation of risk into the steady state allows for monetary policy to affect banks' liability structure.[542] However, as Bianchi (2014) notes, the portfolio choice is only relevant in the model of de Groot (2014) if banks' leverage constraint binds.[543] In contrast, the banking model presented here does not link the willingness of workers to hold equity to the volume of liabilities and assets as in the model by de Groot (2014).[544] Rather, the demand for equity is determined by the actual return of equity vis-à-vis the return of the alternative asset. Thus, as long as monetary policy affects the returns on banks' assets, and thus banks' profitability, there will be feedback effects on its liability structure with the approximation around the deterministic steady state.

Thus, this study uses the concept of the non-stochastic steady state. The non-stochastic steady state of an NK DSGE model can usually be found recursively equation by equation. However, due to the complexity of the model presented here, this is not as straightforward. Instead, the method of Christiano et al. (2003) can be employed, whereby some of the endogenous variables are set exogenously guided by empirical data allowing to solve for some of the parameters endogenously.[545] This is useful since some parameters are highly model-specific and abstract, and thus difficult to calibrate. While the value of, for example the interval sizes of bank-specific and entrepreneur-specific shocks, B_ψ and E_ψ respectively, are difficult to determine, the spreads between various interest rates can be set guided by empirical data and previous studies. In the banking model, the endogenous variables set

539 See Devereux and Sutherland (2011: 346)
540 See Bianchi (2014: 163). See Rabitsch, Stepanchuk and Tsyrennikov (2014) for a study on the accuracy of various solution methods.
541 Admittedly, the parameter determining the portfolio shares, ω_1, is not estimated. However, it is not calibrated to a single value either. Rather, the parameter is a function of other parameters and variables. Thus, ω_1 changes during the estimation procedure as the estimated parameters change.
542 See de Groot (2014: 118f)
543 See Bianchi (2014: 163)
544 See de Groot (2014: 125f). The model by de Groot (2014) is based on Gertler et al. (2012).
545 See Christiano et al. (2003: 1171f). See, for example, Gabriel et al. (2010: 21, appendix B) for an illustration of this approach. Cantore et al. (2013: 419f) use this approach for calibration of the model's parameters.

exogenously are:

$$\begin{bmatrix} \varrho^B & p(\psi^B) & \varrho^E & p(\psi^E) & \phi^E & {}^{C_E}\!/_{Y} \end{bmatrix} \tag{4.1}$$

where ϕ^E denotes entrepreneurs' leverage ratio defined as ${}^{QK}\!/_{N_E}$. The corresponding parameters solved for endogenously are:

$$\begin{bmatrix} B_\psi & \mu^B & E_\psi & \mu^E & \xi_E & \eta_E \end{bmatrix} \tag{4.2}$$

Furthermore, the parameters ω_1 and μ^N are set such that the model-implied steady state leverage ratio of banks and the government's budget constraint, respectively, are fulfilled.

Yet, for the computations in chapters 5 and 6, the exact computation of the complete steady state of the non-linear model is not necessary. As noted above, the estimation and subsequent simulations are based on the log-linear approximation of the banking model. In turn, the log-linear approximation to the non-linear banking model is derived by log-linearising the relevant model equations around the non-stochastic steady state.[546] The steady state of the resulting log-linear model is characterised by all variables (defined as deviations from the steady state) being equal to 0. As a matter of notation, the steady state of a variable Z_t will be donated by Z, and the log-deviation of this variable from its steady state by $\hat{z}_t$.

The constraints imposed by the use of the log-linear model overlap nicely with the research agenda of this thesis. The use of the local approximation is appropriate and sufficient since the focus of this study lies on the impact of non-systemic bank failures on monetary policy. Since the log-linear approximation is only valid in the close vicinity of the non-stochastic steady state, large deviations or shocks cannot be traced. This aligns well with this study's focus on a 'normal' business cycle instead of a financial crisis, as well as the focus on non-systemic bank failures. Furthermore, permanent shocks, that is shocks which entail a change in the non-stochastic steady state, are ruled out. As will be shown in the last section of this chapter, the relevant steady state, around which the model is log-linearly approximated, is locally stable and determinate. Thus, any displacement of the banking model economy from its steady state analysed in this thesis is transitory, that is the model economy always returns to its stable, determinate long-run equilibrium. The approach also implies that fundamental, structural changes in the non-stochastic steady state (other than the differences between the financial accelerator and banking models) are not described in this study.[547] Chapter 6 analyses the characteristics of this transition back

[546] As before, this non-stochastic steady state is required to be locally stable and determinate, as will be shown later in this chapter.
[547] Section 5.4 provides further details on the different non-stochastic steady states of the financial accelerator and banking models.

to the original steady state from which the banking model is disturbed.[548] The focus is on the responses of endogenous variables to exogenous disturbances, as is straightforward using the log-linear model. Again, this is in line with the focus on business cycles and non-systemic bank failures.

So if the model is transformed, why is there a need to solve for the non-linear model steady state? In terms of the approximation, most variables only enter in terms of their deviation from the non-linear steady-state value while their steady-state values do not enter the system of equations. Thus, the non-stochastic steady state could be deemed irrelevant for subsequent analyses. Yet, to the contrary, there are various equations in the log-linear model which include variables evaluated at their non-linear steady-state values. Again, in order to compute these steady-state values, the parameters in eq. (4.2) need to be determined. Thus, to calibrate these parameters or determine their prior distributions, the deterministic steady state of the non-linear banking model is calculated for given values for eq. (4.1) as described above.[549] The only change is that the steady-state values of ϱ^B, $p(\psi^B)$ and $p(\psi^E)$ are calibrated as well.[550] Then, the resulting values of the parameters in eq. (4.2) are taken as an indication for appropriate calibration and prior distributions. The exact details are discussed in section 5.2.2.

Against this background, section 4.3 describes the log-linear model in terms of the canonical NK framework. The section in particular presents the changes which arise as a result of incorporating financial frictions in this framework by comparing the banking and financial accelerator models to a simple NK model. Furthermore, section 4.4 explores the equilibrium stability and determinacy consequences of certain parameter constellations. Beforehand, however, the next section 4.2 takes a step back and explores the different concepts of entrepreneurial net worth and bank equity and their relationships with the credit spread. Since some analytical results can be derived, in section 4.2 only, the non-stochastic steady state of the banking model is used.

[548] This equally applies to the financial accelerator model.

[549] In particular, σ_B, μ^B, σ_E, μ^E are estimated while ξ_E, and η_E are calibrated, see section 5.2.2.

[550] Note that these three are still endogenous variables, that is enter as deviations from the steady state. However, during the log-linearisation it was not possible to eliminate the steady-state values of these variables, and others which depend on these variables, from the relevant equations such that the steady state values of these three need to be determined. Given the complexity of the model, they could only be calibrated.

4.2 Partial Equilibrium Analysis: Leverage and the Credit Spread

In deriving the financial accelerator model in Bernanke et al. (1999) (BGG), the authors argue that external financing via bank loans introduces a wedge between the risk-free rate of interest and the real return on real capital.[551] This is because entrepreneurs cannot issue risk-free bonds to finance capital purchases. Instead, for banks to be willing to grant loans, they must expect to receive a return (including default costs) at least equal to the risk-free rate. Thus, the resulting optimal state-contingent loan contract assigns all aggregate risk to the entrepreneur while the bank bears only idiosyncratic risk, which it can diversify by offering loan contracts to many entrepreneurs.[552] In equilibrium, optimal capital purchases of entrepreneurs must satisfy an incentive compatibility constraint which states that the real return on real capital is equal to the product of the real risk-free return and the entrepreneurial risk premium.[553] This leads to a spread between the real return on real capital and the real risk-free return formed by the entrepreneurial risk premium. Furthermore and crucially, this risk premium is inversely related to the net worth of entrepreneurs.[554]

The introduction of a second financial friction between banks and workers widens the spread between the real risk-free return and the real return on real capital further. In the banking model, the relevant return for the specification of the optimal loan contract is not the real risk-free return but the real wholesale return.[555] The real wholesale return is in turn the product of the bank risk premium and the real risk-free return.[556] Thus, in equilibrium, the real return on real capital is equal to the real risk-free return times the product of entrepreneurial and bank risk premiums. Hence, as long as the bank risk premium is strictly greater than 1, the spread between the real risk-free return and the real return on real capital is larger in the banking model than in the financial accelerator model where only the entrepreneurial risk premium defines the spread.[557]

Furthermore, both entrepreneurs' and banks' default probabilities rise with their re-

[551] See Bernanke et al. (1999: 1353f)
[552] See Bernanke et al. (1999: 1352)
[553] See 3.3 for more details.
[554] See Bernanke et al. (1999: 1354)
[555] For the derivations, see sections 3.3 and 3.6.
[556] The real deposit return is equal to the real risk-free return in equilibrium. According to eq. (3.45b), the real deposit return is a linear function of the real risk-free return. Given that ξ^r and ν^d are small, the real deposit return and the real risk-free return differ only marginally in general.
[557] Note that both risk premiums enter the arbitrage conditions eqs. (3.16) and (3.59) multiplicatively. In the log-linear approximation to the model used in the following chapters risk premiums enter additively. Then, the condition is that the bank risk premium is strictly greater than 0 for the spread to be larger in the banking model. Only non-negative risk premiums are considered.

spective leverage ratios.[558] With higher default probabilities due to higher leverage, risk premiums should rise. However, there is a crucial difference between entrepreneurs and banks which leads to opposing relationships between leverage and the respective risk premium. For entrepreneurs, net worth alleviates the agency problem as with higher net worth the entrepreneur has a higher stake in his business. This reduces the entrepreneurial risk premium for a given capital stock. For banks, the agency problem exists between them and equity-holders. As will be shown here, the bank risk premium decreases with an increase in leverage, ceteris paribus.

The link between the respective risk premiums and leverage ratios can be derived analytically from the incentive compatibility constraints, eqs. (3.13) and (3.56). The incentive compatibility constraint for bank loans (eq. (3.13)) is:

$$(\Gamma^E - \mu^E G^E) R_k QK = R_w (QK - N_E) \tag{4.3}$$

Dividing through by R and N_E yields:

$$(\Gamma^E - \mu^E G^E) c_s \phi^E = \varrho^B (\phi^E - 1) \tag{4.4}$$

rearranging for the entrepreneurial leverage ratio and noting that the credit spread c_s is defined as $c_s = \varrho^B \varrho^E$ gives:

$$\phi^E = \frac{1}{1 - (\Gamma^E - \mu^E G^E) c_s (\varrho^B)^{-1}} \tag{4.5}$$

where the first derivative of the leverage ratio with respect to the credit spread (keeping ϱ^B and the respective shares of the real capital return going to entrepreneurs and banks constant at their steady-state values) is non-negative. Except for the presence of the risk premium associated with banks, this is the same relationship as in the financial accelerator model of BGG.[559] The higher is the entrepreneurial leverage ratio, the higher is the risk premium. With higher leverage, entrepreneurs' probability of default increases. Thus, credit conditions tighten so as to offset higher losses due to entrepreneurial default.

The corresponding link between the bank risk premium and bank leverage is derived from equity-holders' incentive compatibility constraint (eq. (3.56)):

$$\Big(\Gamma^B(\psi^B) - \mu^B G^B(\psi^B)\Big) R_w B = R_d \Big(B - (1 - \xi^r) D\Big) \tag{4.6}$$

[558] See appendix section B.1 for details.
[559] See Bernanke et al. (1999: 1353), eq. (3.8)

Dividing through by R and D leads to:

$$\left(\Gamma^B(\psi^B) - \mu^B G^B(\psi^B)\right)\frac{c_s}{\varrho^E}\frac{B}{D} = \left(\frac{B}{D} - (1-\xi^r)\right) \tag{4.7}$$

rearranging, this yields for the loan-to-deposit ratio Φ^B:

$$\Phi^B = \frac{1-\xi^r}{1-\left(\Gamma^B(\psi^B) - \mu^B G^B(\psi^B)\right)c_s(\varrho^E)^{-1}} \tag{4.8}$$

The derivative of the loan-to-deposit ratio with respect to the credit spread under the corresponding assumptions as in the entrepreneurial case is non-negative as well.[560] This means that the loan-to-deposit ratio increases with the credit spread. Conversely, the loan-to-equity ratio, that is banks' leverage ratio, decreases with an increasing credit spread.[561] Put differently, the bank risk premium decreases with an increasing share of deposits in the loan volume.[562] The diametrically opposed relationships between the leverage ratios and the risk premiums of banks and entrepreneurs arise because the agency problem affects the holdings of equity in the case of banks but the holdings of external finance in the case of entrepreneurs. For entrepreneurs, a higher level of net worth moderates the asymmetric information problem. In contrast, for banks, a lower equity share lowers the downside risks of holding bank equity, ceteris paribus. These downside risks involve the complete eradication of bank equity for failing banks. The costs of bank failure are smaller for equity-holders if there is less bank equity to lose.[563]

The agency problem between banks and workers does only affect banks' liability structure, but also the quantity of physical capital demanded by entrepreneurs. In the financial accelerator and banking models the equilibrium credit spread and capital stock are determined at the intersection of the real capital demand and cost of funds curves for a given entrepreneurial net worth.[564] Real capital demand is given by rearranging eq. (3.3), the definition of the real return on real capital. The cost of funds curve is given by eq. (4.5). They are depicted in fig. 4.1 which shows entrepreneurial capital demand and the cost of funds curves for the financial accelerator and banking models.

[560] That is, assuming constant steady-state shares of bank auxiliary functions and a constant entrepreneurial risk premium.

[561] Whether or not a lower leverage ratio will also occur if the credit spread is low in the steady state, as compared to a steady state with both higher credit spread and leverage ratio, depends on the whole system, especially the distribution of the bank-specific shock ψ^B, the resulting auxiliary bank functions, and finally the absolute levels of banks' assets and liabilities. As noted above, for the derivations here the auxiliary bank functions and the entrepreneurial risk premium were explicitly kept fixed.

[562] This can be seen by rearranging eq. (4.7) for the bank risk premium ϱ^B $(= c_s/\varrho^E)$ and taking the first derivative with respect to the deposit to loan share (D/B). This first derivative is negative.

[563] To see this, see chapter 3, eq. (3.51).

[564] See Bernanke et al. (1999: 1355)

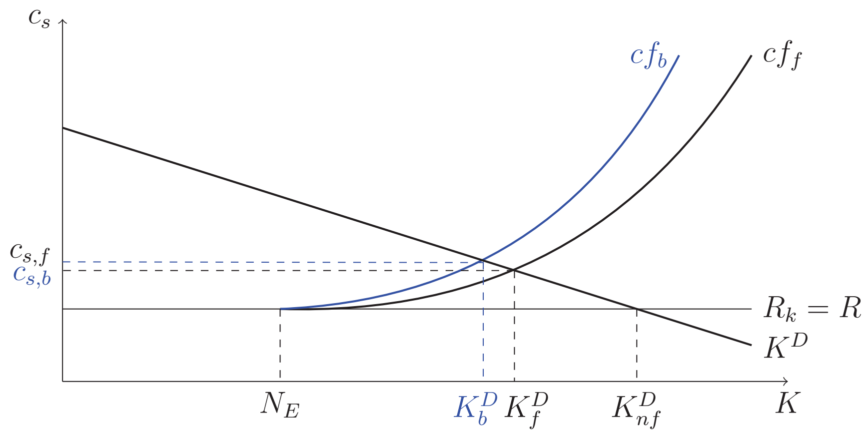

Figure 4.1: Real Capital Demand (K^D) and Cost of Funds Curves based on fig. 1 in Bernanke et al. (1999: 1354); curves were drawn under the assumption that all other variables are constant and equal to their steady-state values, and that N_E is the same in the financial accelerator and banking models. cf_f is the cost of funds curve in the financial accelerator model, cf_b the corresponding curve in the banking model. Axis labels with subscripts b and f denote the respective quantities in the banking and financial accelerator models, K_{nf}^D denotes the capital stock that would be demanded without financial frictions.

In a model without financial frictions, the quantity of real capital demanded by entrepreneurs K_{nf}^D is determined at the intersection of real capital demand with the horizontal line $R_k/R = 1$.[565] Consider the financial accelerator model next. The credit spread is zero as long as net worth is higher or equal to the capital stock to be purchased since entrepreneurs are fully self-financed and do not need bank loans. This is shown by the flat part of the cost of funds curve at $R_k/R = 1$ in fig. 4.1. However, for values of the capital stock exceeding entrepreneurs' net worth, entrepreneurs' financing costs increase with leverage. This explains the upward-sloping part of the cost of funds curve cf_f when the entrepreneur uses a combination of internal and external finance.[566] This is due to the financial friction between entrepreneurs and banks. An exogenous increase in the level of entrepreneurial net worth leads to a rightward shift of the cost of funds curve in fig. 4.1. This is in line with the positive relationship between entrepreneurial leverage and the respective risk premium derived above.

The introduction of the financial friction between banks and workers leads to a rotation of the cost of funds curve to cf_b to the left. For a given level of entrepreneurial net worth N_E, the quantity of real capital demanded will be lower in the banking model than in the financial accelerator model. Since the risk premium of banks ϱ^B enters the cost of funds curve, the extent to which the cost of funds curve rotates to the left in fig. 4.1 depends on the leverage ratio of banks. Ceteris paribus, a higher loan-to-equity ratio corresponds to a lower bank risk premium and credit spread, which means that cf_b rotates less.

565 Again, in this case entrepreneurs offer risk-free bonds for financing demanded by workers as a form of saving.
566 See Bernanke et al. (1999: 1354)

The model thus replicates the asymmetric financing situations of banks and entrepreneurs that Admati and Hellwig (2013) describe. Admati and Hellwig (2013) argue that borrowing is cheaper for banks than for non-financial firms because taxpayers partially cover the costs of bank borrowing.[567] In the banking model, a higher bank equity base increases, ceteris paribus, the bank risk premium. With a downward sloping loan demand curve, bank loans and by extension capital demand decrease. In contrast, higher entrepreneurial net worth reduces the entrepreneurial risk premium. Again, along the downward sloping capital demand curve in fig. 4.1, this leads to an increase in the real capital stock. As the real capital stock directly affects the productive capacity of the economy as well as financing constraints, the leverage ratios of banks and entrepreneurs have consequences for the real economy. The terms bank *equity* and entrepreneurial *net worth* were purposefully chosen to highlight the different roles these have for the financial situation of banks and entrepreneurs.

What is more, the fact that bank deposits are insured plays a role. In contrast to holders of bank equity, deposit-holders do not view bank deposits as risky. This is because deposits are insured and are thus covered even in the case of bank failure. What is the implication of the assumption of workers regarding bank deposits as risk-free? Assume for a moment that bank deposits are not insured and deposit-holders would bear the consequences of bank default similarly to equity-holders. Then, the distinguishing characteristic between bank deposits and bank equity becomes blurred. Furthermore, deposit-holders would also demand a risk premium, even though this may be lower than the one on bank equity if bank deposits are served preferentially. Thus, the fundamental friction of the incidence of bank failure exists independently of the deposit insurance scheme. The result of the deposit insurance scheme is a more straightforward derivation of the credit spread. This does not, however, affect the structure workers' consumption and leisure decisions, as these are separate from the portfolio choice problem.[568]

As argued before, it is not clear how the choice between different (risky) financial assets should affect a worker's utility other than through the realised portfolio return which is the rationale for separating these optimisation problems. Nevertheless, there is another possibility for workers to take into account the consequences of bank failure. This is accomplished by a change in the modelling of taxes when the deposit insurance scheme is in place. In the banking model, taxes are non-distortionary in the first-order approximation. Therefore, workers as holders of bank deposits do not perceive that bank failures lead to higher outlays in the governmental budget, and thus higher taxes. If taxes were endogenous in the

[567] See Admati and Hellwig (2013: 8f), bank bailouts are argued to be one example of subsidies on bank borrowing, see Admati and Hellwig (2013: 9).

[568] Chapter 6 will discuss the separation of workers' optimisation problems and some of the consequences for the effects on monetary policy more thoroughly.

first-order approximation, workers' consumption and leisure decisions would be affected by changes in deposit insurance outlays. As will become clear in chapter 6, the ignorance of deposit-holders in terms of foreseeing and incorporating the tax-related consequences of bank failure merely shuts off a further mechanism through which bank default can affect the conduct of monetary policy. Since the treatment of fiscal policy is intentionally kept short in the banking model, the main part of this thesis abstracts from this additional mechanism.

In conclusion, entrepreneurial net worth and bank equity function differently in the banking model. The next section aims to highlight how the banking model compares more generally to a model which does not feature bank failure. To facilitate comparability with the literature, the changes are discussed in terms of the NK DIS-PC-MP framework.

4.3 The Log-Linear New Keynesian DIS-PC-MP Representation

To gain an intuition for the workings of the banking model, this section will deal with the generic three-equation representation of NK DSGE models: the dynamic IS function, the Phillips Curve and a monetary policy rule. In contrast to classical economic theory, output and inflation are not determined independently of the path of interest rates and thus a monetary policy rule for the interest rate is necessary to close the NK model even in the simplest case.[569] As will be shown below, this simple representation is not attainable for the banking model due to the complexity surrounding portfolio choice and the frictions in the banking sector. Nevertheless, it is possible to discuss the similarities and differences between this simple NK DSGE layout and the financial accelerator and banking models in this reduced form representation.

4.3.1 A Simple New Keynesian Model

A simple New Keynesian model with sticky prices can be represented by the following system of three equations:[570]

$$\pi_t = \beta \mathbf{E}_t[\pi_{t+1}] + \kappa \,\widehat{gap}_t \tag{4.9}$$

$$\widehat{gap}_t = \mathbf{E}_t[\widehat{gap}_{t+1}] - \frac{1}{\sigma}\Big(\hat{r}_{n,t} - \mathbf{E}_t[\pi_{t+1}]\Big) \tag{4.10}$$

$$\hat{r}_{n,t} = \nu_\pi \pi_t + \nu_y \widehat{gap}_t + \epsilon_{M,t} \tag{4.11}$$

569 See Galí (2008: 49)

570 See Walsh (2003: 244, 247), eqs. (5.68), (5.69) and (5.72), my notation. Note that while eq. (5.72) in Walsh (2003: 247) does not include the output gap, the output gap is included here for comparability with the banking model. See also Woodford (2003: 245f), eqs. (1.12), (1.13) and (1.14), my notation. Details on the derivation can be found in Galí (2008) or Walsh (2003), for instance.

This three-equation system is expressed in terms of the log-linear approximation to the relevant non-linear equations.[571]

Equation (4.9) is the NK Phillips Curve (PC) which constitutes the aggregate supply block of the model and determines inflation π for a given path of the output gap $\widehat{gap}$.[572] It is derived from the optimal price setting behaviour of (consumption) goods producers resulting in an equation linking inflation to marginal costs.[573] In a second step, marginal costs can be linked to the output gap via the labour market equilibrium condition.[574] κ is thus a function of production and utility function parameters.[575]

Equation (4.10) is the NK dynamic IS (DIS) equation. The DIS curve is derived by combining the intertemporal consumption Euler equation with the economy's budget constraint.[576] σ is the coefficient of relative risk aversion.[577] The NK DIS function links the evolution of the expected real interest rate and inflation to the output gap. More specifically, in the three equation framework the DIS equation determines the output gap for a given real interest rate.[578] It can thus be argued to be the analogue of the Hicksian IS curve, written as a dynamic equation and derived from the maximisation problem of individual agents.[579]

These two equations determine inflation and the output gap, respectively, given the output gap on the one hand, and inflation and the nominal interest rate on the other. To close the model, an equation for the path of the nominal interest rate is necessary. The standard assumption is that there exists a central bank which is in charge of setting the nominal interest rate following a Taylor rule as in eq. (4.11). ν_π and ν_y are parameters governing the central bank's responsiveness to changes in inflation and the output gap. Hence, in the NK model, monetary policy is not neutral given that the path of the nominal interest rate affects the output gap via the DIS equation.[580]

This system of three difference equations in three endogenous variables characterises

[571] This presumes that the deterministic steady state is stable and determinate. For more details on these issues see section 4.4.
[572] See Woodford (2003: 241)
[573] See Galí (2008: 47). See King (2000: 90) for a simple mathematical derivation.
[574] Since labour is the only input of production, real marginal costs are given by the ratio of the real wage to the marginal product of labour, see Walsh (2003: 238).
[575] See Galí (2008: 47ff) for a definition and derivation.
[576] See Wickens (2008: 365)
[577] See Wickens (2008: 361)
[578] See Galí (2008: 49)
[579] See Woodford (2003: 242)
[580] See Galí (2008: 49). As noted above, this use of neutrality differs slightly from the one used by Goodfriend and King (1997), see footnote 339 in chapter 3. Here, monetary policy being non-neutral means that monetary policy impacts the real economy.

the whole model: equilibrium in the goods and labour markets, optimal saving/borrowing decisions through the Euler equation and monetary policy. It is straightforward to analyse different monetary policy rules and the stability of this system. However, this simplicity is attained only by abstracting from key concepts. Since labour is the only production input, there is no physical capital and thus no investment. Similarly, there is no government except for the interest-rate setting central bank, and hence no taxes or government spending. Furthermore, the derivation of the DIS equation requires separability of the utility function in both time and consumption/leisure dimensions and a well-chosen power functional form.[581]

In the context of a more complex model the complexity also transfers to the representation in the DIS-PC-MP format. Including only investment (and hence physical capital) and the government extends above system to a system of seven difference equations.[582] Furthermore, the inclusion of the financial sector with frictions in loan and bank liability markets enlarges this system even further. This makes an analytical derivation of, for example, the stability realm of various parameters impractical. This is the reason subsequent analyses in section 4.4 and chapters 5 and 6 are conducted using numerical computations. Even considering only the simple three-equation system, there are various complications. The derivation of the DIS-PC-MP equations for the financial accelerator and banking models in the following paragraphs allows to see the similarities and differences between the simple model and the financial friction(s) models in condensed and accessible form.

The procedure in the following sections is to first include physical capital, investment, habit and indexation as well as the financial accelerator between entrepreneurs and banks as the financial accelerator model. In a second step the changes due to the inclusion of the financial friction between banks and workers and the portfolio choice problem are presented. To ensure comparability, the monetary policy rule is the same in the financial accelerator and banking models.[583] Since it is simply the log-linear approximation to the monetary policy rule presented in chapter 3, it is discussed with the banking model.

4.3.2 The Financial Accelerator Model

The financial accelerator model is a standard NK DSGE model with financial accelerator and features the same general layout and frictions as the banking model. To be precise, these are: the optimisation problems of entrepreneurs, retailers and capital investment funds, and the form of workers' utility function, all as presented in chapter 3. However,

[581] See the derivations in Galí (2008) or Walsh (2003).
[582] See Woodford (2003: 361)
[583] Optimal monetary policy is not as such dealt with in this study. See the discussions later in this chapter and in chapter 6 for more details.

there is no agency problem between banks and workers, and thus no portfolio problem, in the financial accelerator model. This means that in the financial accelerator model the loan contract is specified with respect to the real risk-free return, instead of the wholesale return used in the banking model.[584] Also, since there is no deposit insurance scheme, the fiscal policy is is simply described by the equality of the exogenous government consumption process with the tax volume.

4.3.2.1 The New Keynesian Phillips Curve

For the financial accelerator model, the NK PC expressing inflation as the sum of expected future inflation and the deviation of marginal cost from its steady-state value can be derived similarly to the simple model, with the addition of lagged inflation in the relationship. The resulting Phillips Curve of the financial accelerator model is given by:[585]

$$\pi_t = \frac{\beta}{1+\beta\gamma^p}\mathbf{E}_t[\pi_{t+1}] + \frac{\gamma^p}{1+\beta\gamma^p}\pi_{t-1} + \kappa_{ff}\widehat{mc}_t \tag{4.12}$$

where

$$\kappa_{ff} = \frac{(1-\beta\xi^p)(1-\xi^p)}{(1+\beta\gamma^p)\xi^p} \tag{4.13}$$

The mathematical derivation of this formula follows the same procedure as for the simple NK model.[586] The similarity is due to the fact that both models feature the same kind of price friction: Calvo-style price staggering. The introduction of lagged inflation in the NK PC curve in the financial accelerator model is the result of price indexation (governed by the parameter γ^p).[587] Past inflation is more important in the NK PC curve when more prices that cannot be set optimally are indexed to inflation. Conversely, setting $\gamma^p = 0$, eq. (4.12) also held in the simple NK model if marginal costs were explicitly defined as a separate endogenous variable and not substituted for the output gap in eq. (4.9).

Yet, while in the simple model marginal costs can be substituted to derive a relationship between the output gap and inflation, this is not possible in the financial accelerator model. This is a result of the more complex definition of marginal costs. The steps for deriving the relationship between inflation and marginal costs are the same: The starting point is the price-setting decision, which concerns retailers in the financial accelerator model. As can be shown, retailers' real marginal costs are equal to the ratio of wholesale prices to final

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[584] See Bernanke et al. (1999: 1349)

[585] See Smets and Wouters (2003: 1135), eq. (32), my notation. Note that the exogenous mark-up shock process is left out for a clearer exposition. Strictly speaking, the mark-up shock process enters eq. (4.12) additively.

[586] See Galí (2008: 46ff) and Walsh (2003: 234ff and 263ff) for derivations without price indexation and Christiano et al. (2005a: 26f) and D. Romer (2012: 345f) for derivations with price indexation.

[587] See Smets and Wouters (2003: 1135)

retail goods prices.[588] This latter ratio can be related to the labour demand equation of entrepreneurs. Thus, as in the simple model, the derivation includes the use of the labour supply and demand optimality conditions (eq. (3.76) and eq. (3.2)). The former equates the real wage to the marginal rate of substitution between consumption and leisure, and the latter condition equates the real product wage (that is, in terms of wholesale prices) to the marginal product of labour.[589] Then, in the next step, the final retail goods market equilibrium condition is used to substitute for consumption.

In the simple NK model, these steps lead to an expression for marginal costs a a linear function of the output gap and utility and production function parameters.[590] In contrast, in the financial accelerator model the expression for marginal costs is more complex due to the inclusion of investment, government consumption and the terms associated with the financial friction in the economy's resource constraint as well as the inseparabilities introduced in workers' utility function. To see this, note that in the simple model without investment, government spending and a financial friction, the log-linear approximation to the final retail goods market condition is simply:

$$\hat{y}_t = \hat{c}_t \tag{4.14}$$

that is, changes in aggregate demand are equal to changes in consumption. In contrast, the log-linear approximation to the final retail goods market equilibrium condition (eq. (3.93)) in the financial accelerator model is given by:

$$\hat{y}_t = \frac{C_W}{Y}\hat{c}_{w,t} + \frac{C_E}{Y}\hat{c}_{e,t} + \frac{I}{Y}\hat{i}_t + \frac{\Upsilon^G}{Y}\hat{\upsilon}^g_t + \frac{MoC^F}{Y}\widehat{moc}^F_t \tag{4.15}$$

Thus, the expression for marginal costs becomes mathematically more cumbersome. Instead of being able to substitute $\hat{c}_t$ in the labour market equilibrium condition directly with $\hat{y}_t$, $\hat{c}_t$ is now replaced by $\frac{1}{C_{W/Y}}(\hat{y}_t - (\frac{C_E}{Y}\hat{c}_{e,t} + \frac{I}{Y}\hat{i}_t + \frac{\Upsilon^G}{Y}\hat{\upsilon}^g_t + \frac{MoC^F}{Y}\widehat{moc}^F_t))$ where MoC^F stands for aggregate monitoring costs. While government consumption does not complicate the simplification process much as it is assumed to be an exogenous autoregressive process, the log-linear approximation of investment, entrepreneurs' consumption and monitoring costs are complicated functions of the probability functions of the entrepreneur-specific shock and/or the capital stock, its price and real return, and thus impede an illustrating and meaningful equation reduction exercise (see appendix section B.2). As noted above, only including physical capital, investment and government consumption already increases the system to seven difference equations plus three exogenous processes.[591] Furthermore,

[588] See Walsh (2003: 355)
[589] See Walsh (2003: 355)
[590] See Galí (2008: 48)
[591] This extended system appends dynamic equations for capital and investment and splits the NK (D)IS and PC equations each into two separate difference equations. See Woodford (2003: 361)

the capital stock does not only impact marginal costs indirectly via above mentioned variables, but also directly since it enters the production function, which is used for substitution.

Moreover, optimal labour supply depends on workers' utility function which differs in the financial accelerator model from the simple NK model. In particular, the financial accelerator model features a utility function that is time-inseparable and inseparable between consumption and leisure. This matters because workers' optimal labour supply condition is used to substitute for the real wage and thus relate marginal costs to consumption and output.[592] In the simple model, the log-linear approximation to the optimal labour supply condition can be expressed as:[593]

$$\hat{w}_t - \hat{p}_t = \eta \hat{h}_t + \sigma \hat{c}_t \tag{4.16}$$

where the left-hand side is the difference between the log-deviations of the nominal wage and the price level from their respective steady state level, η is the Frisch elasticity of labour supply, and σ is the degree of risk aversion, as before.[594] The counterpart to this equation for the financial accelerator model is given by:

$$\hat{w}_t - \hat{p}_t = \frac{\hat{c}_{w,t} - \chi \hat{c}_{w,t-1}}{1-\chi} + \frac{H}{1-H}\hat{h}_t \tag{4.17}$$

where H is the steady-state value of labour input in the production process. Combining these complications and defining X_t^F as aggregate retail goods demand less workers' consumption demand, an expression for marginal costs can be derived.[595] Marginal costs in the financial accelerator model are then:

$$\begin{aligned}
\widehat{mc}_t &= \left(\frac{1}{(C_W/Y)(1-\chi)} + \left(\frac{1}{(1-H)\alpha} - 1\right)\right)\hat{y}_t - \frac{\chi}{(C_W/Y)(1-\chi)}\hat{y}_{t-1} \\
&\quad - \frac{1}{(C_W/Y)(1-\chi)}\frac{X^F}{Y}(\hat{x}_t^F - \chi \hat{x}_{t-1}^F) - \frac{1}{\alpha(1-H)}(\hat{v}_t^a + (1-\alpha)\hat{k}_{t-1}) \\
&= \lambda_1^{PC}\hat{y}_t + \lambda_2^{PC}\hat{y}_{t-1} + \lambda_3^{PC}(\hat{x}_t^F - \chi\hat{x}_{t-1}^F) + \lambda_4^{PC}(\hat{v}_t^a + (1-\alpha)\hat{k}_{t-1})
\end{aligned} \tag{4.18}$$

where the last line simplifies the parameter terms to single coefficients.[596]

[592] Remember that in the simple model output was equal to consumption.

[593] See Walsh (2003: 238), unnumbered equation, my notation. The relevant derivations can be found in Walsh (2003: 234ff).

[594] See Galí (2008: 52). The underlying utility function is: $U_t = C_t^{1-\sigma}/(1-\sigma) - N_t^{1+\eta}/(1+\eta)$, see Galí (2008: 42), unnumbered equation, my notation.

[595] See appendix section B.3 for details. Note that although wholesale and final output are not the same, the deviations around the steady state approximated up to first order are equal since $Y_t = (1-c)Y_t^W$ where c is a constant, and as was noted above, price dispersion does not impact first-order dynamics, see Christiano et al. (2011: 297).

[596] This means, λ_1^{PC} is a substitute parameter function for the whole term pre-multiplying $\hat{y}_t$ in the first line of the equation. The same applies to the remaining λ^{PC}'s.

Strictly speaking, all variables except for the exogenous processes in eq. (4.18) should have a financial accelerator model superscript F, since the deviations of output from their steady-state levels are different in the financial accelerator and the banking models. For example $\hat{y}_t$ evolves differently in response to a shock in the financial accelerator model than in the banking model.[597] However, to emphasise the changes, only those variables whose mathematical definition changes in the banking model are marked with a model superscript F.

Considering the coefficients of the deviations, there are some notable features. By definition α, χ, H, and ${C_W}/{Y}$ take values between 0 and 1. Thus, λ_1^{PC}, the coefficient multiplying $\hat{y}_t$, is strictly positive while λ_2^{PC}, λ_3^{PC} and λ_4^{PC} are negative. This sign of λ_4^{PC} is consistent given that both technology and capital increase the marginal productivity of labour. Thus, if the marginal productivity of labour increases, retailers' real marginal cost decreases.

The relationship between the output gap and marginal costs in the simple model corresponding to eq. (4.18) is:[598]

$$\widehat{mc}_t = \tilde{\kappa}\,\widehat{gap}_t \tag{4.19}$$

where $\tilde{\kappa}$ is a function of production and utility function parameters.[599]

What is more, there is a notational difference between eqs. (4.18) and (4.19). The reference point for calculating deviations is natural output in eq. (4.19), while it is the respective steady-state value in eq. (4.18).[600] The output gap could be introduced into eq. (4.18), yet this would not reduce the complexity of eq. (4.18) as is the case in the simple model. In fact, the only term that would drop out with certainty is $\hat{a}_t$ given that it is an exogenous autoregressive process. In the simple model, writing the equation in terms of the output gap allows both for a natural economic interpretation, but also a simplification since the other component of marginal costs in the simple model - technology - drops out. Given that there are more variables in the financial accelerator and banking models that affect marginal costs which do not drop out, the transformation would merely lead to redefining the deviation of the capital stock from its steady state into the deviation of the capital stock from its natural counterpart value. This latter value is not necessarily equal to the steady state but also reacts to shocks. While the output gap is an established definition, redefining

597 See, for instance, chapter 6 for the evolution of different variables to a monetary policy shock.

598 See Galí (2008: 48), eq. (20), my notation.

599 More specifically, $\tilde{\kappa} = \sigma + {(\eta+\alpha)}/{(1-\alpha)}$, where σ and η are defined as above, and $1-\alpha$ is the partial elasticity of output with respect to labour, see Galí (2008: 43, 48), eq. (20), my notation.

600 Given that all model variables are stationary and the condition of a stable and determinate steady state, the economy will return to the long-run equilibrium when displaced by exogenous shocks. See section 4.4 for details on stability and determinacy of equilibrium.

capital and other demand components in terms of their deviations from a natural counterpart does not make the dynamics more transparent. Hence, the notation here follows Woodford (2003) and considers deviations from the deterministic (long-run) steady state.[601]

Apart from this notational difference, there are various aspects to note concerning the NK PC of the financial accelerator model. Firstly, while they do not explicitly appear in eq. (4.18), workers' discount rate and the elasticity of output with respect to labour affect marginal costs indirectly via the steady-state value of labour input H. Thus, utility function parameters affect the link between marginal cost and output deviations in both the simple and the financial accelerator models although potentially to different extents.

Secondly, note that marginal cost deviations from the steady state increase with increases in the current deviation of output from its steady state $\hat{y}_t$, but decrease with increases in lagged output deviations $\hat{y}_{t-1}$. The first observation is in line with the simple model where marginal costs are proportional to the output gap. The negative sign of lagged output deviations is due to habit persistence in the utility function. By definition, $|\lambda_1^{PC}|$ will be larger than $|\lambda_2^{PC}|$. Thus, increases in current retail goods demand will increase marginal costs, but in general to a smaller extent than in the simple model due to habit persistence. Given that habit persistence, as well as investment adjustment costs, were introduced to increase the persistence of consumption and investment, respectively, following shocks, and thus by extension output, the reaction of marginal costs should also be smoother within this framework.

Thirdly, factors of production affect the relationship between the output gap and marginal costs. As noted before, marginal costs of retailers can be defined as the ratio of the nominal wage to the marginal product of labour. As both technology and the capital stock raise the marginal productivity of labour, real marginal costs decrease given a negative λ_4^{PC}. What is more, the capital stock affects other variables in eq. (4.18) and thus marginal costs also indirectly. Changes in the capital stock in period t affect marginal costs indirectly via investment spending in period t, and the volume of entrepreneurs' consumption and monitoring costs through the endogenous price of capital and thus the real return on real capital in period t. Hence the exact effect is unclear from this analytical perspective, yet can be evaluated through numerical simulations.

Fourthly and related, aggregate demand components affect marginal costs. Since the relationship is derived using workers' optimality conditions, the main effect is due to consumption. The relationship between workers' consumption demand and the real wage

[601] Due to a similar reasoning the derivation of the DIS curve presented below would not simplify (except for technology) further, too, if it were written in terms of output gap deviations.

can be seen in eq. (4.17): ceteris paribus ($\hat{h}_t = 0$), $\hat{c}_t > 0$ necessitates an increase in the real wage $\hat{w}_t - \hat{p}_t$. For a set of preferences concerning intertemporal substitution and risk aversion, given hours worked and wealth, workers only consume more if they earn more in the same period. Irrespective of whether this increase in the real wage is due to an increase in the nominal wage rate or a decrease in inflation, marginal costs of retailers will increase.[602]

However, other aggregate demand components may also affect marginal costs. This is due to the analytical derivation: hours worked are substituted for the production function in deriving eq. (4.18) the result of which is the more complex definition of λ_1^{PC} as compared to the other λ^{PC}'s. The following equation must hold for an increase of one of the components of aggregate demand other than workers' consumption to not affect marginal costs and thus inflation:

$$\frac{C_E}{Y}\hat{c}_{e,t} + \frac{I}{Y}\hat{i}_t + \frac{\Upsilon^G}{Y}\hat{\upsilon}_t^g + \frac{MoC^F}{Y}\widehat{moc}_t^F = 0 \tag{4.20}$$

If, on the other hand, the left-hand side of eq. (4.20) is positive (negative), then these aggregate demand components increase (decrease) retailers' real marginal cost. Therefore, it is not only the aggregate level of output (or demand) which affects marginal costs in the financial accelerator model, but also its composition.

To sum up, in the financial accelerator model, inflation depends on past and expected future inflation as well as deviations of real marginal cost from its steady state. Except for the presence of lagged inflation, this is the same result that emerged from the simple NK model. Furthermore, lagged inflation enters because of price indexation. In contrast, the link between real marginal costs and the output gap is complicated due to the financial friction and the introduction of governmental consumption, physical capital and investment. As in the simple model, deviations of marginal cost are positively linked to deviations of output. However, this relationship is affected by other aggregate demand components and production inputs.

4.3.2.2 The New Keynesian Dynamic IS Curve

As in the simple model, the NK DIS curve in the financial accelerator model is derived by combining the consumption Euler equation with the economy's resource constraint. The log-linear approximation to the consumption Euler equation in the financial accelerator model is given by:[603]

$$\hat{u}_{c,t} = \mathbf{E}_t[\hat{r}_{n,t+1}] - \mathbf{E}_t[\pi_{t+1}] + \mathbf{E}_t[\hat{u}_{c,t+1}] \tag{4.21}$$

[602] To see this, note that marginal costs of retailers are given by (time subscripts were dropped for clearer notation): $MC = {}^{P^W}\!/_{P} = {}^{W^N}\!/_{\alpha Y^W}$.

[603] This is essentially the log-linear approximation to eq. (3.77), where the real portfolio return is substituted for the real risk-free return.

where the log-linear approximation to marginal utility of consumption in period t is given by:

$$\hat{u}_{c,t} = \Big((1-\eta_l)(1-\sigma_c)-1\Big)\frac{\hat{c}_{w,t}-\chi\hat{c}_{w,t-1}}{1-\chi} + \eta_l(\sigma_c-1)\frac{H}{1-H}\hat{h}_t \tag{4.22}$$

Combining eqs. (4.21) and (4.22) yields the consumption equation linking the path of consumption to the expected real interest rate:

$$\begin{aligned}\hat{c}_{w,t} = &\frac{1}{1+\chi}\mathbf{E}_t[\hat{c}_{w,t+1}] - \frac{\chi}{1+\chi}\hat{c}_{w,t-1} + \frac{z_h}{(1+\chi)z_c}\Big(\mathbf{E}_t[\hat{h}_{t+1}]-\hat{h}_t\Big)\\ &+\frac{1}{(1+\chi)z_c}\Big(\mathbf{E}_t[\hat{r}_{n,t+1}]-\mathbf{E}_t[\pi_{t+1}]\Big)\end{aligned} \tag{4.23}$$

where z_h and z_c are given by:

$$z_h = \eta_l(\sigma_c-1)\frac{H}{1-H} \tag{4.24}$$

$$z_c = \frac{(1-\eta_l)(1-\sigma_c)-1}{(1-\chi)} \tag{4.25}$$

Similar to the discussion concerning the NK PC curve, the extended aggregate resource constraint complicates the derivation of the DIS curve as well. Combining the consumption eq. (4.23) with the economy's resource constraint yields:

$$\begin{aligned}\hat{y}_t = &\frac{1}{1+\chi}\mathbf{E}_t\left[\hat{y}_{t+1}-\frac{X^F}{Y}\hat{x}^F_{t+1}\right] + \frac{X^F}{Y}\hat{x}^F_t + \frac{\chi}{1+\chi}\left(\hat{y}_{t-1}-\frac{X^F}{Y}\hat{x}^F_{t-1}\right)\\ &+\frac{z_h}{(1+\chi)z_y}\Big(\mathbf{E}_t[\hat{h}_{t+1}]-\hat{h}_t\Big) + \frac{1}{(1+\chi)z_y}\Big(\mathbf{E}_t[\hat{r}^n_{t+1}]-\mathbf{E}_t[\pi_{t+1}]\Big)\end{aligned} \tag{4.26}$$

where z_y is given by:

$$z_y = \frac{(1-\eta_l)(1-\sigma_c)-1}{(C_W/Y)(1-\chi)} \tag{4.27}$$

Using the production function to substitute for hours worked in eq. (4.26) yields:

$$\begin{aligned}\hat{y}_t = &\frac{z_y\alpha+z_h}{(1+\chi)z_y\alpha+z_h}\mathbf{E}_t[\hat{y}_{t+1}] + \frac{\alpha}{(1+\chi)z_y\alpha+z_h}\Big(\mathbf{E}_t[\hat{r}_{n,t+1}]-\mathbf{E}_t[\pi_{t+1}]\Big)\\ &+\frac{\chi z_y\alpha}{(1+\chi)z_y\alpha+z_h}\left(\hat{y}_{t-1}-\frac{X^F}{Y}\hat{x}^F_{t-1}\right)\\ &-\frac{z_y\alpha}{(1+\chi)z_y\alpha+z_h}\frac{X^F}{Y}\Big(\mathbf{E}_t[\hat{x}^F_{t+1}]-(1+\chi)\hat{x}^F_t\Big)\\ &-\frac{z_h}{(1+\chi)z_y\alpha+z_h}\Big(\mathbf{E}_t[\hat{v}^a_{t+1}]-\hat{v}^a_t+(1-\alpha)\Big(\mathbf{E}_t[\hat{k}_t]-\hat{k}_{t-1}\Big)\Big)\\ = &\lambda^{IS}_1\mathbf{E}_t[\hat{y}_{t+1}] + \lambda^{IS}_2\Big(\mathbf{E}_t[\hat{r}_{n,t+1}]-\mathbf{E}_t[\pi_{t+1}]\Big) + \lambda^{IS}_3\left(\hat{y}_{t-1}-\frac{X^F}{Y}\hat{x}^F_{t-1}\right)\\ &+\lambda^{IS}_4\Big(\mathbf{E}_t[\hat{x}^F_{t+1}]-(1+\chi)\hat{x}^F_t\Big)\end{aligned}$$

$$+ \lambda_5^{IS}\Big(\mathbf{E}_t[\hat{\upsilon}^a_{t+1}] - \hat{\upsilon}^a_t + (1-\alpha)\Big(\mathbf{E}_t[\hat{k}_t] - \hat{k}_{t-1}\Big)\Big) \tag{4.28}$$

where again the last three lines following the second equality sign simplify the parameter terms to single coefficients.[604]

Comparing eqs. (4.10) and (4.28), it is clear that current and expected next period's deviation of output from its steady-state value and the expected real interest rate, namely the difference between the expected risk-free nominal interest rate and expected inflation (first line of eq. (4.28)), are related in both models.

However, there are also several differences. Firstly, eq. (4.28) is a difference equation of second order. The presence of lags of output and aggregate demand components is the result of time-inseparability in the utility function. The inseparability between leisure and consumption in the utility function is the reason for the presence of current and expected deviations of hours worked from its steady state in eq. (4.26). Neither of these features is present in the simple model. Secondly, the NK DIS curve of the financial accelerator model involves more variables which affect the mentioned relationship, similar to the NK PC above. These are the factors of production (labour in eq. (4.26) or capital and technology in eq. (4.28)), and the components of aggregate demand.

Thirdly, the relationship is furthermore not only affected by one utility function parameter (σ) but by a whole range of utility and production function parameters. By definition the following parameter ranges apply: $0 < \eta_l < 1$, $0 < \chi < 1$, $0 < \alpha < 1$, $0 < {}^{C_W}/_{Y} < 1$ and $0 < H < 1$. The value of σ_c, however, cannot be determined by such considerations. The derivation steps used for the simple NK model and the consumption equation (eq. (4.23)) imply a positive value for λ_1^{IS}. Thus, when $\sigma_c > 1$, the parameter constellation must be such that z_h is smaller in absolute value than αz_y such that both denominator and numerator of λ_1^{IS} are negative, and if $\sigma_c < 1$, then $\lambda_1^{IS} > 0$ for the bounds of the other parameters as above.[605] Thus, the signs of the λ^{IS}'s are:

$$\begin{aligned} &\lambda_1^{IS},\, \lambda_3^{IS},\, \lambda_5^{IS} > 0 \quad \& \quad \lambda_2^{IS},\, \lambda_4^{IS} < 0 \quad \text{for} \quad \sigma_c > 1 \\ &\lambda_1^{IS},\, \lambda_3^{IS} > 0 \quad \& \quad \lambda_2^{IS},\, \lambda_4^{IS},\, \lambda_5^{IS} < 0 \quad \text{for} \quad 0 < \sigma_c < 1 \end{aligned}$$

Since σ_c is estimated, the exact size of the parameter σ_c will be discussed together with

[604] The simplification is analogous to the NK PC curve above, see also footnote 596.

[605] There is a third possibility which leads to $\lambda_1^{IS} > 0$, which requires that z_h is larger in absolute value than $(1+\chi)z_y$ such that denominator and numerator become positive. However, this would not be in line with the sign of λ_2^{IS} which should be negative given the derivations in section 4.3.1 and the consumption eq. (4.23).

all other parameters in the following chapter.[606]

To sum up, the time-inseparability of the utility function leads to a system of difference equations of second order, the inseparability of consumption and leisure yields the presence of production function variables as well as production and utility function parameters in the DIS curve. Finally, government spending, investment and physical capital complicate the substitution of consumption for output when deriving a link between inflation, interest rates and output as for the NK PC.

4.3.2.3 Completing the Financial Accelerator Model

In contrast to the simple NK model, the financial accelerator model is not completely characterised by this three equation system. The NK PC (eqs. (4.12) and (4.18)) determines the path of inflation for a given path of output $\hat{y}$, entrepreneurs' consumption $\widehat{ce}$, investment $\hat{\imath}$, capital $\hat{k}$, monitoring costs $\widehat{moc}$, technology $\hat{\upsilon^a}$ and the other exogenous processes. Monitoring costs and entrepreneurial consumption are functions of the threshold of the entrepreneur-specific shock $\hat{\psi}^E$, the return $\hat{r}_k$ and the lagged price of capital $\hat{q}$, and capital itself. Thus, these functions can be inserted into the definition of marginal costs which now depend on the entrepreneur-specific shock, capital, its real return and lagged price of capital instead of entrepreneurial consumption and monitoring costs. Thus, the log-linear approximation to the equations for the path of capital (eq. (3.37)), investment (eq. (3.39)) and the price of capital (eq. (3.3)) need to be added. The arbitrage condition for the real return on real capital is given by a modified version of the banking model condition eq. (3.16):[607]

$$\mathbf{E}_t\left[\hat{r}_{k,t+1}\right] = \mathbf{E}_t\left[\hat{\varrho}^E_{t+1} + \hat{r}_{t+1}\right] \tag{4.29}$$

This equation links the expected real return on real capital to the expected risk-free return (eq. (3.92)) via the expected risk premium $\hat{\varrho}^E$ (eq. (3.17)). The risk premium in turn is a function of the threshold of the entrepreneur-specific shock which is determined by eq. (3.13). Since entrepreneurial net worth is again a function of lagged capital, its lagged price and current return, the definition of the entrepreneur-specific shock threshold becomes a first-order difference equation in capital, its return and price. Finally, the log-linear approximations to the definitions of the auxiliary financial functions Γ^E (eq. (3.10)) and G^E (eq. (3.11)) as well as their derivatives are needed.

Secondly, for a given path of inflation, the risk-free interest rate, investment, capital,

[606] Incidentally, σ_c is estimated to be larger than 1, thus λ_5^{IS} is positive, implying that (expected) increases in technology or physical capital increase output.

[607] Since the financial accelerator model does not include the friction between banks and workers, the relevant reference return in the incentive compatibility constraint of banks to grant loans is the real risk-free return, and not the real wholesale return.

the return and price of capital, the entrepreneur-specific shock threshold, risk premium and the auxiliary financial functions as well as the exogenous processes, the NK DIS curve (eq. (4.28)) determines the path of output. Thirdly, the monetary policy function determines the nominal risk-free interest rate (log-linear approximation of eq. (3.91)).

The rational expectations equilibrium is characterised by a set of paths for the 14 endogenous variables:

$$\begin{bmatrix} \hat{y} & \hat{\pi} & \hat{r}_n & \hat{r} & \hat{i} & \hat{k} & \hat{q} & \hat{r}_k & \hat{\psi}^E & \hat{\varrho}^E & \hat{G}^E & \hat{\Gamma}^E & \hat{G}^{E\prime} & \hat{\Gamma}^{E\prime} \end{bmatrix}$$

that satisfy eq. (4.12) (where $\widehat{mc}$ is substituted using eq. (4.18)) eq. (4.28), and the log-linear approximations to eqs. (3.3), (3.13), (3.17), (3.37), (3.39), (3.91), (3.92) and (4.29) with above substitutions and the log-linear approximations to the auxiliary entrepreneurial functions eqs. (3.10) and (3.11) as well as derivatives of these auxiliary entrepreneurial functions, at all time periods, given the exogenous processes Υ_t^A, Υ_t^E, Υ_t^G, Υ_t^I, Υ_t^K, Υ_t^{MS}, Υ_t^P.

4.3.3 The Banking Model

4.3.3.1 The New Keynesian Phillips Curve

The NK PC of the banking model is (using the same steps as for the simple and financial accelerator models):

$$\pi_t = \frac{\beta}{1+\beta\gamma^p}\mathbf{E}_t[\pi_{t+1}] + \frac{\gamma^p}{1+\beta\gamma^p}\pi_{t-1} + \kappa_{ff}\widehat{mc}_t \tag{4.30}$$

with:

$$\kappa_{ff} = \frac{(1-\beta\xi^p)(1-\xi^p)}{(1+\beta\gamma^p)\xi^p} \tag{4.31}$$

where marginal costs $\widehat{mc}_t$ are defined as:

$$\begin{aligned} \widehat{mc}_t &= \left(\frac{1}{({}^{C_W}/{}_Y)(1-\chi)} + \left(\frac{1}{(1-H)\alpha} - 1\right)\right)\hat{y}_t - \frac{\chi}{({}^{C_W}/{}_Y)(1-\chi)}\hat{y}_{t-1} \\ &\quad - \frac{1}{({}^{C_W}/{}_Y)(1-\chi)}\frac{X^B}{Y}\left(\hat{x}_t^B - \chi\hat{x}_{t-1}^B\right) - \frac{1}{(1-H)\alpha}\left(\hat{v}_t^a + (1-\alpha)\hat{k}_{t-1}\right) \\ &= \lambda_1^{PC}\hat{y}_t + \lambda_2^{PC}\hat{y}_{t-1} + \lambda_3^{PC}\left(\hat{x}_t^B - \chi\hat{x}_{t-1}^B\right) + \lambda_4^{PC}\left(\hat{v}_t^a + (1-\alpha)\hat{k}_{t-1}\right) \end{aligned} \tag{4.32}$$

and $\hat{x}_t^B$ is defined as:[608]

$$\frac{X^B}{Y}\hat{x}_t^B = \frac{C_E}{Y}\hat{c}_{e,t} + \frac{I}{Y}\hat{i}_t + \frac{\Upsilon^G}{Y}\hat{\upsilon}_t^g + \frac{MoC^B}{Y}\widehat{moc}_t^B \tag{4.33}$$

and $\widehat{moc}_t^B$ is defined in appendix section B.2.

The relationships between marginal cost and inflation are the same in the banking and financial accelerator models. In turn, marginal costs are defined very similarly in the banking and financial accelerator models. The relevant change for the NK PC in the banking model in terms of a formal definition are transactions costs. In the banking model, this term is the sum of transaction costs incurred by banks, workers and the government due to insolvency of entrepreneurs and banks. In the financial accelerator model, this term only included the costs incurred by banks in monitoring defaulting entrepreneurs.

Yet, in contrast to the banking model, the financial accelerator model introduced a new aggregate demand component: entrepreneurs' consumption. While the banking model as an extension of the financial accelerator model also includes entrepreneurs' consumption, there is no additional 'banker's consumption' term in the resource constraint.[609] This approach was deliberately not taken so as to explicitly model the dynamics of the liability side of banks from the demand side instead of imposing them exogenously. Furthermore, in presenting the financial accelerator, Bernanke et al. (1999) emphasise that standard calibration ranges should ensure that entrepreneurial consumption and monitoring costs remain of lesser importance for model dynamics.[610] Hence, whether to include an extended family approach or not is of lesser significance. Arguing in this vein obviously also reduces the significance of the new definition of monitoring costs and thus the difference of the NK PC between the financial accelerator and banking models in terms of formal definitions. In conclusion, the formal definition of the NK PC curve is very similar in the banking and financial accelerator models.

4.3.3.2 The New Keynesian Dynamic IS Curve

The fundamental change in this three-equation representation which is triggered by the financial friction between banks and workers can be found in the DIS equation (eq. (4.34)). In the banking model the portfolio return enters the Euler equation, while in the simple and financial accelerator models the Euler equation was in terms of a risk-free return.

608 Note that government spending Υ^G is an autoregressive process both in the financial accelerator and in the banking model. However, the governmental budget constraint in the financial accelerator model is simply that taxes are equal to government consumption, whereas in the banking model more income and expense items enter (see section 3.8).

609 This is because the extended family approach was not used for the banking business.

610 See Bernanke et al. (1999: 1362)

Using the same steps as in the financial accelerator model, I arrive at the following DIS curve representation:

$$\begin{aligned}
\hat{y}_t = &\frac{z_y\alpha + z_h}{(1+\chi)z_y\alpha + z_h}\mathbf{E}_t[\hat{y}_{t+1}] + \frac{\alpha}{(1+\chi)z_y\alpha + z_h}\Big(\mathbf{E}_t[\hat{r}_{pn,t+1}] - \mathbf{E}_t[\pi_{t+1}]\Big) \\
&+ \frac{\chi z_y \alpha}{(1+\chi)z_y\alpha + z_h}\Big(\hat{y}_{t-1} - \frac{X^B}{Y}\hat{x}^B_{t-1}\Big) \\
&- \frac{z_y\alpha}{(1+\chi)z_y\alpha + z_h}\frac{X^B}{Y}\Big(\mathbf{E}_t[\hat{x}^B_{t+1}] - (1+\chi)\hat{x}^B_t\Big) \\
&- \frac{z_h}{(1+\chi)z_y\alpha + z_h}\Big(\mathbf{E}_t[\hat{v}^a_{t+1}] - \hat{v}^a_t + (1-\alpha)\Big(\mathbf{E}_t[\hat{k}_t] - \hat{k}_{t-1}\Big)\Big) \\
= &\lambda_1^{IS}\mathbf{E}_t[\hat{y}_{t+1}] + \lambda_2^{IS}\Big(\mathbf{E}_t[\hat{r}_{pn,t+1}] - \mathbf{E}_t[\pi_{t+1}]\Big) + \lambda_3^{IS}\Big(\hat{y}_{t-1} - \frac{X^B}{Y}\hat{x}^B_{t-1}\Big) \\
&+ \lambda_4^{IS}\Big(\mathbf{E}_t[\hat{x}^B_{t+1}] - (1+\chi)\hat{x}^B_t\Big) \\
&+ \lambda_5^{IS}\Big(\mathbf{E}_t[\hat{v}^a_{t+1}] - \hat{v}^a_t + (1-\alpha)\Big(\mathbf{E}_t[\hat{k}_t] - \hat{k}_{t-1}\Big)\Big)
\end{aligned} \tag{4.34}$$

Note that again that X^B_t is defined in terms of the more complex transaction cost definition as used for the NK PC of the banking model. More importantly, in contrast to the simple and financial accelerator models where the central bank is able to manipulate the nominal interest rate and thus the savings behaviour of households directly, this is not necessarily true in the banking model. In the latter, the nominal portfolio rate is equal to the nominal interest rate set by the central bank only in the long-run deterministic equilibrium. In the long-run deterministic equilibrium all shocks are zero (presently and expected in the future), thus there is no aggregate risk and for workers to be willing to hold bank equity, the nominal return must be at least as high as the nominal return on bank deposits and vice versa.[611] Hence, in the long-run deterministic equilibrium the nominal return on equity is equal to the nominal deposit return, which is in turn equal to the nominal risk-free return. If the economy is outside its long-run deterministic steady state and if equity and deposit holdings are both strictly positive, then developments in the banking sector affect the nominal return on equity which in turn affects the nominal portfolio return, and finally the savings and consumption behaviour of workers.

Consider for example an increase in the policy return: this will tend to lower asset prices which will then lower the real return on real capital. This lowers profits in the entrepreneurial and banking sectors which tends to lower the return on equity. In this scenario the portfolio return will certainly increase less than the initial impulse of the nominal policy rate, but depending on the portfolio composition of the representative

[611] This line of argument presumes the non-stochastic steady state to be locally stable and determinate, see section 4.4 for the corresponding analysis.

worker may also decrease or remain the same if both effects exactly cancel out.[612] Given that the intertemporal Euler equation characterises the optimal intertemporal consumption behaviour of workers, they will then only adjust their consumption/saving profile if the real portfolio return changes. Thus, if monetary policy induced changes in bank profitability lead to a situation where the portfolio return does not change, then monetary policy does not affect workers' consumption. In sum, monetary policy may still curb interest rate sensitive investment via the financial accelerator. In contrast, the transmission of monetary policy to the savings behaviour of workers may be seriously impeded.[613]

4.3.3.3 Monetary Policy

The specification of the Taylor rule in the banking model was already explained in section 3.8.2. The following paragraph is intended as a brief comparison with the specification presented for the simple NK model. The log-linear approximation to the Taylor rule in the banking model (eq. (3.91)) is given by:

$$\hat{r}_{n,t} = \rho_R \hat{r}_{n,t-1} + (1-\rho_R)\theta_\pi \hat{\pi}_t + (1-\rho_R)\theta_y \widehat{gap}_t + \epsilon_{M,t} \tag{4.35}$$

The Taylor rule specification of the banking model shows that the central bank changes the nominal policy return in response to deviations of inflation and output from their respective steady-state values as in the simple model. The only crucial change from the simple model is that the banking model Taylor rule features interest rate inertia as explained in section 3.8.2. This means that the deviation of the policy return from its steady-state value in period t depends on its own lag. Therefore, while the paths of output and inflation may vary between the simple and banking models, the response of the central bank to these variables is generally comparable.

The choice for an Taylor-type interest rate rule is common in monetary policy analysis using DSGE models. Other kind of rules, for instance a money supply rule, are certainly possible but would necessitate a different model layout.[614] The evaluation of different monetary policy rules as well as the optimal policy reaction to banking sector fragility are interesting topics. Nonetheless, such an encompassing agenda is out of the bounds of this study. Rather, I focus on one kind of monetary policy rule to examine the consequences of bank failure.[615] While optimal policy is not treated explicitly, chapter 6 will deal extensively with the trade-off between different monetary policy objectives for the given

[612] The consequences of monetary policy are analysed in detail in chapter 6 using simulation techniques.
[613] Note that a similar reasoning would probably apply if workers held entrepreneurial equity instead of (or in addition to) bank equity since an increase in the policy rate would still tend to reduce entrepreneurial profits and thus the return on entrepreneurial equity.
[614] See section 2.2 for a justification for using an interest rate rule.
[615] Note that the strength of monetary policy's reaction to inflation, for example, is allowed to differ between the banking and financial accelerator models. These parameters are estimated, see chapter 5.

monetary policy rule. Future research can build on this and determine optimal policy coefficients for a single rule, as well as compare different monetary policy rules.

4.3.3.4 Completing the Banking Model

The representation of the financial accelerator model in terms of 14 equations with 14 endogenous variables is not sufficient to characterise the equilibrium in the banking model. First of all, the expression of monitoring costs includes transaction costs incurred by workers and the government in the banking model, which is used for substituting monitoring costs in the NK DIS and PC functions. Nevertheless, monitoring costs in both models can be described as functions of auxiliary entrepreneur-specific and/or bank-specific shock functions, capital, its return and price. Thus, only the auxiliary functions of banks' financial friction and their derivatives need to be added due to this complication (eqs. (3.52) to (3.54)). Secondly, the arbitrage condition (eq. (3.59)) between the real return on real capital and the real risk-free return includes the risk premiums of both entrepreneurs and banks in the banking model.[616] Hence, the equation for the risk premium of banks (eq. (3.60)), as well as the threshold of the bank-specific shock (eq. (3.56) holding with equality) need to be added. Due to the definition of the threshold and the inclusion of the portfolio return in the NK DIS curve, the equation for the return on bank equity (eq. (3.48b)) enters the system.[617] The previous variables depend on the financial volumes of loans, deposits and equity. Using the definition of entrepreneurial net worth again, loans can be expressed as a first-order difference equation in capital, its return and price. Finally, bank equity and deposits are determined by workers' asset demand equations (eqs. (3.81) and (3.82)). Using the balance sheet identity of banks, these can be transformed into difference equations of first order to eliminate the aggregate wealth level.

The rational expectations equilibrium is characterised by a set of paths for the 25 endogenous variables:

$$\begin{bmatrix} \hat{D} & \hat{e} & \hat{r}_e & \hat{\psi}^B & \hat{\varrho}^B & \hat{G}^M & \hat{G}^B & \hat{\Gamma}^B & \hat{G}^{M\prime} & \hat{G}^{B\prime} & \hat{\Gamma}^{B\prime} \end{bmatrix}$$

and

$$\begin{bmatrix} \hat{y} & \hat{\pi} & \hat{r}_n & \hat{r} & \hat{i} & \hat{k} & \hat{q} & \hat{r}_k & \hat{\psi}^E & \hat{\varrho}^E & \hat{G}^E & \hat{\Gamma}^E & \hat{G}^{E\prime} & \hat{\Gamma}^{E\prime} \end{bmatrix}$$

that satisfy eq. (4.12) (where $\widehat{mc}$ is substituted using eq. (4.32)) eqs. (4.34) and (4.35), and the log-linear approximations to eqs. (3.3), (3.13), (3.16), (3.17), (3.37), (3.39), (3.48b), (3.56), (3.59), (3.60), (3.81), (3.82) and (3.92) with above substitutions and the log-linear

[616] Equation (3.59) specifies a relationship between the real return on real capital and the real deposit return. Since the real deposit return is a linear function of the real risk-free return (eq. (3.45b)), the real deposit return can be substituted easily for the real risk-free return in eq. (3.59).

[617] Equation (3.48b) solves for the return on bank equity given all other variables.

approximations to the auxiliary financial functions eqs. (3.10), (3.11) and (3.52) to (3.54) as well as derivatives of these auxiliary financial functions, at all time periods, given the exogenous processes Υ_t^A, Υ_t^B, Υ_t^E, Υ_t^G, Υ_t^I, Υ_t^K, Υ_t^{MS}, Υ_t^P.

Strictly speaking, 12 of these equations are not difference equations; however, to substitute for the threshold shock in the auxiliary financial function equations and the risk premium involves both in the financial accelerator and the banking models the use of a first-order difference equation. This would unnecessarily complicate the notation without enabling further insights. To finish this presentation and gain an initial understanding of the differences between these three models, the next section discusses the relationship between the NK DIS and monetary policy shocks in these three models.

4.3.3.5 The Nominal Policy Return and the Dynamic IS Curve

Consider a positive, unexpected increase in the nominal policy return: this increases the policy interest rate and, ceteris paribus, in the simple and financial accelerator models this should lower output relative to its steady-state level.[618] In particular, this channel assumes that expectations about future output deviations and the composition of output, future inflation, technology and capital are unaffected. Comparing the size of the effect the policy interest rate may have on output in the simple and financial accelerator models, consider the coefficients: $-1/\sigma$ and λ_2^{IS} in eqs. (4.10) and (4.28) respectively. For reasonable values of the utility function and production function parameters, the former will be larger in absolute value than the latter.[619] In the banking model, this direct effect is further reduced due to the fact that the portfolio rate, which is given by $r_{p,t} = r_{d,t} + V_t^e(r_{e,t} - r_{d,t})$, enters the NK DIS curve. Thus, only $(1 - V_t^e)$ of the increase of the policy rate affects output directly. If, for example, workers distribute their wealth equally between bank equity and deposits, then $V_t^e = 0.5$, which means that the direct effect of an increase of the policy interest rate reduces to $0.5\lambda_2^{IS}$.

However, this simple analysis neglects the fact that the relationship between the policy rate and output is affected not only by the expected inflation rate, but also by technology and capital as well as other aggregate demand components, which in turn depend on capital, its price and return. Both in the financial accelerator and banking models, the real return on real capital must be equal to the sum of the real policy rate and the risk

[618] This is usually implemented as a monetary policy shock. More details on this topic are provided in chapter 6. Yet, this discussion is not limited to monetary policy shocks but also an increase in the policy rate as stipulated by the Taylor rule. However, the latter would be a reaction of an increase in either inflation of the output gap, making this discussion even more complex.

[619] For instance, assume $C_W/Y = 0.5$, $\eta_l = 0.9$, $\sigma_c = \sigma = 1.5$, $H = 0.35$, $\chi = 0.7$, $\alpha = 0.7$. Then $\lambda_2^{IS} = -.124$.

premium (risk premiums).[620] With an increase in the policy rate, the reaction of the real return on real capital will depend on the risk premiums of entrepreneurs and banks, which in turn depend on the capital stock, its price and expected return. A similar reasoning applies to the effect of the policy return on the return on bank equity in the banking model. Thus, any statement about the actual effect of the policy rate on output depends on the dynamics of the other equations in this simultaneous system of difference equations.

Furthermore, the inherent simultaneity and the concept of rational expectations used in this study makes the use of standard comparative statics in a graphical representation at least disadvantageous. As King (2000) notes, while a graphical representation of the DIS, PC and monetary policy (MP) curves is possible, the dynamics of the model cannot be captured adequately by a comparative-statics analysis of these curves without regard of the potential feedback effects of expectations of future realisations.[621] Crucially, the entire (expected) path of the model economy through time needs to be derived by solving for the variables and expectations of future realisations of these variables simultaneously.[622] Only with this knowledge can the effects of (un-)expected changes be depicted using curves.[623] As a result, this study uses numerical solution and simulation techniques to derive the path of the model economy in the following chapters. Based on this solution, various methods, such as impulse response analysis, are employed to discern and portray the dynamics and characteristics of the banking model. Before developing this line of analysis the last section of this chapter will examine stability and determinacy issues of the banking model equilibrium.

4.4 Determinacy and Stability Analysis

4.4.1 Determinacy and Stability Conditions for DSGE Models

The stable and determinate equilibrium of a model is often the focus of economic analyses. This is also the case in this study. While Gandolfo (2010) goes as far to assert that unstable equilibria can be considered to be of minor importance for economic analysis, it has to be acknowledged that sunspot solutions, multiple equilibria and self-fulfilling prophecies are interesting research agendas in their own right.[624] Yet, they are not the motivation of this study. The motivation of this study is to discern effects of non-systemic bank failure for the conduct of monetary policy. Thus, one crucial part of the analysis

[620] That is, concerning the log-linear approximation. In the non-linear model presented in chapter 3, the real return on real capital is equal to the product of the real policy rate and the risk premiums.
[621] See King (2000: 54)
[622] See King (2000: 54)
[623] See King (2000: 54)
[624] See Gandolfo (2010: 334, 351). Gandolfo (2010: 351f) also acknowledges that there are cases where instability is a desirable model feature or research focus.

concerns the transmission of monetary policy. Considering unstable and indeterminate equilibria would complicate severely or even impede this analysis. For instance, stable but indeterminate equilibria are characterised by the fact that the response of the economy to an exogenous shock cannot be traced uniquely.[625] This is rather disadvantageous for comparing the response to unexpected monetary policy changes in two different models. One may still compare, for example, whether the band of possible paths increases or not. Yet, this is not very helpful in answering the question of this study. It is crucially about the consequences of the additional financial friction for monetary policy. For a sensible analysis of monetary policy effects in chapter 6 I require the parameters constellation to be such that the system is locally stable and determinate. This is the rationale for exploring the stability and determinacy implications of parameter constellations in this section before proceeding with the estimation of the model.

Stability of equilibrium exists for a system if all motions from an arbitrary initial state lead to the stable point and if perturbations of the system from this point stay in the vicinity of this point.[626] The system is indeterminate if there are many possible solutions to the equilibrium conditions.[627] Thus, determinacy requires a unique equilibrium. These concepts are in global terms. If these definitions only hold in the vicinity of the equilibrium point, that is stability and determinacy require the perturbation and distance from the equilibrium point to be small, the equilibrium is deemed locally stable and determinate.[628]

The following analysis will be constrained to local stability. In recent years, global solution methods and thus analyses of global stability have increased; however, local stability remains predominant. Global solution methods are advantageous for models where the reaction of the system to large deviations from the equilibrium state or the implications of strong non-linearities are of interest.[629] Neither of these elements is critical in the financial accelerator or banking models. Moreover, global solution methods are numerically and computationally more demanding and time-consuming.[630] Hence, they quickly become infeasible as the number of state variables increases.[631] Furthermore, for the comparative purposes of the present research, I deem local analysis to be sufficient. The focus is on how non-systemic bank default in general affects the economy and monetary policy in

[625] See Lubik and Schorfheide (2004: 190)
[626] See Gandolfo (2010: 353)
[627] See Woodford (2003: 45)
[628] See Gandolfo (2010: 353)
[629] See Holden and Paetz (2012: 3). An example is the modelling of the zero lower bound of the policy interest rate, see Holden and Paetz (2012: 2).
[630] See Holden and Paetz (2012: 3)
[631] See Holden and Paetz (2012: 3f). This is similar to the discussion about heterogeneous agent models, see section 3.1.2. There has been research on decreasing the 'curse of dimensionality' for global solution methods; yet, these other methods may come at the cost of low accuracy, see Holden and Paetz (2012: 4).

particular with respect to a model where bank default does not occur. These differences already surface in the vicinity of the steady state as indicated in the previous section and will be shown in subsequent chapters. The discussion in the previous section already assumed the local concept, as a first-order log-linear approximation is only accurate in the vicinity of the point around which the equations are log-linearised.[632] Other interesting questions such as how the system reacts to a large number of defaulting banks which require global methods are left to future research.[633]

Stability and determinacy are characteristics of a dynamic system, thus need to be analysed in terms of all the parameters of a model.[634] Given the large number of parameters in the banking and financial accelerator models, computing determinacy and stability regions are non-trivial issues. To this end, the widely-used method developed by Blanchard and Kahn (1980) is employed. Blanchard and Kahn (1980) consider models in the following state-space form:[635]

$$\begin{bmatrix} \mathbb{X}_{t+1} \\ \mathbf{E}_t[\mathbb{Y}_{t+1}] \end{bmatrix} = \mathbf{A} \begin{bmatrix} \mathbb{X}_t \\ \mathbb{Y}_t \end{bmatrix} + \mathbf{B}\mathbb{Z}_t \tag{4.36}$$

This state-space form divides the model structure into a vector of predetermined endogenous variables $\mathbb{X}$, and a vector of non-predetermined endogenous variables $\mathbb{Y}$; the vector $\mathbb{Z}$ is composed of exogenous variables, and the matrices $\mathbf{A}$ and $\mathbf{B}$ contain functions of the model's parameters.[636] The realisation of a predetermined variable in period $t+1$ depends on the information set at time t.[637] It is thus independent of the variables updated in the information set at time $t+1$.[638] In contrast, the realisation of a non-predetermined variable in time $t+1$ is dependent on the information set at time $t+1$. In the banking model, the endogenous variables Λ, Λ^{FP}, I, I^{FP}, Π, R_k, R_k^{FP}, R_d, R_e, R_w, R_p, ϱ^E, Υ^K and Υ^I are non-predetermined variables collected in vector $\mathbb{Y}$, all shocks (ϵ) are exogenous and thus included in $\mathbb{Z}$, and the remaining variables belong to $\mathbb{X}$.[639]

The condition for stability and determinacy of equilibrium depends on the number of unstable roots or equivalently the number of explosive eigenvalues of the matrix $\mathbf{A}$. A stable and determinate equilibrium exists for a given parameter vector under the condition

632 See Devereux and Sutherland (2011: 362)
633 One such interesting question would be to trace and explain the financial crisis of 2007-8. Yet, to make such a task worthwhile, a more elaborate model of the liability side of banks would be required and would possibly also need further agents such as specialised financial intermediaries to describe investment banking.
634 See Cochrane (2011: 593)
635 See Blanchard and Kahn (1980: 1305), eq. (1a), my notation
636 See Blanchard and Kahn (1980: 1305)
637 See Blanchard and Kahn (1980: 1305)
638 See Blanchard and Kahn (1980: 1305)
639 The superscript FP denotes variables which belong to the simple flexible-price NK model used for calculating the output gap, see appendix section A.2 for details.

that there are is an equal number of explosive eigenvalues and non-predetermined variables.[640] In contrast, if the number of eigenvalues outside the unit circle is larger than the number of non-predetermined variables, then the equilibrium point is unstable.[641] Finally, the steady-state solution is indeterminate if there are fewer eigenvalues outside the unit circle than the number of non-predetermined variables.[642]

This method involves solving a polynomial of an order which is equal to the sum of predetermined and non-predetermined endogenous variables, thus quickly becomes analytically intractable.[643] The financial accelerator model in its reduced form has 14 endogenous variables, while the banking model contains 25 endogenous variables. This translates into solving polynomials of 14th and 25th order for stability and determinacy purposes which is analytically impractical. Thus, the results presented in the next two subsections were derived by numerical computations using the software package Dynare.[644] Due to space limits, the presentation is limited to two sets of parameters. Due to the focus on monetary policy, the first set of parameters to be discussed are the reaction coefficients in the Taylor rule in section 4.4.2. Furthermore, given the ad-hoc nature of workers' asset demand functions as well as the specificity to the banking model, section 4.4.3 will concentrate on the reaction coefficients of workers' portfolio allocation to the respective returns.

4.4.2 The Taylor Principle

The Taylor principle concerns the coefficients in the monetary policy rule. For the contemporaneous type considered here (eq. (4.35)) it states that, ceteris paribus, for the solution to be stable and determinate, the coefficients governing the reaction of the nominal policy interest rate to deviations of inflation and the output gap must be large enough such that the real policy rate rises whenever inflation rises.[645]

The precise determinacy and indeterminacy regions for various parameters depend on the model structure. In the simple NK model of section 4.3.1, which reduces to

[640] See Blanchard and Kahn (1980: 1308)
[641] See Blanchard and Kahn (1980: 1308)
[642] See Blanchard and Kahn (1980: 1308)
[643] See Blanchard and Kahn (1980: 1309)
[644] All computations were carried out with Matlab and the software platform Dynare. For coding (of the model, of the estimation and analysis experiments in this and subsequent chapters) the Dynare manual (Adjemian et al. (2011)), the Matlab help section, and the resources made available during the Summer School 'The Science and Art of DSGE Modelling' (2014) at the Centre for International Macroeconomic Studies, School of Economics at the University of Surrey were helpful and valuable. The tool developed by Schlömer (2016), URL in list of references, was used to convert pictures.
[645] See Galí (2008: 78f). 'Contemporaneous' means that the monetary policy rule stipulates a reaction to current inflation. The determinacy condition for a model with a monetary policy rule which reacts to expected future inflation additionally requires the reaction not to be too strong, see Galí (2008: 79).

two equations in two unknowns, the determinacy region can be represented analytically. Consider the monetary policy rule eq. (4.11), reprinted here for convenience:

$$\hat{r}_{n,t} = \nu_\pi \pi_t + \nu_y \widehat{gap}_t + \epsilon_{M,t} \tag{4.37}$$

which is a contemporaneous Taylor-type rule without interest rate persistence. The necessary and sufficient condition for equilibrium determinacy is given by:[646]

$$\nu_\pi + \frac{(1-\beta)}{\kappa}\nu_y > 1 \tag{4.38}$$

Including interest rate persistence in the monetary policy rule where ρ_R controls the degree of interest rate persistence gives a monetary policy rule of the kind:

$$\hat{r}_{n,t} = \rho_R \hat{r}_{n,t-1} + \nu_\pi \pi_t + \nu_y \widehat{gap}_t + \epsilon_{M,t} \tag{4.39}$$

The condition for equilibrium determinacy is then:[647]

$$\nu_\pi + \frac{(1-\beta)}{\kappa}\nu_y > 1 - \rho_R \tag{4.40}$$

Thus, the boundary between the determinacy and indeterminacy regions shifts downwards for the model with interest rate persistence relative to the boundary of the model without interest rate persistence.

As already noted above, such a neat analytical expression is not available for either the banking model or the financial accelerator model. Instead, the determinacy and indeterminacy regions are numerically computed. The following discussion is limited to two monetary policy rule parameters, θ_π and θ_y. Interest rate persistence is a feature of the banking model. However, there are two reasons for keeping ρ_R fixed in this exercise. Firstly, ρ_R has the only effect of shifting the boundary in parallel in the simple NK model. Secondly, the Taylor principle is mainly concerned with the reaction to deviations in inflation and the output gap. Finally, the interest rate persistence parameter does not affect the Taylor principle just discussed. To see this, note that the Taylor rule parameters in the banking and financial accelerator models are related to the respective parameters in eq. (4.39) above by the following identities:

$$\nu_\pi = (1-\rho_R)\theta_\pi \tag{4.41a}$$

$$\nu_y = (1-\rho_R)\theta_y \tag{4.41b}$$

646 See Woodford (2003: 254), eq. (2.7), and Galí (2008: 77), eq. (10), my notation, parameters are defined as in section 4.3.

647 See Woodford (2003: 255), eq. (2.9), my notation.

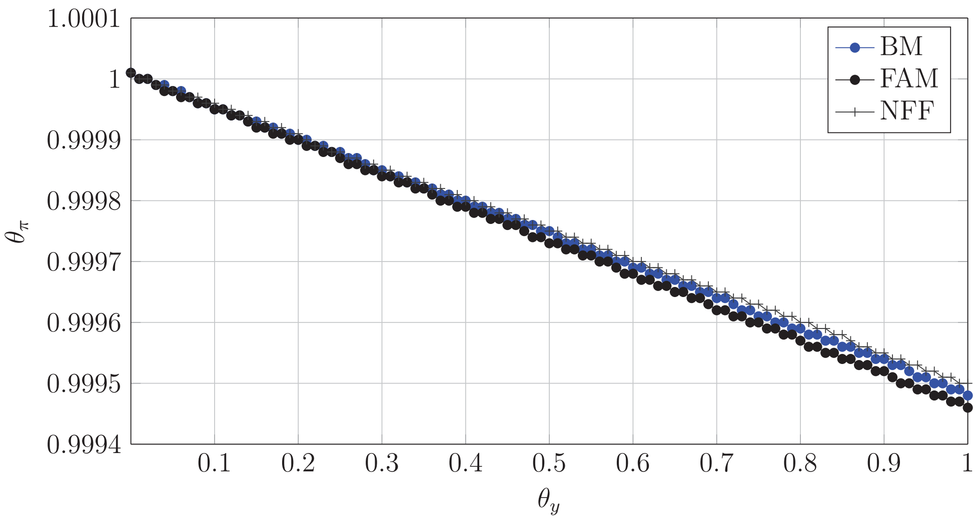

Figure 4.2: Determinacy Boundaries for Taylor Rule Parameters for the banking model (BM), the financial accelerator model (FAM), and the no-financial-frictions model (NFF); in all three models, the parameters are set to the posterior mean of the banking model except for the reaction coefficients in the Taylor rule θ_π and θ_y.

Dividing eq. (4.40) by $(1-\rho_R)$, eq. (4.40) can equally be written in terms of the parameters used in the banking model monetary policy rule:

$$\theta_\pi + \frac{(1-\beta)}{\kappa}\theta_y > 1 \tag{4.42}$$

The boundaries between determinacy and indeterminacy are depicted in fig. 4.2 for the banking and financial accelerator models and a no-financial-frictions model for reference. The no-financial-frictions model is the NK part of the banking model, that is it features all frictions except for the financial frictions between entrepreneurs and banks on the one hand, and banks and workers on the other hand, and thus also does not include portfolio choice.[648] The upper boundary of θ_y is set to 1 as it is sufficient to show the different slopes for the three models.[649] All possible combinations of θ_π and θ_y in fig. 4.2 are stable. Points on the respective line and above in fig. 4.2 are stable and determinate, while points below the line are indeterminate.[650] To illuminate the differences between the models, the scaling of the y-axis is very fine: the differences in the slopes of the determinacy boundaries are visible when the value of θ_π changes in 10^{-4} steps.

648 This means that financial intermediation in the no-financial-frictions model collapses to $R_k = R$. The determinacy region for the no-financial-frictions model does not necessarily need to be equivalent to the analytical boundary derived for the simple NK model in eq. (4.40). This is due to the various frictions present in the no-financial-frictions model which set it apart from the simple NK model. These frictions include, for instance, habit persistence and investment adjustment costs.

649 Furthermore, the posterior distribution of θ_y centres around 0.1, thus lies comfortably within the bound considered in fig. 4.2, for the benchmark model as well as during most sensitivity analyses. There is only one exception where $\theta_y > 1$, but in this case θ_π is sufficiently high to satisfy the Taylor principle, see section 5.5.

650 This assertion is true for values of θ_y between 0 and 1 on a 0.01 scale, and for θ_π values between 0.99946 and 1.00001 on a 0.00001 scale. These scales are sufficient for the purposes of this study.

Parameter	Banking Model		Financial Accelerator Model		No-Financial-Frictions Model	
θ_y	0	1	0	1	0	1
θ_π	1.00001	0.98483	1.00001	0.98415	1.00001	0.98531

Table 4.1: Determinacy Boundaries for Taylor Rule Parameters (Prior Mean of the Banking Model); in all three models, the parameters are set to the prior mean of the banking model except for θ_π and θ_y; entries in the row for θ_π designate the smallest value of θ_π for which the equilibrium is determinate.

All three models satisfy the Taylor principle. If θ_y is 0, then θ_π has to be strictly greater than 1 for the equilibrium to be determinate. In this exercise, setting θ_y to 0, a value of θ_π of 1.00001 was sufficient to ensure determinacy in both the banking and financial accelerator models, as well as the no-financial-frictions model. In contrast, when θ_y is 0, $\theta_\pi = 1$ yielded indeterminate equilibria in all three models. This is in line with the analytical result for the simple NK model in eq. (4.42). Furthermore, as θ_y increases, the restriction on θ_π relaxes and the lowest value of θ_π for which the model is determinate decreases. The relative change, however, is larger for θ_y than for θ_π considering the axes scaling. This implies that a high responsivity (that is over or close to one) of the nominal policy return to inflation is necessary to ensure equilibrium determinacy. This requirement is moderated only to a small extent by an increasing responsivity to the output gap.

There are differences between the slopes of the respective boundaries for the three models. Relative to the no-financial-frictions model, the determinacy boundary of the financial accelerator tilts downwards, that is the determinacy region expands. In contrast, the boundary for the banking model does not tilt downwards as much relative to the no-financial-frictions model. Yet, considering that these differences are relevant on a 0.00001 scale, the boundaries can be deemed reasonably similar. This result is reassuring, given that the financial accelerator model is an extension of the no-financial-frictions model, and the banking model in turn is an extension of the financial accelerator model.

Furthermore, this finding signifies that the mathematical terms multiplying θ_y in terms of eq. (4.42) change due to the model structure. Since all models use the same values for the remaining parameters, changes in the respective boundary are due to additional parameters or parameters that drop out of an analytical representation equivalent to eq. (4.42).[651] As a robustness check to this result, the determinacy boundaries were also computed using the prior mean of the banking model (see section 5.2.2). Table 4.1 shows the lowest values of θ_π corresponding to the value of θ_y for which the equilibrium is determinate. A similar pattern to fig. 4.2 emerges: for $\theta_y = 1$, the value of θ_π necessary

[651] In fig. 4.2, all parameter values are set to the posterior mean values of the banking model (see section 5.3).

for determinacy is lowest for the financial accelerator model, followed by the banking model. Thus, the determinacy region is smallest for the no-financial-frictions model.[652] Yet, additional financial frictions do not enlarge the determinacy region per se, as can be seen by the fact that the determinacy region for the banking model with two financial frictions is smaller than for the financial accelerator model with only one financial friction.

4.4.3 Portfolio Choice Parameters

As outlined above, the banking model is an extension of the financial accelerator model. The banking model includes many more variables, but only two more non-predetermined variables than the financial accelerator model: the return on bank equity R_e and the return on bank deposits R_d.[653] These enter the asset demand equations of workers. Thus, the next stability exercise will focus on the parameters in workers' asset demand functions, ω_1, ω_2 and ω_3.

Figure 4.3 displays the (in-)stability/determinacy regions for the reaction coefficients in the asset demand equations, ω_2 and ω_3 for three values of the equity-to-wealth ratio ω_1.[654] Figure 4.3a shows the various combinations of ω_2 and ω_3 when ω_1 is set to its value calibrated at the posterior mean of the banking model (benchmark calibration).[655] In fig. 4.3b the value of ω_1 is set lower than in the benchmark case, that is $\omega_1 = 0.25$, meaning that workers hold a quarter of their portfolio as bank equity. Conversely, ω_1 is higher than in the benchmark case, that is equal to 0.75, in fig. 4.3c.

Consider first the benchmark banking model parametrization in fig. 4.3a. The pattern is intriguing. There are two instability regions within the stable determinacy region. These instability regions, however, are not around a corner. There are combinations with lower values of either one or both ω_2 and ω_3 which yield a stable determinate equilibrium, as well as many combinations with larger values of both. This means that a strong reaction of workers' asset demands leads to stable, determinate equilibria. Also, if workers' only respond very timidly to changes in returns, the equilibrium is also stable and determinate. Yet, if the reaction is only somewhat stronger, the equilibrium becomes unstable. While this is a peculiar pattern, it resembles to some extent the Taylor principle with

652 Again, this applies for the grid of the parameter space already considered in fig. 4.2, see footnote 650.

653 In addition, one non-predetermined endogenous variable is exchanged. In the banking model, the wholesale return R_w is a non-predetermined variable; yet R_w is not present in the financial accelerator model. Instead, the real risk-free return R is a non-predetermined variable in the financial accelerator model. R is a predetermined variable in the banking model due to the model structure.

654 All other parameters are set to the posterior mean of the banking model, see section 5.3. Preliminary exploratory analysis over a larger coarse grid from 0 to 10 did not reveal any further regions of instability, but resulted in all points with values of either ω_2 or ω_3 larger than 1 being determinate equilibria.

655 As will be explained in chapter 5, ω_1 is neither estimated nor calibrated to a particular value. Rather, it is calibrated to a function of other estimated parameters.

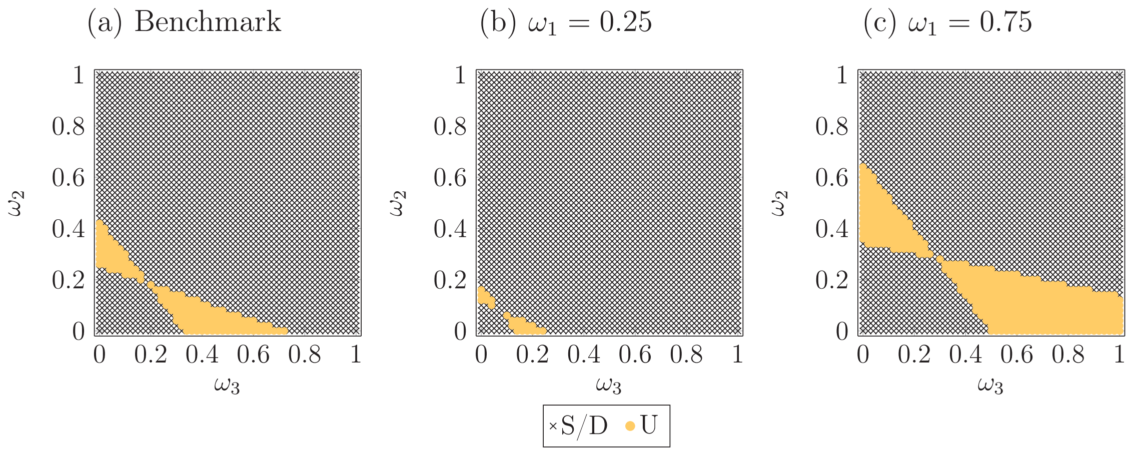

Figure 4.3: Determinacy Boundaries for Asset Demand Parameters; all parameters except for ω_1, ω_2 and ω_3 are set to the posterior mean of the banking model; for the left panel, the steady-state equity share ω_1 is set to the mean value resulting from the banking model posterior estimation, in the middle and right panels ω_1 is set to 0.25 and 0.75, respectively; S/D denotes stable, determinate equilibria, and U denotes unstable equilibria.

a forward-looking interest rate rule: In this case, the determinate and stable equilibria region is bounded by below by the condition discussed in the previous section, as well as bounded by above due to a second condition.[656]

Furthermore, the instability region is asymmetric in combinations of ω_2 and ω_3. Instability can arise if ω_2, that is the reaction of workers' asset demands to the return on bank equity, is below 0.5. Conversely, equilibria may be unstable if ω_3, that is the responsivity to the deposit return, is below 0.8. The reason for this observation may lie in the different determinants of the real deposit and real equity returns. On the one hand, the real return on bank deposits is a linear function of the real risk-free return. On the other hand, the real return on bank equity is also linked to developments in the banking sector. From this perspective, the result that the instability regions are asymmetric in these two parameters appears reasonable rather than surprising.

Moreover, the equilibrium share of equity in wealth ω_1 plays a considerable role. Consider figs. 4.3b and 4.3c: fig. 4.3b presents the instability/determinacy regions for a lower value of ω_1 than in fig. 4.3a. The size of the instability region in fig. 4.3b is smaller than in fig. 4.3a. Conversely, fig. 4.3c presents the instability/determinacy regions for a higher value of ω_1 than in fig. 4.3a. Here, the instability region is larger than in fig. 4.3a. Thus, this shows that the size of the instability region becomes smaller as the share of equity in wealth, ω_1, decreases.

To understand this result, assume that ω_2 and ω_3 are fixed. A higher value of ω_1

[656] See Galí (2008: 79ff)

means that the demand for bank equity holdings reacts less strongly to a change in either expected return, ceteris paribus.[657] Conversely, the effect of a change in either expected return on bank deposit holdings is larger.[658] This is because the log-linear model is written in terms of log-deviations from the steady-state value. If ω_1 is larger, the share of equity in wealth is larger, thus the level of bank equity is larger and a given absolute change in levels yields lower percentage deviations from the steady state. The fact that the size of the instability regions is the larger, the higher is the share of equity in wealth may be explained by the resulting consequences for banks' liability management. Relative changes in bank equity and bank deposits have non-trivial effects for the arbitrage condition determining the bank risk premium and by extension entrepreneurs' credit conditions.[659] Then, ceteris paribus, a quantitatively smaller reaction of bank equity to real returns due to a higher bank equity share in wealth increases the chances for equilibrium instability, as shown in fig. 4.3. However, this relationship does not hold generally, since a high equity share or a strong responsivity of deposit demand and conversely a small responsivity of equity demand do not as such yield unstable equilibria. This can be seen in fig. 4.3, since as noted above, instability regions appear in the middle of the parameter space, not at either limit.

Counter-intuitively, a higher equity share in wealth leads to bigger instability regions in the banking model. Yet, this result should not be interpreted as an outright contradiction with the rationale of bank capital regulation.[660] There are two reasons why the result in fig. 4.3 should be taken with caution. Firstly, the incidence of more unstable combinations of ω_2 and ω_3 does not necessarily mean that there are overall more unstable parameter combinations with a higher equity-to-wealth ratio since there are many more parameters in the banking model. Moreover, one may argue that the alternative parameter calibrations for ω_1 in figs. 4.3b and 4.3c are too far apart to be valid in terms of a first-order log-linear approximation. In particular, ω_1 is by definition tightly connected to banks' leverage ratio and by extension the bank risk premium. Related, the bank risk premium is very sensitive to bank leverage, or equivalently the bank equity to wealth ratio. This results in a comparatively small band of 'permissible' values of bank leverage. Incidentally, estimation yields a value of 0.568 for ω_1 at the posterior mean of the parameter vector.[661] Thus, these alternative values for ω_1 may be connected to counterfactual steady-state values for these

[657] The reaction coefficients of bank equity demand are (ω_2/ω_1) and $-(\omega_3/\omega_1)$ for the bank equity and bank deposit returns, respectively, see eq. (3.84) in chapter 3.

[658] See eq. (3.85) in chapter 3

[659] As stated above, the steady-state bank risk premium is ceteris paribus positively related to the steady-state equity-to-loan ratio and by extension to the steady-state equity share in workers' wealth (in the non-linear banking model).

[660] For an exposition for higher bank capital requirements see Admati and Hellwig (2013: 169).

[661] Introducing internal equity may be a possibility to align the banking model equity share with real world observations.

variables, raising again validity questions of this stability exercise. Overall, the graphs in fig. 4.3 illustrate that all three asset demand equation parameters affect determinacy and stability of the banking model. While the exact influence of ω_1 remains elusive, it is nevertheless important to note its potential.

Thus, these portfolio choice equations cannot be regarded in isolation to analyse stability and determinacy. Unfortunately, given that an analytical derivation is intractable within the bounds of this study, the precise nature of how these parameters affect matrix $\mathbf{A}$ in eq. (4.36) and its eigenvalues remains ambiguous. The important result for the following chapters is that there are parameter combinations which yield equilibrium instability. The Markov chain Monte Carlo Metropolis Hastings estimation algorithm used in chapter 5 deals with this issue insofar that parameter vector draws which do not produce a determinate equilibrium are rejected and thus do not enter estimates of parameter moments.[662] Thus, only parameter combinations which produce determinate equilibria are considered henceforth.[663]

[662] See An and Schorfheide (2007: 131). See chapter 5 for details on the estimation method.

[663] There has been research on including at least the indeterminate parameter space in estimation exercises in recent years, see for example Farmer and Khramov (2013) and Lubik and Schorfheide (2004). Yet, for once this does not deal with instability and furthermore, such an exercise would not contribute substantially to the principal research agenda of this study, and is thus left to future research.

Chapter 5

Estimation

The previous chapter determined the non-stochastic steady state of the banking model, as well as part of its determinacy and stability realms. Furthermore, it showed to what extent the additional financial friction of the banking model changed the log-linear approximation of the dynamic stochastic general equilibrium (DSGE) model in terms of the New Keynesian (NK) DIS-PC-MP framework. The previous chapter showed that the space for deriving results analytically is relatively limited, due to the complexity of the banking model. In order to evaluate the dynamic properties of the banking model, specific values need to be attached to the parameters which was accomplished by estimating the model. Thus, the primary objective of this chapter is to present the results of the estimation of the model's parameters. Furthermore, this chapter aims to evaluate how well the banking model fits the data. To this end, the estimation results of the financial accelerator model are presented and used as a reference point.

This chapter is structured as follows. Section 5.1 presents the estimation methodology and the reasons for choosing the Bayesian estimation technique. Next, section 5.2 describes the data and prior distributions. The following section 5.3 reports the results of the estimation exercise. Section 5.4 assesses the empirical performance of the banking model vis-à-vis the financial accelerator model. Finally, this chapter closes with a short discussion about the sensitivity of the results to different prior distributions and time frames in section 5.5.

5.1 Estimation Methodology

5.1.1 Overview of Estimation Approaches

The eventual task of an estimation exercise is to determine the values of the various parameters that enter the model. The following paragraphs are intended as a short discussion of the most prominent estimation methods, and the gain in using Bayesian methods. For various reasons, Bayesian estimation has become increasingly popular in the last decade for estimating DSGE models.[664]

There is a plethora of different estimation methods, each with its specific advantages and disadvantages. Maximum likelihood (ML) has been one popular method before the onset and widespread use of Bayesian methods in (macro-)economics.[665] Key tenets of ML are the assumption of the model being the true data generating process (DGP) and the use of all model equations in the estimation process.[666] Yet, there are two major problems with using ML for estimating DSGE models. Firstly, the current generation of DSGE models, while becoming increasingly complex, are a highly stylised abstraction from reality - from ad-hoc assumptions such as investment adjustment costs to the specification of exogenous shocks. This poses a problem for applying ML, since inference is only valid for a model representing the true DGP with the parameters being unknown.[667] Secondly, the likelihood function of a DSGE model is generally not 'well-behaved': there are flat regions and kinks. This leads to serious problems for various maximisation routines since the maximisation algorithm may not be able to find the true maximum of the likelihood over the parameter space.[668]

Another popular approach to estimating DSGE models is the generalised method of moments (GMM). GMM is an umbrella for various methods of which ML estimation may be argued to be a special case.[669] More generally, GMM is centred on the estimation of population moment conditions which state that the expectation of a vector of functions, defined over the parameter set and the data, is zero when the true parameter values are used.[670] These conditions may require the distance between model and data moments to be minimised but may also come in the form of maximum extremum conditions.[671] Concerning the problem of stochastic singularity of DSGE models, GMM is argued to be

[664] See Guerrón-Quintana and Nason (2013: 487ff) for a short history of DSGE model estimation.
[665] See Guerrón-Quintana and Nason (2013: 487)
[666] See Canova (2007: 213)
[667] See Canova (2007: 440)
[668] See Fernández-Villaverde (2010: 7) and Fernández-Villaverde, Guerrón-Quintana and Rubio-Ramírez (2010: 370)
[669] See Greene (2012: 547)
[670] See A. R. Hall (2013: 313)
[671] See Canova (2007: 166)

more robust than ML since GMM only requires moments to be linearly independent while ML requires the much stronger restriction of linearly independent variables.[672] Moreover, if the model is correctly specified, GMM has the same statistical properties as ML, but has been shown to be faster and computationally less demanding than ML.[673]

However, the researcher's flexibility in choosing moment conditions to be included in the estimation comes at a cost. A DSGE model will probably lead to restrictions on the DGP not borne out by the data. Yet, choosing only a subset of the system for estimation may neglect important cross-equations restrictions which are vital to the dynamics of the model. Secondly, care needs to be taken concerning the moments of the data the model is matched to. Impulse-response-matching estimation, such as used among others by Christiano et al. (2005a), in particular requires that the impulse responses the model is matched to are a valid representation.[674] The probably most prominent example of controversial impulse responses is the so-called price puzzle in vector autoregression (VAR) analyses; thus, such an approach necessitates a detailed discussion of the construction of the VAR before even starting the estimation of the model. Thirdly, the GMM estimator does not always perform satisfactory in small samples which are pervasive in macroeconomics.[675] Finally, Canova and Sala (2009) have noted that (weak) identification and observational equivalence are a common problem in DSGE models.[676] Since GMM and ML identify model parameters using the same information on theoretical first moments, identification problems apply to both ML and GMM.[677]

In light of these problems, the researcher may choose not to estimate the parameters at all but conduct a calibration exercise. Calibration does not assume that the model is a correct representation of the DGP of the variables.[678] Given the highly schematic specification of DSGE models, this is a clear advantage. The difference between calibration and many estimation procedures is that calibration does not necessarily entail exactly specifying how the model diverges from reality.[679] Instead, the calibration exercise is intended to ensure that (some) features of the observables are met by the model.[680] Put differently, using calibration, the researcher seeks to explain certain developments in observable variables using a

[672] See Ruge-Murcia (2007: 2600). Stochastic singularity arises principally in linearised DSGE models since there are often fewer structural shocks than the number of observable variables in the model, see Ruge-Murcia (2007: 2600).
[673] See Ruge-Murcia (2013: 464) and Ruge-Murcia (2007: 2633)
[674] Christiano et al. (2005a: 3, 15ff) estimate a subset of parameters minimizing the distance of model-implied responses to the responses of a vector autoregression model to a monetary policy shock and calibrate all other parameters.
[675] See Fernández-Villaverde et al. (2010: 369)
[676] See Canova and Sala (2009: 448)
[677] See Guerrón-Quintana and Nason (2013: 488)
[678] See Canova (2007: 248)
[679] See Canova (2007: 248)
[680] See Canova (2007: 251)

model which he believes to be a highly stylised and incomplete characterisation of reality.[681] Normally, these 'developments' are correlations and ratios of standard deviations. The calibration is deemed acceptable if these developments are indeed matched by the model.[682]

The problem in the present context is that this procedure of comparing correlations and standard deviations is not very instructive for comparing model specifications. Given the size of the model and the number of parameters to be determined, it would be rather difficult to ensure that the results reflect different model specifications and not 'lucky' parameter constellations. Even if various parameter constellations were computed, there would have to be choices on what constitutes a good approximation and how to measure deviations from actual data in terms of correlations and variances only in order to compare models.

This objection might be easier to decline if there existed some form of known reasonable range for the parameters that are to be set. In fact, there are parameters which appear in many models and there exists some form of consensus for the value of the parameters. Other parameters may be directly related to observables; for instance, the calibration of the steady state share of hours worked in workers' time endowment can be guided by statistically collected labour market data.[683] However, there are many other parameters, especially model-specific parameters, which are not as easy to determine. In the banking model these include, for instance, the parameters governing the size of the entrepreneur- and bank-specific shock intervals. Therefore, above objection still holds.

In contrast, Bayesian estimation allows for the estimation of the complete system of equations while at the same time addressing uncertainty about the model specification and identification problems.[684] Firstly, the Bayesian approach considers information from outside the dataset used for estimation, thus alleviating the problems associated with a flat likelihood function. Parameters are not unknown fixed values to be determined, but stochastic variables from the Bayesian point of view.[685] The process of estimation is thus seen as updating old information with new data.[686] In addition, as in the case of

681 See Canova (2007: 251)
682 See Canova (2007: 251)
683 Note that the models considered here abstract from unemployment. Furthermore, the share of leisure vis-à-vis consumption η_l is the parameter in the utility function, and not the share of hours worked. Yet, as explained in section 4.1, the procedure to find the steady state endogenises some parameters (in this case η_l) by setting some steady-state variable (here H) to a specified value. While η_l is difficult to determine, H can be related to observables. Appendix section C.1 specifies the data sources.
684 Numerous authors have listed the advantages of Bayesian methods. See for example Lubik and Schorfheide (2006), Fernández-Villaverde (2010) and Fernández-Villaverde et al. (2010) for more information.
685 See Koop (2003: 2) and Poirier (1995: 301)
686 See Greene (2012: 697)

calibration, the Bayesian paradigm does not presuppose that the model represents the actual DGP.[687] In particular, model misspecification does not render the results from Bayesian estimation inconsistent.[688] However, in contrast to calibration, uncertainty about estimates and the specification of the model can be evaluated using Bayesian estimation results since they come in the form of estimated posterior distributions.[689] Finally, model comparisons are straightforward by computing posterior model odds or comparing the log-likelihoods of different models.

Bayesian estimation is not without criticism. Apart from philosophical discussions about the subjectivity of the Bayesian approach, the specification of the parameters' prior distributions is a contentious issue.[690] Similar to setting parameters when using calibration, forming prior distributions for some parameters is relatively straightforward. However, for others, especially considering the parameters entering the exogenous processes, it may be difficult to find appropriate information from outside the dataset to substantiate the prior distribution. The major advantage of the Bayesian method is that in cases where there is only limited information available, the researcher may always choose a very diffuse or a uniform prior. As the prior variance affects the weight of the prior mean vis-à-vis the likelihood in computing the posterior mean, this implies that the influence of the prior mean is reduced, ceteris paribus.[691] In conclusion, making the process of forming the prior distribution as transparent as possible is a crucial issue. Thus, section 5.2.2 will explain thoroughly the prior distributions used for estimating the banking model.

5.1.2 Details on Bayesian Estimation of DSGE Models

As noted above, Bayesian analysis does not start from the presumption that the parameters have fixed unknown values. Rather, the process of estimation is characterised by updating beliefs by using new information.[692] The central element is Bayes' Theorem as applied to estimation purposes:[693]

$$p(parameters|data) = \frac{p(data|parameters)p(parameters)}{p(data)} \tag{5.1}$$

687 See Canova (2007: 440)
688 See Fernández-Villaverde and Rubio-Ramírez (2004: 154)
689 See Canova (2007: 440)
690 See Greene (2012: 695)
691 See Herbst and Schorfheide (2016: 32)
692 See Greene (2012: 697). The next paragraphs are intended as a short overview and account of the methods used in this study. There are many introductory (and advanced) resources on Bayesian econometrics and its application to DSGE models, and any list given here can only be arbitrary. For more details on these issues see for example Canova (2007), An and Schorfheide (2007) and Herbst and Schorfheide (2016) as well as other references cited subsequently.
693 See Greene (2012: 696), unnumbered equation, my notation.

where the left-hand side is the distribution of interest, that is the posterior distribution of the parameters. $p(data|parameters)$ is the joint distribution of the observed variables conditional on the parameters, that is the likelihood function. $p(parameters)$ is the prior distribution of the parameters and $p(data)$ is the marginal likelihood of the data.[694] The marginal likelihood of the data does not change during estimation since it does not depend on the vector of parameters. Thus, eq. (5.1) can be simplified to:[695]

$$p(parameters|data) \propto p(data|parameters)p(parameters) \tag{5.2}$$

Equation (5.2) shows that the posterior distribution of the parameters given the data is proportional to the product of the prior distribution of the parameters and the likelihood function.[696] The prior distribution, that is the beliefs of the researcher before seeing the current data, is updated using the current dataset to form a new set of beliefs, which is the posterior distribution.[697]

While the right-hand side of eq. (5.2) is relatively straightforward to calculate, the difficulty arises during the calculation of the left-hand side of eq. (5.2) for a DSGE model. The prior distributions for the individual parameters are set by the researcher. They are by definition known and their multivariate distribution is straightforward to calculate. The likelihood function can be evaluated using the Kalman filter.[698] The main problem with applying eq. (5.2) to a DSGE model arises because there is usually no analytical expression for the posterior distribution.[699] Thus, it is generally not possible to sample from the posterior distribution directly to compute distribution moments.[700]

As a result of these analytical difficulties, various methods have been developed to remedy this problem numerically.[701] The results in sections 5.3 to 5.5 are derived using the

694 See Greene (2012: 696) and Herbst and Schorfheide (2016: 29)
695 See Greene (2012: 696)
696 See Greene (2012: 696f)
697 See Greene (2012: 697)
698 See Guerrón-Quintana and Nason (2013: 497). There is a set of additional assumptions which make the Kalman filter optimal in the linear case, these include normality conditions for shock innovations and the initial state of the model, see Guerrón-Quintana and Nason (2013: 497).
699 See Fernández-Villaverde (2010: 21)
700 See Fernández-Villaverde (2010: 21)
701 See Canova (2007: 353ff) and Guerrón-Quintana and Nason (2013: 489ff) for a discussion of various methods. The choice for the method used here is in particular based on its wide use in the related literature, as well as because Canova (2007: 369) found methods based on Markov chains to outperform those based on, among others, importance sampling.

Markov chain Monte Carlo (MCMC) Metropolis Hastings (MH) Algorithm.[702] The MH algorithm is a specific form of MCMC methods which generates the target distribution through simulation for intractable distributions.[703] Put in a nutshell, the MH algorithm works as follows: after initializing at a specific realisation of the parameter vector, draw a new parameter vector from some candidate distribution.[704] Then, the draw is either accepted or not. The probability of accepting a draw depends on the posterior distribution evaluated at the new parameter vector: the draw is always accepted if it is higher than the posterior distribution evaluated at the parameter vector of the previous draw and with a certain probability if it lowers the posterior distribution relative to the previous draw.[705] If the draw is rejected, the chain stays at the previous draw. This procedure is repeated numerous times until the distribution of draws has converged to the posterior distribution of interest.[706]

A priori the number of repetitions is not known and may take too long to be practical. Thus, as in Justiniano and Preston (2010), for instance, the MH algorithm was started here at the posterior mode found by running numerical optimisation routines.[707] Similarly, the proposal variance was set to the negative of the inverse of the Hessian at the posterior mode.[708] The scale parameter of the proposal distribution was set to ensure an average acceptance ratio between 25% and 35% which is within the range usually considered appropriate in the literature.[709] Convergence of the chains was checked based on various measures, see section 5.3 for details.

[702] More specifically, the random walk version of the MCMC MH algorithm was used. Since the algorithm converged successfully (see below), there was no need to use a more complicated MH algorithm. All computations were carried out with Matlab and the software platform Dynare. For coding (of the model, of the estimation and analysis experiments in the previous, current and next chapters) the Dynare manual (Adjemian et al. (2011)), the Matlab help section, and the resources made available during the Summer School 'The Science and Art of DSGE Modelling' (2014) at the Centre for International Macroeconomic Studies, School of Economics at the University of Surrey were helpful and valuable. The tool developed by Schlömer (2016), URL in list of references, was used to convert pictures.

[703] See Canova (2007: 359, 367)

[704] See Canova (2007: 367)

[705] See Herbst and Schorfheide (2016: 53). The acceptance probability in the latter case depends on the likelihood function and the prior distribution evaluated each at the old and new draws, and the candidate distribution, see Herbst and Schorfheide (2016: 53).

[706] See Chib and Greenberg (1995: 328)

[707] See Justiniano and Preston (2010: 103f). This practice is common in the literature, see S. Schmidt and Wieland (2013: 1474f). See also Adjemian et al. (2011: 55f) for the implementation in Dynare.

[708] See Herbst and Schorfheide (2016: 68) and Adjemian et al. (2011: 55f)

[709] See Herbst and Schorfheide (2016: 69)

5.2 Data and Prior Distributions

5.2.1 Data

The dataset used for estimation comprises 9 time series on Germany since the banking model features 9 shocks. The equality between the number of time series and the number of shocks is a necessary condition for estimation since otherwise the model would be stochastically singular.[710] The time series span the time period between 1994Q1 and 2015Q2, although the first observation is lost due to statistical adjustments.[711] On the real side of the economy the dataset includes real gross domestic product (GDP), real private consumption and real private investment expenditures, as well as the number of hours worked.[712] For the financial side of the economy, the real loan volume, real bank equity, the nominal policy interest rate and the return on entrepreneurial equity are included.[713] The final observable is the inflation rate. All observables used in the estimation process are stationary and demeaned by the sample mean and all observables except for inflation and the interest rates are in per capita terms.[714] Figure 5.1 displays the time series in the dataset graphically.

Most growth rates in fig. 5.1 are within a -2% and 1% band. Investment, bank equity and the return on entrepreneurial equity are generally more volatile. Inflation appears to be comparatively volatile up to 2000. The financial crisis of 2007-8 and its aftermath left their marks in terms of a large decrease in output, investment and the nominal interest rate. All other variables do not exhibit particular noteworthy peaks during this crisis time. It is striking that the growth rate of neither bank loans nor bank equity exhibits an extraordinarily large decline around 2007-8. In particular, bank loans grew at positive rates up to 2000, then at negative rates until 2007, and have exhibited oscillatory behaviour since then. In contrast, the series of positive and negative growth rates has been more oscillatory for bank equity from the start of the dataset. Just prior to the financial crisis, the growth rate of bank equity peaked. While a precise tracking and explanation of these time series is beyond the scope of this study, these features are worth remembering when dealing with the results of the sensitivity analysis with respect to different time periods.

[710] See Cantore et al. (2013: 432)

[711] The starting point of the sample is restricted to 1994 by the EONIA rate which is available since January 1994, see European Central Bank (2015b), URL in list of references.

[712] Real private consumption and real private investment expenditures are referred to as consumption and investment in the following for simplicity.

[713] Even though this study concerns non-systemic bank failure, the dataset does not include a time series for bank failure in Germany. This is primarily due to data availability problems. See Blank et al. (2009: 358ff) for details on the incidence of bank distress events, including bank failure and mergers, in Germany. Also, section 5.2.2 will extensively discuss the calibration of the steady-state bank default probability.

[714] See appendix section C.1 for details.

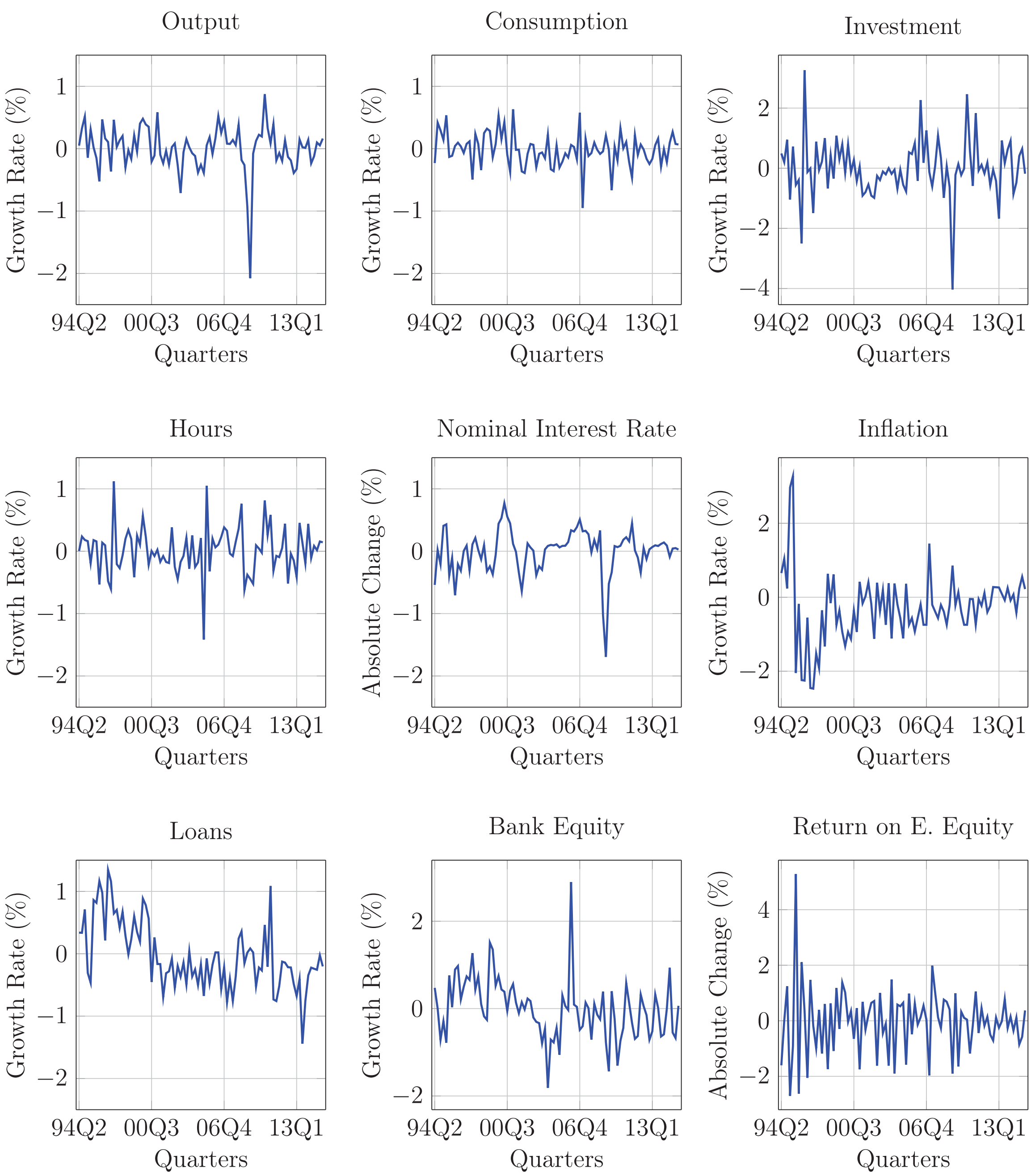

Figure 5.1: Dataset Information: Time Series Used in Estimation; see appendix section C.1 for detailed information on the dataset and the references to data sources. Return on E. Equity denotes Return on Entrepreneurial Equity.

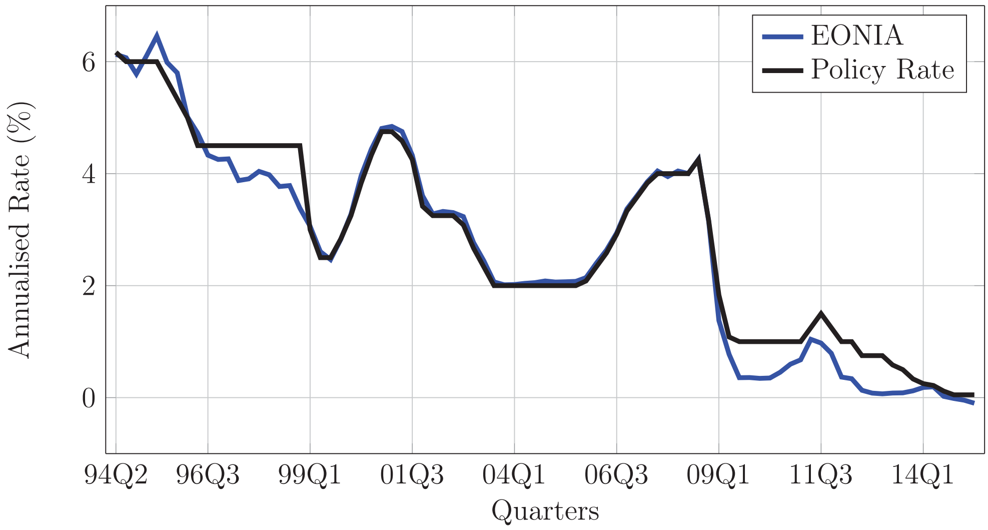

Figure 5.2: Comparison of Monetary Policy and EONIA Interest Rates; policy rate (black line): measured up to 1998Q4 by the Lombard rate and from 1991Q1 onwards by the main refinancing rate of the ECB, sources: Deutsche Bundesbank (2016d) and Deutsche Bundesbank (2016g), URLs in list of references; EONIA rate (blue line), source: European Central Bank (2015b), URL in list of references.

Given that the introduction of the Euro falls into the first third of the sample period, the question arises why this study uses German and not Euro area (EA) data. First of all, the time period includes pre-European Central Bank (ECB) data when monetary policy was still the sole responsibility of individual states.[715] Yet, this was not the key factor determining the decision. More importantly, while the financial crisis of 2007-8 exposed financial sector fragility in many countries, financial systems and financial conditions are nevertheless country-specific. Using only aggregate EA data would potentially mask the interlinkages between financial sectors, monetary policy and the real economy due to effects in one country counteracting effects in another. Thus, to appropriately study this issue in the EA setting necessitates a multi-country model with a common monetary policy, where effects are allowed to be different and potentially asymmetric. This study may be thus seen as a step based on which multi-country research may progress.

This approach comes at the cost of abstracting from real-world ECB actions which react to inflation and the output gap measured at the EA level. Using disproportionate data spans for the different monetary policy regimes, it is hardly possible to properly distinguish between the Bundesbank and ECB regimes in this study.[716] Nevertheless, I would like to underline that the focus of this study is not the discussion of how either the Bundesbank conducted or the ECB conducts monetary policy, nor how they should have, but rather how monetary policy can be affected by a fragile banking sector. The study of disaggregated data is indispensable in this respect, and the estimation based on German

715 However, in the run-up to the monetary union, monetary policy was coordinated, see Quint and Rabanal (2013: 19).

716 See section 2.2 for a short discussion of the different monetary policy regimes in Germany.

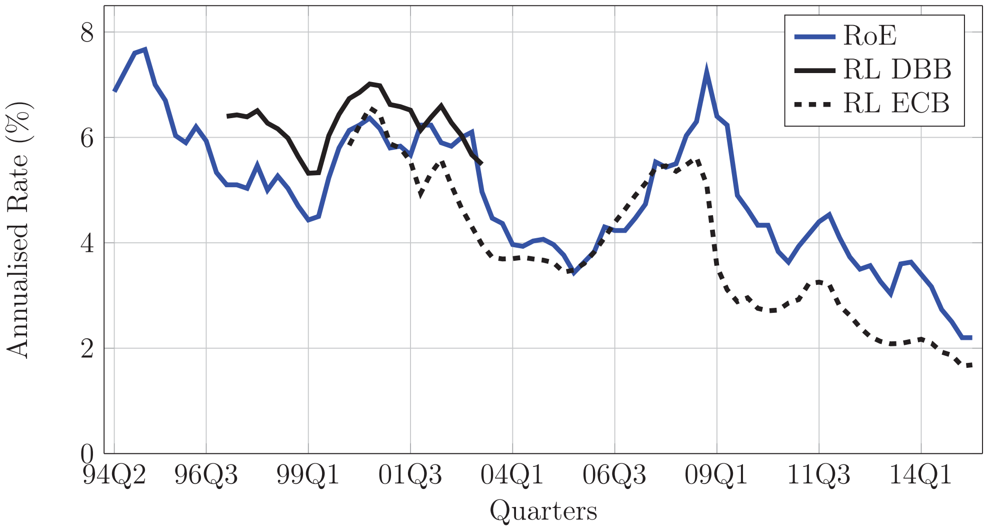

Figure 5.3: Interest Rates on Entrepreneurial Liability Measures; quarter averages; return on entrepreneurial equity (RoE, blue line): 1994Q2-2015Q2, see appendix section C.1 for more details, source: Deutsche Bundesbank (2016f), URL in list of references; Loan Rate 1 (RL DBB, black solid line): 1997Q1-2003Q2, interest rate on long-term loans to business and self-employed persons with a fixed interest rate and a volume between 500,000 and 5 Million Euro, effective average rate, source: Deutsche Bundesbank (2016e), URL in list of references; Loan Rate 2 (RL ECB, black dashed line): 2000Q1-2015Q2, loans to non-financial sector, new business, all volumes, source: European Central Bank (2016a), URL in list of references.

data is a means to this end. As a final remark, the sensitivity analysis in section 5.5 evaluates whether the Bundesbank or ECB periods, taken separately, yield different results.

Some choices on the specific data series need to be explained.[717] To begin with, the nominal risk-free interest rate, that is, the policy interest rate, is measured by the EONIA rate. There are three reasons for this choice. Firstly, over the time span considered here, there has not been one central bank in charge of monetary policy but two. A second complication arises due to the fact that the Lombard rate and the main refinancing rate, respectively, did not fluctuate much. In fact, there have been several extended time periods where the policy rate stayed constant, such as between 1996Q2 and 1998Q4 and between 2003Q3 and 2005Q3 (see fig. 5.2). As a final note, fig. 5.2 shows the evolution of the EONIA rate and the relevant monetary policy rate. Both interest rates are highly correlated, and indeed almost identical in the period between 1999Q1 and 2009Q1. Thus, the EONIA rate can be viewed as a good instrument to relate to the nominal policy rate in the model.

Furthermore, the use of the return on entrepreneurial equity is not a standard feature. The return on entrepreneurial equity is included to elucidate the different dynamics of the risk-free return and the real return on real capital in the model. Unfortunately, there

[717] For the specific data series used see appendix section C.1.

is no coherent data available on the macroeconomic concept of the real return on real capital as used in the banking model. The use of the return on entrepreneurial equity as a proxy is justified by theoretical model-specific considerations and further data limitations: entrepreneurs equate the real return on real capital to the marginal financing cost of bank loans. Ideally, I would thus want to use the bank loan rate as a measure. However, statistics on bank loan rates to businesses are available consistently only for relatively short sub-periods of the considered time span, as can be seen in fig. 5.3 (black dashed and solid lines). In contrast, the return on entrepreneurial equity is consistently available over the complete time span (see fig. 5.3, blue line). Then again, the banking model does not feature entrepreneurial equity. Yet, the rationale of cost minimisation equally applies to different forms of entrepreneurial financing. If entrepreneurial equity was available in the banking model, the marginal financing costs of entrepreneurial equity and bank loans should be equal.[718] Apart from this theoretical point of view, fig. 5.3 indicates that returns on different entrepreneurial liability measures evolved similarly. In conclusion, these considerations lead to the use of the return on entrepreneurial equity as a proxy for the real return on real capital.

Finally, the GDP deflator is used to measure the inflation rate. Instead, many central banks such as the ECB and the Federal Reserve measure inflation in terms of a consumer price index.[719] Yet, the use of the GDP deflator for estimating monetary DSGE models is not uncommon.[720] Moreover, the GDP deflator matches the model price index on theoretical grounds, since there is only one price for consumption and investment goods.

5.2.2 Prior Distributions

There are 46 parameters in the banking model to be set. Some parameters are calibrated as is conventional practice in the literature. The 13 calibrated parameters are shown in table 5.1. There are several reasons for calibrating these parameters. Firstly, the dataset in its growth rate form is not informative on parameters which correspond to steady-state ratios. Also, some parameters are not identified in the model. Finally, one way to interpret these calibrated parameters is to see them as very tight prior distributions.

First of all, the elasticity of substitution between retail goods ζ does not enter the log-linear approximation to the model used for estimation. ζ is thus not identified by the

[718] This assumes that all contracts last one period as always in the banking model. Furthermore, this assumes that the information asymmetries for entrepreneurial equity are the same as for bank loans, thus resulting in equal required rates of return.

[719] The ECB targets the Harmonised Index of Consumer Prices, the Federal Reserve targets the price index for personal consumption expenditure, see European Central Bank (2015a) and Board of Governors of the Federal Reserve System (2016b), URLs in list of references.

[720] See for instance Christiano, Motto and Rostagno (2010), Smets and Wouters (2003) and Villa (2013)

model, and its value is calibrated to correspond to a 15% steady-state mark-up between wholesale and final retail goods prices.[721] This value is within the range found in the literature.[722] ζ appears in the log-linear model because the log-linear approximation to the aggregate demand relation depends on the steady-state values of its components, that is, the steady-state consumption-to-output ratio, among others. These steady-state values in turn depend on the price mark-up. In contrast, taxes are non-distortionary up to a first-order approximation, and thus the tax rate τ does not enter first-order dynamics. Hence, the tax rate does not need to be calibrated (or estimated).

The second set of calibrated parameters is determined by model-specific theoretical considerations. Retailer's marginal cost parameter c is set so that retailers make zero profits in the steady state. Workers' steady-state equity to wealth ratio ω_1 is a scaling parameter in the linear approximation to the model.[723] It is thus set to match the division of bank equity and bank deposits determined by the agency problem between banks and equity holders in the steady state. Furthermore, the deposit insurance fee parameter ν^d is set such that the real deposit interest rate is equal to the real policy rate in the steady state. As can be seen in table 5.1, these three parameters are not set to a specific value, but are functions of other estimated parameters and steady-state variable values. They are thus updated during the estimation exercise.

Thirdly, some calibrated parameters are used in virtually all DSGE models. These are mainly parameters pertaining to the real side of the economy. This includes the depreciation rate δ, which is set to a quarterly rate of 2.5%, and the partial elasticity of output with respect to labour α, set to 0.66. The latter value also corresponds to the long-term average ratio of labour income to gross value added in Germany, which can be related to the marginal product of labour on theoretical grounds.[724] The steady-state government consumption to output ratio Υ^G/Y is set to 18.8%, that is its long-term average measured by national accounts.[725]

Finally, the remaining calibrated parameters relate to financial frictions. The first two, η_E and ξ_E, determine roughly the allocation of entrepreneurial profit between en-

[721] Note that the calibration refers to the steady state of the non-linear model, since the steady-state values of all endogenous variables in the log-linear model are zero, given that endogenous variables in the log-linear approximation to the model are defined as log-deviations from the steady-state value in the non-linear model.
[722] See, for instance, Del Negro and Schorfheide (2008: 1200) for the US and Gerali et al. (2010: 122) and Quint and Rabanal (2013: 20) for the EA.
[723] See eqs. (3.84) and (3.85) in chapter 3
[724] See Sachverständigenrat zur Begutachtung der Gesamtwirtschaftlichen Entwicklung (2014: 114)
[725] See Eurostat (2016), URL in list of references. This average value is obtained both for the time period considered in the estimation exercise (1994Q2-2015Q2) and for the available period (1991Q1-2015Q3) for the time series.

Parameter		Value
elasticity of substitution between retail goods	ζ	$7\ ^2/_3$
retailer's cost parameter	c	$^1/_\zeta$
(*) workers' steady-state equity-to-wealth ratio	ω_1	$\frac{1-\xi^r}{\phi^B-\xi^r}$
(*) deposit insurance fee parameter	ν^d	$^{\xi^r}/_\beta$
depreciation rate	δ	0.025
partial output elasticity with respect to labour	α	0.66
steady-state government-consumption-to-output ratio	$^{\Upsilon^G}/_Y$	0.188
fraction of net worth transferred to new entrepreneurs	ξ_E	0.0019
probability of staying an entrepreneur	η_E	0.9835
steady-state entrepreneurial default probability	$p(\psi^E)$	0.02
entrepreneur-specific shock interval parameter	E_ψ	0.6955
(*) steady-state bank default probability	$p(\psi^B)$	0.01
(*) steady-state bank risk premium	$\varrho(\psi^B)$	0.004375
(*) bank-specific shock interval parameter	B_ψ	0.5789

Table 5.1: Parameter Calibration; starred parameters (*) are specific to the banking model.

trepreneurial net worth and entrepreneurial consumption. These two parameters are set such that the steady-state leverage ratio of entrepreneurs is equal to 1.5, and the average life of an entrepreneur is 15 years. The former value is in line with statistical data on company balance sheets in Germany: the average ratio of bank liabilities to business equity between 2005 and 2014 was 0.5, which, by the balance sheet definition eq. (3.4) corresponds to a leverage ratio of 1.5.[726] The latter assumption about the life-time of an entrepreneur is somewhat longer than considered in the financial accelerator model of Bernanke et al. (1999) and the EA application in Villa (2013), for instance.[727]

The last five parameters are tightly linked, in the sense that the parameters governing the interval of the bank-specific and entrepreneur-specific shocks are solved for in the steady state of the non-linear model as a function of the respective default probability and respective risk premium of 1.75% (annually) each. It is straightforward then to set the steady-state bank risk premium to 1.75% (annually). Entrepreneurial and bank default probabilities are set to 0.02 and 0.01, respectively. These values are guided partially by the literature and partially by German data. Bernanke et al. (1999) calibrated their model using an entrepreneurial default frequency of 3%, while more recently in EA models, for instance, Quint and Rabanal (2013) and Darracq Pariès et al. (2016) used values of 2.5% and 2.8%, respectively.[728] Data on bankruptcy filings in Germany states an annual

[726] See Deutsche Bundesbank (2015a), URL in list of references, for balance sheet data. The average ratio of the balance sheet total to equity was 3.8 over the same time period. However, other liabilities such as trade payables, pension provisions, and liabilities against affiliated companies are not present in the banking model. Thus, to calibrate the parameters, the ratio mentioned in the text is used.

[727] In Bernanke et al. (1999: 1368) and Villa (2013: 19), the calibration of the survival rate indicates an entrepreneurial life-time of about 9 years with a leverage ratio of 2.

[728] See Bernanke et al. (1999: 1368), Quint and Rabanal (2013: 19) and Darracq Pariès et al. (2016: 26)

Parameter		**Distri-bution**	**Prior Mean**	**Prior St.Dev.**
workers' discount rate	β	B	0.996	0.002
consumption habit parameter	χ	B	0.70	0.10
Calvo pricing parameter	ξ^p	B	0.75	0.10
price indexation rate	γ^p	B	0.75	0.15
investment adjustment cost parameter	ϕ_I	N	4.00	1.50
Taylor rule parameter	ρ_R	B	0.70	0.10
Taylor rule parameter	θ_π	N	1.70	0.10
Taylor rule parameter	θ_y	IG	0.125	0.05
degree of non-separability between consumption and leisure	σ_c	N	3.00	0.375
steady-state hours worked	H	B	0.35	0.05
(*) minimum reserve ratio	ξ^r	B	0.01	0.005
(*) reaction coefficient to bank equity return	ω_2	IG	1.00	0.50
(*) reaction coefficient to bank deposit return	ω_3	IG	1.00	0.50
entrepreneurial default transaction cost parameter	μ^E	B	0.0257	0.002
(*) bank default transaction cost parameter	μ^B	B	0.0006	0.0002
(*) governmental transaction cost parameter	μ^N	B	0.0006	0.0002

Table 5.2: Prior Distributions for Estimated Structural Parameters; IG denotes inverse gamma distribution, B denotes beta distribution and N denotes normal distrubution; starred parameters (*) are specific to the banking model.

default frequency of 0.8% in 2013.[729] However, the number of filed company bankruptcy proceedings was significantly higher in all years from 2002 to 2012, indicating a higher default frequency.[730] Data on bank default in Germany is rare. Sector statistics on bankruptcy filings in Germany suggests that between 2004 and 2015, less than half as many companies from the financial sector filed bankruptcy as the average over all sectors.[731] These considerations form the basis for the calibration.[732]

All other parameters are estimated. The prior distributions for the estimated parameters are collected in tables 5.2 and 5.3. Concerning distributional forms, beta distributions are assumed for parameters which are bounded between 0 and 1, inverse gamma distributions are used for parameters which are non-negative, and normal distributions for all others. In general, the standard deviations are set to reflect a reasonable span of values. For conventional parameters, the prior distributions are more or less standard in the literature.

[729] See Statistisches Bundesamt (2016c), URL in list of references

[730] See Statistisches Bundesamt (2015b: 3). Unfortunately, data on default frequencies is only available for 2013.

[731] See Statistisches Bundesamt (2015c). These filings ranged from 43% to 51% of the average filings between 2008 and 2015, and were about 20% before. However, up until 2007, the sector classifications contained 14 sectors, and 18 afterwards which affects the average, see Statistisches Bundesamt (2015c). Thus, these numbers should only be taken as a rough guide.

[732] Furthermore, the calibration of banks' default probability is in line with bank distress events of type IV reported in Blank et al. (2009: 361).

The prior mean for workers' discount factor β is set to hit a 1.62% annual nominal interest rate. The prior distributions for workers' habits χ, the Calvo pricing parameter ξ^p, the degree of indexation γ^p and investment adjustment costs ϕ_I, as well as the monetary policy function parameters are standard and in line with Smets and Wouters (2003).[733] The prior distribution of the degree of non-separability between consumption and leisure σ_c, centred around 3, indicates a reasonable degree of non-separability.[734] The other parameter in workers' utility function is the weight on labour η_l which is endogenously determined as a function of steady-state hours worked H. The prior distribution for H is in turn relatively tightly centred around 0.35, in line with values used in the literature, indicating that workers spend 35% of their time endowment working.[735]

The remaining structural parameters are non-standard. The prior mean of the minimum reserve ratio is set at the value in effect in the EA at the time of writing.[736] The prior standard deviation allows for a higher value as was in effect previously.[737] The prior distributions for the parameters in workers' asset demand function cannot be taken from the related literature, since there is no clear consensus. From the theoretical considerations in section 3.7, both reaction coefficients should be positive, thus leading to the inverse gamma distribution. Mean and standard deviation are set identically for both coefficients and are relatively uninformative. The former is guided by the deterministic model steady state where both bank equity and bank deposits are substitutes, the latter due to a lack of information.[738] Assuming equal shares in wealth, that is, $\omega_1 = 0.5$, these prior distributions imply that a 1% change in either return lead to a 2% change in volumes. Note that the standard deviation also includes the case where a 1% change in a return leads to a 1% change in either volume variable, assuming equal shares in wealth. As the sensitivity analysis in section 5.5 shows, the estimates of the other parameters are robust to a change in this prior distribution.

The various transaction cost parameters, μ^E, μ^B and μ^N are not straightforward either.

[733] See Smets and Wouters (2003: 1140ff). Smets and Wouters (2003) is a standard reference for Bayesian estimation of DSGE models for the EA. Estimated large-scale models for Germany are rare, and the chosen prior distributions are standard in the literature on Bayesian estimation, such that the reference to the EA can be justified. Furthermore, Gadatsch, Hauzenberger and Stähler (2015: 1, 17ff), presenting a large-scale open economy model estimated on German (and other) data, use very similar prior distributions for χ, γ^p, ϕ_I and the Taylor rule parameters for the part of the model representing Germany. Since Gadatsch et al. (2015: 6) derive price stickiness using Rotemberg price adjustment costs, the prior distribution of ξ^p is not directly comparable.

[734] This value is a compromise of values used in the literature. Furlanetto and Seneca (2010: 14), for instance, use a mean of 2, Kilponen, Vilmunen and Vähämaa (2013: 12) centre their prior distribution around 5.

[735] Furlanetto and Seneca (2010: 14), for example, use a value of 0.33.

[736] See European Central Bank (2016c), URL in list of references

[737] See European Central Bank (2016c), URL in list of references

[738] This approach is similar to Backus, Brainard, Smith and Tobin (1980: 273) in that it is left to the estimation to determine whether the assets are substitutes or not.

These govern the amount of revenues lost in bankruptcy proceedings. There is a wide range of values used in the literature: for example, Bernanke et al. (1999) set this parameter to 0.12, while Christiano et al. (2010) use a value of 0.94.[739] In the banking model, both μ^E and μ^B are tightly linked to the respective risk premium; thus, their prior means are set to the values which solve for entrepreneurial and bank risk premiums of 1.75% (annually) each. The targets for the risk premiums are in turn guided by values assumed in the literature and the data. Alpanda and Aysun (2014) and Cúrdia and Woodford (2010) set the credit spread due to frictions between borrowers and financial intermediaries to 2%, for instance.[740] The spread between deposit interest and different loan rates ranges between 2.1% and 4.6% in Germany, calculated as the average between 2003 and 2015.[741] Furthermore, as discussed in section 5.5, changing the prior distributions for μ^E and μ^B increases the spread between these two risk premiums but does not impact the estimates of most other parameters significantly. Thus, comparing the results of the benchmark calibration with the results of the sensitivity analysis will shed light on whether the data prefers a more equal or a more disparate division of the total risk premium between the bank and entrepreneurial agency problem. As noted above, preliminary analyses showed that the credit spread, that is the product of the two risk premiums, is very sensitive to these transaction cost parameters. Therefore, the prior standard deviations for μ^E and μ^B are kept relatively tight. Furthermore, the mean and standard deviation of the prior distribution for the governmental transaction cost parameter μ^N use the same values as for μ^B. This implies that the government is as efficient in monitoring banks as equity-holders are.

These values for the transaction cost parameters indicate that only 2.57% and 0.06% of revenues are lost in monitoring entrepreneurs and banks, respectively, during default excluding governmental transaction costs. They are as such much lower than empirical estimates of loss rates in bankruptcies. Davydenko and Franks (2008) report a median recovery rate, that is 1 minus the fraction of monitoring costs, of bank loans for firms going into formal bankruptcy of 0.61 in Germany in his sample.[742] However, this value ranges from 0.46 in the retail/wholesale sector to 0.91 in the services sector.[743] On the

[739] See Bernanke et al. (1999: 1368) and Christiano et al. (2010: 91)
[740] See Alpanda and Aysun (2014: 30) and Cúrdia and Woodford (2010: 13)
[741] Please refer to the discussion on the use of the return on entrepreneurial equity in the estimation for a justification of the use of the loan rate in computing the credit spread (section 5.2.1). The average spread is calculated from monthly data covering the years 2003 to 2015. The deposit rate is measured by the effective interest rate on demand deposits, see Deutsche Bundesbank (2016a), URL in list of references. The spread of 2.1% is calculated with respect to new business loans with maturity up to 1 year and a volume of more than 1 million Euro, see Deutsche Bundesbank (2016b), URL in list of references. The spread of 4.6% is calculated with respect to revolving loans and overdrafts to non-financial corporations, see Deutsche Bundesbank (2016c), URL in list of references.
[742] See Davydenko and Franks (2008: 582)
[743] See Davydenko and Franks (2008: 582)

Parameter		Distri-bution	Prior Mean	Prior *st.dev.*
st. dev. technology shock	σ_A	IG	1.00	2.00
st. dev. government consumption shock	σ_G	IG	1.00	2.00
st. dev. monetary policy shock	σ_M	IG	1.00	2.00
st. dev. mark-up shock	σ_{MS}	IG	1.00	2.00
st. dev. capital quality shock	σ_K	IG	1.00	2.00
st. dev. preference shock	σ_P	IG	1.00	2.00
st. dev. investment adjustment cost shock	σ_I	IG	1.00	2.00
st. dev. entrepreneurial risk shock	σ_E	IG	1.00	2.00
(*) st. dev. bank risk shock	σ_B	IG	1.00	2.00
autocorrelation of Υ^A	ρ_A	B	0.75	0.15
autocorrelation of Υ^G	ρ_G	B	0.75	0.15
autocorrelation of Υ^{MS}	ρ_{MS}	B	0.75	0.15
autocorrelation of Υ^K	ρ_K	B	0.75	0.15
autocorrelation of Υ^P	ρ_P	B	0.75	0.15
autocorrelation of Υ^I	ρ_I	B	0.75	0.15
autocorrelation of Υ^E	ρ_E	B	0.75	0.15
(*) autocorrelation of Υ^B	ρ_B	B	0.75	0.15

Table 5.3: Prior Distributions for Estimated Shock Parameters; IG denotes inverse gamma distribution, B denotes beta distribution; starred parameters (*) are specific to the banking model.

other hand, Carlstrom and Fuerst (1997) report estimates of direct bankruptcy costs of 4% which would correspond more closely to the prior means used here.[744] They also report estimates of indirect bankruptcy costs which are significantly higher.[745] In contrast to the other two transaction cost parameters, μ^N is not constrained by risk premiums, but is inversely related to the tax rate, which remains in reasonable ranges over the whole interval of μ^N. Thus, section 5.5 also reports estimates resulting from a prior distribution for μ^N which is closer to these higher reported estimates.

Prior distributions for standard deviations of shocks and autoregressive coefficients for the model's exogenous processes are generally difficult to set. Hence, prior distributions are set relatively diffusely. The prior mean of the standard deviation of the i.i.d shocks is set to 1 with a standard deviation of 2 of the underlying inverse gamma distribution. The autoregressive coefficients are set to allow for an a priori reasonable degree of persistence in the exogenous processes, which lies in the range of values considered in the literature.[746]

[744] See Carlstrom and Fuerst (1997: 900)
[745] See Carlstrom and Fuerst (1997: 900). Indirect costs include lost sales and profits in their view, see Carlstrom and Fuerst (1997: 900).
[746] See for example Smets and Wouters (2003: 1142f) and Christiano et al. (2010: 94)

5.3 Posterior Estimates of the Banking Model

The results of the posterior estimation are summarised in tables 5.4 and 5.5. As noted in section 5.1, the MH algorithm converges faster if the algorithm is initialised around the posterior mode. Thus, the first two columns present the mean and standard error of the posterior mode. The last three columns of tables 5.4 and 5.5 present the results of the MH algorithm. These statistics are based on 200,000 draws of 5 chains. Convergence was checked using the interval diagnostics developed by Brooks and Gelman (1998) as implemented in Dynare.[747] Furthermore, convergence was analysed using the potential scale reduction factor, as well as CUSUM plots.[748] All of these tests indicated convergence of all chains after the burn-in period. Lastly, note that all parameters are statistically significant from zero, as can be seen from the 90% highest posterior density (HPD) intervals.

Starting with the key friction in NK DSGE models, consider the estimates of the Calvo pricing parameter ξ^p and the price indexation parameter γ^p. The estimated mean of γ^p is within the usual range. Yet, the estimate of ξ^p is very low, which indicates low price stickiness.[749] A value of 0.153 for ξ^p means that on average, a price is in effect for about 1.2 quarters. Comparing with the discussion in section 3.3.1, this corresponds to the lower bound of microeconomic data estimates for Germany. Furthermore, using the NK Phillips Curve (PC) representation described in section 4.3.3, it is clear that the low estimate of ξ^p primarily impacts the relationship between inflation and retailers' marginal costs. Equations (5.3) and (5.4) show the NK PC functions for the banking model at the posterior mean (superscript *po*) and the prior mean (superscript *pr*), where $\xi^p = 0.75$, $\gamma^p = 0.75$ and $\beta = 0.996$:

$$\pi_t^{po} = 0.69\mathbf{E}_t[\pi_{t+1}^{po}] + 0.31\pi_{t-1}^{po} + 3.25\widehat{mc}_t^{po} \tag{5.3}$$

$$\pi_t^{pr} = 0.57\mathbf{E}_t[\pi_{t+1}^{pr}] + 0.43\pi_{t-1}^{pr} + 0.05\widehat{mc}_t^{pr} \tag{5.4}$$

The relationship between lagged and expected future inflation on the one hand and current inflation on the other hand is not profoundly affected. The lower estimate of the indexation parameter leads to a lower coefficient on lagged inflation for the posterior mean parameter values. The somewhat higher coefficient for expected inflation is due to the low estimate of the Calvo pricing parameter. In contrast, whereas a 1% deviation of marginal costs from the steady-state value increases inflation for the prior mean parameter values by only 0.05%, it increases inflation for the posterior mean parameter values by

747 See Brooks and Gelman (1998) and Adjemian et al. (2011: 55f)

748 For the potential scale reduction factor see Brooks and Gelman (1998: 437), for more details on the use of CUSUM statistics as a convergence check see Yu and Mykland (1998). These computations were conducted using the tool kit by Cesa-Bianchi (2012), URL in list of references.

749 For example, the estimate of γ^p is very similar to the corresponding parameter estimate in Smets and Wouters (2003: 1143), while the estimate ξ^p is far lower than in Smets and Wouters (2003: 1143).

Parameter		**Posterior Optimisation**		**Posterior Distribution MH**		
		Mode	St.Dev.	Mean	90% HPD	
workers' discount rate	β	0.997	0.002	0.996	0.993	0.999
consumption habit parameter	χ	0.402	0.061	0.420	0.323	0.519
Calvo pricing parameter	ξ^p	0.141	0.031	0.153	0.107	0.193
price indexation rate	γ^p	0.421	0.173	0.447	0.156	0.728
investment adjustment cost parameter	ϕ_I	0.664	0.127	0.673	0.452	0.881
Taylor rule parameter	ρ_R	0.337	0.060	0.341	0.244	0.436
Taylor rule parameter	θ_π	1.977	0.080	1.983	1.852	2.115
Taylor rule parameter	θ_y	0.092	0.032	0.110	0.061	0.159
degree of non-separability between consumption and leisure	σ_c	3.636	0.295	3.645	3.113	4.179
steady-state hours worked	H	0.514	0.040	0.521	0.455	0.590
(*) minimum reserve ratio	ξ^r	0.011	0.006	0.014	0.004	0.023
(*) reaction coefficient to equity return	ω_2	6.784	2.942	8.813	3.765	14.010
(*) reaction coefficient to deposit return	ω_3	0.697	0.387	0.925	0.433	1.419
entrepreneurial default transaction cost parameter	μ^E	0.026	0.002	0.026	0.022	0.029
(*) bank default transaction cost parameter	μ^B	0.0005	0.0002	0.0006	0.0003	0.0009
(*) governmental transaction cost parameter	μ^N	0.0006	0.0002	0.0006	0.0003	0.0009

Table 5.4: Banking Model: Structural Parameter Estimates. Posterior Optimisation refers to the numerical optimisation of the posterior before MH initialisation, standard errors are based on the Hessian matrix. Posterior Distribution Mean and 90% HPD Interval as well as subsequent computations in the text are based on 200,000 draws from the posterior distribution of the MH algorithm. Starred parameters (*) are specific to the banking model.

Parameter		**Posterior Optimisation**		**Posterior Distribution MH**		
		Mode	St.Dev.	Mean	90% HPD	
st. dev. technology shock	σ_A	0.573	0.047	0.581	0.508	0.653
st. dev. government consumption shock	σ_G	3.021	0.271	3.168	2.667	3.648
st. dev. monetary policy shock	σ_M	1.226	0.146	1.237	1.008	1.465
st. dev. mark-up shock	σ_{MS}	0.840	0.101	0.899	0.728	1.064
st. dev. capital quality shock	σ_K	0.525	0.045	0.531	0.457	0.599
st. dev. preference shock	σ_P	1.481	0.311	1.615	1.129	2.068
st. dev. investment adjustment cost shock	σ_I	18.071	8.708	20.902	9.336	31.786
st. dev. entrepreneurial risk shock	σ_E	11.120	1.562	11.870	9.341	14.379
(*) st. dev. bank risk shock	σ_B	4.224	0.353	4.293	3.701	4.885
autocorrelation of Υ^A	ρ_A	0.959	0.013	0.955	0.934	0.976
autocorrelation of Υ^G	ρ_G	0.888	0.022	0.884	0.846	0.924
autocorrelation of Υ^{MS}	ρ_{MS}	0.726	0.070	0.710	0.592	0.828
autocorrelation of Υ^K	ρ_K	0.423	0.029	0.418	0.370	0.466
autocorrelation of Υ^P	ρ_P	0.931	0.028	0.923	0.875	0.973
autocorrelation of Υ^I	ρ_I	0.958	0.013	0.960	0.940	0.980
autocorrelation of Υ^E	ρ_E	0.114	0.038	0.125	0.058	0.189
(*) autocorrelation of Υ^B	ρ_B	0.941	0.024	0.939	0.900	0.979

Table 5.5: Banking Model: Shock Parameter Estimates. Posterior Optimisation refers to the numerical optimisation of the posterior before MH initialisation, standard errors are based on the Hessian matrix. Posterior Distribution Mean and 90% HPD Interval as well as subsequent computations in the text are based on 200,000 draws from the posterior distribution of the MH algorithm. Starred parameters (*) are specific to the banking model.

3.25%. Comparing the posterior mean estimates of the NK PC with the results from the meta-study by Schorfheide (2008), it is clear that the banking model coefficient for marginal costs is at the upper bound of reported estimates.[750] Consequently, these estimates imply inflation to be much more responsive to a change in marginal costs and, ceteris paribus, to be less smooth in the estimated banking model.

Furthermore, parameters governing the persistence of investment and consumption are also estimated comparatively low. The posterior mean of the investment adjustment cost parameter ϕ_I is estimated at 0.673, and the posterior mean of workers' habit parameter χ is 0.420. Usual estimates of these parameters lie in the ranges of 2-4 and 0.7-0.9 respectively. The immediate effect of these lower estimates is a reduced persistence of consumption and investment. So how might these results be explained? To begin with, these estimates could be attributed to low persistence in the data. Microeconomic estimates by, for instance, Cooper and Haltiwanger (2006) provide support for low investment adjustment costs.[751]

Model-based insight might be provided by the study by Christiano et al. (2005a) who estimate various versions of a standard NK model with separable preferences. Their results show that the estimate of the investment adjustment cost parameter is low when habits are excluded, and the habit parameter is estimated low when the investment adjustment cost parameter is set to a low value.[752] Therefore, low estimates of one of these parameters may be correlated with a low estimate of the other parameter.

Another explanation may be that a model with financial frictions already creates enough persistence, thus standard frictions such as habit persistence and investment adjustment costs play less of a role.[753] Comparing NK DSGE models with and without financial frictions, de Graeve (2008) found the habit parameter to be estimated lower in the financial frictions model than in the model without financial frictions.[754] In a similar comparative exercise Villa (2013) reports a lower mean estimate of the investment adjustment cost parameter in a model with financial frictions à la Bernanke et al. (1999) than in the standard Smets and Wouters (2003) model.[755] Yet, both of these studies cannot

[750] See Schorfheide (2008: 421ff)

[751] See Cooper and Haltiwanger (2006: 623). They note that their estimates are low in comparison to the related literature; however, Cooper and Haltiwanger (2006: 624) argue that higher estimates in the literature are due to measurement error introduced in the estimation process.

[752] See Christiano et al. (2005a: 17). Note that their investment adjustment cost parameter κ is related to the investment adjustment cost parameter ϕ_I in the banking model by $\kappa = 2\phi_I$.

[753] See de Graeve (2008: 3424). Note that this reasoning is analogous to Justiniano and Preston (2010: 105ff) who argue that an open-economy setting partly explains lower values for habit persistence and investment adjustment cost parameters because foreign variables can induce persistence in (home) consumption and investment.

[754] See de Graeve (2008: 3421ff)

[755] See Villa (2013: 21). Due to the large size of the 95% probability intervals, these estimates are not statistically different, see Villa (2013: 21).

entirely support this line of argument. In de Graeve (2008), the estimate of the investment adjustment cost parameter is estimated high both in the model with and without financial frictions, while the habit parameter is estimated similarly across models in Villa (2013).[756] The difference in terms of the lower habit parameter estimate might be explained by the fact that Villa (2013) set the risk aversion parameter in the utility function to 1, whereas de Graeve (2008) estimates this parameter to be 2.15 in the financial frictions model.[757]

Consequently, these observations indicate that low estimates of χ and ϕ_I may be connected to the form of workers' utility function, and thus in the banking model to its non-separability between leisure and consumption. As noted in section 3.7, the separable case corresponds to the limit of σ_c approaching 1. Yet, the posterior mean of the degree of non-separability of leisure and consumption is estimated at 3.645 in the banking model. It is statistically significantly different from the prior mean, indicating that the data is informative on this parameter. Furthermore, the data does not move the parameter to more separability between leisure and consumption. In fact, the posterior distribution lies further away from the separable case. Taken together with the low estimates of χ and ϕ_I, this is in line with the results in Guerrón-Quintana (2008) who finds lower estimates of habit and investment adjustment costs with non-separable preferences as compared to separable preferences.[758]

Turning to the remaining parameters of workers' utility function, note that the posterior mean of the discount rate β is identical to the prior mean. Also, the prior-posterior plot shows that the prior and posterior distributions are the same, indicating that the data is not very informative on the level of the steady-state nominal interest rate.[759] Since the data used in the estimation only included differenced time series, this result is not surprising. In contrast, steady-state hours worked H are estimated relatively high, at 0.521. This implies that workers spend more than half of their time endowment working. This results in a higher steady-state output level relative to the prior mean of 0.35, ceteris paribus. Also, since steady-state hours worked are directly related to the share of leisure in the utility function, the higher estimate has the effect of decreasing this share and increasing the share of consumption in utility. Hence, this higher estimate implies that workers value leisure less, and consequently work more. From this point of view, the result is in line with values for the share of consumption in non-separable utility functions.[760] Consequently, while the estimate of H is too high when looking at data on hours worked, it is in line with estimates concerning the specific form of the utility function.

[756] See de Graeve (2008: 3421) and Villa (2013: 21)
[757] See the utility function in Villa (2013: 8), and the estimation results in de Graeve (2008: 3421).
[758] See Guerrón-Quintana (2008: 3621)
[759] See fig. C.1 in appendix section C.2
[760] See for example Guerrón-Quintana (2008: 3621) and Backus, Kehoe and Kydland (1993: Table 3)

Focusing on the monetary policy rule, it can be seen that the Taylor rule coefficients for inflation and the output gap are consistent with previous estimates in the literature. In contrast to earlier findings, however, interest rate persistence is estimated to be low. This fits the estimation results on sticky prices, habit persistence and investment adjustment costs. As described above, these estimates imply lower persistence in the behaviour of the respective endogenous variables. Hence, there appears a general pattern of lower persistence induced by these additional real frictions.

Turning to the structural parameters specific to the banking model, the data generally appears to be informative, with two exceptions. Considering first the reaction coefficients to bank equity and deposit returns in workers' asset demand functions, it is evident that workers react differently to changes in the risky bank equity return and the safe bank deposit return. Both parameters are statistically significant. Even though the 90% HPD intervals are rather wide, they do not overlap. Thus, bank equity and bank deposits cannot be deemed perfect substitutes except for the deterministic steady state.[761] Assuming equal shares in wealth, the point estimates indicate that the representative worker increases his bank equity holdings by 15.776% if both returns are expected to increase by 1%, and consequently decreases his bank deposit holdings by the same percentage.[762] Conversely, if both returns are expected to decrease by 1%, a worker decreases his equity holdings by 15.776%. This is due to the reaction coefficient on the expected equity return ω_2 being estimated much higher than the reaction coefficient to the expected deposit return ω_3. This fits the behaviour of a risk-averse worker, since if times are expected to be good, the chances of the equity return to be less than the steady-state return are low. The worker then expands his equity-to-wealth share. In contrast, if expectations of the future short-term development of bank profits and thus returns are pessimistic, the probability of low bank returns and bank default is higher and the worker invests comparatively more in the safe asset.

The minimum reserve ratio ξ^r affects the change in the real deposit return due to a change in the real policy return. In the deterministic steady state the real deposit return is equal to the real risk-free return. Due to the fact that deposit insurance fees are governed by a fixed parameter, the real deposit return will change by $(1 + \xi^r)\%$ if the real policy rate changes by 1%. For small ξ^R this is a comparatively small effect. The posterior mean of ξ^r is higher than the prior mean which was set equal to the minimum reserve ratio in

[761] Furthermore, these estimates are far away from the instability regions detected in section 4.4.

[762] The assumption of equal share of bank deposits and bank equity in workers' wealth is not abstract, since the estimation yielded a value of 0.568 for ω_1. This appears unrealistic from the point of view of observed bank leverage ratios (see table 5.1 for the relationship between ω_1 and banks' leverage ratio in the banking model). Yet, as the estimates and simulations are based on the log-linear approximations, and thus deal with deviations from the steady state, this should tend to understate, rather than overstate, the friction associated with risky bank equity since a given level change will translate into a smaller % change when bank equity is higher, ceteris paribus.

effect in the EA at the time of writing. However, since the minimum reserve ratio in the EA was 2% prior to 2012, the posterior estimate is still reasonable.[763] The transaction cost parameters μ^E, μ^B and μ^N do not appear to be updated by the information in the dataset. Prior and posterior means are almost identical and the prior-posterior plots show almost identical distributions.[764] These results suggest that the absolute size of monitoring costs does not affect model dynamics materially. The sensitivity analysis in section 5.5 further analyses the impact of the chosen prior distributions for the estimation results concerning these transaction cost parameters.

Finally, the estimates of the parameters governing the shock processes are largely in line with results in the literature in general. There are two estimates which stand out: the standard deviations of the investment cost and entrepreneurial risk shocks, σ_I and σ_E. The very low autocorrelation estimate of the entrepreneurial risk shock process ρ_E may indicate that the data was not able to distinguish properly between big, weakly autocorrelated shocks and small, highly autocorrelated shocks.[765] The high estimate of the standard deviation of the investment adjustment cost shock σ_I is probably related to the low estimate of the investment adjustment cost parameter ϕ_I. A 20.902% shock interval above and below the mean estimate of ϕ_I is $[0.532, 0.814]$, which is, as discussed above, still evidence of rather low investment adjustment costs. As a final note, the 90% HPD interval for σ_I is very wide, implying that the mean estimate may not be a very precise description.

Concerning the remaining estimates of shock standard deviations, there are notable differences in terms of their size between shocks pertaining to the supply and demand sides. Demand side shocks, meaning government spending and preference shocks, are generally larger than supply side shocks, meaning technology, capital quality, and mark-up shocks. This excludes the (supply side) investment adjustment cost shock, which was already discussed in the previous paragraph. The standard deviation of a government spending shock is about six times the standard deviation of a technology or capital quality shock, and more than three times the standard deviation of a mark-up shock. Financial shocks, meaning the entrepreneurial and bank risk shocks, are yet more volatile than demand or supply side shocks, except for the investment adjustment cost shock. Finally, the monetary policy shock is estimated to be more volatile than supply side shocks, but less volatile than demand and financial shocks.[766]

763 See European Central Bank (2016c), URL in list of references
764 See fig. C.1 in appendix section C.2
765 Preliminary exercises yielded a posterior mode with the latter property, that is, small σ_E with high ρ_E. However, the log-likelihood indicated that this mode was dominated by the mode used for the estimation reported in the text, even if only slightly.
766 The monetary policy shock is not grouped with the other shocks since monetary policy is the focus of this study.

Focusing on the estimated autocorrelation parameters, the patterns are not as clear-cut. Considering only the exogenous capital quality and mark-up processes would indicate a lower autocorrelation for supply side shock processes as compared to demand shock processes. However, the exogenous technology and investment adjustment cost processes are highly autocorrelated. The former may be explained by the fact that the data was expressed in per-capita and not in efficiency units. The latter, however, is relatively surprising given the standard deviation of ϵ_I. Finally, exogenous financial shock processes are also not clearly more highly autocorrelated than other shock processes, as the autocorrelation of one exogenous process (Υ^E) is estimated very low, whereas the other (Υ^B) is estimated comparatively high.

To sum up, the posterior estimates of the banking model are plausible. As will be seen in chapter 6, the banking model is able to create long-lasting reactions of real variables even though persistence parameters are estimated comparatively low. Whether or not differences in the estimated volatilities and autocorrelation parameters of the various exogenous processes translate into a major impact of one kind of shock for the evolution of the endogenous variables will also be evaluated in chapter 6. Beforehand, this chapter will assess the empirical fit of the banking model with these estimates vis-à-vis the financial accelerator model and discuss the sensitivity of these estimation results in sections 5.4 and 5.5, respectively.

5.4 Evaluation of the Banking Model's Empirical Performance

5.4.1 Posterior Estimates of the Financial Accelerator Model

Before turning to the discussion about the empirical fit of the banking model, this section first presents the results of the estimation of the financial accelerator model. These estimates form the reference against which the performance of the banking model is evaluated. As detailed in chapter 4, the financial accelerator does not feature the financial friction between workers and banks, as well as the portfolio choice problem of workers.[767] Thus, there is no model-equivalent to the time series of bank equity used in the estimation of the banking model, and also, the bank risk shock is not present in the financial accelerator model. Hence, there are 8 shocks and 8 observables to estimate the financial accelerator model. The posterior estimates for the financial accelerator model are summarised in tables 5.6 and 5.7.

The dataset is otherwise the same as the one used for the banking model.[768] The calibra-

[767] For details, see section 4.3.2.
[768] See section 5.2.1 and appendix section C.1

tion and prior distributions are the same as in the banking model for all parameters which are also present in the financial accelerator model.[769] The structure of tables 5.6 and 5.7 is equivalent to the one of tables 5.4 and 5.5. The posterior mean and 90% HPD intervals are based on 200,000 draws from 5 chains of the MH algorithm. Convergence was checked by the same means as for the banking model.[770] All checks indicated convergence after burn-in.

If the overlap of 90% HPD intervals is taken as a measure, then the posterior estimates in tables 5.6 and 5.7 are similar to the estimates of the banking model in tables 5.4 and 5.5, respectively.[771] Furthermore, the posterior distributions for the banking and financial accelerator models are generally close together, as can be seen from figs. C.1 and C.2 in appendix section C.2. The result of close similarity of parameter estimates is in line with previous results in the literature on comparing models with different sets of financial frictions and without financial frictions.[772]

There are only a few cases where the estimate of the posterior mean of one model does not fall into the 90% HPD interval of the other model. These include workers' consumption habit parameter χ and the standard deviation of the preference shock σ_P. In both cases the estimate is lower in the banking model, indicating that lower habit persistence and smaller shocks to the marginal utility of consumption are necessary for the banking model to fit the data. Both a larger habit persistence parameter and larger preference shocks imply a more volatile path for consumption, ceteris paribus. Thus, either the introduction of the bank equity time series into the estimation process or the model layout work to make the path for consumption more volatile, thus necessitating lower habit persistence and smaller preference shocks.[773]

Thus, the estimates of the posterior distributions can be deemed roughly similar for the banking and financial accelerator models. With a few exceptions, the additional bank-specific friction does not as such impact parameter estimates. In order to asses whether the banking model improves the financial accelerator model in terms of data fit, the next subsections consider three criteria, which are popular in the literature in turn: marginal likelihoods, steady-state ratios and second moments. While marginal likelihood comparisons are a truly Bayesian concept, steady-state ratios and second

[769] See section 5.2.2, stars indicate parameters that do not apply to the financial accelerator model.
[770] See section 5.3 for details.
[771] See Villa (2013: 20) for this line of argument with respect to similarity between posterior estimates.
[772] See, for instance, de Graeve (2008) and Merola (2015) for studies using US data and Villa (2013) for the EA.
[773] Since the estimates of the reduced-dataset banking model, which is estimated on the same dataset except for the exclusion of the bank equity time series, are similar to the benchmark banking model, it appears to be the case that model dynamics are the main reason. See below for more details on the reduced-dataset banking model.

Parameter		**Posterior Optimisation**		**Posterior Distribution MH**		
		Mode	St.Dev.	Mean	90% HPD	
workers' discount rate	β	0.997	0.001	0.996	0.993	0.999
consumption habit parameter	χ	0.508	0.057	0.519	0.429	0.613
Calvo pricing parameter	ξ^p	0.160	0.037	0.167	0.109	0.213
price indexation rate	γ^p	0.414	0.212	0.459	0.167	0.753
investment adjustment cost parameter	ϕ_I	0.700	0.144	0.716	0.475	0.953
Taylor rule parameter	ρ_R	0.340	0.061	0.346	0.248	0.443
Taylor rule parameter	θ_π	1.976	0.082	1.981	1.844	2.114
Taylor rule parameter	θ_y	0.091	0.023	0.108	0.061	0.153
degree of non-separability between consumption and leisure	σ_c	3.869	0.312	3.881	3.362	4.390
steady-state hours worked	H	0.547	0.039	0.551	0.486	0.617
entrepreneurial default transaction cost parameter	μ^E	0.026	0.002	0.026	0.023	0.029

Table 5.6: Financial Accelerator Model: Structural Parameter Estimates. Posterior Optimisation refers to the numerical optimisation of the posterior before MH initialisation, standard errors are based on the Hessian matrix. Posterior Distribution Mean and 90% HPD Interval as well as subsequent computations in the text are based on 200,000 draws from the posterior distribution of the MH algorithm.

Parameter		**Posterior Optimisation**		**Posterior Distribution MH**		
		Mode	St.Dev.	Mean	90% HPD	
st. dev. technology shock	σ_A	0.572	0.044	0.579	0.505	0.651
st. dev. government consumption shock	σ_G	3.469	0.328	3.621	3.051	4.180
st. dev. monetary policy shock	σ_M	1.218	0.142	1.229	0.995	1.462
st. dev. mark-up shock	σ_{MS}	0.958	0.112	1.016	0.818	1.214
st. dev. capital quality shock	σ_K	0.517	0.042	0.523	0.452	0.593
st. dev. preference shock	σ_P	2.350	0.442	2.517	1.741	3.269
st. dev. investment adjustment cost shock	σ_I	17.123	5.920	19.571	8.310	30.717
st. dev. entrepreneurial risk shock	σ_E	11.379	1.466	12.063	9.494	14.523
autocorrelation of Υ^A	ρ_A	0.970	0.012	0.965	0.944	0.986
autocorrelation of Υ^G	ρ_G	0.888	0.023	0.886	0.848	0.923
autocorrelation of Υ^{MS}	ρ_{MS}	0.696	0.077	0.678	0.554	0.806
autocorrelation of Υ^K	ρ_K	0.422	0.028	0.418	0.371	0.466
autocorrelation of Υ^P	ρ_P	0.952	0.022	0.944	0.906	0.983
autocorrelation of Υ^I	ρ_I	0.958	0.013	0.959	0.938	0.981
autocorrelation of Υ^E	ρ_E	0.111	0.041	0.122	0.056	0.185

Table 5.7: Financial Accelerator Model: Shock Parameter Estimates. Posterior Optimisation refers to the numerical optimisation of the posterior before MH initialisation, standard errors are based on the Hessian matrix. Posterior Distribution Mean and 90% HPD Interval as well as subsequent computations in the text are based on 200,000 draws from the posterior distribution of the MH algorithm.

moment comparisons are more broadly used. There are many more possibilities to evaluate the relative and absolute fit of models. The following discussion will focus on these three because of their wide use and expediency.

5.4.2 Banking vis-à-vis Financial Accelerator Model: Marginal Likelihoods and Data Match

Dimension I: Marginal Likelihood One popular method to compare models from a Bayesian perspective is the calculation of posterior odds ratios. The posterior odds ratio $PO_{1,2}$ is defined as:[774]

$$PO_{1,2} = \frac{p(model_1|data)}{p(model_2|data)} \tag{5.5}$$

where $p(model_1|data)$ is the posterior model probability of model 1 given by:[775]

$$p(model_1|data) = \frac{p(data|model_1)p(model_1)}{p(data)} \tag{5.6}$$

This can be interpreted in a similar vein as the application of Bayes' Theorem to parameter estimation, only this time to models. $p(model_1)$ is the prior probability of model 1 and comprises the beliefs of the researcher concerning the validity of model 1.[776] $p(data)$ is the marginal likelihood of the data, as above. Finally, $p(data|model_1)$ is called the marginal likelihood (of model 1), which is a function of the prior distribution and likelihood used in calculating the posterior distribution of the parameters.[777] The marginal likelihood can be interpreted as an expression for the probability of the model given the data with respect to other models.[778] Similar to the computation of the posterior distribution of parameters, the marginal likelihood is defined in terms of a high-dimensional integral and thus a numerical approximation is necessary.[779] There exist various methods to compute a numerical approximation to the marginal likelihood, in the following the approximation using the modified harmonic mean estimator is reported.[780]

The posterior odds ratio contrasts the marginal likelihood of model 1 with the marginal likelihood of model 2, to elucidate whether the data is in favour of one specific model.[781] Combining eqs. (5.5) and (5.6) yields:

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[774] Koop (2003: 4), eq. 1.7, my notation.
[775] Koop (2003: 4), eq. 1.5, my notation.
[776] See Koop (2003: 4)
[777] See Koop (2003: 4). This term may also be called marginal data density, see for example Herbst and Schorfheide (2016: 40f).
[778] See Geweke (1999: 14f)
[779] See Herbst and Schorfheide (2016: 93)
[780] See Geweke (1999: 42ff) and Herbst and Schorfheide (2016: 93ff)
[781] While posterior odds ratios are illustrative for comparing two models, numerous models can be compared by calculating posterior model probabilities, see also Koop (2003: 4).

$$PO_{1,2} = \frac{p(data|model_1)p(model_1)}{p(data|model_2)p(model_2)} \tag{5.7}$$

The special case of assuming equal prior probabilities, $p(model_1) = p(model_2)$ is called the Bayes Factor.[782] The comparison then reduces to comparing marginal likelihoods. For transparency, equal prior probabilities are assumed in the following. In this case, if $PO = 1$, then the marginal likelihoods of both models are equal. In general, a value of PO larger than 1 indicates a preference for model 1, whereas a value lower than 1 indicates that model 2 is preferred.

A crucial condition is that $p(data)$ is the same used in the estimation of model 1 and model 2 such that it cancels out in deriving eq. (5.7). For comparative purposes in terms of marginal likelihoods this is intuitive: if the dataset used for estimating model 1 were different from the dataset used in estimating model 2, then the researcher cannot distinguish between the effects of different datasets or model implications for estimating the parameters. As noted above, the dataset used for estimating the financial accelerator model necessarily excluded the time series for bank equity.

To enable the comparison, a reduced-dataset version of the banking model is estimated, using the same dataset as for the financial accelerator model, and excluding the exogenous bank risk shock process Υ_B. The assumptions about the calibrated parameters and the prior distributions are the same as for the complete banking model.[783] The results from the posterior estimation are presented in appendix section C.3. In general, these estimates are in line with the results of the complete banking model.[784]

The logarithm of the marginal likelihood is -804.91 for the banking model (reduced dataset) and -811.20 for the financial accelerator model. The Bayes Factor for the reduced-dataset banking model versus the financial accelerator model is then:

$$PO_{BM,FAM} = \frac{\mathrm{e}^{-804.91}}{\mathrm{e}^{-811.20}} \approx 5.39 * 10^2 \tag{5.8}$$

which is clearly greater than 1. Thus, the banking model (reduced dataset) is preferred to the financial accelerator model according to this measure.

The size of the difference between the marginal likelihoods between those two models is difficult to assess. In terms of posterior probabilities, the comparison is rather futile. With only two models, the posterior probability for model 1 will be higher than 90% as

[782] See Koop (2003: 5). Bayes Factors have to obey the principle of transitivity, see Robert (2001: 351).
[783] See section 5.2.2
[784] See appendix section C.3 for details.

soon as the log model likelihoods differ by 1 point.[785] Comparing these Bayes Factors with other reported numbers in the literature may also be only a rough guide, since this measure crucially depends on the dataset, model structure and parameter set. In this respect, it should be noted that the Bayes Factor is biased in favour of the model with fewer parameters.[786]

The scale created by Jeffreys (1961) is sometimes cited for interpreting Bayes Factors.[787] According to this scale, the Bayes Factor $PO_{BM,FAM}$ of $5.39 * 10^2$ indicates that the evidence against the financial accelerator model is decisive.[788] Yet, it has been pointed out that the bounds of the scale by Jeffreys (1961) are somewhat arbitrary.[789] Kass and Raftery (1995), for instance, propose different bounds with stricter requirements for considering evidence against a model as decisive.[790] Even on the stricter scale by Kass and Raftery (1995), $PO_{BM,FAM}$ still presents decisive evidence against the financial accelerator model. The arbitrariness of the bounds can be resolved by following an explicit loss function approach.[791] Yet, for the purposes of this study, the indication of aforementioned scales is sufficient.

Based on this result, the banking model estimated on the reduced dataset can be deemed superior in terms of data fit.[792] Nevertheless, according to the Bayesian perspective, this preference does not translate into an outright rejection of the financial accelerator model. Rather, the results of various models should be weighted by their posterior probability to reach some form of model average.[793] As already discussed above, the restriction to two models lends big support to the banking model in terms of posterior probabilities.[794] Yet, there may be other models which fit the data better, but which are not included here. In fact, from a theoretical perspective, even if one model improves on another, it may be a poor description of reality.[795] In this study, no further model versions will be introduced to alleviate this shortcoming since the maximisation of forecasting performance or model fit is not the core research question. Rather, this discussion is intended to gauge

785 With two models, the posterior probability of model 1 is given by $p(model_1|data) = {}^{PO_{1,2}}/_{(1+PO_{1,2})}$, see Koop (2003: 4), unnumbered equation, my notation.

786 See Rabanal and Rubio-Ramírez (2005: 1161)

787 See, for instance, Rabanal and Rubio-Ramírez (2005: 1160)

788 See Jeffreys (1961: 432). Note that the scale in Jeffreys (1961: 432) refers to the Bayes Factor notation where the null hypothesis to be tested is the numerator, which is opposite to the notation used here.

789 See Robert (2001: 228)

790 See Kass and Raftery (1995: 777)

791 See Robert (2001: 228)

792 Model misspecification does not pose a problem for this comparison, since the Bayes Factor remains a consistent method to choose among different models even if they are incorrectly specified, see Fernández-Villaverde and Rubio-Ramírez (2004: 159).

793 See Canova (2007: 339) and Koop (2003: 27)

794 With equal prior probabilities, the posterior probabilities of the banking and financial accelerator models are 99.76%, and 0.24%, respectively.

795 See Canova (2007: 455)

Model	Y	C_W/Y	I/Y	K/Y	B/Y
Data		0.554	0.196	21.219	4.818
BM	1.308	0.485	0.225	8.992	2.997
FAM	1.472	0.444	0.254	10.164	3.417
BM ($\varrho^B = 0$)	1.393	0.443	0.254	10.164	3.417

Table 5.8: Steady-State Values: Banking and Financial Accelerator Models; values for data-based ratios are the average ratios over the estimation period in the dataset used for estimation for C_W/Y, I/Y and B/Y. The value of K/Y is calculated as the average between 1994-2013, since gross fixed assets are only available for this time period, source: Statistisches Bundesamt (2016b), URL in list of references.

the empirical performance of the banking model with respect to the financial accelerator model on which it is based. As further checks to this end, the next section will consider two calibration-based measures: comparison of model-implied steady-state ratios and second moments to data-based statistics.

Dimension II: Steady-State Ratios Table 5.8 presents the steady-state values of selected endogenous variables for the banking and financial accelerator models.[796] These values are computed for the respective parameter vector at the posterior mean, as presented in tables 5.4 and 5.5 for the banking model and in tables 5.6 and 5.7 for the financial accelerator model. The data-based ratios are computed from the estimation dataset for C_W/Y, I/Y and B/Y, using level data. The reported ratios in table 5.8 are the averages over the time period 1994Q2-2015Q2. K/Y was computed by dividing gross fixed assets measured at the end of the year by the output of the last quarter of the respective year.[797] This choice of dividing the end-of-year stock of capital by the quarterly flow measure output was made to ensure consistency with the model-based ratios as the banking and financial accelerator models are written in quarterly terms.

In a nutshell, the level of output Y and the ratios of investment, capital and loans to output (I/Y, K/Y, B/Y) are lower, while the ratio of consumption to output C_W/Y is higher in the banking model as compared to the financial accelerator model. These differences between the banking and financial accelerator models in table 5.8 can be explained in

[796] In the interest of space, the choice of reported variables is based on highlighting key differences between the steady states as well as the following considerations. The steady-state inflation rate is not explicitly reported because it is the same in the banking and financial accelerator models, the steady-state volume of hours worked is an estimated parameter reported in tables 5.4 and 5.6, and bank equity is not present in the financial accelerator model. Since the posterior estimates of workers' discount factor β and the transaction cost parameters μ^E and μ^B do not differ fundamentally from their respective prior distributions, the steady-state values of the nominal risk-free return and the real return on real capital correspond to the respective targets reported for specifying the prior distributions for β, μ^E and μ^B in section 5.2.2. Thus they are also not reported here again.

[797] See Statistisches Bundesamt (2016a), URL in list of references, and Schmalwasser and Weber (2012) for more details on the use of gross fixed assets as a measure of the capital stock and its calculation for Germany.

terms of two factors: the steady-state real return on real capital and the steady-state volume of hours worked. Due to the inclusion of the second financial friction between banks and workers, the equilibrium spread between the real return on real capital and the real risk-free return is larger in the banking model. This larger real return on real capital implies a larger steady-state marginal product of capital, which in turn can only be accomplished through a lower capital stock per hour worked.[798] A lower capital stock, ceteris paribus, then implies a lower output given the production function. Similarly, by the production function, the lower estimate of the steady-state volume of hours worked in the banking model works in the same direction.

Furthermore, consider the counterfactual experiment of setting the bank risk premium to 0 in the banking model.[799] This reduces the spread between the real return on real capital and the real risk-free return to the entrepreneurial risk premium. Thus, the steady-state real return on real capital in the banking model would be the same as in the financial accelerator model. As can be seen in the last row of table 5.8, output is still lower in the banking model due to the lower steady-state volume of hours worked. In contrast, the other ratios are now almost identical in the banking and the financial accelerator models. Thus, the differences in the ratios noted above are principally due to the higher real return on real capital in the banking model.

Lastly, note that the higher real return on real capital moves $^{C_W}\!/_Y$ and $^{I}\!/_Y$ closer to the data-implied ratios, while it conversely moves $^{B}\!/_Y$ and $^{K}\!/_Y$ further away. Since the financial accelerator model's implied capital-to-output ratio is already below the data-implied ratio, the latter observation is easily explained by the even lower capital stock in the banking model. The lower capital stock in the banking model outweighs the effect of lower output such that $^{K}\!/_Y$ is lower than in the financial accelerator model. Since steady-state investment is equal to the depreciated capital stock, and the depreciation rate is a parameter calibrated to the same value in both models, lower $^{K}\!/_Y$ implies lower $^{I}\!/_Y$, which in fact is closer to the data-implied ratio of $^{I}\!/_Y$. By the retail goods market clearing condition, this decrease in $^{I}\!/_Y$ must be compensated by other aggregate demand components. The government spending to output ratio $^{\Upsilon^G}\!/_Y$ is a calibrated value, monitoring costs only count as a small

798 Also, since the estimated steady-state volume of hours worked H is lower in the banking model than in the financial accelerator model, and a lower H induces a lower marginal product of capital for a given capital stock, the reduction in the capital stock to increase the marginal product of capital is even larger than in the case of keeping the volume of hours worked constant.

799 This means setting the bank risk premium to 1 in the non-linear model, since $R_k = \varrho^E \varrho^B R_d$. In the log-linear approximation to the model the equation is given by $\hat{r}_k = \hat{\varrho}^E + \hat{\varrho}^B + \hat{r}_d$, thus $\hat{\varrho}^B$ needs to be set to 0. Additionally, another change is necessary since the transaction cost parameter associated with the loan market friction was estimated differently in the banking and financial accelerator models. In order to facilitate comparability, μ^E is set to 0.026, which is the value estimated for the financial accelerator model. This change in parametrization does not affect the qualitative results discussed in the main text.

Observable j	st.dev.(j)/st.dev.$(\hat{y})$			$corr(j, \hat{y})$		
	Data	BM	FAM	Data	BM	FAM
$\hat{c}_w$	0.72	0.93	1.07	0.29	0.70	0.64
$\hat{i}$	2.59	2.86	2.89	0.76	0.74	0.71
$\hat{h}$	1.01	0.42	0.46	0.44	0.46	0.37
π	2.50	0.56	0.48	-0.14	-0.05	-0.06
$\hat{r}_n$	0.95	0.61	0.50	0.56	-0.08	-0.12
$\hat{r}_k$	3.17	1.02	0.83	0.12	-0.07	-0.07
$\hat{b}$	1.44	6.78	4.79	0.14	-0.02	0.36
$\hat{e}$	1.86	6.90	N/A	0.18	-0.02	N/A

Table 5.9: Second Moments: Data, Banking and Financial Accelerator Models; reported moments for both models are the mean of the respective posterior distribution of moments.

fraction of output and the ratio of entrepreneurial consumption to output also decreases because the negative effect of the smaller capital stock outweighs the positive effect of the higher real return on real capital. Thus, it is workers' consumption to output ratio which fills the gap in aggregate demand opened by the lower capital stock. Again, a higher consumption to output ratio is closer to the data-implied ratio.

Dimension III: Second Moments As a next step, consider second moments of the data used in estimating the models and the model-implied second moments. These are summarised in table 5.9. Columns 2 to 4 report standard deviations of the variables as fractions of the standard deviation of output, columns 5 to 7 report the correlation between output and the respective variable. Note that in contrast to the steady state comparison, all computations in this section refer to the measures as used in the estimation. This means that moments for empirical data series are based on the log-differenced time series, while model-implied moments are based on the log-deviation from the steady state.

To begin with, note that the moments of the banking and the financial accelerator models look rather similar. Given that the former builds on the latter, and that posterior estimates were similar, this result is not very remarkable. Nevertheless, there are some notable differences which are outlined in the following paragraphs.

Starting with real variables, the second moments of investment are overall closer to the moments in the data than those of consumption and hours worked for both models. While both the banking and the financial accelerator model fare badly for the correlation between consumption and output, the banking model improves on the ratio of the standard deviations of consumption and output as compared to the data. In particular, the banking model is able to replicate the empirical observation that consumption is less volatile than output. In contrast, in the financial accelerator model consumption is more volatile than output.[800] Moreover, both models underestimate the volatility of hours worked. While the data suggests that hours worked are as volatile as output, both models indicate that the standard deviation of hours worked is only between 42% and 46% of the one of output.[801] Yet, the model-implied correlation between hours worked and output of the banking model is almost spot-on. The financial accelerator model slightly underestimates this correlation. The model-implied second moments for investment are close to the empirical data. The banking model improves on the financial accelerator model marginally both in terms of cross-correlation and in terms of the volatility of investment with respect to output.

Turning to the monetary and financial sides of the economy, both models' performance generally declines. Both models cannot replicate the large volatility of inflation and the real return on real capital as compared to output. Yet, the banking model improves on the financial accelerator model. Firstly, the model-implied standard deviations as fractions of the standard deviation of output are higher for inflation, the nominal interest rate and the real return on real capital in the banking model, even though they are still considerably lower than the second moments for inflation and the real return on real capital seen in the data. Turning to correlations, both the banking and the financial accelerator models estimate almost no correlation between these three variables and output. This can be deemed roughly in line with the empirical data, which only shows a low positive correlation between the real return on real capital and output and a low negative one for inflation and output. Yet, the nominal return is clearly positively correlated with output, which neither model is able to match.

In contrast to the underestimation of volatility for returns, the volatility of bank loans (and bank equity in the banking model) vis-à-vis output is overestimated both in the banking and the financial accelerator models. The financial accelerator model fares better than the banking model in terms of volatility of bank loans, but worse in terms of correlation between output and bank loans. This points to a general pattern: both models imply a larger volatility of financial quantities as opposed to returns than is observable in the empirical data. It may be that the model design is such that quantity and price

[800] The result of higher consumption volatility in the financial accelerator model is in accordance with the discussion of the higher estimates of the habit parameter and the standard deviation of the preference shock in the financial accelerator model (see above).

[801] Wickens (2008: 407) argues that a comparatively low variability of hours worked with respect to output, coupled with a high correlation of wages with output can be taken as a sign that a model is not able to replicate rather inflexible wages coupled with a more flexible employment process. In the banking model, for example, the correlation between output and wages is roughly 0.91. Wickens (2008: 408) suggests that model statistics can be aligned more closely with the respective data-based statistics by introducing wage stickiness and further exogenous shocks. Thus, model-implied volatility statistics for hours worked may be too low in the banking and financial accelerator models because wages are completely flexible. Incorporating wage rigidities in the spirit of price rigidities may remedy this shortcoming.

effects are not clearly delimited. Given the reduced-form representation of bank equity, for instance, this result indicates that there is space for explicitly modelling price and quantity effects of financial volumes.

In conclusion, model-implied correlations of the banking and financial accelerator models are largely similar. This is in line with previous results described above. Yet, it can be argued that the banking model improves on the financial accelerator model in terms of empirical fit as measured by second moments. Since the additional friction in the banking model impacts workers' decision problem, the fact that the model is able to capture the lower volatility of consumption as compared to the financial accelerator model points to an advantage of the banking model in this respect. Both models perform well in terms of investment moments. In fact, the banking model marginally improves the empirical fit in this respect on the financial accelerator model.

Combining these results with the ones on marginal likelihoods and steady-state ratios, there are three main results. Firstly, the banking model with the estimated parameter vector described in this chapter fits the data reasonably well. Secondly, the banking model improves on the financial accelerator model in terms of data fit in all three considered dimensions, although not monotonically for each variable. It should be noted that this improvement appears moderate. Thirdly, the underestimated volatility of returns and inflation, as well as the overestimated volatility of bank loans and bank equity, are clear shortcomings. The poor fit in these dimensions shows the compromises the estimation procedure had to make in order to fit the data overall. Some weaknesses, such as the low capital-to-output ratio, could be remedied by an appropriate recalibration of the parameters. For others, one of which is the underestimation of return and inflation volatilities, it seems unlikely that such a path would yield much improved results.[802] Before proceeding with further analysis, the sensitivity of the estimation results to the chosen prior distributions and time periods needs to be evaluated. The results are presented in the subsequent section.

5.5 Sensitivity Analysis

Various sensitivity tests were conducted in order to examine whether the selection of parameter calibration and prior distributions or the choice of time period have a significant

[802] A higher capital-to-output ratio could potentially be achieved by decreasing the real return on real capital. This decrease may, however, not improve the model fit in terms of volatilities, given that the real return on real capital is lower in the financial accelerator model than in the banking model, and the financial accelerator model fares worse in terms of the volatility of the real return on real capital than the banking model. Yet, this last conjecture is not clear-cut, as estimated volatilities depend on the whole system.

impact on the posterior results as presented in the previous sections. The sensitivity analysis proceeded along two dimensions: one is the sensitivity to the calibration of parameters and prior distributions, the second dimension is in terms of the considered time periods. Since the focus of this research is the additional financial friction between banks and workers, the prior sensitivity tests concentrate on the additional parameters as compared to the financial accelerator model.

In terms of prior distributions, three sensitivity tests are reported in appendix section C.4: an asymmetric risk premiums ($\varrho^{E/B}$) prior, an equal friction size prior and an alternative asset demand parameters prior. In the first experiment, the assumption about the entrepreneurial risk premium being of equal size as the bank risk premium is dropped. Instead, the prior distributions for μ^E and μ^B assume the credit spread to be distributed asymmetrically, with the banking sector friction contributing 1.00625% quarterly, while the entrepreneurial risk premium is reduced to 1.0025% quarterly. Then, the transaction cost parameters μ^E and μ^B are of comparable size implying that costs incurred in entrepreneurial and bank default are of similar size. In contrast, the prior mean for the governmental transaction cost parameter μ^N is centred at 0.2. This value was chosen to investigate whether the data is more in line with small monitoring costs, or with the larger values for monitoring costs reported in the literature.[803]

The second prior sensitivity test instead assumes an equal size of financial frictions. Put in a nutshell, all parameters which can be attributed to either friction are set to the same values for both the entrepreneurial liability friction and the bank liability friction. This firstly concerns the size of the risk premiums, but also the calibrated steady-state default probabilities of banks and entrepreneurs, for instance.[804] The third prior sensitivity test reduces the prior mean of the asset demand parameters ω_2 and ω_3 equally. Note that bank equity and bank deposits are still assumed to be perfect substitutes in equilibrium, since this is a steady-state property of the banking model.

The results of all three sensitivity tests can be found in table C.6 in appendix section C.4.[805] Consider first the sensitivity to an asymmetric $\varrho^{E/B}$ prior and a same friction size prior. Except for the transaction cost parameters, the posterior estimates of the structural parameters are very close to the benchmark banking model in tables 5.4 and 5.5

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[803] See the discussion in section 5.2.2
[804] See appendix section C.4 for details.
[805] The computational procedure was the same as for the benchmark banking model, details are also reported in appendix section C.4.

for both sensitivity tests.[806] For all structural parameters (except the transaction cost parameters) the 90% HPD intervals overlap substantially and the posterior mean estimates are reasonably similar. The posterior distributions for μ^E are in each case indistinguishable from the prior distribution. This implies that the data is not informative on this parameter, neither for the benchmark banking model nor for the two sensitivity tests. The posterior distributions for μ^B show a slight reduction in the posterior mean as compared to the respective prior mean. This result indicates that transaction costs in case of bank default tend to be lower.

Yet, given that the differences are comparatively small and the prior and posterior distributions overlap to a large degree, the actual significance of this result is limited. Hence, the findings from this sensitivity analysis should not be taken as evidence in favour or against an equal or asymmetric distribution of financial frictions. The data rather appears not informative enough on these parameters. In contrast, the estimate of the posterior mean for μ^N in the asymmetric $\varrho^{E/B}$ prior test is markedly different from its prior mean. The posterior mean of 0.086 for μ^N also means that it is different from the estimate in the benchmark banking model. The simplistic assumptions about fiscal policy, however, prevent a meaningful interpretation of the findings on the governmental transaction cost parameter. In the end, the dynamics of the model and the data appear to force the various transaction cost parameters to rather low values. The judgement of 'rather low' is made with reference to the discussion in section 5.2.2.

Turning to the estimates for the exogenous processes, there are some differences between the benchmark banking model and the sensitivity tests. In particular, the standard deviation of the entrepreneurial risk shock σ_E is significantly larger with the asymmetric $\varrho^{E/B}$ prior distribution than the benchmark prior distribution. This is probably a result of the lower monitoring cost parameter μ^E and the lower entrepreneurial risk premium, as the estimate of σ_E with the equal friction size prior is similar to the benchmark prior estimates. Furthermore, the higher volatility of the government consumption process with the asymmetric $\varrho^{E/B}$ prior is probably related to the higher estimate of μ^N as compared to the benchmark prior distribution. With higher monitoring costs the government budget is more strongly affected by developments in the banking sector. In turn, government

[806] The posterior estimates for ω_2 could be argued to be a further case where posterior estimates significantly differ. The benchmark model's mean estimate does not fall in the 90% HPD interval in the asymmetric $\varrho^{E/B}$ prior distribution case, and is only marginally in the interval in the equal friction size prior case. Yet, in both sensitivity tests, the 90% HPD interval for this parameter is much smaller than in the benchmark banking model. In fact, the intervals overlap almost perfectly with the lower half of the 90% HPD interval of the benchmark model. Furthermore, both sensitivity tests produced estimates for ω_2 which are significantly above 1, and both sensitivity tests' mean estimates fall comfortably into the benchmark model's 90% HPD interval for this parameter. Thus, the general pattern of a large ω_2 is robust to these sensitivity tests and thus, ω_2 is not discussed extensively here.

consumption has to adjust to keep the budget in balance which can be taken as an explanation for the higher volatility σ_G.

The third prior sensitivity test changed the prior distributions of the parameters in workers' asset demand equations. As the results in the last three columns of table C.6 show, the estimates of all parameters except for ω_2 and ω_3 are robust. There are no significant differences between the benchmark banking model and this alternative asset demand prior version. In contrast, the posterior mean of the coefficient governing the reaction to the real equity return, ω_2, is much higher than in the benchmark banking model. This is surprising given that the assumed alternative asset demand prior distribution was centred at a lower mean value. Conversely, the reaction coefficient to the real deposit return, ω_3, is significantly lower than in the benchmark version. As in the benchmark version, the estimated posterior distribution of ω_3 for the alternative prior is almost identical to the prior distribution.[807] It appears that it is the spread between the reaction coefficients which is informed by the data, not the reaction to the respective returns. This is likely since bank equity is an observable in the estimation process and not a deposit or bank equity return. Thus, it seems probable that the estimation procedure targets a particular volatility of bank equity. If, then, the model-implied correlation between the real equity and real deposit returns is high, a smaller reaction coefficient to one of them seemingly implies a stronger reaction coefficient to the other return.[808]

The results of the sensitivity analysis in terms of the sample period are reported in tables C.7 and C.8 in appendix section C.4. There are two different cut-off points considered in these exercises, that is in total 4 sets of posterior estimates are compared. The first cut-off point is the transition from monetary policy being conducted by the Bundesbank to the monetary policy conduct of the ECB in 1999. These two sets of estimates are referred to by the Bundesbank and ECB periods, respectively. The second exercise divides the sample into a pre-financial-crisis period, and a financial-crisis to post-financial-crisis period. These are accordingly referred to as the pre-crisis and crisis periods. The prior distributions and parameter calibration are the same as in the benchmark banking model this time.[809] Similarly, the computational procedure is the same as before, and details can be found in appendix section C.4.

Concerning this sensitivity analysis, the posterior estimates of the Bundesbank period are very distinctive: the 90% HPD intervals do not overlap or overlap only marginally for 10 out of the 16 structural, and 14 out of the 17 shock parameters with the respective

807 A graphical visualisation for the benchmark banking model can be found in fig. C.1.
808 The model implies a close co-movement between the real bank equity return and the real deposit return due to the incentive compatibility constraint of equity-holders.
809 See section 5.2.2.

90% HPD intervals of the benchmark banking model estimates. The remaining similarly estimated parameters are mainly the ones on which the data does not seem to be informative (workers' discount rate and the transaction cost parameters). These differences might be due to the underlying data. In particular, inflation and the return on entrepreneurial equity appear to be more volatile between the second quarter of 1994 and 2000.

A second explanation for this difference could be a markedly different behaviour of monetary policy during the Bundesbank period as compared to the ECB period. As pointed out in chapter 2, even though both periods can be characterised by one policy rule, the weights attached to different sub-targets differed. This view is underscored firstly by the different estimates of the monetary policy rule parameters, with the parameter governing the response to the output gap being estimated relatively high. Secondly, as can be seen from columns 5-7 of table C.7, the posterior estimates of the ECB sample are very similar to the benchmark banking model. Only in three cases (σ_M, ρ_K and ξ^p) are the respective posterior means not included in the other's 90% HPD intervals. In these cases, however, their 90% HPD intervals overlap. Following this line of argument, these estimates indicate that the ECB period features more strongly in the estimates of the complete sample period than the Bundesbank period.

What is more, it may appear counter-intuitive that the estimated reaction to the output gap is higher in the Bundesbank period. Yet, these results may be considered plausible if the relevant monetary aggregate is highly correlated with the output gap. Since there is no explicit money market in the banking model, this line of argument has to be taken with caution. Furthermore, such a high estimate contradicts the findings of Hayo and Hofmann (2006) who estimate a central bank Taylor rule, similar to the one used here, for Germany for both the Bundesbank and ECB periods separately.[810] Not only is the output gap reaction coefficient of the Bundesbank period significantly below one, but it is also estimated to be lower than the corresponding coefficient in the ECB period.[811] While Hayo and Hofmann (2006) suggest that this difference is due to the underlying structure of the economy rather than monetary policy conduct, this cannot be used as an explanation for the estimation of the banking model using different datasets.[812]

Rather, the different estimates may be due to the short dataset used in this study: the sample of the Bundesbank period comprises only 20 observations, while the ECB period comprises 65 observations. Thus, the sample might be too small to properly estimate all 33 parameters of the banking model. This is underscored by the fact that posterior mean

[810] See Hayo and Hofmann (2006: 649ff). Hayo and Hofmann (2006) use data from 1979 to 1998 for the Bundesbank period and from 1999 to 2003 for the ECB period.
[811] See Hayo and Hofmann (2006: 651)
[812] See Hayo and Hofmann (2006: 655)

estimates of the Bundesbank period are for the most part comparatively close to the prior means. Unfortunately, an extension of the Bundesbank sample by using pre-1994Q2 data is not easily accomplished and would necessitate further assumptions and data adjustments. To sum up, there is an indication for the Bundesbank period yielding different parameter estimates. Yet, due to the small sample and the closeness to the prior, this finding has to be qualified in terms of its strength.

Lastly, consider the estimates for the pre-crisis and crisis periods. Overall, these estimates are in line with the benchmark banking model. There are, nevertheless, a few differences worth commenting on. To start with, habit persistence is estimated higher in both periods as compared to the benchmark sample. Yet, the 90% HPD intervals overlap. Secondly, this first finding may be connected to the estimate of the steady-state value of hours worked, which is marginally lower in the pre-crisis period but markedly lower in the crisis period. Given that the estimated means of habit persistence are 0.529 and 0.551 for the pre-crisis and crisis periods, respectively, indicating a moderate degree of habit persistence, and the posterior means of the steady-state volume of hours worked is markedly higher than the prior mean, these results do not disagree with the findings reported in section 5.3. Thirdly, the estimated mean of the Calvo pricing parameter ξ^p is significantly higher for the crisis period than for the benchmark period, although it is still low as compared to the prior mean. The posterior mean of the indexation parameter γ^p is also estimated higher for the crisis period. Yet, the 90% HPD intervals of γ^p in both versions overlap to a large degree since they are estimated to be rather wide. These estimates then suggest a higher degree of price stickiness in the crisis period than in the pre-crisis period. This may reflect the lower degree of volatility of inflation at the end of the sample (and thus crisis) period.[813] Finally, there are some differences concerning the parameters of the exogenous shock processes.[814] Differences in these parameters over different sample periods are not too surprising. Furthermore, these differences are generally comparatively minor, such that they can be most probably attributed to different data volatilities.

Taken together, these findings suggest that parameter estimates are robust to excluding or only considering the period which followed the recent crisis. This is in line with the conclusion in European Central Bank (2010), stating that the interest rate pass-through

[813] See fig. 5.1 in section 5.2.1.

[814] Incidentally, the investment adjustment cost shock process is estimated much less volatile and autocorrelated in both the non-crisis and crisis periods. This is probably connected to the higher estimate of the investment adjustment cost parameter ϕ_I. These results underscore the explanation for the investment adjustment cost process estimates given in section 5.3, Furthermore, the findings of this sensitivity tests do not contradict that the investment adjustment cost parameter ϕ_I is estimated low, since the posterior means are still considerably below the prior mean and the 90% HPD intervals are rather wide and include the benchmark mean estimate in both sub-periods.

process did not break down in the EA in the wake of the financial crisis.[815] While parameter estimates are not as such directly related to the interest rate pass-through, the conclusion in European Central Bank (2010) indicates that there were no fundamental changes in the underlying structure.[816] Furthermore, the elements of the transmission process itself were similar to the one in periods without financial instability.[817] Unconventional monetary policies may have contributed to this steadiness.[818] While unconventional monetary policies are not explicitly dealt with in this study, they may thus serve as an explanation for the similar estimates of the pre-crisis and crisis periods.[819]

In sum, the sensitivity analysis showed that the estimation results of the benchmark banking model are generally robust to changes in the dataset and prior distributions. One exception to this finding is the estimation on the Bundesbank period, which yielded considerably different posterior distributions. Furthermore, the analysis underscores the intuition in section 5.3 that the data is not very informative on some parameters, specifically the transaction cost parameters. A manifold of other sensitivity tests could potentially be conducted. These include, for instance, the sensitivity to the calibration to standard parameters such as the depreciation rate. Yet, such exercises cannot be handled within the bounds of this study and are left to future research.

[815] See European Central Bank (2010: 96)
[816] See European Central Bank (2010: 96)
[817] See European Central Bank (2010: 96)
[818] See Darracq Pariès et al. (2016: 39)
[819] See section 6.3.1 for a short discussion why unconventional monetary policies are excluded from this study.

Chapter 6

Monetary Policy Transmission and Policy Trade-offs in the Banking Model

The previous chapter presented the result of the estimation concerning the banking and the financial accelerator models. For, one it showed that the estimates of the two models are relatively similar. Yet, the previous chapter also demonstrated that introducing non-systemic bank failures into a New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model with financial accelerator improves the empirical fit. Building on the findings of the previous chapters, this chapter aims to answer the research questions of this thesis. To this end, two types of analysis are conducted: impulse response analysis and Taylor curves. The first tracks the evolution of the model economy after being disturbed from its steady state. The second sheds light on the policy trade-off between inflation and output gap stabilisation as monetary policy goals.[820] Taken together, these analyses will highlight the differences which arise when banks are allowed to fail in a macroeconomic model. Thus, this chapter provides an integrated assessment and discussion of the links between non-systemic bank fragility and monetary policy.

This chapter is structured as follows. Firstly, the transmission of monetary policy impulses is the focus of section 6.1. Section 6.2 discusses the trade-off between inflation and output gap stabilisation faced by the central bank in its conduct of monetary policy and how it is affected by the incidence of non-systemic bank default using Taylor curves. Finally, section 6.3 explores how introducing macroprudential instruments affects the previous results on the transmission of monetary policy and the monetary policy objectives trade-off.

[820] In this chapter, stabilisation refers to the act of decreasing the volatility of the respective variable. The concept is thus different from the analysis of the stability of the model equilibrium conducted in chapter 4.

6.1 Monetary Policy Transmission with Non-Systemic Bank Default

6.1.1 Reaction to a Monetary Policy Shock

The central bank conducts monetary policy in the banking model using a Taylor-type interest rate rule. The rule specifies that the central bank changes the nominal risk-free return only when it observes a deviation of inflation or the output gap from their respective steady-state values.[821] Since the banking model features long-run monetary neutrality, changing the nominal risk-free return when the economy rests in the steady state will lead to short-run movements, but will not affect the steady state. Any such policy would engineer a departure from stable prices without any permanent effect on real variables. As a consequence, the central bank merely reacts to developments in the economy to maintain price stability. At the same time, it is rather complicated to study the transmission of monetary policy when the nominal risk-free return merely changes as a result of a displacement of the model economy from its steady state. In such a scenario, movements in endogenous variables might be caused by factors other than monetary policy.[822] Then, consequences of monetary policy actions are difficult to disentangle from other driving factors.

Therefore, this section makes use of the concept of monetary policy shocks.[823] In the financial accelerator and banking models the monetary policy shock ϵ_M is an additive factor in the Taylor rule.[824] The shock changes the nominal risk-free return unexpectedly, and as a result displaces the economy from its steady state. Thus, this exogenous change in the nominal risk-free return highlights the effects of monetary policy on the evolution of the model economy. One interpretation of such a shock is that it represents a measurement error on the part of the central bank.[825] Another interpretation is that these shocks are

[821] Remember that the Taylor rule in chapter 3 is written in terms of the nominal risk-free return, whereby returns and interest rates are linked to each other by the following relationship: $return = 1 + interest\,rate$. Using the term interest rate would not change the findings with regard to contents.

[822] See also Christiano et al. (1999: 68) on this issue.

[823] All computations were carried out with Matlab and the software platform Dynare. For coding (of the model, of the estimation and analysis experiments in the previous and this chapters) the Dynare manual (Adjemian et al. (2011)), the Matlab help section, and the resources made available during the Summer School 'The Science and Art of DSGE Modelling' (2014) at the Centre for International Macroeconomic Studies, School of Economics at the University of Surrey were helpful and valuable. The tool developed by Schlömer (2016), URL in list of references, was used to convert pictures.

[824] See eq. (4.35); note that this chapter deals with the log-linear approximation to the non-linear model presented in chapter 3.

[825] This interpretation has been touched upon in chapter 2 when justifying the central bank target of 0% inflation in this model. As noted there, while measurement error has been used as a justification for targeting a slightly positive inflation rate, there are good reasons for using the 0% inflation target in the banking model even in the case of the interpretation of monetary policy shocks as measurement errors.

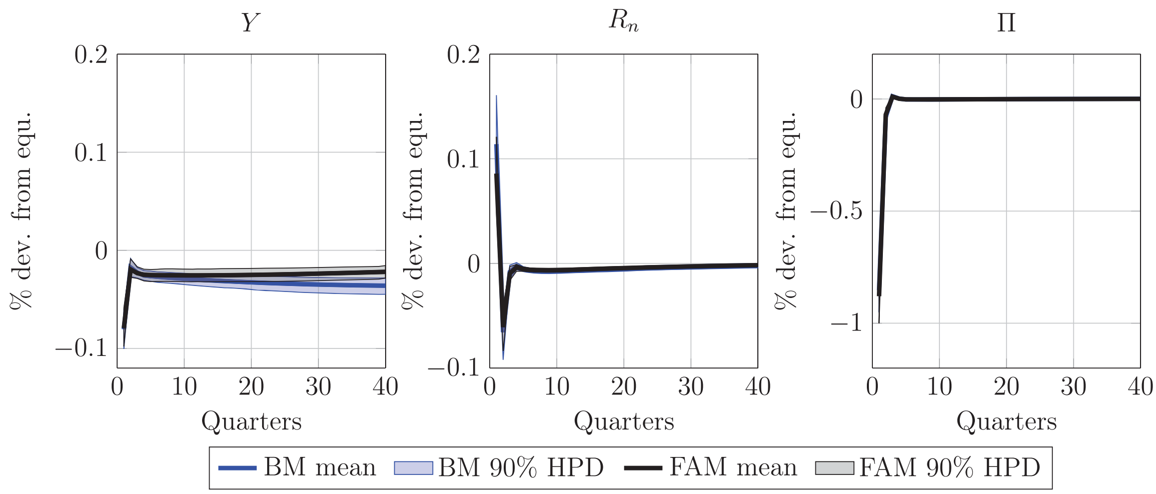

Figure 6.1: Reaction of GDP (Y), the Nominal Risk-Free Return (R_n) and Inflation (Π) to a Contractionary Monetary Policy Shock for the banking model (BM) and the financial accelerator model (FAM); $\epsilon_{M,1} = \sigma_M$, $\epsilon_{M,s} = 0$, $s = 2 : 40$, BM (blue line): banking model evaluated at the posterior mean of the banking model, FAM (black line): financial accelerator model evaluated at the posterior mean of the financial accelerator model, shaded areas indicate 90% highest posterior density (HPD) intervals for the respective model; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

noise, which cannot be separated from movements in inflation and the output gap, or more generally represent unspecified influences. In any event, such a shock induces a monetary policy action which is not warranted by previous movements in inflation or the output gap. As a result, it is useful in analysing monetary policy transmission.

Consider a sudden, unexpected positive shock to the nominal risk-free return.[826] The size of the shock is set equal to the estimated standard deviation of the monetary policy shock. This may appear at odds with the practice of, for instance the European Central Bank (ECB) which changed its policy rates in discrete steps of (multiples of) 0.25% up until 2014.[827] Yet, the Taylor rule of the banking model describes a rule for changing policy rates (or the nominal risk-free return, respectively) on a continuous interval. Furthermore, given the linearity of the model, the absolute magnitude of the shock only plays a secondary role for analysing the transmission. The qualitative results do not change when the shock size is set to hit a 0.25% increase in the nominal risk-free return.[828] Also, since the standard deviation is estimated based on German data, a one standard deviation shock means that roughly 68% of monetary policy shocks ϵ_M are estimated to be smaller in absolute size (monetary policy shocks follow a normal distribution). Thus, the majority of shocks were estimated to be smaller or equal to this shock size.

[826] The experiment could easily be conducted using a negative monetary policy shock which would represent expansionary monetary policy. The results would be symmetrical.

[827] Since 2014, the ECB has decreased its main refinancing rate twice by 0.1 % and, at the time of writing, lastly in March 2016 by 0.05%, see European Central Bank (2016e: S7), URL in list of references.

[828] The monetary policy shock needs to be set to 2.665 to achieve this increase in the nominal risk-free return.

The timing is as follows. The economy initially rests in its steady state, and at the start of quarter 1, the nominal risk-free return is shocked by $\epsilon_{M,1}$. From the second quarter onwards, the monetary policy shock is set to zero.[829] All other shocks are zero at all times.[830] Thus, after the initial shock, any changes in the nominal risk-free return and the other endogenous variables are entirely due to the adjustment of the system to the disturbance. Irrespective of the duration of the adjustments, impulse response functions as analysed here trace the response of the system back to its original stable steady state. This means that a shock does not change the steady state, but only displaces the model economy temporarily from it.

Figure 6.1 displays the responses of the gross domestic product (GDP), the nominal risk-free return and inflation for both the financial accelerator and banking models after such a contractionary monetary policy shock.[831] Additionally, fig. 6.2 shows the responses of investment, workers' consumption and the net worth of entrepreneurs to the same monetary policy shock.[832] The responses are measured as percentage deviations from the respective steady-state values. In terms of terminology, unless otherwise stated, a 'positive' reaction or an 'increase' signify that the value is above the steady-state value. Conversely, a 'negative' reaction or a 'decrease' denote values below the steady state.

The mean standard deviation of the monetary policy shock is estimated at 1.237 for the banking model and 1.229 for the financial accelerator model. This would imply that the nominal risk-free return would be 1.237% and 1.229%, respectively, above its steady-state value in quarter 1. Comparing with the y-axis in the second panel of fig. 6.1, it is clear that the nominal risk-free return actually increases by only about a tenth of the size of the shock.[833] This can be explained using the assumption of perfect information and the responsiveness of monetary policy to inflation and the output gap. On the one hand, ceteris paribus, the nominal risk-free return increases due to the monetary policy shock

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829 This means, $\epsilon_{M,1} = \sigma_E$, $\epsilon_{M,s} = 0$, $s = 2 : \infty$.

830 That is, $\epsilon_{x,t} = 0$, $t = 1 : \infty$, where $x = A, B, E, G, I, K, MS, P$. These assumptions on the shock values imply that all movements from $t = 1$ onwards are deterministic.

831 Unless stated otherwise, variables are defined in real terms. In spite of this rule, returns are always denoted real or nominal, as appropriate.

832 Since entrepreneurs' consumption is not derived from utility maximisation, this discussion concentrates on the behaviour of workers' consumption. Entrepreneurs' consumption responds very similar to entrepreneurs' net worth given that both variables have similar functional forms. Remember that the main part of entrepreneurs' profits is used to build up net worth, whereas the remaining part constitutes entrepreneurs' consumption, see eqs. (3.18) and (3.19) in chapter 3. Since the share of entrepreneurs' consumption is calibrated comparatively small, the restriction of consumption to workers' consumption is adequate.

833 Also note that fig. 6.1 depicts draws from the distribution of impulse responses, not the impulse responses of draws from the distribution of parameters. This is important insofar the mean responses depicted in fig. 6.1 do not necessarily imply that these were computed at the mean parameter vector. Even so, this difference is of minor practical importance, as can be seen by comparing fig. 6.1 with fig. 6.3, for example.

by the size of the shock. On the other hand, ceteris paribus, the central bank reacts to decreases in the output gap and inflation by lowering the nominal risk-free return in line with the Taylor rule coefficients.[834] Hence, the monetary policy impulse disturbing the system is larger than the change in the nominal risk-free return.[835] Note that this does not affect the focus on the transmission of monetary policy. The fact that the nominal risk-free return in quarter 1 does not increase as much as the monetary policy shock merely signifies that the shock is moderated by the downturn induced by the contractionary monetary policy shock.

To build a point of reference, consider the impulse response functions of the financial accelerator model.[836] This is the reference model in which banks do not default.[837] The effects of monetary policy in the financial accelerator model mainly work through the interest rate and balance sheet channels.[838] The interest rate channel works through decreasing investment demand by increasing the general level of interest rates. Thus, aggregate demand declines. At the same time, lower aggregate demand puts downward pressure on prices through entrepreneurs' marginal costs, in turn decreasing inflation.[839] The balance sheet channel additionally affects monetary policy transmission through the effect of interest rates on asset prices. Higher interest rates mean lower asset prices, in this

[834] The contemporaneity assumption of the Taylor rule is not crucial for there to exist a difference between the nominal risk-free return and the policy shock. Consider the counterfactual experiment where the central bank sets the nominal risk-free return as a function of the expected values of inflation and the output gap. All other equations are unchanged and the parameters are the same as before. Then, the responses of GDP, inflation and the other endogenous variables would be amplified as compared to the responses of the banking model in figs. 6.1 and 6.2. Secondly, the nominal risk-free return would actually decrease upon impact of the shock, due to the expected paths of inflation and the output gap to evolve much further below their steady-state values. Thus, the reaction of the nominal risk-free return does not equal the size of the monetary policy shock in this case either.

[835] The crucial point here is that all agents are fully informed. Entrepreneurs and retailers observe the incidence of the shock, thus adjust their production and pricing choices even before the central bank has set the nominal risk-free return. Private agents also know how the central bank will react to these choices which leads to the responses depicted in figs. 6.1 and 6.2. Perfect information and perfect foresight tend not to occur too often in reality. Yet, such a mechanism just described may be partially reflected in the use of central bank communications to explain the conduct of monetary policy in terms of forward guidance.

[836] Note that for clarity the scale of the y-axis is different for in the graphs of fig. 6.1 as compared to the graphs in fig. 6.2. Also, the y-axis scales for inflation in fig. 6.1 and for entrepreneurial net worth in fig. 6.2 are different from the y-axis scales of the other two plots in the respective figure.

[837] See chapter 4 for more details.

[838] This reflects the modelling approach. The working capital channel of monetary policy, among others, is not present in the banking or financial accelerator models. It could, however, be easily added by having part of the wage bill (paid by entrepreneurs) pre-financed, and thus creating additional loan demand for this purpose. Then, retail goods prices are also affected through the impact of the loan rate on entrepreneurs' wage costs.

[839] Since the steady-state inflation rate is zero, contractionary monetary policy leads to deflation in this case. However, there is no debt-deflation channel at work in this model, and the model is log-linearised around its steady state. This suggests that deflation does not lead to asymmetric effects as compared to a positive inflation rate. In fact, an expansionary monetary policy shock looks like a mirror image of the contractionary shock discussed in the text. More generally, in linear models, the shape of the impulse response is independent of the shocks' size and sign, see Canova (2007: 137).

case the price of physical capital. As the price of physical capital decreases, entrepreneurs receive lower cash flow from selling their depreciated capital stock at the end of the period. This immediately leads to a decrease in entrepreneurial net worth (fig. 6.2) and as a result to a higher entrepreneurial default probability.[840] In turn, this leads to tighter credit conditions, that is the external finance premium increases. As a result, entrepreneurs' capital demand decreases and consequently, investment and aggregate demand decline further.

Inflation shows a quantitatively stronger but more short-lived reaction than GDP. The initial effect on inflation is about 10 times stronger than the effect on GDP. At the same time, inflation reverts to the close vicinity of its steady state within one year.[841] The short-lived reaction of inflation is probably related to the low estimates of price stickiness parameters. Only about 17% of retailers cannot optimise their prices in any given period. Thus, the impact of current marginal costs on inflation is very strong.[842] Then, inflation does not deviate from its steady state for a long period of time and the effects of exogenous shocks on inflation quickly phase out. The nominal risk-free return behaves similarly due to the high reaction coefficient on inflation, θ_π, in the Taylor rule. As a consequence of these two observations, it is clear that real returns do not deviate from their respective steady states for a long period of time either.

In contrast, variables such as consumption[843] and investment only slowly return to their respective steady-state values. They recover eventually since real returns are close to their steady-state levels and shocks are zero, and as such there is no further motivation for deviations from the steady state.[844] Aggregate demand variables do not adjust at the same speed as real returns because of the presence of real and financial frictions. For consumption, the presence of habits leads to a smooth path. Investment takes long to recover to its steady state due to investment adjustment costs which penalise volatility

[840] Since this model consists of representative agents, the balance sheet channel leads to adverse effects on the balance sheet of the representative entrepreneur. Empirical studies on the balance sheet channel usually assume that borrowers are heterogeneous in terms of their balance sheet strength, see Beck et al. (2014: 3). Size can be an indicator of the balance sheet channel in that smaller firms contract their borrowing more than others, see Beck et al. (2014: 3) and section 2.4. Yet, the Bernanke et al. (1999) approach relates financing conditions to net worth through the representative agent to model the balance sheet channel. Differences among entrepreneurs arise due to idiosyncratic shocks in the model, see section 3.3.

[841] After 3 quarters, the deviation of inflation from its steady-state value is less than 0.01%.

[842] See section 5.3 for a comparison of prior and posterior mean values for the coefficients of the NK Phillips Curve and the weight of marginal costs in terms of its effects on current inflation for the banking model. Since the estimates of the banking and financial accelerator models are similar, the discussion there equally applies to the financial accelerator model.

[843] Henceforth, the term 'consumption' is used to denote 'workers' consumption'. If explicit reference is made to the retail goods demand of entrepreneurs, the term 'entrepreneurs' consumption' is used.

[844] Also, all variables eventually return to their steady state levels given the assumptions about this experiment, that is temporary shocks which do not change the steady state.

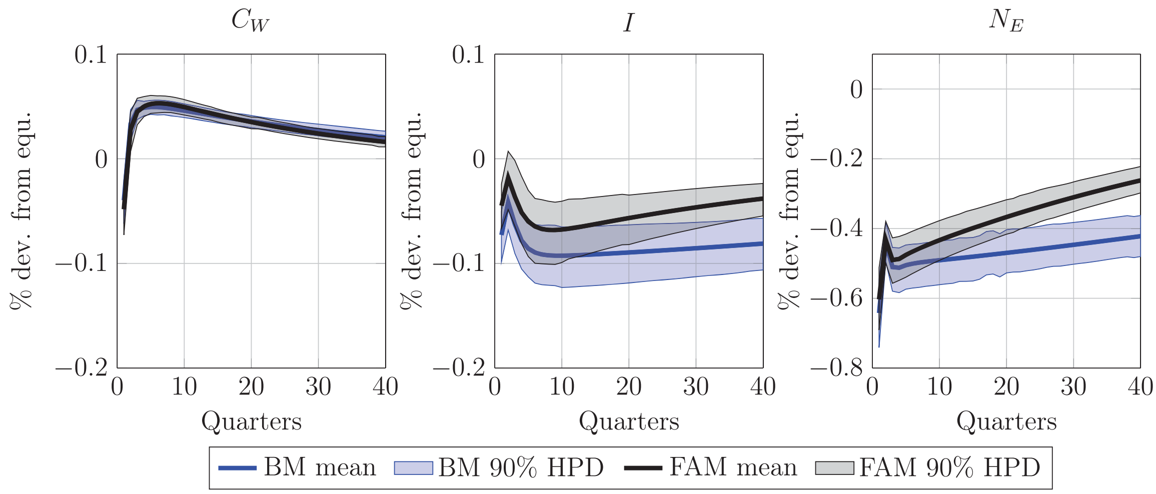

Figure 6.2: Reaction of Workers' Consumption (C_W), Private Investment (I) and Entrepreneurial Net Worth (N_E) to a Contractionary Monetary Policy Shock for the banking model (BM) and the financial accelerator model (FAM); $\epsilon_{M,1} = \sigma_M$, $\epsilon_{M,s} = 0$, $s = 2 : 40$, BM (blue line): banking model evaluated at the posterior mean of the banking model, FAM (black line): financial accelerator model evaluated at the posterior mean of the financial accelerator model, shaded areas indicate 90% HPD intervals for the respective model; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

in investment growth. Hence, capital investment funds optimally smooth the path of investment over time in response to shocks. Furthermore, the balance sheet channel as just discussed increases persistence in real variables' responses additionally through entrepreneurs' net worth. Since entrepreneurs' net worth changes with retained earnings, the reaction of investment is even more sluggish. Thus, real and financial frictions prolong the duration of the displacement of real variables from their steady state in response to a monetary policy shock.

Having established this point of reference, how does non-systemic bank default affect monetary policy transmission? The responses of the endogenous variables in the banking model are depicted by the blue lines showing the effects of a monetary policy impulse when there are always some (non-systemic) banks which fail.[845] The behaviour of endogenous variables in the banking model generally coincides with the financial accelerator model, but differences emerge in the details. Initially, the nominal risk-free return increases, and GDP and inflation decline following a contractionary monetary policy shock. Interestingly, the responses of inflation and the nominal risk-free return are very similar to the corresponding responses in the financial accelerator model.[846] In contrast, the reaction of GDP shows

[845] Remember that there is a constant probability of bank default in the steady state of the banking model. Furthermore, this probability changes endogenously in response to exogenous shocks when the banking model is displaced from its steady state. In the aggregate, the (individual) probability of bank default coincides with the share of failing banks. Thus, the terms 'probability of bank default' and 'share of failing banks' are used interchangeably. See chapter 3 for details on bank failures in the banking model.

[846] As noted above, the large estimate of θ_π ties the evolution of the nominal risk-free return closely to inflation.

differences between the banking and financial accelerator models. In particular, GDP takes longer to reach its trough in response to a contractionary monetary policy shock, and thus stays below its steady-state level for longer in the banking model. To see this, consider the solid lines in fig. 6.1 representing the mean response. In quarter 12 the paths of GDP in the financial accelerator and banking models diverge. In the financial accelerator model, GDP reverts back to its steady-state level from period 12 onwards. In contrast, GDP in the banking model continues to decline. There are three important factors which contribute to the different behaviour of GDP in the banking model: Firstly, the longer-lasting decline in GDP is tightly linked to the financial situation of entrepreneurs; secondly, the amplified response results from the additional bank balance sheet channel; and finally, the responses of workers' consumption and investment are counteracting with respect to GDP.

Concerning the first factor, the longer-lasting decline in GDP in the banking model is mainly explained by entrepreneurs' consumption and investment decisions and not by workers' consumption choices.[847] The quantitatively most important components of GDP are workers' consumption and investment, and to a lesser extent entrepreneurial consumption.[848] From fig. 6.2, it is clear that the evolution of consumption in the banking model is roughly similar to the equivalent in the financial accelerator model. One may argue that consumption reverts more slowly to its steady-state value in the banking model than in the financial accelerator model. Yet, the size of this difference is small as compared to the significantly more sluggish response of investment in the banking model. Furthermore, the response of entrepreneurs' consumption is comparable to the one of entrepreneurs' net worth because both crucially depend on entrepreneurs' cash flow.[849] Thus, entrepreneurs' consumption also stays longer below its steady-state level in the banking model than in the financial accelerator model.[850] So, the longer-lasting response of GDP can be principally attributed to the observation that entrepreneurial balance sheets are weakened for a longer period of time, which in turn decreases both investment and entrepreneurial consumption.

To the second point, as in the financial accelerator model, both the interest rate and balance sheet channels are at work in the banking model. An increase in the nominal risk-free return means that the return used as a reference for setting other returns is higher, thereby decreasing investment through a generally higher level of financing costs. The

[847] In turn, the difference in entrepreneurs' consumption and investment decisions is mainly explained by the bank balance sheet channel, as argued below.

[848] Admittedly, other components, that is government consumption and transaction costs contribute to aggregate demand. However, government spending is an exogenous process, and the government spending shock is set to zero, such that government spending stays at its steady-state value. Transaction costs are only a minor fraction of aggregate demand under the chosen parametrization. Thus, they do not play a role here either.

[849] See footnote 832 above in this chapter

[850] This follows from the graph for entrepreneurial net worth in fig. 6.2.

balance sheet channel additionally depresses entrepreneurial net worth through decreasing asset prices and cash flow. This induces an increase in the external finance premium which leads to a further reduction in investment and thus aggregate demand. In addition, there is a third channel which explains the response amplification of entrepreneurial net worth, investment and GDP in the banking model. This channel is the bank balance sheet channel.

The bank balance sheet channel implies that contractionary monetary policy also affects banks' financing conditions. For one, the higher nominal risk-free return leads to an increase in the returns on bank liabilities. By assumption the real deposit return increases linearly with the real risk-free return. This assumption can be justified by alluding to arbitrage opportunities. Unless other assumptions on additional benefits of bank deposits are introduced, workers are only willing to hold bank deposits if they pay the same risk-free return. The assumption of no other risk-free assets can then only be practicable if the real return on deposits adjusts in line with the real risk-free return.[851] The incentive compatibility constraint for bank equity mandates the expected return on bank equity to increase with the expected deposit return.[852]

As a consequence, banks increase the return on their asset (loans) to pay for the higher rates of return on their liabilities. As such, higher bank loan rates are an expected result of monetary policy. The crucial feature here to constitute a bank balance sheet channel is the fact that entrepreneurs' external financing rate increases by more than without fragile banks. This in fact happens in the banking model, as the real wholesale return increases by more than the real risk-free return.[853] As the real wholesale return is the required return on loans, this increases entrepreneurs' financing costs in addition to the increase due to a weakening of entrepreneurs' balance sheet. Thus, capital demand decreases by more, leading to lower investment and aggregate demand. This is linked to a larger decline in the price of physical capital. The lower price of physical capital reduces entrepreneurs' cash flow again, worsening the financial position of entrepreneurs in terms of net worth. With lower net worth, credit conditions tighten further and entrepreneurs'

[851] The banking model does not feature any additional risk-free assets because workers would always be indifferent between holding any of them absent any additional assumptions. The arbitrage reasoning in the text is thus hypothetical. Admittedly, there may be circumstances which enable banks to set a real deposit return lower than the real risk-free return such as when banks possess market power. Models with monopolistic banks are one such example, see, for instance, Darracq Pariès et al. (2016) or Dib (2010).

[852] Note that upon impact, financial contracts have already been negotiated and the return on bank equity is simply equal to bank profits per equity. That is, the returns on bank equity and bank deposits may differ ex-post any shocks. See also the discussion on the behaviour of consumption below on this issue.

[853] As a reminder, the real wholesale return is the return the loan branch has to pay on the loan volume to the wholesale branch. The expected real return from lending including default costs has to match the real wholesale return, otherwise banks would not lend. In the financial accelerator model, the real risk-free return is the opportunity cost of lending.

marginal financing costs increase by more. As lower net worth this period means lower net worth next period, higher marginal financing costs have repercussions for the economy's recovery. With entrepreneurial net worth recovering more slowly, investment and GDP respond more sluggishly. Furthermore, as investment declines more in the banking model, the capital stock also falls by more. This subsequently lowers the productive capacity of the economy as well as depressing entrepreneurial revenues. In sum, recovery is a slower process in the banking model. This explains the more sluggish response of real variables in the banking model.

A peculiar feature of the bank balance sheet channel emerging from the banking model is that it does not work through a prolonged increase in the bank risk premium.[854] In fact, the risk premium associated with bank default slightly declines.[855] This result appears at odds with the observation that bank fragility leads to tighter credit conditions. Yet, this apparent contradiction can be resolved by considering the distinct concepts of bank equity and entrepreneurial net worth. Entrepreneurial net worth increases through retained profits and is depleted when profits are lower than expected. Thus, the evolution of entrepreneurial net worth in the past affects current entrepreneurial net worth which in turn influences current financing conditions of entrepreneurs. In contrast, bank equity is completely paid out each period. The bank risk premium for bank equity held from period t to $t+1$ is determined by the profits of period $t+1$ expected at t. These expected profits do not depend on the return on equity paid at the end of the previous period, but instead on the expected revenue from the loan business with entrepreneurs. If, for example, the economy enters a lower than normal state due to a contractionary monetary policy shock, the altered environment leads banks to increase their internal wholesale return, so as to satisfy the constraint on their liability side. Thus, banks pass on the mandated increase in returns onto entrepreneurs. In contrast, entrepreneurs cannot simply increase the real return on real capital. As a result, entrepreneurs must adjust their capital demand to remain profitable.

Finally, consider the third observation on the behaviour of GDP following a monetary policy shock: consumption and investment working in opposite directions. To begin with, the deviation of GDP is largest in the quarter when the monetary policy shock hits because both consumption and investment decrease. Afterwards, in the second quarter, the nominal risk-free return decreases as monetary policy reacts only to the decrease in inflation and

[854] This observation opens the debate about whether the channel identified here is a balance sheet channel in the sense identified for entrepreneurs. As the channel here works through banks' balance sheet constraint in terms of the required returns, this study continues to denote the mechanism by bank balance sheet channel in order to differentiate it from entrepreneurs' balance sheet channel even though contractionary monetary policy does not increase the bank risk premium.

[855] The response is on a scale of 10^{-3} percentage points. The bank risk premium decreases for two quarters, then marginally stays above its steady-state level.

GDP and the effect of the monetary policy shock vanishes. This has an expansionary effect on the economy.[856] Yet, with inflation close to its steady-state level afterwards, there is no warrant for further large monetary policy actions. Then, the expansionary effect vanishes and the slump in entrepreneurial net worth, real investment and GDP deepens again. While investment stays below its steady-state level for all periods in fig. 6.1, consumption is higher than its steady-state level after quarter 2. Increased consumption somewhat offsets the negative effect of investment on aggregate demand, but not completely, as GDP remains below its steady state for the whole considered period.

An intriguing question relates to the fact that GDP does not bottom out during the displayed time frame. In comparison, the paths of both consumption and investment show clear signs of a trough and a movement back to the steady state.[857] Investment reaches its trough in quarter 9 and consumption its peak (neglecting the first quarter) in quarter 5. At the same time, the response of GDP is due to different speeds of adjustment of these two aggregate demand components. Consumption moves back to the steady state quicker than investment, which results in the change in GDP being more and more driven by changes in investment. Consider the change between quarters 10 and 40: the deviation of consumption from its steady-state value decreases about 2.5 times as much as the deviation of investment from its steady state (in absolute terms). Thus, the sum of the two yields a decrease of GDP over this time period.[858] GDP eventually returns to its steady-state value, given the stability of the model and given that aggregate demand components return. Yet, this takes a very long time.

This discussion begs the question of whether it is particularly realistic that GDP does not return to its steady state after 10 years following a one-time monetary policy shock. This is rather long. However, recent research has provided evidence from a historical perspective that financial distress or crises are linked to deeper and longer recessions.[859] While the particular length of the simulated reaction may not be realistic, the results in this section fit this pattern of a fragile financial sector amplifying and prolonging endogenous movements of the system. Zhang (2009), for instance, also shows that a bank capital friction prolongs the responses to a monetary policy shock.[860] The focus should

[856] 'Expansionary' is used here to denote an effect which leads to levels of aggregate demand components which are higher than the period before. Strictly speaking, GDP and investment are still below their steady-state values, although higher than in the previous quarter.

[857] This applies similarly to entrepreneurs' consumption. Given that entrepreneurs' consumption is quantitatively less important for aggregate demand than the other two components discussed in the text, it is ignored here to streamline the argument.

[858] In the financial accelerator model, investment returns to its steady state at a much faster pace, thus GDP reaches its trough after 12 quarters.

[859] See Bordo and Haubrich (2010: 1, 17), Jordà, Schularick and Taylor (2013: 4ff) and Reinhart and Rogoff (2009: 173, 230)

[860] See Zhang (2009: 23f)

thus be on the direction of the effects, while their absolute size and the resulting absolute time it takes for GDP to return to its steady state should be interpreted with caution.

The findings on the different responses in the financial accelerator and banking models are roughly in line with previous findings in the literature. The observation that the bank balance sheet channel affects the response of GDP while the one of inflation is not changed significantly is in line with the econometric results of Ciccarelli et al. (2013). Based on a panel vector autoregression (VAR) using Euro area (EA) data, Ciccarelli et al. (2013) show that the response of GDP to a monetary policy shock varies over time and was particularly strong during the financial crisis 2008-09.[861] In contrast, the response of inflation was comparatively uniform over time.[862] Also, the amplification effect of the bank balance sheet channel generally agrees with findings from the DSGE-model-based literature.[863] In the model by Markovic (2006), for instance, an additional bank-specific financial friction induces a stronger reaction of investment and GDP.[864] Furthermore, the amplification effect of bank-based financial frictions has also been found in studies with different assumptions about the nature of bank capital. Davis (2010), for example, show that a financial accelerator friction and a bank capital friction each amplify the response of GDP and investment to roughly the same extent, although the differences are quantitatively small.[865]

Usually, the impulse response function of consumption shows it to be decreasing for a prolonged period of time after a monetary policy shock.[866] While the simulated response of consumption here is unusual, it is not unprecedented. In fact, the behaviour of consumption presented here is in line with the simulation results of Markovic (2006). The results in Markovic (2006) suggest that consumption does not respond very differently comparing a model with only an entrepreneurial balance sheet channel with a model which features an exogenous probability of bank default affecting the return on bank equity.[867] Similar to fig. 6.2, consumption decreases upon impact of the contractionary monetary policy

[861] See Ciccarelli et al. (2013: 21)
[862] See Ciccarelli et al. (2013: 21)
[863] The model-based literature has also found results which differ in terms of the additional effect of bank default. Angeloni and Faia (2009: 15) and Meh and Moran (2004: 29), for example, find that bank default leads to a dampening effect on GDP. In Angeloni and Faia (2009) bank default occurs due to bank runs and they relate the dampening effect to relationship lending, see Angeloni and Faia (2009: 2f, 15). Similarly, in Meh and Moran (2004: 11) bank default is due to insufficient diversification on the part of banks. While the overall effect is dampened, their bank friction induces higher persistence of investment in response to a contractionary monetary policy shock, which is in fact in line with the results of this study, see Meh and Moran (2004: 30).
[864] See Markovic (2006: 30)
[865] See Davis (2010: 25f, 56). Yet, Davis (2010) does not find a notable difference in terms of the duration of deviations from the steady state or dissimilar effects on inflation and GDP.
[866] See, for instance, Gadatsch et al. (2015: 31)
[867] See Markovic (2006: 30)

shock, but subsequently shows a positive hump-shaped response in both cases in Markovic (2006).[868] Furthermore, for a bank-based financial friction to affect mainly investment and to a lesser extent consumption has been shown in the literature, for example in Zhang (2009) where households also hold bank equity and bank deposits.[869]

So why does consumption show this pattern, and why does bank default not fundamentally affect the path? The explanation lies partly in parameter estimates which allow consumption to respond promptly to standard wealth and substitution effects. The substitution effect outweighs the wealth effect initially, and vice versa over the long term. As real returns rise following the shock, workers save more and reduce their consumption. Subsequently, the central bank reduces the nominal risk-free return as it observes lower output and inflation. Thus, with higher wealth and the substitution effect inducing higher consumption today, workers' consumption rises. Real returns subsequently stay close to their steady-state levels, but worker's wealth has increased, such that the positive wealth effect on consumption is still present but gradually phases out. Conversely, with higher habit persistence and a higher share of consumption in the utility function, coupled with a stickier inflation response, a standard hump-shaped response of workers' consumption could also arise in the banking model.

The other part of the explanation for the behaviour of consumption relates back to the discussion about dynamic IS (DIS) curves and monetary policy in chapter 4. The DIS curve is derived from workers' optimisation problem and the economy's resource constraint. The main difference of the DIS curves in the banking and financial accelerator models concerned the presence of the real portfolio return in the former and the real risk-free return in the latter. Yet, this section showed that workers' consumption does not evolve very differently in the banking and financial accelerator models. The reason for this similarity is that the real portfolio return in the banking model and the real risk-free return in the financial accelerator model evolve similarly, although not identically. The incentive compatibility constraint facing banks' liability management states that the expected real bank equity return needs be equal to the expected real deposit return. Yet, even though workers' expect the remuneration on bank equity and bank deposits to be equal, this also means that the real bank equity return may differ ex-post shock realisations from its ex-ante expectation and from the real deposit return. However, these differences are generally rather small, given that the effects of small shocks are analysed in vicinity of the steady state. While, for example, the real portfolio return does not increase as much as the real deposit return in the banking model following a monetary policy shock, the difference is not large enough to induce a substantially different consumption behaviour.

[868] See Markovic (2006: 30)
[869] See Zhang (2009: 23)

The fact that the difference between the DIS curves in terms of returns does not yield noticeable differences may be taken as a weakness of the modelling approach. Alternatively, this observation may rather be interpreted as showing that the banking model does not create any synthetic arbitrage opportunities. In the financial accelerator model, workers' consumption/saving choice is directly anchored at the real risk-free rate. Chapter 4 argued that this link is not as direct in the banking model because only part of workers' portfolio consists of the risk-free asset. However, the fact that bank equity has to pay the same return including default costs, the link between the real risk-free return and workers' consumption/saving choice is still intact. Thus, the real portfolio return does not differ systematically from the real risk-free rate ensuring that there are no free arbitrage opportunities.

This also means that workers cannot expect to earn a real return on their portfolio which is higher than the real risk-free return by investing in riskier bank equity. For one, absent further assumptions or restrictions, a higher return of either bank deposits or bank equity would make workers want to hold only one of the assets, that is the one which is remunerated more highly. Moreover, the derivation of the bank risk premium ensures that equity-holders are exactly compensated for the risk of bank default and low bank profits in expectations. There are no other differences between bank deposits and bank equity (other than the risk of default or low profits) which would warrant a further spread between the two respective returns. Nevertheless, deriving the bank risk premium solely as a consequence of bank default can only be a partial explanation. The explanation of the equity premium in this study by default risk only should be seen as one aspect. Further aspects certainly play a role and have been used in the literature to motivate a spread between bank equity and other bank liabilities.[870] Instead of a mere weakness, the focus on one explanation for the bank risk premium is a benefit for discerning the impact of non-systemic bank default. It shows that even though the real portfolio return does not behave very differently from the real risk-free return, small changes can have significant effects for the decision-making process of banks, the financing costs of entrepreneurs and eventually aggregate demand.

It may be argued that the marginal effect on consumption is related to the specific form of the government budget. After all, the government in the banking model is confined to a balanced budget. Furthermore, the assumptions about taxes guarantee that private agents' optimality conditions are unaffected by changes in taxes in the log-linear approximation. However, the general results presented above hold for the case when workers' tax rate

[870] See, for example, the discussion in section 2.5.

changes with the budgetary position of the government.[871] Adjusting the relevant equations means that the labour market clearing condition is affected by changes in income taxes due to changing governmental outlays.[872] However, leisure and consumption decisions are still separate from the portfolio choice decision. Thus, modelling endogenous taxes in this way merely opens up another avenue through which financial frictions affect the economy: namely, the labour market.

Assume, for instance, that government expenditures increase. Since the government is confined to a balanced budget, this necessitates higher tax income. Therefore, the tax rate increases, ceteris paribus. Increased tax rates affect workers' labour/consumption choice: per hour worked, they receive less wage income, ceteris paribus, which tends to reduce consumption. The additional channel is evidenced by the fact that the impact of a monetary policy shock on GDP is somewhat stronger in the financial accelerator model with endogenous taxes than in the benchmark financial accelerator model. Somewhat surprisingly, the effect works in the opposite direction for the banking model: the impulse response function for GDP shifts upwards in parallel. This means, that in the short term, the deviation of GDP from its steady state is smaller in the banking model with endogenous taxes than in the corresponding endogenous-tax financial accelerator model, but over the long term it is larger in the endogenous-tax banking model, because the response of GDP is generally longer-lasting in the banking model. The asymmetric effect of endogenising taxes in these two models is due to different characterisations of the government budget. In the banking model, deposit insurance fees increase as a result of increased deposit holdings, which counters the adverse effects of increased deposit insurance outlays in the short term. Thus, tax rates counter-intuitively decrease in the banking model following a monetary policy shock, thus yielding a dampened response with respect to the exogenous tax banking model. The fundamental channel pointed to above, however, is the same as in the financial accelerator model, merely in the opposite direction.

If there is a link between the government budget, taxes and workers' optimality conditions, why is this not already included in the benchmark banking model? Firstly, the result that the banking model yields a long-term amplified, and longer-lasting response of output following a monetary policy shock with respect to the financial accelerator model holds irrespective of whether income taxes are exogenous or endogenous to the decision-making of workers. So, endogenous taxes can be interpreted as a secondary factor in discerning the consequences of bank default. Related, it may be argued that the treatment of workers' optimality conditions should be connected more generally, that is leisure and consumption

[871] Since the benchmark banking model does not feature capital taxes at all, only labour income taxes are discussed.

[872] Instead of the log-linear approximation to eq. (3.76), the equation used for this experiment is $\hat{w}_t - \hat{p}_t = -\hat{u}_{h,t} - \hat{u}_{c,t} + \overline{\tau}/(1-\overline{\tau})\hat{\tau}_t$ where $\overline{\tau}$ is the steady-state income tax rate.

decisions should be linked to workers' portfolio choice. In fact, in the banking model, the aggregate volume of workers' saving is connected to the consumption decision. However, the crucial mechanism in the banking model concerns the composition of workers' saving. It is not clear in which way holding either bank deposits or bank equity should be connected to the consumption/leisure decision other than through the return on workers' portfolio. Another option to link the government's budget to the portfolio choice problem would be through taxes on capital income. Yet, this relates to the third reason why taxes are kept exogenous in the banking model: a more elaborate modelling of taxes necessitates a more thorough treatment of the government's budget, including the decision between debt and tax financing. Such a more thorough treatment would then also discern whether above mentioned behaviour of taxes (and tax rates) in the banking model holds for a more realistic setting of government finances. Thus, an interesting avenue of future research is the link between fiscal and monetary policies in economies with fragile banking sectors.

Finally, the question arises whether the disparate behaviour of the economy in the financial accelerator and banking models is due to the different size of the total credit spread. To this end, the following experiment was conducted: increase the monitoring cost parameter μ^E in the financial accelerator model, such that the credit spread in the financial accelerator model is roughly equal to the total credit spread in the banking model.[873] The impulse responses of real variables to a contractionary monetary policy shock in this large-credit-spread financial accelerator model are amplified with respect to the benchmark financial accelerator model. The largest deviation of GDP from its steady state is more than twice the one of the benchmark financial accelerator model.[874] Furthermore, GDP reaches its trough only after about 30 quarters. Thus, the deviation of GDP from its steady state lasts longer in the large-credit-spread financial accelerator model, but not as long as in the banking model. Furthermore, while the absolute deviation of GDP from its steady state is comparable for the benchmark financial accelerator and banking models for the first quarters, the absolute deviation is much larger in the large-credit-spread financial accelerator model.

There are a few noteworthy conclusions to draw from this. Firstly, the share of the credit spread due to the entrepreneurial risk premium impacts the size of the response of real variables to a monetary policy shock to a large extent. Conversely, this means that it is not so much the reaction of the credit spread which affects the strength of monetary transmission, but rather the origin of this credit spread. As a corollary, the increase in transaction costs which is necessary to yield a certain increase in the credit spread is much larger for the friction between entrepreneurs and banks than for the friction between banks

[873] More precisely, μ^E changes to 0.051, resulting in a steady state credit spread of 3.48%.
[874] Inflation and the nominal risk-free return do not respond materially differently.

and equity-holders. However, while the bank risk premium may not have a large impact in terms of the largest absolute deviation from the steady state, it does affect the time it takes for the economy to return to its steady state. While the deviation of, for example, investment and entrepreneurs' net worth from their respective steady states is larger in the large-credit-spread financial accelerator model than in the banking model, investment and entrepreneurs' net worth return to their respective steady states at a faster speed in the large-credit-spread financial accelerator model. In fact, the deviation of entrepreneurs' net worth from its steady state is smaller in the large-credit-spread financial accelerator model than in the banking model from (roughly) quarter 24 onwards. Thus, this experiment further underscores the finding that the incidence of bank default prolongs the responses of endogenous variables, which is in line with results in the literature cited above.

To summarise, the fundamental mechanisms at work in the financial accelerator model are also present in the banking model. Additionally, non-systemic bank default gives rise to a bank balance sheet channel in the banking model. The bank balance sheet channel amplifies and prolongs the responses to a monetary policy shock of real variables pertaining to entrepreneurs' decision-making. In contrast, the existence of bank default does not affect workers' consumption materially. A second conclusion relates to the discussion of parameter estimates in chapter 5. Low (estimated) nominal (price) stickiness leads to a quick return of inflation to its steady-state value after a monetary policy shock. In contrast, real variables exhibit sluggish behaviour despite the comparatively low estimates of real friction parameters.[875] Therefore, the results concerning the additional bank-specific friction underscore the argument that financial frictions prolong endogenous developments of aggregate demand components.

What do these results imply for the conduct of monetary policy? For one, the way in which a monetary policy impulse is transmitted to inflation is not significantly affected by the introduction of non-systemic bank default. Whether the model exhibits bank default or not, the path of inflation in response to monetary policy shocks does not change. Simultaneously, if the central bank engages in flexible inflation targeting so as to moderate (contractionary) effects on GDP, the incidence of bank default indicates that a given monetary impulse has quantitatively larger effects on real variables. Furthermore, there are two reasons for considering bank default even if the inflation rate is the only objective for the central bank. First, to the extent that monetary policy affects inflation through influencing aggregate demand, these results imply that the central bank has to induce a larger and longer-lasting decline in GDP for the same response of inflation to occur. The second reason is presented in section 6.2 concerning the central bank's capabilities

[875] These include, for example, the habit persistence parameter χ and the investment adjustment cost parameter ϕ_I.

with respect to stabilising inflation (and the output gap). However, before analysing the consequences for monetary policy from a different angle, the next section tries to illuminate the underlying mechanism with two more experiments: the impact of steady-state fragility and the importance of the roll-over nature of bank equity.

6.1.2 Monetary Policy Transmission, Banks' Default Probability and Equity Habits

This section assesses the impact of the severity of steady-state bank fragility and impediments to instantaneous portfolio adjustments on the dynamic adjustments to a monetary policy shock. To this end, the experiment of an unexpected, one-off contractionary shock to the monetary policy rule is repeated with different assumptions about the steady-state probability of bank default and workers' asset demand equations.[876] Otherwise, the set-up and the assumptions concerning monetary policy shocks and other shocks are the same as in section 6.1.1.

Concerning the first experiment, two cases are considered: a high and a low fragility state. In the high fragility banking model the steady-state default probability $p(\overline{\psi}^B)$ is set to 0.1. In the low fragility banking model $p(\overline{\psi}^B)$ is set to $1 * 10^{-7}$. These alternative values for $p(\overline{\psi}^B)$ are somewhat arbitrary. The objective was to choose a lower and a higher value than the benchmark calibration. The high fragility value can be deemed a speculative upper bound. For instance, considering the US between 1973 and 2015, the assets of failed banks as a share of total assets reached a maximum of about 5.4% in 1989.[877] During the financial crisis of 2007-8 this ratio peaked at around 3.3% in 2008.[878] On the other hand, the low fragility value can be interpreted as the other extreme in which banks do not actually default. Note that in this case banks are still constrained by the incentive compatibility constraint of equity-holders.

Figure 6.3 depicts the reactions of GDP, the nominal risk-free return and inflation to a contractionary monetary policy shock. The blue line depicts the reaction under the benchmark parametrization. Note that in contrast to figs. 6.1 and 6.2, these lines trace the reaction of the banking model at the posterior mean of the parameter vector. As the

[876] Note that the banks' probability of default is equal to the share of failing banks in a given period, see footnote 845.

[877] See Federal Deposit Insurance Corporation (2015), URL in list of references, and Board of Governors of the Federal Reserve System (2015), URL in list of references, for data; own computations based on yearly aggregation. In the banking model all banks are alike. Thus, the assets of failed banks as a share of total assets of the banking sector can be taken as a guide for the fraction of all banks failing in any given period in the banking model.

[878] See Federal Deposit Insurance Corporation (2015), URL in list of references, and Board of Governors of the Federal Reserve System (2015), URL in list of references, for data; own computations based on yearly aggregation.

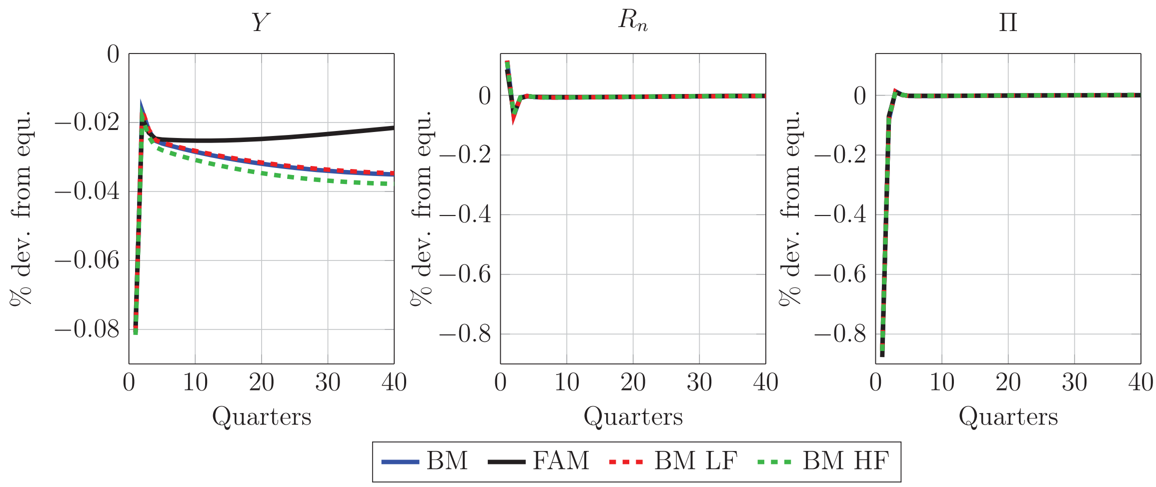

Figure 6.3: Impact of Banks' Default Probability on the Reaction to a Contractionary Monetary Policy Shock; $\epsilon_{M,1} = \sigma_M$, $\epsilon_{M,s} = 0$, $s = 2 : 40$, BM (blue line): benchmark banking model evaluated at its posterior mean, FAM (black line): financial accelerator model evaluated at its posterior mean, BM LF (red dashed line): low-fragility banking model evaluated at the posterior mean of the banking model with $p(\overline{\psi^B}) = 1 * 10^{-7}$, BM HF (green dashed line): high-fragility banking model evaluated at the posterior mean of the banking model with $p(\overline{\psi^B}) = 0.1$; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

banking model is not re-estimated for these two different parametrizations of $p(\overline{\psi}^B)$, there is simply no distribution of impulse responses to draw from.[879] The red dashed line depicts the reaction of the low-fragility banking model. The green dashed line in turn shows the high-fragility banking model. For reference, the reaction of the financial accelerator model economy is included (black solid line).

The differences in the paths of inflation and the nominal risk-free return are comparatively marginal. Yet, in line with previous accounts, GDP reacts differently whether the probability of bank default in the steady state is low or high. The high-fragility banking model parametrization results in a stronger output deviation from its steady state, as compared to the benchmark version. Conversely, the low-fragility banking model exhibits a lower GDP deviation from its steady state, as compared to the benchmark banking model. Yet, this latter difference is negligible. In all cases, however, the deviation of output from its steady-state value is larger in absolute value than for the financial accelerator model.

Consequently, it is not only the existence of bank fragility as such which yields a stronger response of GDP to monetary policy. The severity of steady-state fragility affects the response of the model economy to a monetary policy shock. Ceteris paribus, the higher is the steady-state probability of bank default, the stronger is the reaction of GDP. Intuitively, this is reasonable: as the size of banking sector fragility increases, the impact

879 Since the aim of this section is to show the impact on dynamics, and not to assess the sensitivity of the estimation to different calibrations, the model is not estimated again.

of the additional financial friction weighs heavier. Conversely, with low steady-state bank fragility, the response of GDP moves closer to the financial accelerator model.

Yet, there is still a marked difference between the financial accelerator model and the low-fragility banking model. There are two reasons for this. First, while the steady-state bank default probability is lower in the low-fragility banking model, bank default is still endogenous and oscillates around its steady-state value after a monetary policy shock. Second, the constraint on banks' liabilities is still present. Workers still view bank equity as riskier than bank deposits, since the return on bank equity is not risk-free even if there is only a negligible chance that all is lost. The additional bank balance sheet channel is still at work, although reduced.[880] Thus, investment and entrepreneurial net worth stay below their respective steady states for a longer period of time in the low-fragility banking model than in the financial accelerator model. As a result, GDP reacts more strongly.

This finding should not be confused with a temporary increase in banks' default probability. Since this probability is an endogenous variable, the share of failing banks changes in response to exogenous shocks even in the benchmark banking model. Therefore, this experiment essentially compared the responses of the banking model starting at three steady states which differ in terms of the share of failing banks. Relating this finding to, for example, the end of a financial crisis when bank fragility may be high, can be misleading because this necessarily presumes that the steady state changed. Whether or not monetary policy can be judged more effective in these circumstances not only goes beyond this study's research question because of this consideration, but also because of its focus on non-systemic bank failures. Seen from this perspective, the result of no visible change in the response of inflation is not surprising.

The second experiment concerns the ease of adjustment of workers' portfolio. In the benchmark banking model workers' bank equity (and bank deposit) demand depends on changes in wealth and expected returns. Now, a lag is introduced similar to interest rate inertia in the Taylor rule or consumption habits. There are many possible explanations for why portfolio shares are not immediately adjusted to their optimal levels following a shock. One interpretation may be that workers form some form of habits in bank equity holdings, which leads workers to only partially adjust their stock of equity in response to increased wealth or expected deviations of returns from their steady states. Others include information frictions or transaction costs. Yet, the exact underlying microfoundation is not crucial for the illustrative purposes of this experiment.

[880] Incidentally, credit conditions in the low-fragility banking model are tighter in the first two periods as compared to the benchmark model, but are softer afterwards.

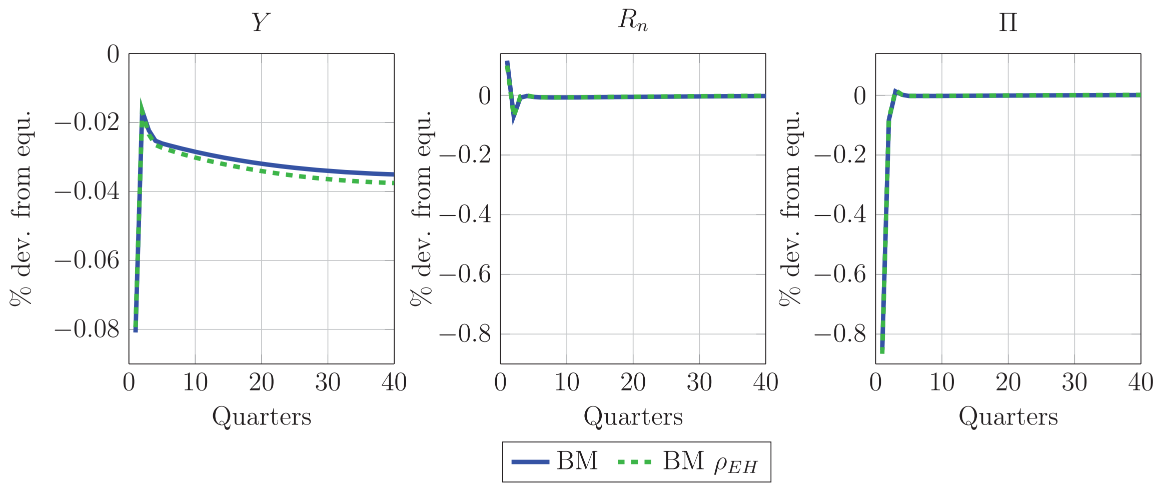

Figure 6.4: Impact of Equity Habits on the Reaction to a Contractionary Monetary Policy Shock; $\epsilon_{M,1} = \sigma_M$, $\epsilon_{M,s} = 0$, $s = 2:40$, BM (blue line): benchmark banking model evaluated at its posterior mean, BM ρ_{EH} (green dashed line): banking model evaluated at its posterior mean with $\rho_{EH} = 0.5$; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

With equity habits the log-linear approximation to the asset demand equation for bank equity holdings becomes:

$$\hat{e}_t = \rho_{EH}\hat{e}_{t-1} + (1-\rho_{EH})\hat{v}_t + (1-\rho_{EH})\frac{\omega_2}{\omega_1}\mathbf{E}_t\left[\hat{r}_{e,t+1}\right] - (1-\rho_{EH})\frac{\omega_3}{\omega_1}\mathbf{E}_t\left[\hat{r}_{d,t+1}\right] \qquad (6.1)$$

where ρ_{EH} is a parameter measuring the size of the habit, and deposit demand is simply the remaining part of workers' wealth.[881] The higher is ρ_{EH}, the lower is the reaction of bank equity demand to changes in real returns or workers' wealth, ceteris paribus. Through the incentive compatibility constraint of equity-holders this leads to instantaneous feedback effects on banks' optimisation problem. Figure 6.4 shows the responses of GDP, the nominal risk-free return and inflation to a contractionary monetary policy shock with and without an 'equity habit'. Again, the assumptions about the monetary policy and all other shocks are the same as for the benchmark banking model in section 6.1.1.

Similar to previous experiments, the nominal risk-free return and inflation are not significantly affected. Yet, with an equity habit, the response of GDP is amplified with respect to the benchmark banking model. In the benchmark banking model, workers choose the portfolio shares based on expected future returns, that is, on expected future bank profits (among others). With bank equity habits, bank equity held from the end of period t to the end of period $t+1$ not only depends on expected bank profits in period

[881] The assumption that workers form habits in bank equity holdings and not bank deposits is based on the reasoning that bank equity is risky. For example, determining the optimal level of bank equity holdings potentially entails information costs which are left unspecified in the banking model. Also, using the definition of workers' wealth, bank deposits can be expressed as a function of current wealth, the expected returns on bank equity and bank deposits and the lagged bank deposit volume. This expression for bank deposits then has a similar interpretation as eq. (6.1).

$t+1$, but also on bank profits of period t expected at the end of period $t-1$. This leads the past to affect future (portfolio) decisions. Thus, the stronger effect on GDP is due to workers' sticky portfolios and the resulting adjustment lags.[882]

This simple experiment elucidates the consequences of frictions in portfolio adjustments and/or raising new bank equity.[883] A similar result arises in Markovic (2006), where the introduction of equity adjustment costs to a model with bank default triggers an amplification of the output response.[884] The finding of the banking model with equity habits suggest that the consequences of bank default are less severe, for investment and GDP among others, if there are no impediments in adjusting portfolio shares. Furthermore, sluggish portfolio adjustment appears to make it more difficult for banks to service their liability commitments as credit conditions tighten more in this case.[885] This again relates to the results of Kiley and Sim (2014). In their model, sudden increases in the costs of issuing new equity lead to declines in investment and output.[886] Overall, the friction on banks' liability side becomes more severe when there are further obstacles or costs associated with an immediate adjustment to new conditions.

Summing up these two experiments, the more probable bank default is, that is the higher is the share of failing banks in a given period, the higher is the impact of monetary policy on GDP. Yet, given the small differences between the benchmark case and the low fragility banking model, the effects are rather small when the probability of bank default is already small. This implies that merely reducing steady-state fragility does not remove the dynamic effects of bank default. Secondly, including habits in the adjustment of portfolio shares also amplifies the effect on GDP in the banking model. Supporting the findings in section 6.1.1, the path of inflation remains almost unchanged. The results of this section then imply that consideration for the effects of monetary policy on aggregate demand is more important when banking sector fragility is high and when there are frictions in portfolio adjustments.

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[882] Note that the bank risk premium does not behave very differently when equity habits are present. As for the benchmark banking model, banks increase interest rates on the asset side in line with their liability side leading to the stronger effect on entrepreneurs' capital demand and eventually GDP.

[883] This may also be related to instability - determinacy boundary findings for different asset demand function parameters. As shown in section 4.4.3, a higher equity share in workers' wealth increased the instability region (see fig. 4.3). Ceteris paribus, a higher equity share lowers the coefficients of workers' equity demand on the respective returns. Equity habits have the same effect on these coefficients. Thus, the larger instability region may be related to stronger responses of the models' endogenous variables to exogenous shocks.

[884] See Markovic (2006: 30)

[885] Over the first few quarters following the shock, sometimes the model with, and sometimes the model without bank equity habits induces tighter credit conditions. Over the medium to long term, it is the model with equity habits which features tighter credit conditions than the model without.

[886] See Kiley and Sim (2014: 186f)

6.1.3 Importance of Monetary Policy Shocks for the Model Economy

To gauge the importance of monetary policy shocks as well as of other shocks included in the banking model, this section presents the results of the forecast error variance decomposition (FEVD) analysis.[887] There are two reasons for conducting this analysis. First, the estimates of the standard deviations of the various shocks in chapter 5 showed significant differences. Thus, the question is whether these differences resurface considering the importance for the dynamics of the model economy. Second, the previous sections analysed the transmission of monetary policy shocks. Then, the question arises whether monetary policy shocks are important in their own right, or whether the analysis was merely an illustrative device.

The FEVD is a means to quantify the relative impact of different exogenous shocks. In particular, an FEVD shows the fractions of the forecast error variance of a variable due to individual shocks.[888] On a technical note, the FEVD is calculated from the moving average representation of the model.[889] The forecast error is then the difference between the value at time $t + s$ and its expectation at time t, where s is the forecast horizon.[890] In this experiment, a shock can be considered important if it contributes significantly to the forecast error variance. This again is not definite as to what may be deemed significant. However, the objective of this section is to compare the shocks' importance with respect to each other. Thus, the exercise is inherently relational and as such, this section aims to discern on whether there are many shocks which are equally important, or whether there is only a single very important shock, and which these are. Table 6.1 displays the FEVD for the horizons 1, 8, 20 and 32. These forecast horizons roughly correspond to the business cycle, indicating the importance of various shocks in the short term (horizon 1), medium term (horizons 8 and 20) and the long term (horizon 32). The FEVD is reported for variables which were matched to observables in the estimation process.

First consider the variables which form the core of DSGE models: GDP, inflation and the real risk-free return. GDP is mainly driven by innovations in technology ϵ_A which explain more than half of the forecast error variance. The remaining forecast error variance is explained by a bundle of other shocks which changes over time. The second largest contributor only reaches between 10% and 15% of the forecast error variance at any horizon.

[887] A historical decomposition of the error variance would be another means to this end. However, a historical decomposition would be more constrained in the sense that shock sequences are matched to the estimation data, while the FEVD allows for a more general interpretation of the importance of shocks in the banking model.
[888] See Lütkepohl (2005: 64)
[889] See Fernández-Villaverde, Rubio-Ramírez and Schorfheide (2016: 123f)
[890] See Fernández-Villaverde et al. (2016: 123)

		$\hat{y}$	$\hat{r}$	$\hat{\pi}$	$\hat{c}_w$	$\hat{i}$	$\hat{e}$	$\hat{b}$	$\hat{r}_k$
s=1	ϵ_A	0.413	0.039	0.039	0.241	0.153	0.036	0.035	0.086
	ϵ_B	0.001	0.002	0.002	0.007	0.005	0.078	0.003	0.002
	ϵ_E	0.144	0.393	0.393	0.011	0.208	0.320	0.244	0.453
	ϵ_G	0.081	0.080	0.080	0.085	0.267	0.084	0.085	0.151
	ϵ_I	0.002	0.003	0.003	0.013	0.072	0.001	0.001	0.050
	ϵ_K	0.014	0.028	0.028	0.006	0.000	0.242	0.327	0.048
	ϵ_M	0.024	0.291	0.291	0.012	0.002	0.084	0.151	0.004
	ϵ_{MS}	0.134	0.015	0.015	0.251	0.016	0.006	0.004	0.027
	ϵ_P	0.062	0.025	0.025	0.250	0.154	0.024	0.026	0.055
s=8	ϵ_A	0.553	0.043	0.037	0.352	0.192	0.009	0.006	0.067
	ϵ_B	0.003	0.002	0.003	0.008	0.009	0.087	0.002	0.001
	ϵ_E	0.027	0.551	0.413	0.003	0.032	0.120	0.101	0.543
	ϵ_G	0.016	0.086	0.075	0.093	0.254	0.028	0.025	0.123
	ϵ_I	0.016	0.005	0.007	0.022	0.121	0.005	0.005	0.030
	ϵ_K	0.098	0.032	0.026	0.007	0.010	0.400	0.466	0.041
	ϵ_M	0.006	0.116	0.273	0.011	0.001	0.193	0.232	0.008
	ϵ_{MS}	0.058	0.016	0.014	0.105	0.005	0.018	0.021	0.022
	ϵ_P	0.098	0.023	0.027	0.273	0.252	0.017	0.017	0.040
s=20	ϵ_A	0.534	0.043	0.037	0.466	0.220	0.016	0.017	0.067
	ϵ_B	0.004	0.002	0.004	0.005	0.010	0.069	0.006	0.001
	ϵ_E	0.015	0.549	0.410	0.002	0.021	0.075	0.066	0.542
	ϵ_G	0.017	0.086	0.076	0.127	0.203	0.053	0.055	0.123
	ϵ_I	0.035	0.008	0.009	0.015	0.148	0.004	0.004	0.032
	ϵ_K	0.127	0.032	0.026	0.014	0.018	0.400	0.430	0.041
	ϵ_M	0.006	0.116	0.271	0.014	0.003	0.185	0.207	0.008
	ϵ_{MS}	0.030	0.016	0.014	0.059	0.004	0.022	0.024	0.022
	ϵ_P	0.107	0.023	0.030	0.173	0.250	0.062	0.067	0.040
s=32	ϵ_A	0.509	0.043	0.037	0.492	0.231	0.034	0.036	0.067
	ϵ_B	0.004	0.002	0.004	0.005	0.010	0.058	0.008	0.001
	ϵ_E	0.012	0.549	0.407	0.002	0.019	0.059	0.053	0.542
	ϵ_G	0.021	0.086	0.076	0.135	0.184	0.071	0.074	0.122
	ϵ_I	0.050	0.008	0.009	0.024	0.159	0.007	0.008	0.032
	ϵ_K	0.140	0.032	0.026	0.016	0.025	0.354	0.381	0.041
	ϵ_M	0.007	0.116	0.269	0.013	0.004	0.168	0.182	0.008
	ϵ_{MS}	0.023	0.016	0.014	0.043	0.004	0.022	0.023	0.022
	ϵ_P	0.109	0.023	0.032	0.146	0.241	0.103	0.110	0.040

Table 6.1: Forecast Error Variance Decomposition for the Banking Model; mean of the distribution of decomposition draws.

The significance of technology shocks is reasonable given that a real business cycle model is at the core of the banking model, and that the data used for GDP was adjusted to per capita but not efficiency units. Furthermore, and potentially surprising given the results of the previous sections, monetary policy shocks ϵ_M only explain a small fraction of the forecast error variance of GDP at all horizons.

This is in stark contrast to inflation and the real risk-free return. In both cases, monetary policy shocks contribute about 30% to the forecast error variance in the short term. This share stays roughly constant over the medium and long term for inflation. In contrast, the corresponding share for the real risk-free return declines substantially over the medium and long term. To put this observation into perspective, consider again the impulse response analysis of section 6.1.1. After a monetary policy shock, the impact on inflation and the real risk-free return dissipates quickly, while the effect on GDP is long-lasting.[891] The FEVD suggests that monetary policy shocks contribute very little to the forecast error variance of GDP, but very much to the forecast error variance of inflation and the real return. Taking a closer look at the scales of fig. 6.1, however, might indicate the reason for this apparent conflict: while GDP decreases by only about 0.1% due to a one standard deviation monetary policy shock, inflation decreases by 1%. Thus, a monetary policy shock has a larger impact on inflation than on output in percentage terms. There are other shocks which have a larger quantitative effect on GDP than the monetary policy shock, for instance a technology shock.[892] Thus, the apparently conflicting results can be reconciled.[893]

Surprisingly, the other and in fact major contributor to the forecast error variance of both inflation and the real risk-free return is the entrepreneurial risk shock ϵ_E. One explanation may be the estimated size of the standard deviation. The standard deviation of ϵ_E is estimated to be about 3 times larger than the one of government consumption shocks, and roughly 10 times larger than the one of monetary policy shocks. Yet, this can hardly be the only reason. The standard deviation of the investment adjustment cost shock ϵ_I was estimated twice the size of ϵ_E, and ϵ_I only marginally contributes to the variance decomposition of any of these three endogenous variables. Again, the quantitative reaction to such a shock plays a role. Upon impact of ϵ_I, the percentage change in inflation is 0.12%. The entrepreneurial risk shock increases inflation by 0.90% upon impact.[894] The difference in size is similar for the real risk-free return. Conversely, the low shares of ϵ_I may be connected to the low estimates of the adjustment cost parameter ϕ_I. Even this large shock interval implies only moderate investment adjustment costs, because ϕ_I is comparatively low.[895] Thus, while the estimated size of the shock may not provide a good explanation, the sizes and responses of the parameters and variables affected by the shock may provide more intuition.

[891] Note that while the response of the real risk-free return was not depicted, the corresponding short-lived reaction is a consequence of the responses of inflation and the nominal risk-free return, as noted in section 6.1.1.

[892] See fig. D.1 in appendix section D.1 for a graphical comparison of the impulse response functions to technology and monetary policy shocks.

[893] Note that this does not moderate the importance of the results in section 6.1.1 since there the focus is on how monetary policy shocks are transmitted through the model economy.

[894] In both cases inflation is below its steady state in subsequent quarters.

[895] See section 5.3

Furthermore, it is surprising that the mark-up shock ϵ_{MS}, which directly affects inflation, contributes only a small share to the forecast error variance of inflation at all horizons. This observation can be related to two factors. Firstly, prices are not very sticky in the banking model. Thus, comparatively small mark-up shocks are sufficient to generate inflation volatility.[896] Secondly, considering the impulse response function following a positive one-standard deviation mark-up shock shows that inflation increases by 0.21%. In comparison with, for instance, monetary policy shocks this reaction is small in absolute terms. Thus, while mark-up shocks directly impact inflation, their quantitative impact is smaller than the one of other shocks. Hence, mark-up shocks contribute less in terms of the FEVD.

Forecast errors in consumption are mainly explained by technology and a mixture of mark-up, preference and government spending shocks at various horizons. The importance of technology shocks can be related to the importance of technology shocks for GDP and thus national income. Preference shocks ϵ_P directly impact the marginal utility of consumption and thus the optimal path of consumption over time. Mark-up shocks impact consumption through their effect on inflation and thus real returns. It is interesting to note that the impact of such shocks on consumption is larger than the variable (inflation) through which the shock is transmitted. In the long term the government consumption shock ϵ_G becomes more important concerning the forecast error variance of consumption. Related, government consumption shocks also contribute most to the FEVD of investment in the short term, and stay a significant contributor over the complete forecast horizon.[897] As a consequence, the large influence of government consumption shocks for both consumption and investment can be interpreted as a sign of crowding out.[898]

Turning to financial variables, for both bank equity and bank loans, the capital quality shock ϵ_K is the main shock explaining the forecast error variance.[899] Monetary policy shocks are also an important contributor for bank loans and bank equity, especially in the long term. Capital quality shocks are important because they affect the value of capital, thus the cash flow and net worth of entrepreneurs. The impact of monetary policy shocks on entrepreneurial net worth is clear from the preceding impulse response function analysis. The importance for bank loans is thus a logical extension since bank

[896] Note that this is the same but reversed argument of Smets and Wouters (2003). Smets and Wouters (2003: 1161f) find mark-up shocks to be very important for inflation. Smets and Wouters (2003: 1162) argue that given that their estimates imply very sticky prices, large mark-up shocks are necessary to generate inflation volatility.

[897] The entrepreneurial risk shock and the investment adjustment cost, preference and technology shocks are the main contributors to the forecast error variance of investment in addition to government consumption shocks. Yet, their respective shares vary over time.

[898] This is underscored by the impulse response function of a government spending shock: GDP increases initially, and both investment and consumption decrease.

[899] That is, excluding the short term. In the short term, entrepreneurial risk shocks are the single most important shock, see below.

loans fill the gap between the capital stock and entrepreneurial net worth. Remarkably, financial shocks are not the major contributor for bank equity and bank loans, especially in the long term. Of these two variables, the bank risk shock ϵ_B contributes more to the forecast error of bank equity.[900] The entrepreneurial risk shock has a large impact on bank equity as well as bank loans in the short term, but its share decreases quickly over time.

In general, the bank risk shock accounts for only a minor fraction of the FEVD, while the entrepreneurial risk shock plays a much more prominent role. Why do bank risk shocks not contribute more to the FEVD? To answer this question, consider again the consequences of entrepreneurial and bank risk shocks. Both work in a similar way: they increase the shock interval from which bank- and entrepreneur-specific shocks are drawn. Thus, for a given default threshold, more banks and entrepreneurs default, respectively. This increases monitoring costs and risk premiums. One possible indication for the results in this section might lie in the different magnitudes of monitoring costs. In case of default, the creditors of entrepreneurs pay 2.5% of the remaining assets, while banks' creditors only pay 0.6%.[901] This line of argument is at least partially supported by considering the banking model with the asymmetric $\varrho^{E/B}$ prior distribution which yields more similar estimates of monitoring costs.[902] The relative contribution of ϵ_B to the FEVD generally increases under the asymmetric $\varrho^{E/B}$ prior distribution.[903] ϵ_E continues to contribute more in the short term. In contrast, excluding for inflation and returns, ϵ_B generally contributes more to the FEVD in the long term. At the same time, the impact of ϵ_E on the real risk-free return, the real return on real capital and inflation remains many times larger than the impact of ϵ_B in both banking model versions. Thus, monitoring costs do not explain the asymmetry on their own.

The FEVD for the real return on real capital highlights a further aspect of the asymmetry. Here, the entrepreneurial risk shock contributes the largest share of all shocks both in the short and the long term.[904] An explanation for this significance might be the tight connection of entrepreneurial risk shocks with entrepreneurial net worth. As outlined in section 6.1.1, the impact on entrepreneurial net worth was instrumental in explaining the response of investment and also aggregate demand to a monetary policy shock. Thus, as entrepreneurial risk shocks directly impact entrepreneurial net worth, the effects are transmitted through the economy and time because entrepreneurial net worth comes from

[900] Moreover, the bank risk shock is the single most important shock for the real return on equity, contributing 57% of the FEVD at horizon 1, and still 56% after 20 quarters.
[901] These are the estimated values for μ^E and μ^B, respectively, see section 5.3.
[902] For details on this alternative prior distribution and estimation results, see appendix section C.4.
[903] The FEVD in table D.1 in appendix section D.2 compares the results of the benchmark and asymmetric risk premiums prior distributions.
[904] Furthermore, the second largest contribution is from government consumption shocks, which is probably connected to the crowding-out effect of government spending on investment noted above.

retained earnings of the last period. In contrast, bank equity is completely paid out every period. The new bank equity collected only depends on the expected next period profits, and not on previously disbursed bank equity or current returns. Yet, the contemporaneous returns on bank liabilities are mainly affected by bank risk shocks. In fact, the bank risk shock explains more than half of the forecast error variance of the real return on bank equity. The returns on bank liabilities impact consumption through workers' optimisation problem. Yet, the effects are comparatively small, as can be seen by the small contributions of bank risk shocks to the FEVD. Hence, a major contributing factor to the asymmetry between shocks to entrepreneurs' and banks' balance sheets appears to be that bank equity is paid out in full every period while entrepreneurial net worth depends on retained earnings.

Differences in the relative contributions of various shocks over time are difficult to link to specific estimates or characteristics. There are again several factors affecting the results, such as parameter estimates of a shock's standard deviation and the autocorrelation coefficient of the process which includes the respective shock, as well as the structure of the banking model. They all affect the moving average process from which the FEVD is derived. The results in table 6.1 indicate that some shocks have a strong impact over all considered horizons, while others are more important in the short or long term. For instance, the forecast error variance of output is mainly explained by innovations in technology over the short, medium and long term. In contrast, monetary policy shocks affect real returns strongly in the short term, but much less in the long term.

This last observation is crucial because it informs about the importance of predictable monetary policy in the banking model. If monetary policy shocks are interpreted as measurement errors, then these have significant effects on real returns in the short run. However, while measurement errors become less important for real returns over time, they are one of the principal drivers in the forecast error variance of inflation both in the short as well as in the long run. Thus, over both the short and long term, inflation expectations err to a significant extent when monetary policy changes in unpredictable ways. Importantly, inflation expectations in turn have a non-negligible impact on the actual price-setting behaviour of retailers.[905] Then, these results corroborate the view that making monetary policy predictable facilitates the anchoring of inflation expectations and forecasts. In contrast, long-term forecasts of real returns and aggregate demand mainly err due to other supply and demand shocks. Consequently, these results mirror the concepts of monetary non-neutrality in the short run and monetary neutrality in the long run.

Overall, shocks pertaining to either the demand or supply side (Υ^A, Υ^G, Υ^I, Υ^K, Υ^{MS},

[905] See the discussion about posterior estimates in section 5.3. While the influence of marginal costs on current inflation is the largest, the effect of expected inflation is non-negligible.

Υ^P) mainly contribute to the forecast error variance of real variables, while monetary and financial shocks mainly contribute to real returns and inflation. The financial volumes bank loans and bank equity are explained by all three kinds of shocks. The higher importance of real shocks vis-à-vis monetary policy shocks for real variables reflects a similar conclusion in the macroeconomic literature.[906] In particular, these results are in line with, for instance, Holtemöller and Schmidt (2008), who also find monetary policy shocks to be mainly important for real returns.[907] Nevertheless, an FEVD is highly dataset- and model-specific. As a counterexample using data on Germany in a structural VAR, de Graeve et al. (2008) find the monetary policy shock not to be very important, but rather their financial distress shock to be the single most important shock.[908] In any event, scarce reports of this kind of analysis in the literature also prevent a thorough comparison with the existing literature here. Given model specificity, the potential reduced-form interpretation of these shocks and the potential sensitivity to different sets of shocks, these results cannot be generalised.[909] Rather, they should be regarded as supplementary information for the preceding and following analyses in this chapter.

The results of the relative impact of entrepreneurial and bank risk shocks are in line with the findings of Jimenéz et al. (2012) and Ciccarelli et al. (2013). Both studies indicate that bank-specific characteristics are important only in crisis times while non-financial firm-specific characteristics play a crucial role both in normal and crisis times.[910] While there are no explicit crisis and non-crisis times in this study, these findings are comparable. Consider again the banking model estimates with the asymmetric risk premiums prior distribution. Bank risk shocks become (somewhat) more important as real resource costs spent on monitoring banks rise. By arguing that the proportion of real resource costs rises during crises, due to spillover effects for example, the connection between this FEVD and the econometric results can be made. Thus, bank risk shocks do not have a large weight in the benchmark parametrization. Yet, their weight becomes larger as the cost associated with bank default increases.

906 See Woodford (2009: 272)

907 See Holtemöller and Schmidt (2008: 15). Holtemöller and Schmidt (2008) build a small NK model and estimate it using data on Germany over the period 1975-1998.

908 See de Graeve et al. (2008: 217f). There are many possible explanations for the differences between studies, such as time period, dataset and methodology.

909 Also, other studies using different models or datasets find mixed results. Jermann and Quadrini (2012), using Canadian data and a model without banks, for instance, find that financial shocks mainly explain GDP and investment. Similar to the results for the banking model, Jermann and Quadrini (2012: 268) also find the monetary policy shock to be mainly important for inflation, while mark-up shocks play a more marginal role. In contrast, also using Canadian data and a model without banks (but a different financial friction), Bailliu et al. (2015: 154) find a sizeable impact of their financial shock on the nominal risk-free return and inflation. In their model GDP and consumption are mainly explained by preference shocks, see Bailliu et al. (2015: 154).

910 Jimenéz et al. (2012: 2f) and Ciccarelli et al. (2013: 23f). Note that this also supports the findings in section 6.1.2 that higher steady-state bank default rates imply a stronger impact.

The relative significance of these two shocks links to the roles of the corresponding balance sheet channels. As argued before, the decomposition of the credit spread with respect to entrepreneurial and bank risk premiums matters for the size and duration of the reaction of GDP to a monetary policy shock. The findings so far suggest that the main mechanism revolves around the entrepreneurial balance sheet channel, while the bank balance sheet channel fulfils an amplifying role in the banking model. This is in line with the results in Markovic (2006). In the model by Markovic (2006), the addition of the financial friction associated with entrepreneurs leads to a significant change in impulse responses after a monetary policy shock. In contrast, the addition of bank-specific frictions leads to a further amplification, but not fundamentally different behaviour.[911] Similarly, the explanation of the transmission of monetary policy in the banking model revolved around the amplifying effects of the bank balance sheet channel on the entrepreneurial balance sheet channel. Overall, the results of the FEVD support this description.

In conclusion, returning to the two questions posed at the beginning of this section, there are the following results: Firstly, the size of the estimated standard deviation of a shock may not be a good guide for judging the importance of a shock in terms of the FEVD on its own. Rather, other factors play a role for the assessment in terms of the FEVD, such as the size of the impact of a shock on endogenous variables as measured, for instance, by the impulse response function. Secondly, monetary policy shocks contribute a significant share to the FEVD of inflation and the real risk-free return. Crucially, this significance of monetary policy shocks arises when taking the effects of other forms of noise, for instance on consumers' preferences, into account. Thus, compared to other forms of distortions, monetary policy shocks matter to a significant extent for inflation forecasts. This implies that when conducting a rule-based policy in order to anchor private agents' expectations, the central bank has to be careful to act in accordance with the rule. Finally, this section also shed more light on the consequences of different modelling assumptions about net worth/equity. The fact that entrepreneurial net worth comes from retained earnings induces a dependence on past developments which is in contrast to the roll-over nature of bank equity. Different shares in the FEVD for the bank risk shock vis-à-vis the entrepreneurial risk shock reflect this modelling structure and are in line with empirical results.

[911] See Markovic (2006: 28ff)

6.2 The Trade-off between Inflation and Output Gap Stabilisation with Non-Systemic Bank Default

The previous section on monetary policy transmission established the following key results: non-systemic bank default impacts the pass-through of monetary policy impulses, and the bank balance sheet channel mainly affects the response of GDP, while the impact on inflation is marginal. For a central bank principally concerned with inflation stabilisation this would imply that there are no major changes in terms of steering inflation. There are two qualifications which are added to this conclusion in this section. The first concerns the single focus on inflation stabilisation: If the central bank only regards inflation as an objective, is the 'achievable' inflation volatility under a given monetary policy regime really unaffected by non-systemic bank default? The second concerns the ranking of monetary policy objectives: If the central bank puts weight on output stabilisation in conducting monetary policy, what happens to the trade-off between inflation and output gap stabilisation if non-systemic bank default is introduced? Answering these two questions is the objective of this section. It will show that, and how the possibilities of the central bank in terms of inflation (and output gap) stabilisation change in the banking model as compared to the financial accelerator model.

The topic of this section relates to the vast literature on the design of optimal monetary policies. The question there is how monetary policy should optimally be conducted for a given model. Optimal monetary policy is generally analysed using welfare or ad-hoc loss functions. The welfare function approach to optimal policy uses the utility function of one or more of the (representative) agents of the model.[912] Then, using a grid or an optimisation routine, for instance, the optimal coefficients in the Taylor rule are computed which maximise the welfare function. The results may be used to quantify welfare improvements from changing the weights of the rule or introducing additional variables.[913] The procedure is very similar for ad-hoc loss functions. The loss function is usually a function of the variance of inflation and output (or output gap), where different weights may be attached to the objectives.[914] Optimal coefficients are computed to minimise the loss function.

While the design of optimal monetary policy is certainly an important topic, this section will take a more general approach. The question is not: what are the optimal coefficients. Rather, it is: irrespective of the particular weights of monetary policy objectives, which

[912] See, for instance, Angeloni and Faia (2013)

[913] Additional variables may be introduced on the rationale of countering financial instability. See Quint and Rabanal (2013: 28f) for an example of such an approach. Also, for instance, Christensen, Meh and Moran (2011) use welfare analysis to examine the welfare consequences of a separate macroprudential policy rule.

[914] See, for instance, Kannan, Rabanal and Scott (2012) and Woodford (2012)

trade-off between inflation and output gap variances does the central bank face. To this end, this study follows Gambacorta and Signoretti (2014) in using Taylor curves. Taylor curves show the possibilities frontier, or put differently, the efficient outcomes of monetary policy.[915] For each possible combination of Taylor rule coefficients in a given grid, the theoretical variances of inflation and the output gap are computed using the posterior mean of the shock parameters.[916] Then, the results are plotted in the $var(\widehat{gap})$ - $var(\hat{\pi})$ space.[917] The lower envelope is the Taylor curve showing the lowest possible variance of the output gap that can be achieved for a given variance of inflation, or vice versa.[918] It is important to note that these Taylor curves do not characterise the central banks' possibilities in the steady state, since in the deterministic steady state all endogenous variables are constant. Rather, the Taylor curves show how the central banks' choice of reaction coefficients affects the variability of inflation and the output gap when the model economy is displaced from its long-run deterministic steady state due to exogenous shocks. Furthermore, the approach is rather general, in that no assumption is made on the desirability of inflation vis-à-vis output gap stabilisation. However, for a given set of weights on the two objectives, the data underlying the graphs can be used to find the parameter combination yielding the minimal loss.

A potential drawback of Taylor curves is that they do not allow any quantitative statements on welfare improvements or losses. Yet, there are a number of reasons for not dealing with optimal policy explicitly and thus abstracting from welfare analysis. Firstly, a discussion about optimal monetary policy naturally leads to questions about discretionary monetary policy or policy under commitment as well as time-consistency.[919] These aspects command a thorough investigation of their own, which is out of the bounds of this study, and is left to future research.[920] Secondly, given that both models are an abstract and certainly incomplete representation of reality, choosing a single combination of coefficients does not appear to be the most fruitful exercise in the present context, even if the coefficient combination is based on welfare comparisons. As will be shown subsequently, parametrization has a significant impact on the trade-off.

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[915] See Gambacorta and Signoretti (2014: 154)

[916] These variances are computed from the models' decision and transition functions, see Adjemian et al. (2011: 40).

[917] *var* denotes variance.

[918] See Gambacorta and Signoretti (2014: 154)

[919] The relevance of discretionary vis-à-vis rule-based monetary policy is explained in Woodford (2003: 19ff). Clarida et al. (1999: 1663, 1675ff), for instance, show in a simple NK model that commitment can improve on discretionary policy.

[920] Essentially, this study assumes that the monetary policy commits to the specific Taylor rule. Also, the central bank has gained credibility for targeting price stability. Finally, time-inconsistency problems are abstracted from by simply assuming that the central bank has to follow its Taylor rule once it has chosen the appropriate coefficients. Thus, this section deals with the question of how the choice of Taylor rule coefficients affects the potential outcomes of monetary policy.

Thirdly, in the context of models with financial frictions the design of optimal monetary policy based on a welfare analysis may come with winners and losers.[921] However, the only fully-specified utility function in the banking and financial accelerator models is the one of the representative worker. Admittedly, entrepreneurs consume as well. Yet, as Faia and Monacelli (2007) note, the risk-neutrality of entrepreneurs implies that the welfare measure is only affected by the mean entrepreneurial consumption level.[922] Since this is constant at the steady state irrespective of the monetary policy rule, their utility measure does not impact welfare rankings of different regimes.[923] Hence, potential welfare conflicts between borrowers and savers cannot be dealt with adequately using the models considered in this study. Lastly, from a practical perspective it can be argued that the monetary policy statute of the ECB mandates price stability, not welfare maximisation.[924] Price stability directly translates into the objective of low inflation variance. Thus, a welfare measure is not strictly necessary to evaluate the central banks' efficiency frontier from this point of view.[925]

The focus on output gap stabilisation in addition to inflation stabilisation can be justified by two considerations. For one, flexible inflation targeting has been adopted in a number of countries. It is derived from the desire to moderate the short-run output consequences of monetary policy.[926] A central bank which conducts flexible inflation targeting is willing to be variable in its short-run inflation target by taking into account the impact of its policy for the path of real variables.[927] Also, it can be argued that output gap stabilisation is a means to inflation stability. The two-pillar strategy of the ECB, for instance, includes an analysis of the risks to price stability stemming from developments in the real economy.[928] Finally, from a theoretic perspective, a loss function with the variances of inflation and the output gap as instruments can be derived from maximizing the utility of the representative household in an NK model.[929] This then translates into the two variables the central banks reacts to using the Taylor rule.

[921] Quint and Rabanal (2013: 28ff), for instance, find asymmetric effects on borrowers and savers, and on periphery and core households in a model on the EA.
[922] See Faia and Monacelli (2007: 3244)
[923] See Faia and Monacelli (2007: 3244)
[924] See The Member States (2012: Article 127, 1, sentence 1)
[925] Note that a welfare approach also relates to the objective of price stability to the extent that agents' utility depends on (the variance of) inflation.
[926] See Galí (2008: 95)
[927] See Galí (2008: 95)
[928] See European Central Bank (2016b, 2017), URLs in list of references
[929] See Woodford (2003: 392ff). For the cases of inflation indexation and consumption habit persistence, the loss functions contain additional lags of inflation and the output gap, see Woodford (2003: 402ff).

Figure 6.5 shows the Taylor curves for the financial accelerator and banking models.[930] The grids for the Taylor rule parameters θ_π and θ_y are 1.25 - 5 and 0 - 2.5, respectively, with step size 0.25. The grid roughly corresponds to the one used by Gambacorta and Signoretti (2014).[931] The lower bound for θ_π is dictated by stability considerations: as shown in chapter 4, the models are unstable for $\theta_\pi \leq 1$. Since the step-size is 0.25, the lower bound is given by the first step which leads to a stable and determinate equilibrium. Note that due to the nature of discrete steps, the Taylor curves presented in fig. 6.5 are actually not continuous, but provide a reasonable illustration of the underlying scatter plot. A remark on terminology: if the central bank is stated to achieve something, this means that it chooses the appropriate coefficients in the Taylor rule. The blue and green lines show the Taylor curve for the banking model with all parameters (excluding the Taylor rule coefficients) set to the posterior mean of the banking model. The blue line shows the complete banking model, while the green line depicts the Taylor curve for the banking model when the bank risk shock is excluded. The solid black line depicts the Taylor curve of the financial accelerator model where all parameters are also set to the posterior mean of the banking model. Thus, the parametrization in the left panel of fig. 6.5 is the same across all models. The second panel is explained below.

There are a couple of noteworthy points which can be taken from fig. 6.5. Firstly, there exists a trade-off between inflation and output gap stabilisation for monetary policy in both the financial accelerator and the banking models. This is evidenced by the negative slope of all Taylor curves. For a central bank which is concerned with output gap stabilisation in addition to a stable path of prices, it will have to trade off a smaller inflation variance for a lower output gap variance in a movement along the Taylor curve.

Furthermore, this trade-off is highly non-linear. When inflation variance is high, comparatively large inflation variance improvements can be achieved by aiming for a slightly higher output gap variance. This trade-off moderates as the inflation variance decreases, and reverses when inflation variance is very low. However, the slope of the Taylor curve

[930] Overall, the results of this section are qualitatively robust to considering lags of inflation and the output gap in the plotting of the Taylor curves, see footnote 929. The results concerning the position of the financial accelerator with financial accelerator parametrization Taylor curve are, however, sensitive to the coefficient multiplying the lag of the output gap. Yet, it is not clear how large this coefficient, which Woodford (2003: 403f) derives for a comparatively simple NK DSGE model, is in either the banking or financial accelerator models since the analytical form of this coefficient is not available here. For one, Woodford (2003: 404) states that, in general, the coefficient is smaller than χ. However, for the banking (or financial accelerator) model it is unclear by how much. Overall, for a sufficiently small coefficient ($\leq 0.5\chi$ using $var(\widehat{gap})$, and $\leq 0.3\chi$ using $var(\hat{y})$) the results of this section hold for this modification. In any event, this study does not focus on optimal policy. Thus, this sensitivity concerning the lag of the output gap should be noted, but is of secondary nature for the analysis here. The objective of this section is to show a central banks' possibility frontier with respect to inflation and output gap stabilisation and not to find the minimal loss.

[931] See Gambacorta and Signoretti (2014: 154)

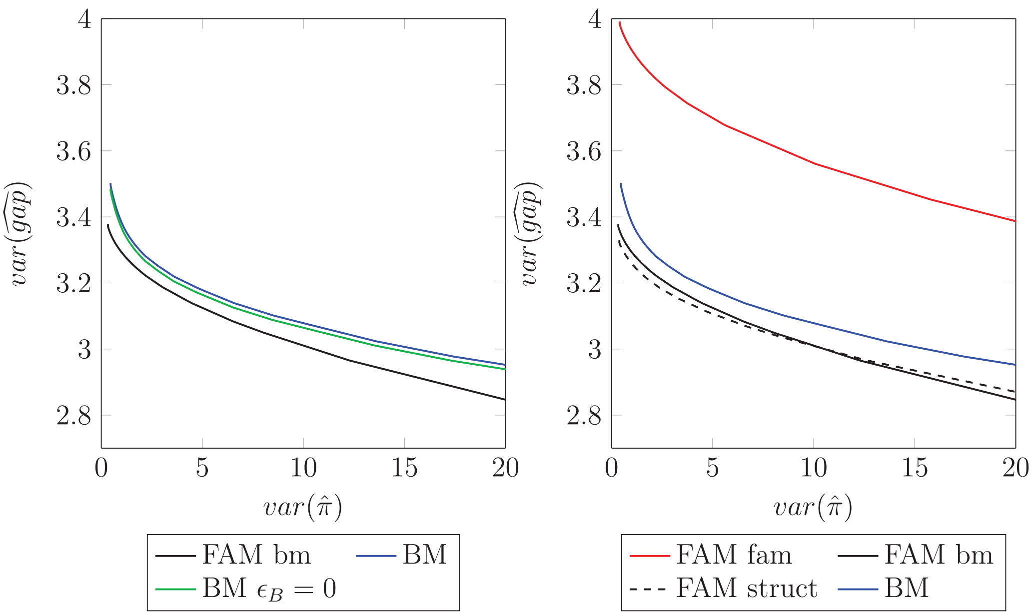

Figure 6.5: Taylor Curves for the Banking and Financial Accelerator Models I; measure of output gap: GDP deviation from GDP in a simple NK model, left panel: parameters are set to the posterior mean of the banking model, right panel: parameters are set to the posterior mean of the banking model for BM and FAM bm, to the posterior mean of the financial accelerator model for FAM fam, and a mixture (shock parameters to the values of the banking model, but structural parameters to the financial accelerator model posterior mean) for FAM struct.

implies that only moderate gains in terms of output gap variance can be achieved by allowing for a higher inflation variance. In its choice of reaction coefficients the central bank appears to have a greater influence on the variance of inflation than on the output gap variance. This directly follows from the different sizes of inflation and output gap variance that are calculated in this exercise. The output gap variance over the specified θ_π-θ_y grid does not fall below 1.99 or above 4.00. In contrast, the variance of inflation varies roughly from 0.33 to 201.[932]

Secondly, the model dynamics of the banking model imply a worse trade-off.[933] If the Taylor curves of the financial accelerator and the banking models are computed using the parameter vector of the banking model, the efficiency frontier in the banking model lies above the efficiency frontier of the financial accelerator model (left panel). Moreover, the shift is not due to the inclusion of the additional bank risk shock ϵ_B in the banking model. As can be seen in fig. 6.5, if ϵ_B is excluded from the banking model, the efficiency frontier of the banking model still lies above the one of the financial accelerator model.

932 The figures in this section show a subset of computed combinations. Unreasonably high inflation variance points, that is points that lie outside the presented axis limits, were not plotted to enable a sensible visual representation. Including these other points does not alter the results.

933 The use of 'worse' in this section does not denote a judgement, but implies that the Taylor curve moves upwards/shifts to the right. This means that for a given output gap variance, the inflation variance is higher.

This result implies that the introduction of non-systemic bank default worsens the trade-off between inflation and output gap stabilisation.[934] The observation relates to the discussion in section 6.1.1: monetary policy has larger effects on GDP at longer horizons in the banking model as compared to the financial accelerator model. Such effects contribute to the shift in the banking model efficiency frontier. Related, inspecting the left end of the curves, the banking model also does not reach the lowest possible inflation variance achievable in the financial accelerator model for the given parameter grid.[935] Thus, even if the central bank ignores the output gap, the minimum inflation variance which can be achieved in the banking model is still larger than in the financial accelerator model.

Thirdly, parameter estimates in general and estimated shock parameters in particular play a crucial role. Consider the second panel in fig. 6.5. The solid black and blue lines are the same as in the first panel of fig. 6.5. The solid red line shows the Taylor curve for the financial accelerator model with the parameters set to the posterior mean of the financial accelerator model. The dashed black line shows the Taylor curve for the financial accelerator model when the structural parameters are set to the posterior mean of the financial accelerator model and shock parameters to the posterior mean of the banking model. Hence, the difference between the solid black and blue lines shows the influence of model dynamics on the trade-off, while the difference between the solid blue and red lines shows the influence of both model dynamics and parameter estimates on the trade-off. Interestingly, the estimation produced a Taylor curve for the financial accelerator model (red line) that lies considerably above the one for the banking model. However, as can be seen from the position of the dashed black line, this upward shift is most probably due to shock parameter estimates. Whether the financial accelerator model is simulated using the posterior mean of the banking or the financial accelerator model for the structural parameters does not substantially influence the position of the Taylor curve. Yet, the values for the shock parameters matter.[936]

934 Also, the banking model induces, among others, a much higher loan variance. A central bank which takes financial factors into account will experience higher loan volatility than in the financial accelerator model irrespective of the parameter values used. To justify the inclusion of financial variables, Cúrdia and Woodford (2009) derive a loss function from the utility functions of heterogeneous households in an NK model with a credit spread arising from real resource costs of banking. Their loss function includes an additional term due to the financial friction, see Cúrdia and Woodford (2009: 31).

935 The minimum inflation variance for the banking model is 0.460, for the financial accelerator model with banking model parameters 0.331, and for the financial accelerator model with financial accelerator parameters 0.404.

936 One interpretation of this finding is that shocks in DSGE models are reduced-form rather than structural, see Chari et al. (2009: 253ff) on this issue. By estimating both models separately, the posterior estimates incorporate any changes in the underlying fundamental processes. While the following text explains the determinants of the changes in the position of the financial accelerator model Taylor curves for different parameter settings, the critique of DSGE model shocks not being structural actually underscores the argument made in the text that it is crucial to estimate, and not only calibrate, the parameters of various models.

Even though the posterior distributions are very similar, the estimation of the banking model produced a better trade-off than the financial accelerator model. How can this be explained? Disentangling the effects due to different shocks, it is clear that this observation is driven by the reaction of the model economy under investment adjustment cost and preference shocks.[937] For these two shocks, the Taylor curve of the financial accelerator model (FAM posterior mean) lies above the banking model Taylor curve. Furthermore, the output gap volatility implied by these two shocks is large as compared to the other shocks. For the other shocks, that is technology, government consumption, capital quality, mark-up, and entrepreneurial risk shocks, the efficiency frontier of the banking model always lies above the one for the financial accelerator model, irrespective of the parameter specification. Appendix section D.3 gives a more detailed account.

The main conclusion which can be drawn from this disaggregation and the discussion in appendix section D.3 is that the banking model does not only show amplified responses to shocks, as for instance with monetary policy shocks, but also dampened responses, most notably concerning investment adjustment cost shocks ϵ_I. Thus, different consequences for the Taylor curves for specific shocks arise. The observation of a dampened response to ϵ_I may appear to contradict previous arguments that the bank balance sheet channel has amplifying effects. Rather, the statement needs to be stated more precisely in terms of which mechanism the bank balance sheet channel amplifies. In particular, the existence of a bank liability constraint leads to a reinforcement of a sub-mechanism of the balance sheet channel, namely the response of entrepreneurs' external finance premium to changes in entrepreneurs' cash flow. The overall effect to ϵ_I also depends on the behaviour of other, non-credit constrained agents.[938] Thus, also in this case, the bank balance sheet channel works as an amplification mechanism. Yet, different developments in other parts of the economy work in the opposite direction which in sum lead to the dampened response. As a consequence, these Taylor curve results do not disagree with the general pattern of the second financial friction leading to an amplification. To the contrary, they lead to a refinement of the previous finding in terms of the main contribution of the bank balance sheet channel which is the reinforcement of the responsiveness of external financing costs of entrepreneurs to cash flow.

937 See appendix section D.3. Figure D.2 in appendix section D.3 depicts the graphs where only one shock at a time is included for computing the Taylor curves. All other shocks are set to zero, similar to the analysis of monetary policy shocks.

938 Higher investment adjustment costs lead capital investment funds to reduce capital supply. The existence of the bank balance sheet channel results in looser credit conditions following a positive investment adjustment cost shock as compared to the financial accelerator model. This leads to a lower decrease in entrepreneurial capital demand, ceteris paribus. Thus, the bank balance sheet channel leads to a dampened response since investment decreases by less due to better than otherwise financing conditions.

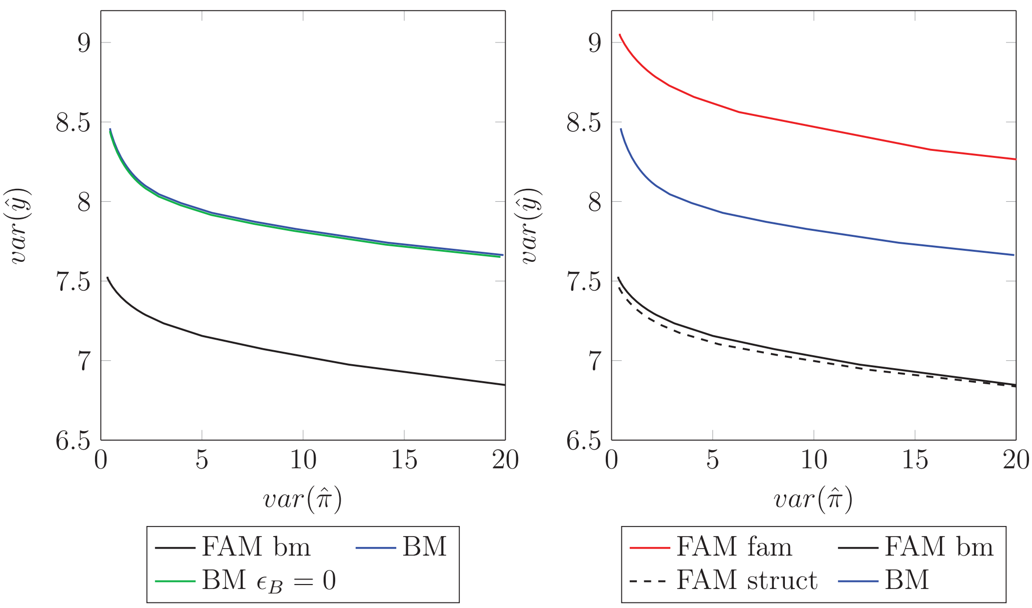

Figure 6.6: Taylor Curves for the Banking and Financial Accelerator Models II; measure of output gap: GDP deviation from its steady-state value, left panel: parameters are set to the posterior mean of the banking model, right panel: parameters are set to the posterior mean of the banking model for BM and FAM bm, to the posterior mean of the financial accelerator model for FAM fam, and a mixture (shock parameters to the values of the banking model, but structural parameters to the financial accelerator model posterior mean) for FAM struct.

Related to this point, it may be argued that the difference between the efficiency frontiers of the banking model and the financial accelerator model is small when parameters are held fixed (see left panel in fig. 6.5). However, this statement depends on the particular measure of the output gap. Using the deviation of output from its deterministic steady state as the measure of the output gap, a slightly different picture emerges.[939] Figure 6.6 repeats the experiment of fig. 6.5 using this measure of the output gap.[940] This output gap measure $\hat{y}$ is more volatile than the previous $\widehat{gap}$ (compare axis ticks), because the steady-state value of GDP is fixed while the potential output gap measure relates to a changing measure of GDP calculated with a simple NK model.[941] Figure 6.6 shows that the difference between the efficiency frontiers, holding parameters fixed, increases (blue and black lines, left panel).[942] Furthermore, this difference is now wider than the difference between the efficiency frontiers using the respective posterior mean of each model (red and blue lines, right panel). The results on the slope and the qualitative ranking of the

[939] As discussed in describing the specific form of the Taylor rule in chapter 3, there is a case for using the deviation of output from its deterministic steady state as a measure of the output gap.

[940] In the simulations for this figure, the different output gap measure was only used for computing the Taylor curve. The central bank still responds to inflation and the output gap with respect to potential output as before. The results are virtually unchanged if the central bank responded to the deviation of output from its steady-state value as well.

[941] The reason GDP changes in the simple NK model is the inclusion of various shocks, that is technology and capital quality shocks, see appendix section A.2.

[942] The effect of the additional shock in the banking model on the location of the efficiency frontier is marginal as before.

Taylor curves, though, remain unchanged.

In summary, both model dynamics as well as parameter estimates impact the trade-off between inflation and output gap stabilisation. The banking model implies more volatility than the financial accelerator model when using the same parameter values. Yet, the estimation produced a set of parameter values for the exogenous processes that move the efficiency frontier of the financial accelerator model above the one of the banking model. Then, what are the implications for monetary policy? One could argue that the central bank should be careful about disentangling the different sources of shocks. If the central bank were able to discern the source of the shock, then it can adjust its policy accordingly by choosing the appropriate Taylor rule coefficients. However, this should be regarded with caution. Firstly, shocks do not happen in an orderly sequence, whereby one shock only hits when the effects of another have phased out. Multiple shocks may happen at once or hit the model economy when the effects of another are still felt. In general, then, the central bank may not be able to disentangle movements caused by one type of shock from those caused by another. Furthermore, changing Taylor rule coefficients frequently so as to respond to different shocks raises time-inconsistency questions. Finally, since shocks are per definition unexpected, any changes in Taylor rule coefficients would be unexpected. Thus, the central bank would encounter problems in anchoring private sector expectations. In the end, the aggregate Taylor curves presented in figs. 6.5 and 6.6 are more adequate in evaluating the possibilities frontier of monetary policy in the present context.

A second implication of the results is the importance of parameters being estimated. Assume that the banking model were the correct representation of reality. Using a calibrated model, a central bank targeting a specific inflation variance would expect a lower output gap variance applying the financial accelerator model than what is achievable. This is because the banking model with the same parameter values leads to a worse trade-off. In contrast, when the models are estimated, the banking model leads to a better trade-off. The central bank would then expect the output gap variance to be much higher for a given inflation variance using the financial accelerator model. Thus, the central bank could then have targeted an even lower inflation variance using the estimated banking model.[943] Furthermore, as the example of the different output gap measure has shown, the differences can be large.

Thirdly, another implication concerns the ranking of different monetary policy objec-

[943] Note that this thought experiment implies that the central bank targeting a specific inflation variance using the financial accelerator model would still yield an inflation variance on or above the banking model Taylor curve under the assumption that the latter represents reality. What is meant in the text is, given some central bank objective function, the result may not be an extremum of this objective function. Using the 'correct' model would potentially yield a different outcome.

tives. While the choice of Taylor rule coefficients has substantial consequences for the resulting variability of inflation, the corresponding range of output gap variability values is tight. Therefore, the Taylor curves suggest that the capabilities of the central bank are comparatively limited in pursuing the goal of output gap stabilisation. This observation lends support to inflation stabilisation as the primary objective of monetary policy. At the same time, the increasing slope at the far left hand of the Taylor curves also supports the mandate to support the general development of the real economy. When inflation variability is very low, any further decreases tend to increase the volatility in the real economy at an increasing pace. Thus, there may be benefits to aiming to smooth the path of the real economy in this case. Overall, these observations suggest that the central bank's capabilities yield a clear hierarchy of objectives: first inflation, and then output gap stabilisation. Yet, this hierarchy should not be taken as definite without respect for other governmental policies' efficiency frontiers as well as a precise objective function.

Finally, these results provide a rationale for targeting a non-zero inflation rate, even though this is not implemented here. Assume the central bank only puts weight on inflation stabilisation. Then, the financial accelerator model, independent of the particular parametrization, implies a lower minimum inflation variance than the banking model.[944] According to this measure, the model with non-systemic bank default constrains the ability to stabilise prices more than the financial accelerator model. Thus, these results provide support for targeting 2% instead of 0% inflation.[945] If non-systemic bank failures imply higher inflation volatility, the argument for a buffer to the zero lower bound or deflation is reinforced. The argument can be made to pursue an even higher inflation target than 2%. Yet, this does not necessarily follow from these results since the minimum inflation variance is still comfortably within the 2% bound.

All in all, this analysis paints a mixed picture. Depending on parameter values, measure of the output gap and shock the Taylor curve of the banking model may show an improved or a worse trade-off than the financial accelerator model. The results emphasise uncertainty: since the true representation of reality is not known, the outcome of any single model cannot be taken for granted as representing possible outcomes of monetary policy. As both models are likely to be an abstract and incomplete representation of reality, it is not feasible to judge which model provides a better foundation for policy decisions. However, applying the Bayesian paradigm of model averaging may be a promising avenue in this

944 See footnote 935 above in this chapter. For the banking model and the financial accelerator model with financial accelerator model parameters the corresponding values for the Taylor rule coefficients are $\theta_\pi = 5$ and $\theta_y = 0$, and for the financial accelerator model with banking model parameters they are $\theta_\pi = 5$ and $\theta_y = 0.25$.

945 This is despite the fact that factors proposed as justifications for a higher target rate of inflation are not present in the banking model.

regard. As the results of this section suggest, when various models are used in conjunction, the target of the central bank will be more appropriately characterised by a range, not a specific point in the $var(\hat{\pi})$-$var(\hat{y})$ graph.

6.3 The Link between Non-Systemic Bank Default and Monetary Policy with Macroprudential Policies

6.3.1 General Aspects of Macroprudential Policy

Previous results established that the incidence of non-systemic bank default has multiple adverse effects for the economy. For one, real resource costs are spent in monitoring defaulting or badly-performing banks. Furthermore, extra outlays enter the governmental budget, potentially leading to tax increases or spending cuts. Finally, the investment cycle, that is the response of investment to shocks, is generally amplified due to banks' impact on entrepreneurs marginal financing costs.[946] In the banking model presented in chapter 3, the deposit insurance scheme is the only governmental policy in place to counter the negative effects of bank default (on workers' budgets in this case).[947] This section considers other instruments which may be implemented to offset the undesirable consequences or preclude the incidence of bank default. In particular, the emphasis is on the impact such policies have on the conduct of monetary policy.

The policies analysed in this chapter are illustrations of macroprudential policy. Especially since the financial crisis of 2007-8, the term macroprudential policy has been popular. It denotes policy instruments directed at promoting systemic financial stability.[948] More specifically, macroprudential policy aims at managing the adverse effects of excessive deleveraging brought about by a shock which affects numerous financial intermediaries.[949] This intention of avoiding deleveraging is the key differentiating feature with respect to microprudential policies. While microprudential policies also aim at enhancing financial stability, their primary focus is on decreasing a particular bank's default probability.[950] Furthermore, it can be argued that, when judging compliance, microprudential regulation is indifferent between a bank reducing its assets or increasing its capital base to decrease its

[946] This list can be extended, but in the interest of space, the text is confined to the most important considerations in this regard. As noted above, the response of investment in the banking model is muted in the case of investment adjustment cost shocks with respect to the financial accelerator model, see footnote 938. See appendix section D.3 for more details.

[947] Admittedly, there are also reserve requirements for bank deposits. Yet, their rationale can be based on safeguarding the payments system. Furthermore, minimum reserves do not play an active role to counter financial fragility in the banking model.

[948] See Bailliu et al. (2015: 148)

[949] See Hanson, Kashyap and Stein (2011: 5)

[950] See Hanson et al. (2011: 4)

default probability.[951] The case for macroprudential regulation rests on the reasoning that microprudential regulation's non-observance of how financial fragility is reduced becomes critical when many (or systemic) banks face problems running the risk of turning into a banking crisis.[952] Thus, macroprudential policies have a systemic point of view.

Even though this thesis does not concern systemic bank failures or financial crises, the impact of macroprudential, and not microprudential, policies will be studied here. The reason is that the banking sector is characterised by a representative bank in the banking model. Then, a microprudential policy would affect all banks equally, and thus the whole banking sector, in the banking model instead of a single bank. Therefore, macroprudential policy is the appropriate banking sector regulation to be studied here. This is not because the banking model features systemic bank failures, which it does not, but rather because the representative bank framework means that the banking sector as a whole is affected by such government intervention.[953]

One objective of macroprudential policies is thus to prevent the build-up of so-called financial imbalances which could potentially unravel in a financial crisis. Examples of macroprudential policies include loan-to-value ratios, capital adequacy ratios and the regulation of the shadow banking sector.[954] Various arguments have been proposed for warranting the introduction of such policies on economical grounds. For one, financial intermediaries' deleveraging or balance sheet shrinkage in a financial crisis creates social costs through fire sales and credit crunches.[955] Also market imperfections such as externalities and moral hazard due to, among others, government guarantees provide a justification.[956] Alpanda et al. (2014) argue that such financial market distortions make financial crises more probable, resulting in negative consequences for macroeconomic stability.[957]

In the case of the banking model the introduction of macroprudential policies can be justified, for instance, by the existence of the deposit insurance scheme. On the one hand, deposit insurance may prevent bank runs and the accompanying adverse consequences involving liquidity mismatch between bank assets and bank liabilities.[958] On the other

[951] See Hanson et al. (2011: 5)
[952] See Hanson et al. (2011: 5)
[953] One could pose the question of whether or not this means that micro- and macroprudential policies coincide in the banking model. However, as emphasised before, this study does not aim for a comprehensive treatment of banking sector regulation. Rather, the purpose of this section is to show how different policies can affect the interactions between financial fragility and monetary policy. Thus, the issue of micro- vs. macroprudential policies is not discussed further.
[954] See, for instance, Hanson et al. (2011) and Beau, Clerc and Mojon (2011) for discussions of various macroprudential instruments.
[955] See Hanson et al. (2011: 5)
[956] See Hanson et al. (2011: 5) and Alpanda, Cateau and Meh (2014: 7)
[957] See Alpanda et al. (2014: 7)
[958] See Diamond and Dybvig (1983: 403f, 415)

hand, it has been argued that deposit insurance schemes produce incentives for excessive risk-taking.[959] Macroprudential policies can then be used to moderate moral hazard on the part of banks.[960] Taking these considerations as a starting point, this study does not aim for an exhaustive treatment of macroprudential policies. Rather, the presence of macroprudential policies is taken as given. The following analyses are meant to exemplify the consequences of macroprudential policies for monetary policy in a model with non-systemic bank default. The objective is to assess the overall impact of bank default both when there is no explicit government policy aimed at reducing banking sector fragility and when there is such a policy in place. Further research can build on this, evaluating various policies in terms of their efficiency and determining optimality.

Furthermore, debates about macroprudential policies are tightly linked to unconventional monetary policies as, for example, have been practised by various central banks since the financial crisis of 2007-8. The reason this study takes into account macroprudential but not unconventional monetary policies is due to the justification of the latter as exceptional measures to deal with exceptional circumstances.[961] In contrast, this study focuses on how banking sector fragility affects the monetary transmission mechanism in normal times and not in crisis times. In the banking model, the monetary transmission mechanism is not completely unearthed by the existence of non-systemic bank default as has been shown in the first two sections of this chapter. Rather, bank default creates another layer through which monetary impulses are transmitted. The focus of this section is on whether and how additional governmental measures aimed at countering financial fragility affect this layer. Therefore, the appropriate policy measures to study in this section are macroprudential policies. The study of the relationships between unconventional and conventional policies and financial fragility are left to research focusing on extreme events where the monetary policy transmission mechanism may be severely impeded.

To this end, this section concentrates on three possible policies: an endogenous deposit insurance factor, a macroprudential Taylor rule (MTR), and a macroprudential credit spread rule (MCS). One way to interpret these three policies is to view them in terms of increasing depth of governmental regulation. The endogenous deposit insurance factor merely adjusts the existing deposit insurance scheme to take financial risks into account. The MTR extends the mandate of the central bank to adjust the nominal risk-free return in response to financial imbalances. The MCS works independently of monetary policy and allows the government to affect the credit spread directly. In this third regime, the central bank sets the nominal risk-free return in response to inflation and output gap

[959] See Hanson et al. (2011: 4)
[960] See Hanson et al. (2011: 4)
[961] See Borio and Disyatat (2009: 26). The authors base their conclusion on the various problems associated with unconventional monetary policies, see Borio and Disyatat (2009: 25f).

deviations as in the benchmark banking model.[962]

As noted above, the deposit insurance scheme in the banking model shields deposit-holders from the (direct) negative consequences of bank default. However, this policy has the side-effect of distorting workers' view of bank deposits as being default-risk-free even though the government budget, and by extension taxpayers, eventually incur the costs of bank default. The question is now to which extent the results change if deposit insurance fees depend on the fragility of the banking sector, and not only on the volume of deposits.[963] This modification is grounded in the objective of shielding the governmental budget in case of increased bank fragility to some extent. The crucial simplification that all banks pay the same share of deposit insurance fees still holds. However, this share now changes with banking sector fragility.

An MTR commands the central bank to 'lean against the wind' in its conduct of monetary policy.[964] This means that the central bank uses its interest rate policy to react to financial imbalances. As financial imbalances build up in the economy, the central bank increases the nominal risk-free return to counteract these pressures. Such a policy is a contentious issue. Proponents argue that it may help in preventing economic instability, while opponents reply with legitimacy and feasibility problems of such a policy.[965] For instance, from a welfare-theoretic view such a macroprudential Taylor rule can be justified. In analysing optimal monetary policy, Cúrdia and Woodford (2009) derive a loss function which includes a financial indicator variable from the welfare of households in a reduced-form NK framework.[966] The financial variable in the loss function is then warranted by the welfare distortions arising from frictions in the financial intermediation process.[967] Thus, a justification for such a policy in the banking model can be established on the basis of the existence of financial frictions.

Nonetheless, an MTR may be contested on the grounds that the central bank targets multiple objectives with one instrument. This may lead to compromised results concerning all objectives. Badarau and Popescu (2015), for instance, find that a macroprudential policy rule reacting to loan growth has the potential to improve financial stability.[968] However, such a policy does not improve on the standard Taylor rule in terms of price

[962] The exact formulations of these three policies will be explained in section 6.3.2.
[963] As noted in chapter 3, the calculation of deposit insurance fees is legally mandated to include risk considerations in Germany, see footnote 459 in chapter 3. All banks are the same in the banking model. Hence, risk considerations were disregarded in benchmark banking model for simplicity, as banks do not differ in terms of their asset risk profile.
[964] See Beau et al. (2011: 8)
[965] See Beau et al. (2011: 7f)
[966] See Cúrdia and Woodford (2009: 28ff)
[967] See Woodford (2012: 15)
[968] See Badarau and Popescu (2015: 370f)

stability and actually inhibits economic growth.[969] This reasoning leads to the third macroprudential policy considered here. As a separate macroprudential instrument, the MCS is introduced. Thus, as a short-cut to modelling a thorough quantity-based macroprudential policy, here, the government is able to affect the spread between loan and deposit rates directly in response to financial imbalances, without specifying precisely how.[970] This modelling strategy follows Kannan et al. (2012) and Bailliu et al. (2015).[971] Admittedly, the MCS is ad-hoc. Yet, it can be argued that it is a simple implementation of quantity-based macroprudential policies. In Iacoviello (2015), for example, the credit spread depends positively on the size of the capital adequacy requirement.[972] Effects of financial imbalances on the credit spread may work through additional requirements on capital holdings or provisions but these mechanisms are not specified.[973]

There are many more possible macroprudential policies which could be analysed. However, this would easily go beyond the agenda of this study. The choice of instruments is also governed by considerations about model specificities. For instance, there is no opportunity to evaluate regulation aimed at the shadow banking sector, since there is simply no corresponding sector in the banking model. Moreover, quantity-based instruments such as capital adequacy ratios are not explicitly analysed.[974] Capital adequacy ratios target banks' liability management. They introduce a (binding) constraint, beyond which banks cannot borrow. However, agents in the banking model can principally borrow as much as they want. The mechanism stopping agents from borrowing infinitely is increasing interest rates. Lenders, whether they be banks or equity-holders, are only willing to supply funds if they are remunerated adequately. Thus, modelling macroprudential policy using the short-cut via the credit spread rule is more in line with the logic of the banking model.[975]

[969] See Badarau and Popescu (2015: 370f)
[970] See Kannan et al. (2012: 13f) and Bailliu et al. (2015: 152f)
[971] See Kannan et al. (2012: 8, 13f) and Bailliu et al. (2015: 152f)
[972] See Iacoviello (2015: 5f). In fact, there is a great degree of similarity concerning the relationships between the credit spread and the capital requirement in Iacoviello (2015) on the one hand, and between the credit spread and the macroprudential instrument presented below on the other hand.
[973] See Kannan et al. (2012: 12ff)
[974] See for instance Van den Heuvel (2008), Aguiar and Drumond (2007) and Iacoviello (2015) for examples of (binding) bank capital constraints. Loan-to-value ratios are another example of quantity-based instruments. They regulate the asset side of banks' balance sheet. Thus, loan-to-value ratios should be regarded as an instrument to reduce entrepreneurs' riskiness. Since there is no risk-taking channel present in the banking model, such an analysis would probably contribute little to the question of the effects of bank default on monetary policy here.
[975] Related, including some form of bank capital adequacy constraint to reduce banks' reliance on external financing would entail a substantial change in the banking model layout. A bank equity adequacy constraint essentially leads to a model where workers are willing to hold any amount of equity and deposits commanded by governmental regulation. Instead, the rationale in deriving the banking model was to explicitly consider the demand side. A plausible adjustment would then have to be the introduction of internal bank net worth from retained earnings to comply with the kind of policies introduced in many countries. Such more fundamental changes to the banking model are left to future research since these changes would certainly alter the benchmark model behaviour as well, and are supplementary to the principal agenda of this research.

Given that any model is an abstraction from reality, this approach is deemed to be more purposeful in the present context.

It is important to note that these macroprudential policies affect the evolution of the banking model economy when displaced from its stable steady state. Macroprudential policies as discussed in this study do not change the non-stochastic steady state of the banking model. This is in line with the focus on business cycle developments. Thus, macroprudential policies will not be judged depending on whether they reduce banking sector fragility in the steady state. As a consequence of the log-linearisation and the focus on non-systemic bank failures, the development of a financial crisis is not traced here, and thus, macroprudential policies can also not be assessed in terms of preventing financial crises. Rather, macroprudential policies will be evaluated concerning how they affect the adjustments of the model economy back to its steady state when the model economy is displaced from its steady state by exogenous disturbances. This is in accordance with the central concern of this thesis with monetary policy. The primary question is not, can macroprudential policies enhance financial stability.[976] Rather, the question is, assuming that there are macroprudential policies in place, what is the impact of non-systemic bank default on the conduct of monetary policy?

The next section will present the adjustments to the banking model for each policy regime separately. Subsequently, the impact of these instruments on monetary policy will be evaluated using the two tools discussed above: impulse response analysis to a monetary policy shock and Taylor curves. The results suggest that the introduction of macroprudential policies affects the conduct of monetary policy with fragile banks. However, the results differ between the policy regimes as well as concerning the appropriate measurement of financial imbalances.

6.3.2 Macroprudential Policy Regimes in the Banking Model

Endogenous Deposit Insurance Factor Deposit insurance fees in the benchmark banking model are a simple function of the deposit volume. This relationship is given by eq. (3.43), reprinted here:

$$DI_t = \nu^d D_{t-1} \tag{6.2}$$

The first macroprudential instrument introduces a risk factor in computing deposit insurance fees. To this end, assume the fragility of the banking sector to be measured by banks' default probability. The justification for this choice is straightforward: bank default results in extra outlays in the government budget. The bank default probability is directly

[976] Appendix section D.5 discusses the consequences of the different macroprudential regimes with respect to measures of financial stability.

related to these additional outlays and easy to measure. Deposit insurance fees are then governed by the following equation:

$$DI_t^e = \nu_t^{de} D_{t-1} \tag{6.3}$$

where ν_t^{de} is the deposit insurance factor applied to the deposit base, given by:

$$\nu_t^{de} = \omega_{mpp} p \left(\overline{\psi}_t^B \right)^{\omega_{mpe}} \tag{6.4}$$

The superscript e denotes the version of the model with endogenous bank deposit insurance factor. ω_{mpp} and ω_{mpe} are parameters to be determined. In contrast to the benchmark banking model, ν_t^{de} is not a parameter, but an endogenous variable which depends on banking sector fragility. Note that the benchmark banking model of chapter 3 corresponds to the case of $\omega_{mpe} = 0$. What is more, ν_t^d is simply substituted by ν_t^{de} and eq. (6.4) is added to the system of equations.[977] All other relationships are unchanged. For the comparative purposes of this analysis, it is beneficial to have the same steady state for both the benchmark as well as the modified banking model (in terms of the non-linear model). Thus, the calibration of ω_{mpp} and ω_{mpe} is such that the real risk-free return is equal to the real deposit return and to the real effective deposit return in the steady state. Since the analysis will be conducted using the log-linear approximation of the model, only the calibration of ω_{mpe} is relevant.[978]

As before, assume that the real effective deposit return is equal to the real risk-free return. This means that under all circumstances banks are able to adjust the deposit return $R_{d,t}$ in such a way that banks' real effective deposit return R_{ed} is equal to the real risk-free return. Then, deviations in the deposit insurance factor are completely passed through to the real deposit return. In contrast, workers may receive a return on their deposits which differs from the real risk-free return depending on ν_t^{de}.[979] This may be justified by unspecified features of workers' deposit demand, such as transaction services, which make workers hold deposits even though their return is lower than the real risk-free return. More simply, there are no other explicit assets workers can hold in the banking model. Thus, workers cannot hold the hypothetical asset connected to the real risk-free return.[980]

977 Thus, the real effective deposit return banks pay on their deposits is given by $R_{ed,t} = R_{d,t} - \xi^r R_t + \nu_t^{de}$ instead of eq. (3.45a) in chapter 3, and the real return on bank deposits workers receive is given by $R_{d,t} = (1 + \xi^r) R_t - \nu_t^{de}$ instead of eq. (3.45b).

978 The derivation in terms of the non-linear model is illustrative for showing the differences between the benchmark and endogenous deposit insurance scheme.

979 This is true to a certain extent in the banking model with exogenous insurance factor as well. There, the log-linear approximation yields a $(1 + \xi^r)\%$ change of the real deposit return for a 1% change in the real risk-free return. In terms of pass-through, this is equivalent to overshooting. For small ξ^r, this effect is negligible.

980 This assumption is discussed further below.

Furthermore, the opposite assumption, that is for the real deposit return to equal the real risk-free return with banks' effective real deposit return varying around the real risk-free return does not change the results fundamentally. Thus, the implicit assumption is that banks are price-setters on the deposit market and workers are price-takers.[981]

Finally, workers' perception of bank deposits being default risk-free does not change because consumption and portfolio decisions are separate. Hence, bank deposits are still cheaper than bank equity from the point of view of banks, as outlined in section 4.2. Yet, ceteris paribus, an increasing deposit insurance factor induces banks to shift their liability structure towards more bank equity, thus reducing their default probability. This is because, if default banks' probability rises, then banks have to pay higher deposit insurance fees on their deposit base in order to alleviate the governmental budget from the increased probability of having to pay out bank deposits. Banks simply pass on this increase onto deposit-holders by reducing the deposit return. The lower deposit return deposit-holders receive ensures that the effective deposit return banks pay on deposits, which takes into account minimum reserves interest income and deposit insurance fees, still equals the real risk-free return. With the decrease in the real deposit return, the required return on equity also decreases, thus making bank equity less expensive from the perspective of banks.

Macroprudential Taylor Rule The second macroprudential policy concerns the Taylor rule. An MTR combines monetary policy with macroprudential policy. For example, Angeloni and Faia (2013) and Gambacorta and Signoretti (2014) use an MTR policy of this form to study the effects of macroprudential policies.[982] The core of the Taylor rule remains: the nominal risk-free return is adjusted in response to deviations of the output gap and inflation from their respective steady-state levels. In addition, the central bank reacts to financial imbalances. Thus, the MTR has the following general form:

$$\hat{r}_{n,t} = \rho_R \hat{r}_{n,t-1} + (1-\rho_R)\theta_\pi \hat{\pi}_t + (1-\rho_R)\theta_y \widehat{gap}_t + (1-\rho_R)\theta_m \widehat{m}_{tr,t} + \epsilon_{M,t} \tag{6.5}$$

where $\widehat{m}_{tr,t}$ is an additional variable indicating the presence of financial imbalances. θ_m is a parameter measuring the responsivity of the nominal risk-free return to financial imbalances. If financial imbalances build up, that is $\widehat{m}_{tr,t}$ is positive, the central bank observes increasing risks to macroeconomic stability. Hence, the central bank responds with contractionary monetary policy. In contrast, when financial sector developments are weak, the central bank will ease monetary policy in order to promote a recovery.

981 In the long term, banks do not have market power in the banking model so as to set a real deposit return different from the real risk-free return. As noted above, the parameters ω_{mpp} and ω_{mpe} are set appropriately to achieve this result.

982 See Angeloni and Faia (2013: 316ff) and Gambacorta and Signoretti (2014: 154ff)

The question is how to measure financial imbalances, thus how to define $\widehat{m}_{tr,t}$. Here, three different indicator variables are used which show different aspects of financial sector developments. These are lagged loan growth, the real price of physical capital and the loan-to-GDP ratio. The choice of loan growth and asset prices is frequently observed in the literature.[983] Concerning the timing, Kannan et al. (2012) report that contemporaneous loan growth leads to very high values for the reaction coefficients in the Taylor rule when solving for optimal policy.[984] They argue that these large coefficients imply that the central bank achieves low volatility by simply promising large reactions.[985] Thus, lagged loan growth is used here.[986] Finally, the loan-to-GDP ratio is included to analyse whether macroprudential instruments lead to different effects if they are only triggered when loan growth exceeds GDP growth.

Macroprudential Credit Spread Rule Strictly speaking, the credit spread is defined as the difference between loan and deposit rates. In the banking model loan rates are of secondary nature; the key relationships arising from the optimisation problems deal with the real return on real capital, the real wholesale return and the real deposit return. Thus, the appropriate point to introduce this macroprudential rule is the arbitrage condition of banks in granting loans (eq. (3.16)). The arbitrage condition posits that the expected real return on real capital equals the expected real wholesale return times the expected entrepreneurial risk premium.[987] Following Kannan et al. (2012) and Bailliu et al. (2015), the macroprudential instrument enters multiplicatively in this arbitrage condition.[988] This means that the deviation of the instrument from its steady-state value enters additively in the log-linear approximation as given by:

$$\mathbf{E}_t\Big[\hat{r}_{k,t+1}\Big] = \mathbf{E}_t\Big[\hat{\varrho}^{E}_{t+1} + \hat{r}_{w,t+1} + \tau_M \widehat{m}_{cs,t+1}\Big] \tag{6.6}$$

where $\widehat{m}_{cs,t+1}$ is the indicator variable. This is similar to $\widehat{m}_{tr,t}$ in the MTR discussed above. τ_M is a parameter governing the degree to which the credit spread changes with financial imbalances. For comparability, the indicator variables included in the MCS equation are the same as for the MTR: lagged loan growth, the price of physical capital and the loan-to-GDP ratio.

983 For instance, Arango and Valencia (2015), Angeloni and Faia (2013) and Gambacorta and Signoretti (2014) use asset prices, Bailliu et al. (2015), Kannan et al. (2012), Ozkan and Unsal (2013), and Quint and Rabanal (2013) use credit growth, and Quint and Rabanal (2013) also use the loan-to-GDP ratio as the indicator variable (among others).
984 See Kannan et al. (2012: 12f)
985 See Kannan et al. (2012: 12)
986 Experiments with contemporaneous loan growth as the instrumental variable produced results very similar to lagged loan growth.
987 Remember the arbitrage condition governing banks' liability management, which shows that the expected real wholesale return is the product of the expected values of the bank risk premium and the real deposit return. Thus, this condition relates both financial frictions.
988 See Kannan et al. (2012: 8) and Bailliu et al. (2015: 152)

The MCS policy affects the economy as follows. Following a build-up of financial imbalances, for instance 'excessive' credit growth, the MCS is triggered, exogenously increasing the credit spread. Because of this, entrepreneurs' marginal financing cost increases, decreasing entrepreneurs' capital demand. Thus, loan demand decreases and the 'excessive' credit growth is reigned in. To be clear, this policy will also affect non-financial volumes by decreasing investment and thus GDP, ceteris paribus.

Combined Policy Finally, the following simulations also consider the case when MTR and MCS policies are used in conjunction. This means that both additional elements, $\widehat{m}_{tr,t}$ and $\widehat{m}_{cs,t}$ in the Taylor rule and the credit spread, respectively, are used and respond to the same indicator variable. Theoretically, one could combine different indicator variables in each policy rule. Yet, as will be shown further below, this combination already yields a number of interesting scenarios which is sufficient for the illustrative purposes of this section.

Parametrization Some final notes about parametrization and method are necessary. The parameter governing the responsiveness of deposit insurance fees to banks' default probability ω_{mpe} is set to 1 for simplicity.[989] This means that the deposit insurance factor changes one for one with a change in banks' default probability. It is also a procyclical policy: when bank default occurs more frequently, banks pay higher insurance fees to compensate for higher governmental outlays. The reaction coefficient of the indicator variable in the MTR θ_m is set to 0.25, and the parameter governing the impact of the indicator variable in the MCS rule τ_M is set to 0.15.[990] These values are guided by the following considerations. The value for θ_m can be justified as being the first step of the distribution which was used for θ_y in computing Taylor curves.[991] The value for τ_M is a compromise between the values used by Bailliu et al. (2015) (0.05) and by Kannan et al. (2012) (0.3).[992] The sensitivity of the results with respect to this parametrization is discussed in appendix section D.4.

The different policies are evaluated with impulse response functions and Taylor curves. The assumptions for the responses to a monetary policy shock are the same as in section 6.1.1.[993] The parameter grid for θ_y and θ_π for calculating Taylor curves is the same as in section 6.2. Similarly, the lines depicted for the Taylor curves with macroprudential policies in section 6.3.4 are not actually continuous and the graphs only show a subset of the point that were calculated as in section 6.2. Note that the cut-off point in the

[989] All other parameters are set to the posterior mean of the benchmark banking model for the simulations.
[990] Again, all other parameters are set to the posterior mean of the benchmark banking model.
[991] The grid for θ_y ranges from 0 to 2.5.
[992] See Bailliu et al. (2015: 156) and Kannan et al. (2012: 16)
[993] This means $\epsilon_{M,1} = \sigma_M$, $\epsilon_{m,s} = 0$, $s = 2 : \infty$, $\epsilon_{x,t} = 0$, $t = 1 : \infty$, where $x = A, B, E, G, I, K, MS, P$. For details, see section 6.1.1.

Taylor curve graphs in section 6.3.4 is set to 10 for the variance of inflation to discern some differences more clearly. This is also sufficient for this exercise since the qualitative results do not change when higher inflation variance points are included.[994]

6.3.3 Macroprudential Policies and Monetary Policy Transmission

The first experiment tracks the transmission of a monetary policy shock for each macroprudential policy regime separately. Consider first the endogenous deposit insurance factor. Figure 6.7 depicts the responses of GDP, the nominal risk-free return and inflation to a contractionary monetary policy shock.[995] The blue line depicts the benchmark banking model without macroprudential policy, while the green dashed line shows the banking model with endogenous deposit insurance factor. It is clear that the effects of a contractionary monetary policy shock are only marginally different.[996] The responses of inflation and the nominal risk-free return in the endogenous deposit insurance factor banking model are indistinguishable from the responses in the benchmark model. However, the endogenous deposit insurance factor leads to a marginally lower impact on GDP while the time it takes for GDP to return to its steady state is not fundamentally affected. A larger difference between the benchmark banking model and the endogenous deposit insurance factor version can be achieved by increasing ω_{mpe}.[997] Section 6.3.4 and appendix section D.4 will discuss why an increase in ω_{mpe} may not be a good strategy.

This similarity between the banking model with and without the endogenous deposit insurance factor can be explained by the following considerations. The fundamental mechanism transmitting the contractionary monetary policy impulse is still the increase in real returns. It is the determination of the real deposit return which the endogenous insurance factor affects. As the real deposit return changes, so does the required return on bank equity, in turn affecting the bank risk premium as well as the required return on lending, that is the real wholesale return. Entrepreneurs' marginal financing cost, investment and aggregate demand are affected through these two latter factors.

As mentioned in section 6.1.1, banks' financing situation does not deteriorate monoton-

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[994] Besides, based on a loss function with inflation and the output gap as arguments, the maximum inflation variance depicted in the graphs in section 6.3.4 would be in line with central bank preferences regarding output gap variance about three times more important than inflation variance.

[995] Note that the y-axis scales in fig. 6.7 appear to be rather wide because they are aligned with the respective panels in fig. 6.8 for immediate comparability.

[996] The results are virtually unchanged if the endogenous deposit insurance depends on the lagged bank default probability.

[997] That is, up to a certain point. Put differently, higher positive values for ω_{mpe} can lead to a deviation of output from its steady state which is larger than in the benchmark banking model. See section 6.3.4 and appendix section D.4 for more details.

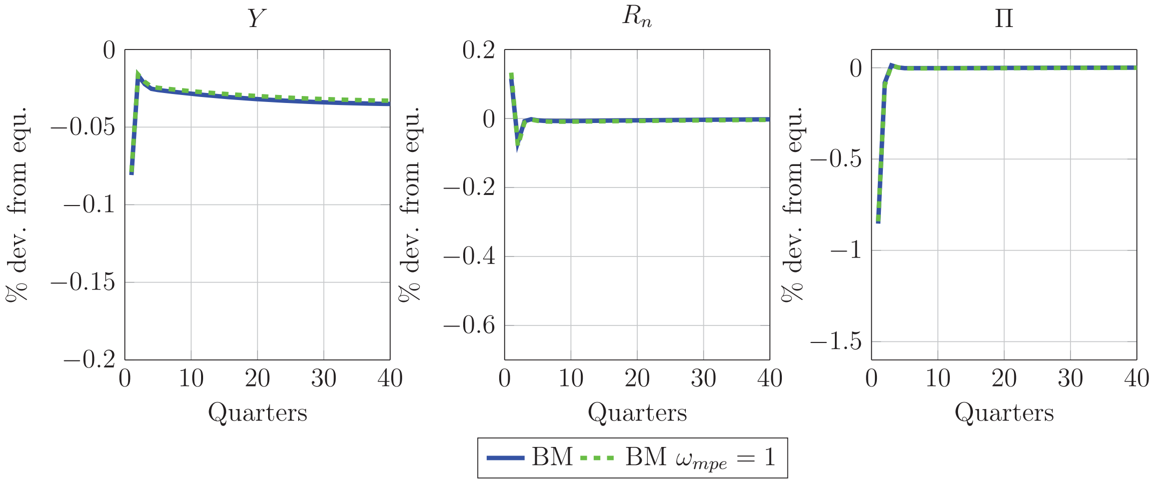

Figure 6.7: Reaction to a Contractionary Monetary Policy Shock with Endogenous Deposit Insurance Factor; BM (blue line): benchmark banking model, BM $\omega_{mpe} = 1$ (green dashed line): endogenous deposit insurance factor banking model; for comparability, the axis ticks in each panel are aligned with the respective bounds in fig. 6.8; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

ically following a contractionary monetary policy as opposed to the one of entrepreneurs. Thus, the deposit insurance factor oscillates around its steady state following the shock as a result of the oscillation in banks' default probability. The oscillation arises due to counteracting effects from the initial shock and subsequent easing of monetary policy coupled with the response of entrepreneurs' loan demand on bank profits. Overall, the response of investment and GDP is dampened with respect to the benchmark model because the phases during which banks' financing situation eases through decreases in the deposit return outweigh the phases of tightening.[998] Put in a nutshell, if the endogenous deposit insurance fee is introduced, there are no fundamental changes to the monetary transmission mechanism in the banking model. There is only a marginal effect of the endogenous deposit insurance factor.[999]

Turn next to the MTR and MCS policies. Figure 6.8 depicts the impulse responses of GDP, the nominal risk-free return and inflation to a contractionary monetary policy shock. The indicator variable is lagged loan growth in the top three panels (fig. 6.8a), the loan-to-GDP ratio in the middle three panels (fig. 6.8b), and the real price of physical capital in the bottom three panels (fig. 6.8c). For each of these three cases, the panels

998 The real deposit return decreases whenever the deposit insurance factor increases. Note that the real effective deposit return the bank faces is always equal to the real risk free return. However, the lower real deposit return workers receive induces workers to be willing to accept a lower real equity return as well. This is meant by the term of an easing bank financing situation.

999 One may argue that the marginal impact of the endogenous insurance factor is due to agents not incorporating the deterioration in the government budget through higher taxes in their decision making. However, the result of a more protracted response in the banking model is robust to changes in the assumptions about the tax rate as in section 6.1.1. This can be explained by the separation of workers' optimisation problems.

depict the reaction of the benchmark banking model without any macroprudential policy (blue solid line), the banking model with an MTR (red dashed line), the banking model with an MCS (green dashed line), and finally the banking model with both the MTR and the MCS in place simultaneously (MTR+MCS, black dashed line).

To begin with, neither the use of the lagged loan growth nor of the real price of physical capital in any policy combination lead to a markedly different response of the considered endogenous variables following a monetary policy shock as compared to the benchmark banking model. There is a small change in the reaction of GDP with financial imbalances being measured by lagged loan growth (top left panel): Here, the MTR policy (red dashed line) leads to a marginally stronger effect in the long run, while the contrary is true for the MCS policy (green dashed line). Yet, both of these differences are similar in scale to the one shown in fig. 6.7. Furthermore, when both the macroprudential Taylor and credit spread rules react to lagged loan growth, the impulse response function of GDP lies in between these separate cases, indicating that the single instruments offset each other.

In contrast, macroprudential policy reacting to the loan-to-GDP ratio leads to significantly altered paths of GDP, inflation and the nominal risk-free return (fig. 6.8b). Consider first the MTR policy (red dashed line). Here, the effect on GDP is stronger both initially and over the long term as compared to the benchmark model. The downward shift of the GDP response function suggests that this policy combination does not decrease the time it takes for GDP to return to its steady state. Furthermore, the MTR policy leads to a marked and long-lasting decrease in inflation. This applies to the nominal risk-free return by extension through the high inflation reaction coefficient in the Taylor rule. Consider then the MCS policy reacting to the loan-to-GDP ratio (green dashed line). Here, the initial reaction is also stronger for GDP, inflation and the nominal risk-free return than for the benchmark model. Additionally, GDP returns to its steady state at a much quicker pace than in the benchmark model. While GDP does not reach the steady state within 40 quarters, the difference in persistence between the benchmark banking model and the MCS policy is noticeable. In contrast, inflation and the nominal risk-free return are reduced for a longer period of time than in the benchmark model, but return to the vicinity of their steady states within 20 quarters. Finally, the MTR+MCS policy leads to an amplified response, which is larger than any other policy combination in fig. 6.8 in the short to medium term, and follows the quicker pace of the MCS policy in terms of the time it takes for the variables to return to their steady states.

The explanation for these dissimilar patterns of the macroprudential policy combinations is two-fold: On the one hand, the sign and size of the induced initial reaction of the indicator variable after a monetary policy shock is important. On the other hand,

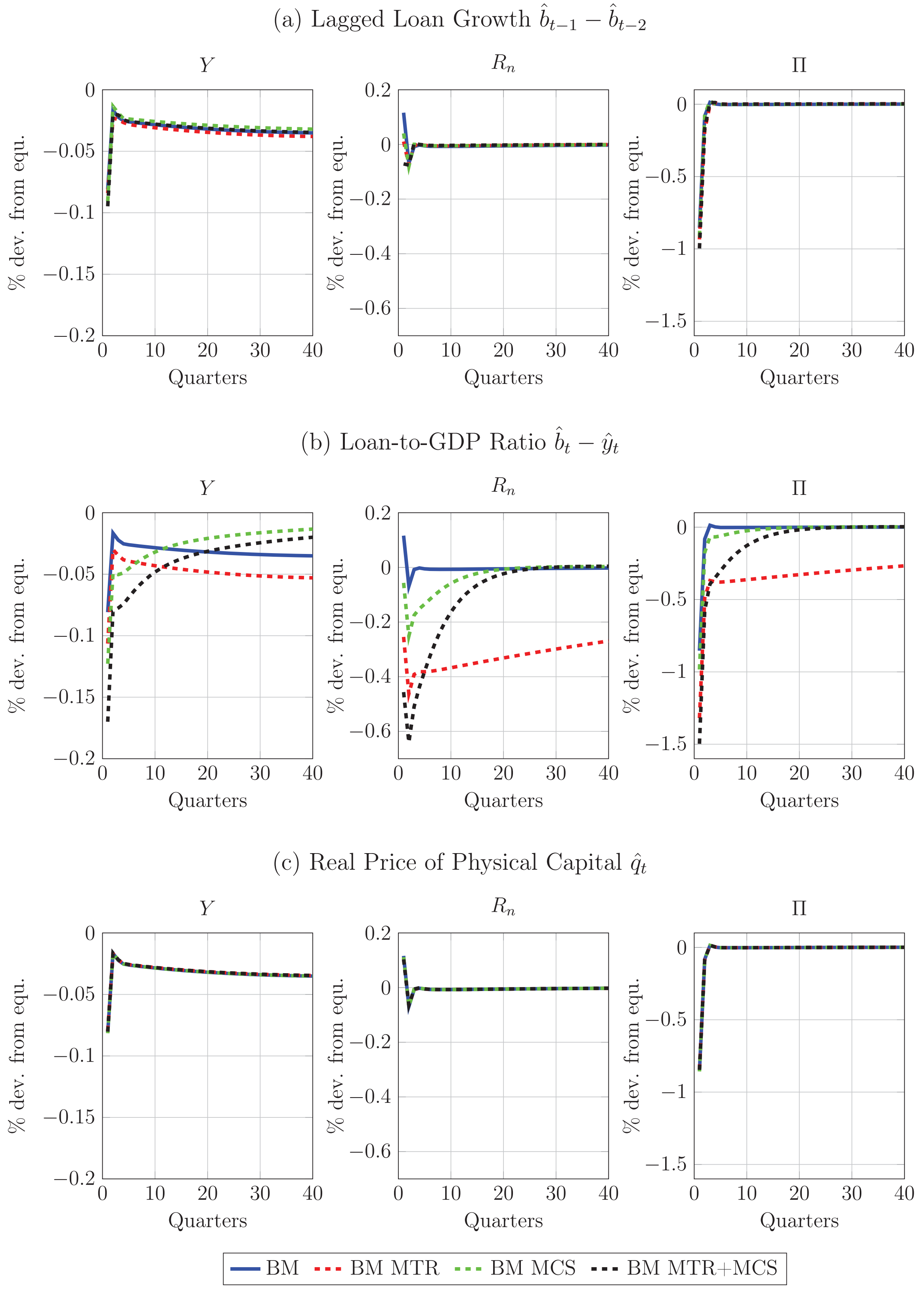

Figure 6.8: Reaction to a Contractionary Monetary Policy Shock with Macroprudential Policies; MTR represents the macroprudential Taylor rule, MCS is the macroprudential credit spread rule and MTR+MCS applies to the case where both of these policies are used in conjunction; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

the duration for which the indicator variable is displaced from its steady state plays a crucial role. Take the MTR policy with the real price of capital as an example of the first point: Following a contractionary monetary policy shock the real price of physical capital decreases. With a macroprudential Taylor rule in place, this leads to downward pressure on the nominal risk-free return. Thus, the introduction of the additional variable in the Taylor rule moderates the contractionary impact of the monetary policy shock on the nominal risk-free return, and by extension on the economy.[1000] In contrast, lagged loan growth and the loan-to-GDP ratio both increase following a monetary policy shock (see below). Thus, using the MTR policy with either of these latter two indicator variables produces a further contractionary effect. Moreover, the real price of physical capital reacts quantitatively less than lagged loan growth and the loan-to-GDP ratio. Thus, the quantitative impact of using the real price of physical capital as the indicator variable is smaller as compared to the other two variables.[1001]

Concerning the time it takes for the indicator variables to return to their steady states after the initial shock, the comparison of lagged loan growth and the loan-to-GDP ratio is informative. Following a contractionary monetary policy shock, entrepreneurial loan demand increases immediately because net worth falls considerably. Due to the sluggish return of entrepreneurial net worth (see section 6.1.1), the loan volume also only slowly returns to its steady state. That means, lagged loan growth shows a stark increase in the second quarter following a contractionary monetary policy shock, and subsequently shows marginally negative growth rates. In contrast, the loan-to-GDP ratio is significantly higher than its steady-state value from the period of the shock, and only slowly reverts to its steady state.[1002] Thus, the use of lagged loan growth can be interpreted as a strong one-off effect. To the contrary, the contractionary effect of the loan-to-GDP ratio on the nominal risk-free return and the credit spread is long-lasting. This explains why the responses of GDP, inflation and the nominal risk-free return are significantly different from the benchmark model when the loan-to-GDP ratio is used as an indicator variable, while the responses are only marginally different in the case of lagged loan growth.

However, the differences between the indicator variables do not explain the asymmetric effects of the MTR and MCS policies. Turn next to the specificities behind the MTR policy. As noted above, contrary to the easing effect of the real price of physical capital,

[1000] The differences are too small to be discernible in fig. 6.8c.

[1001] For the same reasons, the response under the MCS policy is also marginal for the real price of physical capital $\hat{q}$. For the MTR policy with $\hat{q}$ to yield a similar absolute quantitative impact on the nominal risk-free return as lagged loan growth in fig. 6.8a, the coefficient θ_m for $\hat{q}$ would need to be 0.5 instead of 0.25. Since $\hat{q}_t$ has a dampening effect, the large amplifying effects of the loan-to-GDP ratio $\hat{b}_t - \hat{y}_t$ as an indicator variable cannot be replicated.

[1002] The effect of increasing bank loans and decreasing GDP reinforce each other with respect to the increase in the loan-to-GDP ratio.

the peak in lagged loan growth in the second quarter works as a further contractionary element in the Taylor rule. Thus, with monetary policy reacting to lagged loan growth, the nominal risk-free return would turn out higher, ceteris paribus. Private agents are informed about the central banks' policy function and thus expect the additional contractionary monetary policy. This explains why the economy is more strongly affected with the MTR policy as compared to the benchmark banking model.

In contrast to the one-off contractionary effect of lagged loan growth, the use of the loan-to-GDP ratio as the indicator variable has a long-lasting contractionary effect. Thus, the GDP decreases more strongly in the latter case. The long-lasting effect of contractionary monetary policy is also reflected in the prolonged decrease in inflation. In contrast to the one-off monetary policy shock which reduces inflation for only a short time, the contractionary pressure of the loan-to-GDP ratio lasts for a long period of time and induces retailers to smooth their price-setting decision. Thus, inflation only slowly returns to its steady state. In turn, both the long-lasting macroprudential trigger as well as long-lasting low inflation lead to a prolonged decrease in the nominal risk-free return according to the Taylor rule.[1003]

The MCS policy yields results which can be deemed the opposite of the MTR policy. This is due to the fact that the MCS does not increase the general level of interest rates, but instead affects the credit spread. Furthermore, the credit spread under the MCS policy does not rise due to higher default probabilities but exogenously from the point of view of entrepreneurs and banks.[1004] Consider only a contractionary MCS policy due to increases in the loan-to-GDP ratio or lagged loan growth.[1005] With respect to the benchmark banking model, loan demand still increases due to the decrease in entrepreneurs' net worth. Thus, increasing and costlier loans lead to a further fall in investment and GDP initially. Yet, subsequently, entrepreneurs' net worth and investment, and also GDP recover more quickly than in the benchmark banking model. The MCS policy thus induces lower capital demand due to higher marginal financing costs in the first quarters after the shock. This allows entrepreneurs to repair their net worth base and thus reduce their reliance on expensive bank debt more quickly. For the one-off impact of lagged loan growth these differences are marginal. However, for the loan-to-GDP ratio the effects of macroprudential policy are sizeable. In this latter case, the effect is large enough such that investment and net worth return to their respective steady states at a faster pace than

[1003] This reasoning is analogous to the discussion about why the monetary policy shock is larger in absolute size than the resulting change in the nominal risk-free return in section 6.1.1.

[1004] Lagged loan growth does not enter the computation of any risk premium. The loan-to-GDP ratio is not exogenous to the computation of risk premiums. Thus, there may also be indirect effects in this case.

[1005] Given the linearity of the model, the responses are symmetric for the easing effect of the price of physical capital.

in the benchmark banking model with the corresponding consequences for the path of GDP.

Furthermore, the different paths of the MTR and MCS policies are in fact explained by these different dynamics and not, for example, by the impact of parametrization. For instance, for lagged loan growth, both macroprudential instruments imply a contractionary impulse by increasing the nominal risk-free return (MTR policy) or the credit spread (MCS policy), respectively. Yet, with the MTR policy the response of GDP is amplified with respect to the benchmark model, while it is dampened with the MCS policy. The main impact of different parametrizations is on the size of the deviation of endogenous variables from their steady state in response of a monetary policy shock. Furthermore, the sensitivity analysis reported in appendix section D.4 shows that the qualitative results in fig. 6.8 hold for different parameter values.

The way in which the individual MTR and MCS policies move the economy is crucial for understanding the behaviour under the MTR+MCS policy case. This concerns whether the MTR and MCS policies individually work in the same or opposite directions. For lagged loan growth, the MTR and MCS policies individually move the economy in opposite reactions in response to a monetary policy shock. Thus, the individual policies offset each other. In contrast, the MTR+MCS policy with the loan-to-GDP ratio leads to a response which is stronger (initially) than under any single policy instrument since both individual policies work in the same direction. The response is stronger for MTR+MCS than the individual policies, because both individual policies amplify the responses of the endogenous variables as compared to the benchmark model. Subsequently, the lower persistence of the MCS policy outweighs the reaction under the MTR policy. However, when both policies are implemented simultaneously, the response of all three variables is stronger and longer-lasting than when only the MCS policy is in place. Thus, the addition of an MTR to an existing MCS rule has a further contractionary effect, but does not determine by itself the duration of the response.

A related corollary of the analysis of the MCS policy with the loan-to-GDP ratio raises another topic: if the government tightens credit conditions in the short and medium run following a contractionary monetary policy shock, the speed of recovery concerning entrepreneurial net worth, investment and GDP is much higher. Thus, while the balance sheet position of entrepreneurs worsens with respect to the benchmark banking model in the short run, it also means that balance sheets are repaired more quickly. This creates a new trade-off for financial stability if speed of recovery and small impact on entrepreneurial balance sheets are taken as objectives: macroprudential policy may shorten the time of balance sheet repair, but at the cost of depressing the situation immediately after a shock.

Yet, this last result has to be regarded with caution given the reduced-form and ad-hoc implementation of the macroprudential policies. The ability of the government or a macroprudential authority to actually affect the credit spread may be rather limited. Further, and more importantly, such a manipulation (other than a direct regulation of the size of the credit spread) will most probably involve costs of some form for one of the agents. These have been neglected in the interest of clarity, but play a crucial role in determining the efficiency and desirability of any policy. Thus, these results suggest that research in this area should be clear on the specific implementation, costs and benefits of such a policy. Furthermore, the specific implementation of a macroprudential policy does not only impact the evaluation in terms of financial stability. Crucially, this section shows that the specificities of the macroprudential policy affect the assessment of the effects on the conduct of monetary policy.

One important factor which is only touched upon here are adjustment lags. Adjustment lags concern two kinds of lags. They may be on the part of the policy institution which only gradually responds to developments as they are incorporated into the decision-making process. The use of lagged loan growth can be interpreted as an example of such a lag. On the other hand, private agents may be slow in adjusting to new regulatory stimulus. The rational expectations and perfect foresight assumptions of the banking model preclude the incorporation of this latter kind of lag. Furthermore, these two assumptions also prevent the former kind of lags to have any significant effect on the results.[1006] Since private agents know the structure of the model and the monetary policy function, agents' expectations already incorporate the impact of lagged loan growth on the risk-free return in the future. Thus, decision-making lags concerning policy do not have a major impact.

What is more, adjustment lags may not be considered important because they change the transmission of monetary policy shocks. Rather, adjustment lags need to be considered because macroprudential policy reacting with a lag may hit the economy when it is already recovering and the macroprudential impulse is not 'necessary' any more. This question, however, commands a different analysis and focus from the one pursued here. Such an analysis can be primarily interpreted as concerning the response of macroprudential policy to financial shocks. The question is then whether macroprudential policy is able to respond adequately to such (adverse) developments in the financial sector. In contrast, the rationale for studying the impact of macroprudential policies in this thesis is based on the question whether the impact of financial fragility on monetary policy is altered when the government additionally aims to foster financial stability. Financial fragility and macroprudential

[1006] As noted above, results are not qualitatively different when contemporaneous loan growth is used instead of lagged loan growth. In fact, using contemporaneous loan growth shows that the change in the response of GDP after a monetary policy shock is in the same direction but somewhat stronger than for lagged loan growth.

policies can then be interpreted as established features of the banking model economy. While this does not alleviate the need for the correct timing of macroprudential policy, the fact that this kind of policy is taken into account by private agents immediately can be deemed a reasonable starting point. Future research in this direction can then go further and discern the optimal timing, communication and measurement strategies of macroprudential policies.

To conclude, the results suggest that macroprudential policies which imply a small one-off effect on either the nominal risk-free return or the credit spread affect the transmission of monetary policy only marginally. In contrast, if macroprudential policy is triggered over a prolonged period of time, then the responses of GDP, inflation and the nominal risk-free return change significantly. Moreover, the choice of indicator variable is crucial in determining whether macroprudential policy induces a contractionary or an expansionary, short-term or long-lasting effect on the economy. For a more comprehensive assessment of the consequences for monetary policy, the next section will turn to the trade-off between inflation and output gap stabilisation and to the question whether previous results are affected by the introduction of macroprudential policies.

6.3.4 Macroprudential Policies and the Inflation-Output Gap Stabilisation Trade-off

The dynamics of the benchmark banking model led to a deterioration of the inflation-output gap variances trade-off, while the posterior estimation produced a set of parameters that yielded an improvement of the banking model with respect to the financial accelerator model when both models were evaluated using the respective posterior mean.[1007] So, how do different macroprudential policies affect this result?

To this end, fig. 6.9 displays Taylor curves for the various macroprudential policies.[1008] Panels 1 to 3 show the macroprudential policy combinations already considered in fig. 6.8 for each of the three indicator variables.[1009] Again, the benchmark banking model (blue line) is included as a reference. The fourth, bottom right panel shows the Taylor curve for the endogenous deposit insurance factor version without bank risk shocks.[1010]

[1007] See section 6.2

[1008] In computing the graphs the output gap definition of the deviation of GDP from its counterpart in a simple NK model is used, as in fig. 6.5.

[1009] The Taylor curves in fig. 6.9 were also computed using different values for τ_M (0.05 to 0.3 in 0.05 steps) and θ_m (0.5 to 2.5 in 0.5 steps). The results of this section generally hold with these different parameter values. See appendix section D.4 for more details.

[1010] Note that in fig. 6.9 the legend on the left-hand side applies to panels 1-3 concerning the indicator variables lagged loan growth, loan-to-GDP ratio and real price of physical capital, and the legend on the right-hand side applies to the endogenous deposit insurance factor.

Starting again with the endogenous deposit insurance factor, one would expect that the Taylor curve looked similar to the benchmark banking model Taylor curve given the results of the impulse response analysis.[1011] However, the Taylor curve for the endogenous deposit insurance factor model with $\omega_{mpe} = 1$ moves considerably upward: the lowest inflation variance achievable is 6.42, and the lowest possible output gap variance is 49.88 (not depicted). This huge shift is primarily explained by the reaction of the economy to one shock: the bank risk shock ϵ_B. The endogenous deposit insurance factor banking model shows immensely amplified responses to this shock. This is a further reason for not increasing the value of the ω_{mpe} parameter mentioned in section 6.3.3.[1012] Consequently, the Taylor curve for the endogenous deposit insurance fee model without bank risk shocks is depicted in the fourth panel in fig. 6.9. Here, the intuition is proven right. The Taylor curve is almost identical to the benchmark banking model Taylor curve without bank risk shocks. In fact, the macroprudential policy shifts the Taylor curve upwards, but the magnitude of this shift is negligible.

Why are bank risk shocks amplified through this policy to such an extent? A bank risk shock increases the shock interval from which bank-specific shocks are drawn. For a given default threshold level, this increases banks' default probability. Since variables are defined as percentage deviations from the steady state, the resulting change for such a shock is very high. This large volatility only arises in this case because the bank default probability separately enters an equation which is not related to the computation of the bank risk premium. The bank risk shock does not increase the volatility of benchmark banking model dynamics as much because the bank risk premium depends on both extremes of the bank-specific shock interval, and the bank risk shock enlarges both bounds of the interval.[1013]

However, in the endogenous deposit insurance factor version, the deviation of deposit insurance fees from their steady state depend proportionally on the deviation of banks' default probability from its steady state. A stark percentage increase in banks' default probability then leads to an equally stark increase in the endogenous deposit insurance factor. Since this directly affects the real deposit return, the introduction of the endogenous deposit insurance factor increases the volatility through its impact

[1011] See appendix section D.4 for details on the sensitivity of these results to parametrization.

[1012] Setting $\omega_{mpe} = 0.5$ already yields a minimum inflation variance of 1.55 and minimum output gap variance of 11.45. Conversely, $\omega_{mpe} = 5$ yields minimum values of 479.02 and 4185.78 for these two variances, respectively.

[1013] See the Taylor curve comparison between the benchmark banking model and the one without bank risk shocks.

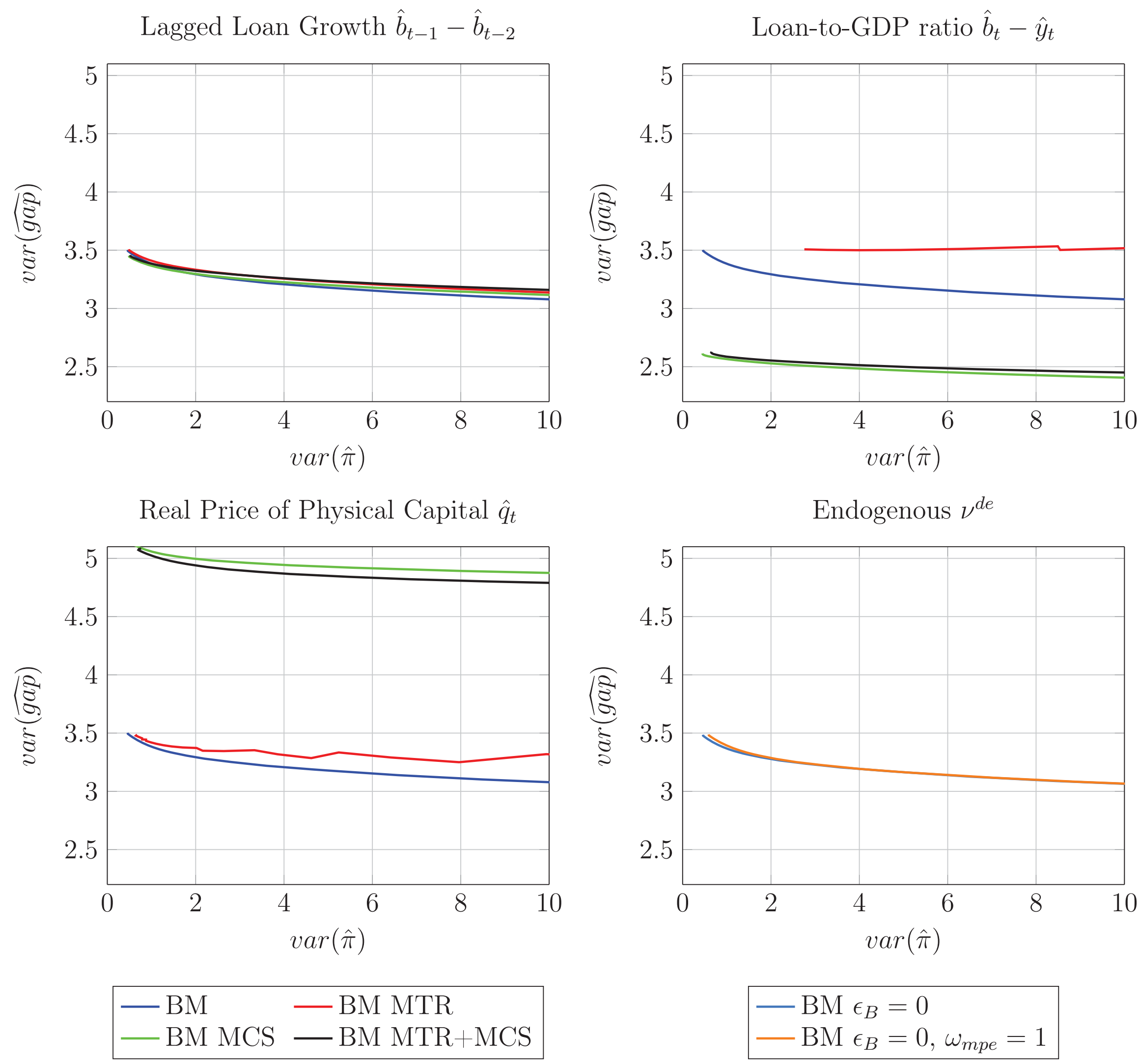

Figure 6.9: Taylor Curves with Macroprudential Policies; the legend on the left-hand side applies to panels 1-3 concerning the indicator variables lagged loan growth, loan-to-GDP ratio and real price of physical capital, the legend on the right-hand side applies to the endogenous deposit insurance factor; MTR represents the macroprudential Taylor rule, MCS is the macroprudential credit spread rule and MTR+MCS applies to the case where both the MTR and MCS policies are in place simultaneously.

on real returns.[1014] This does not mean that the introduction of the deposit insurance factor does not mitigate adverse financial shocks. In fact it can.[1015] However, the crucial implication for monetary policy as analysed here is that it increases volatility vastly.[1016]

[1014] Incidentally, in an FEVD, bank risk shocks become the single most important shock for almost all endogenous variables and contribute more than 90% to the FEVD for a clear majority of variables. This is clearly counterfactual.

[1015] Here, results again depend on the parametrization.

[1016] As discussed in appendix section D.4, this peculiarity with bank risk shocks does not arise when banks' leverage ratio is used instead of banks' default probability. This is because percentage changes in ϕ^B are not as large. Yet, for the same reason, changes in monetary policy transmission are negligible. Thus, banks' default probability is deemed more illustrative. See appendix section D.4 for more details.

Indicator Variable	$\hat{b}_{t-1} - \hat{b}_{t-2}$	$\hat{b}_t - \hat{y}_t$	$\hat{q}_t$
Macroprudential Taylor Rule	0.489	1.579	0.648
Macroprudential Credit Spread	0.491	0.453	0.485
Both	0.517	0.647	0.703

Table 6.2: Minimal Inflation Variance with Macroprudential Policies

Turning to the MTR and MCS policies, it is clear that there are again significant differences both between the rules and concerning the indicator variables. For lagged loan growth, the Taylor curves move negligibly. In fact, the Taylor curve of the MTR is marginally shifted upwards from the benchmark model. The MCS rule tilts the corresponding Taylor curve. This means, for very low inflation variance values (roughly < 1.75), the MCS policy leads to a slightly better trade-off. Yet, for higher values the MCS Taylor curve lies above the blue line, and the trade-off between inflation and output gap variances is worse than in the benchmark banking model.

More sizeable differences appear in the second and third panels for the loan-to-GDP ratio and the real price of physical capital, respectively. With the loan-to-GDP ratio as the indicator variable, the MCS policy Taylor curve shifts noticeably downwards. In contrast, the MTR policy leads to a worsening of the trade-off as compared to the benchmark model, as the corresponding Taylor curve shifts upwards. In the case of the real price of physical capital as the indicator variable, both macroprudential policies lead to a deterioration of the trade-off. Yet, the shift for the MCS policy is much larger than the one for the MTR policy.

Finally, the trade-offs produced by the MTR+MCS policy are not a simple product of the individual policies, contrary to finding of the impulse response analysis. At least in the cases considered here, the MCS policy appears to be instrumental in shaping the MTR+MCS Taylor curve, while the MTR policy seemingly acts as an add-on. For all three indicator variables, the MTR+MCS policy Taylor curve lies very close to the corresponding MCS policy Taylor curve, irrespective of the position of the MTR Taylor curve. For the loan-to-GDP ratio and the real price of physical capital, the MTR+MCS Taylor curve lies in between the respective MTR and MCS Taylor curves. Yet, this is not always the case. Consider lagged loan growth: The MTR+MCS Taylor curve lies above the MCS Taylor curve roughly in parallel. This means that for low inflation variances the MTR+MCS Taylor curve lies in between the respective MTR and the MCS Taylor curves. Yet, for higher inflation variances (roughly > 3.4), the Taylor curve for the MTR+MCS Taylor curve lies above the one of the MTR policy. This underscores the observation that the MCS policy appears to impact the trade-off more in the MTR+MCS case than the MTR policy. Put differently, with an MCS policy in place, adding an MTR policy does not worsen the trade-off as much as when there is no MCS policy. Yet, the real price of physical capital also points to another feature: if both the MTR and the MCS policies individually imply a deterioration of the trade-off, then the combination in terms of the MTR+MCS policy does not need to fare even worse. In this case, adding the MTR policy to the MCS policy dampens fluctuations in response to shocks to some extent, such that the Taylor curve shifts back downwards.

To view the results from a different angle, consider again the respective minimum inflation variance which is achievable in each policy case. These are summarised in table 6.2.[1017] The minimum inflation variance in the benchmark banking model is 0.460. It is clear that all policy and indicator variable combinations lead to an increase in the minimum inflation variance, except for one. This exception is the MCS policy with the loan-to-GDP ratio as indicator variable. Here, the minimum inflation variance is 0.453. Thus, this combination of macroprudential policy and indicator variable provides the opportunity of a marginally lower inflation variance in addition to significantly improving the inflation-output gap variances trade-off.[1018] In contrast, the MTR policy with the loan-to-GDP ratio leads to a significantly higher minimum inflation variance. Taken together, these Taylor curve results suggest that the MCS policy with the loan-to-GDP ratio provides the best trade-off for the central bank of the macroprudential policies introduced here. However, the mixed results concerning all other combinations suggest that general patterns for one kind of policy or indicator variable are difficult to establish.

Nevertheless, there are some noteworthy points. To start with, the tilt-shift in the MCS Taylor curve using lagged loan growth as the indicator variable offers an important insight for optimal policy analysis: Depending on the loss function, there may or may not be a preference for the MCS as compared to the benchmark model. In this example, the Taylor curves for the banking model with and without the MCS policy cut each other at an inflation variance of around 1.75. The corresponding value for the output gap variance is roughly 3.31. Thus, as long as the central bank values inflation variance about twice as highly as output gap variance (in a corresponding loss function), then the MCS policy improves the policy trade-off. However, as the output gap variance becomes more and more important, the MCS policy produces a worse trade-off. As a consequence, a sensitivity analysis is imperative for optimal policy with ad-hoc loss

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[1017] The response coefficients in the Taylor rules for the values in table 6.2 are the following. The reaction coefficient to inflation θ_π is at its upper bound, that is $\theta_\pi = 5$, for all combinations. The reaction coefficient to the output gap θ_y is also at its lower bound, but varies between 0 and 0.5 for different combinations of indicator variable and macroprudential policy.

[1018] Comparing the curves in fig. 6.9 it is clear that this policy also yields the smallest output gap variance of the model versions considered here.

functions. Kannan et al. (2012), for instance, compute optimal Taylor rule coefficients for a variety of central bank preferences in terms of the weight on output gap deviations. They also find some instances where the ranking of the various macroprudential policies changes when preferences change.[1019] Concerning optimal policy analysis based on welfare functions, this remark may not seem as relevant on first sight. However, while welfare functions derive a model-based objective function, the underlying assumptions about the utility of one or more agents are still crucial, potentially affecting policy rankings.

Moreover, previous results in the literature indicate that the type of shock impacts the usefulness of a macroprudential policy regime.[1020] However, this observation can only be partially supported in this study. In particular, the assessment of the position of shock-specific Taylor curves depends on the indicator variable. For the loan-to-GDP ratio, the results of the all-shock Taylor curve generally carry over to the single-shock Taylor curves.[1021] This implies that the MTR Taylor curve shifts upward and the MCS and MTR+MCS Taylor curves downwards with respect to the benchmark banking model.[1022] This is also true for the real price of physical capital MCS and MTR+MCS policies, where the single-shock Taylor curves generally shift upwards.[1023] In contrast, for lagged loan growth, and the real price of physical capital MTR policy, the single-shock Taylor curves wander around the respective benchmark banking model Taylor curve. For either of these policy combinations, there are some shocks which show no shift at all, a tilt in the Taylor curve, or shifts up- or downwards. Given the closeness of the all-shock Taylor curves with these latter macroprudential policies to the benchmark banking model Taylor curve, these results are not surprising.

Nonetheless, the absolute magnitude of shifts in single-shock Taylor curves point to a subordinate role of shock-specific differences. The Taylor curve movements induced by the various macroprudential policies are generally moderate when only one shock is considered. While different shocks induce different volatilities of inflation and the output gap, the introduction of a macroprudential policy generally does not have a major impact on the

[1019] See Kannan et al. (2012: 26f)

[1020] See Angelini et al. (2012: 25f), Bailliu et al. (2015: 161) and Kannan et al. (2012: 35)

[1021] This means that for each single-shock macroprudential Taylor curve the reference is to the banking model Taylor curve computed for the same shock.

[1022] There are two exceptions: Government consumption shocks with either the MCS or the MTR+MCS policy lead to an upward shift of the Taylor curve. Under the MTR policy, the Taylor curve with mark-up shocks tilts marginally. This tilt is also evident for government consumption and financial shocks for the MTR policy. However, the tilt is such that the MTR policy improves the trade-off at high inflation variance values, and worsens it for low such values. Thus, it may be argued that for inflation-concerned central banks the relevant part of the Taylor curve tilts in the same direction as the all-shocks Taylor curve shifts.

[1023] Here, it is the entrepreneurial risk shock which breaks the pattern in showing a downward shift of the MCS and MTR+MCS policies. Also, preference shocks shift the MCS policy Taylor curve downwards.

position of the single-shock Taylor curves.[1024] However, different indicator variables and the parameters governing the rigour of the macroprudential policy reaction emerge as more decisive in explaining different magnitudes. This supports the argument in section 6.2 whereby it may be problematic for the central bank to adjust its rule-based conduct in response to specific shocks. The results of this section further show that the effects of macroprudential policies on policy trade-offs do not warrant a focus on specific shocks since the particular implementation of macroprudential policy exerts a larger influence.

More to the objective of macroprudential policies, their introduction can improve the inflation-output gap variances trade-off when faced with financial shocks. As discussed in appendix section D.3, the Taylor curve of the banking model showed a different slope as compared to the financial accelerator model for the case of entrepreneurial risk shocks. With an MCS policy reacting to the loan-to-GDP ratio, this change in slope is reversed.[1025] In fact, the Taylor curve lies to the left of the respective financial accelerator model Taylor curve when only entrepreneurial risk shocks are considered. What is more, the MCS and MTR+MCS policies always show a (partial) improvement in terms of the Taylor curve with entrepreneurial risk shocks, yet the results are mixed for bank risk shocks and the MTR policy.[1026] This implies that macroprudential policy can mitigate the adverse effects of financial shocks for macroeconomic stability. Yet again, the particular implementation is important.

The result that macroprudential policies can in general improve the inflation-output gap variances trade-off supports related findings in the literature. Bailliu et al. (2015) find that welfare improves when macroprudential Taylor or credit spread rules are used.[1027] They find that different regimes increase agents' welfare to different extents and that the size of the welfare gains depends on the type of shock.[1028] Yet, in contrast to these findings, this study shows that not all macroprudential policy implementations lead to an

[1024] There are again some exceptions. These are capital quality shocks when the loan-to-GDP ratio is used, and investment adjustment cost shocks with the price of physical capital. The fact that these policy combinations induce large shifts in the Taylor curves does not weaken the argument that the type of shock is generally of lesser importance. Given the wide differences seen in the analysis of a monetary policy shock, it would be rather surprising to have no significant shifts in Taylor curves. However, as compared to the other two factors, these exceptions do not increase the weight of shock-specific analyses.

[1025] For bank risk shocks, the Taylor curve is comparatively flat in the $var(\widehat{gap})$-$var(\hat{\pi})$ space for the benchmark banking model. With the MCS policy reacting to the loan-to-GDP ratio, the Taylor curve simply shifts downwards without a noticeable change in slope.

[1026] 'Partial' means that at least a tilt improving the output gap variance for small inflation variances is visible.

[1027] See Bailliu et al. (2015: 161)

[1028] See Bailliu et al. (2015: 161)

improvement of the policy objectives trade-off.[1029] Furthermore, this study corroborates existing research that the usefulness of indicator variables varies. Gambacorta and Signoretti (2014), for example, find that the usefulness as an indicator variable varies for asset prices and credit growth. However, somewhat opposite to the findings here, Gambacorta and Signoretti (2014) find that a macroprudential Taylor rule reacting to asset prices leads to a marked shift in the Taylor curve while the use of credit growth only leads to a marginal shift.[1030] The term 'somewhat' is justified since Gambacorta and Signoretti (2014) consider technology shocks and mark-up shocks separately.[1031] If there are only either technology or mark-up shocks in the banking model, then an MTR policy with either variable leads to a (marginal) leftward or no shift of the Taylor curve. Thus, the finding concerning credit growth is confirmed, while the extent of the shift for asset prices is not matched in the banking model. As discussed further below, the performance of asset prices in the banking model may be connected to the empirical properties of the model.

So far the issue of whether financial stability is actually enhanced with any of these macroprudential policies has not been considered. This is due to the focus on monetary policy. Thus, the issue of how, and to what extent, macroprudential policies may enhance financial stability is of secondary importance. Appendix section D.5 provides more details on how the considered macroprudential policies perform in terms of enhancing financial stability. A clear-cut answer to whether financial stability improves is challenging in the present context due to some difficulties. Given that three different indicator variables are used, should each policy be evaluated with respect to the variance of its indicator variable? Or should each combination be evaluated with respect to a common measure, such as the variance of asset prices or loans? Finally, how should improvements in one dimension but a deterioration in another be evaluated, for instance if the variability of loans increases but the variance of asset prices decreases? These are not theoretical questions. As detailed in appendix section D.5, there is not a single policy and indicator variable combination which achieves a monotonic improvement in all dimensions.[1032] For example, the MCS policy with the real price of physical capital decreases the variance of the real price of physical capital, but increases the variance of the loan-to-GDP ratio. So, is this an improvement in terms of financial stability? Given that there are other combinations of macroprudential policies and indicator variables leading to an improvement in at least one dimension, which

[1029] There are various modelling differences which may explain these differences, not least the lower number of shocks in Bailliu et al. (2015). Also, Bailliu et al. (2015) only consider credit growth. In this respect, the fact that the MCS policy improves the trade-off for low inflation values can be considered in line with Bailliu et al. (2015) since they perform an optimal policy analysis. Furthermore, the welfare gains are generally small in Bailliu et al. (2015) which resembles the closeness of the Taylor curves in fig. 6.9.

[1030] See Gambacorta and Signoretti (2014: 157)

[1031] See Gambacorta and Signoretti (2014: 156ff)

[1032] This excludes the case of a countercyclical deposit insurance factor. The reasons for not considering this policy in more detail here are presented in appendix section D.5.

of them is preferable? From a financial stability perspective, these questions cannot be answered properly within the bounds of this study, not least given the ad-hoc modelling approach, and are thus left to future research.

Besides, the results on macroprudential policies in this chapter have to be qualified in at least three ways. Firstly, in this simple implementation of a macroprudential credit spread rule, the credit spread rises exogenously from private agents' point of view. With a more elaborate microfoundation, second-order or indirect effects may counteract or reinforce observed responses. Secondly, these results have to be viewed in the light of the second moment comparisons in chapter 5. The volatility of bank loans in the banking model is significantly above the one implied by the data. Conversely, the volatility of real returns and inflation in the banking model is much lower than in the data. This might be an explanation for the small impact of macroprudential rules with the real price of physical capital, and the stark differences when the loan-to-GDP ratio is used as the indicator variable. Thirdly, the results on individual shock processes have to be taken with caution. To the extent that the shocks introduced in the banking model do not truly represent structural shocks, the introduction of a macroprudential regime may change the interpretation or the fundamental process.[1033] Particularly the entrepreneurial and bank risk shocks may be criticised for not representing structural disturbances holding up to the Lucas critique.

Moreover, the introduction of the endogenous deposit insurance factor highlights the importance of another assumption of the banking model. The assumption that neither banks nor workers have access to some other form of liability or asset plays a crucial role in the banking model. There is no possibility for workers to save other than through banks. This allows banks to manipulate the real deposit return. More complex effects are to be expected if there is the possibility to buy government bonds, for example. In this case, it is disputable whether banks would be able to charge a real deposit return lower than the real risk-free return.[1034] This is in turn connected to issues of market power and competition in the markets for banks' liabilities as well as for other savings instruments.[1035] The discussion about the ability of banks to raise funds becomes crucial in this regard. Such constraints may work through effects emphasised by the bank lending channel literature, whereby the overall volume of bank liabilities changes. In contrast, they may also work through restraining banks' remuneration policies as modelled in this study. As a consequence of the

[1033] See Chari et al. (2009: 253ff) on the issue of non-structural shocks in DSGE models.
[1034] This relates to the discussion of negative deposit rates which has been spurred by the financial crisis and subsequent exceptionally long period of low policy rates.
[1035] The empirical evidence on competition in the banking sector suggests that monopolistic competition can account for a differential between deposit and other risk-free returns. However, this still presupposes that households cannot or do not want to hold other assets, due to simple participation exclusions or other benefits they receive from holding bank deposits.

reduced form representation of banks' balance sheet, non-insured forms of bank debt as well as other forms of bank capital cannot be studied in the banking model. This enabled the banking model to highlight one possible mechanism through which credit conditions tighten due to bank-specific constraints. Further and ongoing research can build on this and extend the analysis to more elaborate balance sheet compositions.

Finally, the results of this chapter point to the need to study coordination issues of monetary and macroprudential policies. Admittedly, the question of whether macroprudential and monetary policies are coordinated or not has not been explicitly dealt with in this discussion. It is simply not pertinent to the focus of this study because the objective was not to discern the optimal policy mix. Yet, given that in the banking model not a single combination of macroprudential policy and indicator variable results in similar effects for monetary policy transmission and the monetary policy objectives trade-off, it is crucial that spill-over effects to the conduct of monetary policy due to the design of macroprudential policy are taken into account. Recent research is already developing in this direction.[1036]

In a nutshell, irrespective of the potential of macroprudential policies to affect financial stability, such policies have an impact on the capabilities of the central bank in terms of managing macroeconomic stability. Especially policy implementations which trigger a long-lasting and sizeable macroprudential impulse affect the conduct of monetary policy significantly. The results imply that the effects of macroprudential policies should not only be considered as impacting the transmission of monetary policy, but also in terms of monetary policy goals. Moreover, the results suggest that these effects should be incorporated explicitly into the evaluation process so as to be able to communicate the changes effectively and thus make the changes for monetary policy predictable.

Whether or not spill-over effects change the actual implementation is a different question. Therefore, these conclusions should not be interpreted as arguing for macroprudential policies to be decided upon their impact on monetary policy. Any such statement necessitates a thorough evaluation of the objectives of macroprudential as well as other governmental policies themselves. Rather, these conclusions point to the significance of interrelationships between different governmental policies. In line with the comments on fiscal policies, monetary policy transmission and policy trade-off depend on the specific conceptualisation of other governmental policies just as on the other features which form the monetary policy transmission mechanism. Thus, an interesting avenue of future research is the determination and quantitative significance of these spill-over effects and connections.

[1036] See Angelini et al. (2012), for example.

Chapter 7

Conclusion

This study was designed to determine the consequences of non-systemic bank failure for the conduct of monetary policy. The objective was to evaluate how failures of non-systemic banks affect the transmission of monetary policy and the potential to achieve different monetary policy objectives. These two elements were to be assessed for the case that there exists no additional governmental policy targeting financial stability, as well as in the case such a policy exists. Finally, a corollary research question was to judge the relative importance of the financial friction arising from default of non-financial firms versus the one arising from bank default.

To this end, a standard New Keynesian dynamic stochastic general equilibrium model with financial accelerator was extended to incorporate non-systemic bank default. The banking model presented in this thesis incorporates the endogenous determination of non-systemic bank default and of bank leverage through workers' portfolio choice problem. A financial accelerator model without the additional bank friction is used as a reference to discern the effects of non-systemic bank failures. Both the banking and financial accelerator models were log-linearised around their respective deterministic steady states. These log-linear approximations were used for both estimation and simulation. First, the log-linear approximations were estimated on German data using Bayesian techniques. The next and final step consisted in simulating the banking and financial accelerator models for monetary policy analysis purposes. The main instruments used in chapter 6 to present the simulation results were impulse response functions and Taylor curves.

Succinctly, the findings of this thesis can be summarised as follows. Firstly, the incidence of non-systemic bank default affects the transmission of monetary policy. In particular, the introduction of the friction on banks' liability side leading to bank default gives rise to an additional bank balance sheet channel. Incidentally, the bank balance sheet channel does not fundamentally affect inflation. Rather, the bank balance sheet channel has a non-trivial impact on the response of aggregate demand in that monetary policy shocks affect GDP more lastingly than when banks do not default. This study maintained that the main mechanism of the bank balance sheet channel lies in the passing-through behaviour of banks: banks facing tighter financing conditions as a consequence of contractionary monetary policy pass these tighter conditions on to entrepreneurs. Therefore, this bank balance sheet channel works on top of the balance sheet channel based on entrepreneurs' balance sheets. This implies that the bank balance sheet channel has a fundamentally compounding nature. Furthermore, the findings suggest that the amplifying and propagating effects of this bank balance sheet channel are the stronger, the higher is the steady-state level of bank fragility and if there are impediments to the instantaneous adjustment of workers' portfolio shares (that is by extension bank leverage).

Secondly, non-systemic bank default affects the capabilities of the central bank to achieve different monetary policy objectives. If a central bank aims to minimise inflation volatility, the introduction of bank default yields a worse outcome than when banks do not default. Irrespective of the parametrization, when a central bank only cares about inflation, the resulting minimum inflation variance monetary policy can achieve is always higher in the banking model. Moreover, taking output gap stabilisation as an additional (secondary) monetary policy objective into account, banking model dynamics also imply a deterioration of the central bank's trade-off between inflation and output gap variance stabilisation.

Thirdly and related, the results concerning the monetary policy trade-off depend on the parametrization. As noted, banking model dynamics imply a worse trade-off between inflation and output gap variance stabilisation than the dynamics of the financial accelerator model. Yet, the estimation produced a set of parameter estimates that shows a better trade-off for the banking model than the financial accelerator model when each models' own parameter estimates are used in the simulations. The results suggest that careful attention should be paid to the parametrization of the model and that the improvement in terms of empirical fit may be connected to an improved trade-off between monetary policy objectives.[1037]

Thus, this thesis highlights the necessity of sensitivity and robustness analyses. For one, results for the trade-off between monetary policy objectives differ in terms of whether the same parametrization is used or each model is simulated using its own estimated posterior parameter vector. Therefore, uncertainty about models and parameters implies that policy targets are more robustly denominated in terms of ranges instead of specific point values. Another implication concerns research on optimal policy analyses. The possibility that Taylor curves may tilt due to additional policies shows that care should be taken when

[1037] The comparison of empirical fit concluded that the banking model improved upon the financial accelerator model.

specifying loss functions. Sensitivity analyses should be conducted to discern whether policies really improve the trade-off over a wide range of inflation variances, or only for a specific interval.

What do the results imply for the conduct of monetary policy? The findings suggest a hierarchy of monetary policy objectives based on the capabilities of the central bank to impact them: first inflation, then output gap stabilisation. So, taking monetary policy disturbances in isolation for analysing monetary policy transmission, this study found that the effectiveness of interest rate policy with respect to the primary objective of price stability is not affected. Yet, allowing for disturbances in other parts of the model economy, the central banks' capability to minimise inflation variability is impeded with non-systemic bank failures. This suggests a generally more aggressive stance of the central bank when banks can fail.

Even though the central bank is not as influential when it comes to output gap stabilisation, the effects on GDP should not be disregarded. A stronger impact on GDP is important for preparing monetary policy decisions in terms of data-gathering and analysing the economic outlook. Also, private sector expectations about the future economic development change with the incidence of bank failures, which is important for monetary policy conduct to the extent that the central bank wishes to anchor inflation expectations. In this regard, this study corroborated the need for credible and predictable monetary policy for anchoring inflation expectations as long-term forecasts of inflation are critically influenced by unpredictable changes in monetary policy.

Furthermore, to the extent that the central bank conducts some form of inflation targeting, the incidence of bank failures may mean that a central bank reacts more moderately so as to avoid more severe consequences for GDP. Incidentally, this is the opposite of the conclusion about higher inflation volatility above. Thus, if output gap stabilisation is an additional goal of monetary policy, the incidence of bank default raises conflicting implications for monetary policy. This has consequences for the optimal design of monetary policy and the weighting of different monetary policy objectives. Furthermore, an issue which has only been touched marginally here, but becomes especially important for optimal policy design, is that other governmental policies targeted at smoothing the business cycle may (have to) adjust in response to the incidence of bank failure. Therefore, there may be spill-over effects between different economic policies which have not been discussed here.

The issue of policy spill-overs has been highlighted by the discussion about macroprudential policy. Concerning monetary policy transmission, the findings are clear-cut.

Overall, the transmission to inflation is not fundamentally affected, thus interest rate policy remains effective in this respect. However, the nature of the macroprudential trigger affects monetary policy transmission to GDP. The stronger the impact of monetary policy on the financial imbalances which in turn trigger macroprudential policy, the stronger is the effect of monetary policy on GDP. Macroprudential triggers working in the same direction as the monetary policy impulse, that is both either contractionary or expansionary, amplify the response of GDP; macroprudential triggers working in the opposite direction of the monetary policy impulse moderate the response of GDP. Finally, one-off macroprudential triggers have a smaller effect on GDP than macroprudential triggers that are in effect for a prolonged period of time. With respect to the trade-off between inflation and output gap stabilisation, the results are not as clear-cut. In particular, depending on how financial imbalances are measured and with which macroprudential instrument the government responds to them, macroprudential policies can lead to an improvement in terms of the trade-off between policy objectives as well as to a deterioration, noting that the differences can be large.

Thus, both the impulse response and the Taylor curve analyses indicate that there are potentially large consequences of introducing macroprudential policies. Therefore, different governmental policies should not be dealt with separately or modelled in isolation. Rather, the results suggest that the specific implementation of policy changes should be communicated to the central bank on the one hand and to the private sector on the other hand since information and transparency help in discerning potential spill-overs. As argued above, the analyses of the transmission of impulses as well as of the central banks' capabilities to stabilise inflation and the output gap are important for the monetary policy decision-making process. Furthermore, different policies have non-trivial effects for private sector expectations and thus again for central banks' aim to anchor (inflation) expectations.

Nevertheless, this study gives some indication that it is not only transparency between different governmental policies which would be warranted, but also coordination. Some macroprudential policy combinations yielded comparatively large effects in terms of impulse response functions and Taylor curves. This suggests that the decision about implementing a specific macroprudential policy may not only depend on its effects on financial stability. Rather, potentially adverse non-negligible consequences for the conduct and effectiveness of monetary policy may provide a rationale for considering policy spill-over effects during the conceptualisation and implementation stages, and also for coordinating different governmental policies. However, the particular implementations in this thesis are too ad-hoc to make any definite recommendations about any policy (combination). Thus, this study provides a clear imperative for further research on the interactions between monetary and macroprudential policies.

Moreover, the findings of this thesis suggest that the central financial friction impacting the economy is the one on the loan market.[1038] Unforeseen shocks to entrepreneurs' riskiness have a large impact on private sector expectations of nominal and real variables, while similar shocks on banks' riskiness mainly impact the return on bank equity. This difference is partly due to different sizes of monitoring costs associated with these frictions. More important appears to be that in the banking model entrepreneurial net worth is internal, that is accumulated from retained earnings, while bank equity is external and rolled over every period. The findings suggest that the bank balance sheet channel in this form does not play a large role as an endogenous propagating mechanism by itself, but rather as an amplification and propagation mechanism to the entrepreneurial balance sheet channel. Future research can evaluate whether reputation effects, impediments to instantaneous portfolio adjustments or even simply a concept of bank capital which includes accumulated earnings increase the amplification mechanism of the bank balance sheet channel. In these cases, expected bank equity returns may not only depend on the future, but also on past events.

The results from the analysis of macroprudential policies highlight two issues which have been dealt with only marginally. Firstly, this concerns the interactions and relationships between different governmental policies. These links could not be discerned comprehensively in this thesis. Secondly, the specific implementation of macroprudential policies was comparatively ad-hoc. The results highlight that care should be taken when designing policy, but are silent on which policy is preferred when banks can fail. One could introduce further ad-hoc objective functions to choose one policy. However, to fulfil the requirements about sensitivity analyses pointed to above would require a much more thorough treatment of macroprudential policies themselves. The same limitation applies to interactions between fiscal and monetary policies, for example. While both of these issues are important, they are not dealt with extensively because they are secondary to the main focus of this study. What is more, the focus on one additional bank-specific friction (bank failure), coupled with the restrictions on the range of financial assets in the model, constrains the description of possible effects and analysis of potential policy links. Furthermore, caution has to be applied when interpreting the findings of this study in that only one specific form of information asymmetries and one specific type of representing this market imperfection are used in this thesis.

Overall, the results of this thesis confirm and extend previous findings on bank-related frictions in the literature. This study contributes to the literature on the interactions between monetary policy and financial intermediation by assessing the consequences for

[1038] This is in addition to the obvious necessity of indirect financial intermediation to exist for financial intermediaries' financial position to have any significance.

monetary policy transmission and policy-related trade-offs. Moreover, this study contributes to the literatures on bank liability management and portfolio choice as it has shown how non-systemic bank default affects the mechanisms determining loans and credit conditions. Similar to related research, a friction connected to banks' liability side leads to an amplification of monetary policy impulses. Also, the finding of a higher significance of the entrepreneurial balance sheet channel vis-à-vis the bank balance sheet channel agrees with previous findings that banks' balance sheets appear particularly important during crisis times. Furthermore, this study extends existing research by evaluating trade-offs between different monetary policy objectives in terms of its position and its sensitivity to parametrization. Moreover, the disparate patterns found for macroprudential policies only partially agree with results in the related literature. This suggests that more specific research is needed to study the interaction between monetary and macroprudential policies in an environment with non-systemic bank failures. Finally, this thesis is furthermore useful for evaluating the effects of monetary policy for dissimilar financial systems in the Euro area by providing estimates based on German data.

These contributions have already highlighted some potential future research avenues. Concerning the model itself, incorporating additional financial assets and liabilities into macroeconomic models appears to be a promising way forward. Introducing internal bank equity, which is accumulated from retained earnings, may expand the set of potential scenarios to provide context-specific analyses. On the other hand, including other forms of household saving will open up the opportunity to study aggregate flows from banks' balance sheet and the ensuing consequences when bank health deteriorates as well as topics such as banking sector competition, both within and across sectors. To this latter point, heterogeneous agent modelling approaches can further disaggregate the effects by studying different banking business models, for example. To the other end, opening up the economy to examine cross-border flows and links will help in providing a more comprehensive picture of the monetary transmission mechanism in the Euro area. All in all, while this study provides another piece, many remain scattered in the larger puzzle of monetary policy and financial sector interactions.

Appendix

A Appendices to Chapter 3

A.1 Aggregate Output with Price Dispersion

As noted above, price dispersion affects retailers' output. The derivation here follows Christiano et al. (2011); however, the use of price dispersion as a measure of welfare loss dates back at least to Yun (1996).[1039] Output of a single retailer is given by the formula:

$$Y_t(nn_r) = (1-c)Y_t^W(nn_r) \tag{A.1}$$

which must equal the demand for this retailer's output (eq. (3.27)):

$$(1-c)Y_t^W(nn_r) = \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta} Y_t \tag{A.2}$$

where $Y_t^W(nn_r)$ is the amount of the wholesale good used by the retailer to produce its output $Y_t(nn_r)$.[1040] Furthermore, aggregate output over all retailers equals aggregate demand for all retailers' varieties:

$$(1-c)\int_0^1 Y_t^W(nn_r)\mathrm{dnn_r} = \int_0^1 \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta} \mathrm{dnn_r} Y_t \tag{A.3}$$

Note that $\int_0^1 Y_t^W(nn_r)\mathrm{dnn_r} = Y_t^W$, and that $\int_0^1 \left(\frac{P_t(nn_r)}{P_t}\right)^{-\zeta}\mathrm{dnn_r}$ measures the decrease in output because of price dispersion O_t^p.[1041] Then, eq. (A.3) can be written as:

$$(1-c)Y_t^W = O_t^p Y_t \tag{A.4}$$

[1039] See Christiano et al. (2011: 294f) and Yun (1996: 355)

[1040] This differs from Christiano et al. (2011) in that retailers here do not demand factor inputs but a wholesale good. In the derivation of Christiano et al. (2011) factor inputs enter directly, here it is the wholesale good that is used as the input. The result of either approach is the same concerning the definition of aggregate output with price dispersion.

[1041] See Christiano et al. (2011: 295) and thus:

$$Y_t = \frac{(1-c)Y_t^W}{O_t^p} \tag{A.5}$$

which is eq. (3.20) presented in the text.

A.2 The New Keynesian Flexible-Price Model and the Output Gap

For the computation of the output gap, a small-scale New Keynesian (NK) model with flexible prices is used to calculate potential output. It features some real frictions such as consumption habits, investment adjustment costs and monopolistic competition so as to align the small-scale model with the banking model. Yet, prices are completely flexible in this small-scale NK model and there are no financial frictions. This means that the arbitrage condition between the real return satisfying workers' intertemporal consumption decision R_{t+1}^{FP} must be equal to the real return on real capital $R_{k,t+1}^{FP}$: $R_{t+1}^{FP} = R_{k,t+1}^{FP}$. The superscript FP denotes the flexible-price model. There is also only a subset of shocks in the small-scale NK model: technology and capital quality shocks. One could add other shocks also used in the banking model. However, since the discussion will focus on the differences of the banking model with a model without the additional banking frictions, and both models use the same flexible-price NK model for calculating potential output, this is not regarded as a major point.

There are workers, entrepreneurs, retailers, capital investment funds and the government.[1042] Workers consume, work and save.[1043] Entrepreneurs buy the capital stock, and combine it with labour to produce the wholesale good. They then sell the wholesale good to retailers who charge a mark-up, but can adjust prices freely. The final retail good is bought by workers, capital investment funds and the government.

Thus, the following equations carry over to the flexible price economy: eqs. (3.63) and (3.64) (without the exogenous preference process), eqs. (3.76) and (3.78), eqs. (3.1) to (3.3), eqs. (3.39) and (3.94) (without the exogenous investment adjustment cost process) and eq. (3.37). The assumptions for the exogenous processes of technology and capital quality are the same as in the banking model.

What is more, the following adjustments need to be made. Instead of being equal to to the expected real portfolio return, the expected real stochastic discount factor

[1042] Strictly speaking, such a small NK model does not necessitate so many different types of agents. They are kept separate here for comparability with the derivations of the banking model.

[1043] Since there are no financial frictions, workers' savings are remunerated at the real risk-free rate. The savings instrument is not explicitly modelled and there is no portfolio choice.

equals the expected real risk-free return in the small-scale NK model: $\Lambda_{t+1}^{FP} = R_{t+1}^{FP}$. As noted above, this real risk-free return is equal to the real return on real capital absent any financial frictions. Given that there is no price dispersion, output is simply given by $Y_t^{FP} = (1-c)Y_t^{W,FP}$. Furthermore, since retailers can adjust prices instantly, the mark-up is constant and equal to $\zeta/(\zeta-1)$. Finally, output is equal to aggregate demand: $Y_t^{FP} = C_{W,t}^{FP} + G_t^{FP} + I_t^{FP}$. In total, these are 15 equations in 15 unknowns.

The only variable of this equation system which is of direct relevance for the banking and financial accelerator models is aggregate output. The output gap entering the banking (and financial accelerator) model Taylor rule is given by $GAP_t = Y_t/Y_t^{FP}$.

B Appendices to Chapter 4

B.1 Default Probabilities and Leverage

The default probability of banks is crucially determined by the default threshold $\overline{\psi}_t^B$. For a given uniform distribution, the default probability rises with the default threshold. The default threshold itself is determined by the ratio of deposit costs to loan revenue, as defined in eq. (3.48a), which is reprinted here for convenience in its non-stochastic steady-state representation:

$$\overline{\psi}^B = \frac{R_{ed} D}{R_w B} \tag{B.1}$$

Define banks' leverage ratio ϕ^B as B/e. Using the fact that:

$$\frac{D}{B} = \frac{1}{1-\xi^r}\left(1 - \frac{1}{\phi^B}\right) \tag{B.2}$$

the default threshold becomes:

$$\overline{\psi}^B = \frac{R_{ed}}{(1-\xi^r)R_w}\left(1 - \frac{1}{\phi^B}\right) \tag{B.3}$$

Thus, the default threshold, and hence the default probability, is a function of the (constant) reserve requirement, the leverage ratio of the banking sector, and the ratio of the effective deposit return to the wholesale return.

Ceteris paribus, in particular assuming a constant bank risk premium, the first derivative of the default probability $\overline{p}$ with respect to the leverage ratio is thus:[1044]

$$\frac{\partial \overline{p}}{\partial \phi^B} = \frac{\partial \overline{p}}{\partial \overline{\psi}^B} \frac{\partial \overline{\psi}^B}{\partial \phi^B} = \frac{R_{ed}}{2B_\psi R_w (1-\xi^r)} \frac{1}{(\phi^B)^2} \geq 0 \tag{B.4}$$

which is strictly positive.[1045] An increase in the leverage ratio leads, ceteris paribus, to a higher share of banks defaulting in a given period. The same result holds for the relationship between entrepreneurial leverage and default probability. A higher leverage increases the threshold shock which, given a distribution interval, increases the default probability.

[1044] Strictly speaking, the bank risk premium relates the real wholesale return to the real deposit return and not the real effective deposit return. However, for small ξ^r and ν^d, differences are small. Also, the real deposit return is equal to the real effective deposit return in the steady state under the chosen parametrization.

[1045] B_ψ governs the interval size of the uniform distribution of the bank-specific shock and is proportional to the variance of the distribution, see section 3.9.

B.2 Details on Aggregate Retail Goods Demand

Aggregate demand in the banking model is defined as the sum of workers', governmental and entrepreneurs' consumption demand, investment and transaction costs. Governmental consumption is simply an exogenous first-order autoregressive process and investment can be characterised together with a path for the capital stock by eqs. (3.37) and (3.39). As argued in the text, the main difficulty of reducing the complexity arises due to the definitions of transaction costs and entrepreneurial consumption. Transaction costs and entrepreneur's consumption can be expressed as functions of bank-specific and entrepreneur-specific shock probability functions, the return on and price of physical capital and the stock of physical capital. In the financial accelerator model the relevant non-linear equations are:

$$\begin{aligned} C_{E,t} &= (1-\eta_E)(1-\xi_E)\left(1-\Gamma^E(\overline{\psi}_t^E)\right) R_{k,t}Q_{t-1}K_{t-1} \\ &= z_{e,t}R_{k,t}Q_{t-1}K_{t-1} \qquad (B.5) \\ MoC_t^F &= \mu^E G^E(\overline{\psi}_t^E) R_{k,t}Q_{t-1}K_{t-1} \\ &= z_{m,t}^F R_{k,t}Q_{t-1}K_{t-1} \qquad (B.6) \end{aligned}$$

Thus, the log-linear approximations are:

$$\begin{aligned} \hat{c}_{e,t} &= \hat{z}_{e,t} + \hat{r}_{k,t} + \hat{q}_{t-1} + \hat{k}_{t-1} \qquad (B.7) \\ \widehat{moc}_t^F &= \hat{z}_{m,t}^F + \hat{r}_{k,t} + \hat{q}_{t-1} + \hat{k}_{t-1} \qquad (B.8) \end{aligned}$$

In the banking model the corresponding non-linear equations are:

$$\begin{aligned} C_{E,t} &= (1-\eta_E)(1-\xi_E)\left(1-\Gamma^E(\overline{\psi}_t^E)\right) R_{k,t}Q_{t-1}K_{t-1} \\ &= z_{e,t}R_{k,t}Q_{t-1}K_{t-1} \qquad (B.9) \\ MoC_t^B &= \left(\mu^E G^E(\overline{\psi}_t^E) + \left(\mu^N G^N(\overline{\psi}_t^B) + \mu^B G^B(\overline{\psi}_t^B)\right)\left(\Gamma^E - \mu^E G^E(\overline{\psi}_t^E)\right)\right) \\ &\quad R_{k,t}Q_{t-1}K_{t-1} \\ &= z_{m,t}^B R_{k,t}Q_{t-1}K_{t-1} \qquad (B.10) \end{aligned}$$

Then, the log-linear approximations are:

$$\begin{aligned} \hat{c}_{e,t} &= \hat{z}_{e,t} + \hat{r}_{k,t} + \hat{q}_{t-1} + \hat{k}_{t-1} \qquad (B.11) \\ \widehat{moc}_t^B &= \hat{z}_{m,t}^B + \hat{r}_{k,t} + \hat{q}_{t-1} + \hat{k}_{t-1} \qquad (B.12) \end{aligned}$$

or more elaborately the log-linear approximation to aggregate monitoring costs $\widehat{moc}_t^B$ is:[1046]

$$
\begin{aligned}
\widehat{moc}_t^B =& \frac{\mu^E G^E \hat{G}_t^E + (\mu^N G^N + \mu^B G^B)(\Gamma^E \hat{\Gamma}_t^E - \mu^E G^E \hat{G}_t^E)}{\mu^E G^E + (\mu^N G^N + \mu^B G^B)(\Gamma^E - \mu^E G^E)} \\
&+ \frac{(\mu^N G^N \hat{G}_t^N + \mu^B G^B \hat{G}_t^B)(\Gamma^E - \mu^E G^E + \Gamma^E \hat{\Gamma}_t^E - \mu^E G^E \hat{G}_t^E)}{\mu^E G^E + (\mu^N G^N + \mu^B G^B)(\Gamma^E - \mu^E G^E)} \\
&+ \hat{r}_{k,t} + \hat{q}_{t-1} + \hat{k}_{t-1}
\end{aligned} \tag{B.13}
$$

B.3 The Log-linear Approximation to Retailers' Marginal Costs

Marginal costs of retailers in log-linear form are given by:

$$
\widehat{mc}_t = \hat{p}_t^W - \hat{p}_t \tag{B.14}
$$

The log-linear approximations to the labour supply and demand conditions are:

$$
\hat{w}_t - \hat{p}_t = \frac{\hat{y}_t - (X^F/Y)\hat{x}_t^F - \chi\Big(\hat{y}_{t-1} - (X^F/Y)\hat{x}_{t-1}^F\Big)}{(C_W/Y)(1-\chi)} + \frac{H}{1-H}\hat{h}_t \tag{B.15}
$$

$$
\hat{w}_t - \hat{p}_t^W = \hat{v}_t^a + (\alpha - 1)\hat{h}_t + (1-\alpha)\hat{k}_{t-1} \tag{B.16}
$$

where consumption had been substituted for:

$$
\hat{c}_{w,t} = \frac{1}{C_W/Y}\hat{y}_t - \frac{X^F/Y}{C_W/Y}\hat{x}_t^F \tag{B.17}
$$

Combining eqs. (B.15) and (B.16) to eliminate the nominal wage and rearranging for the difference between wholesale and final retail goods prices leads to the equation eq. (4.18) in the text for marginal costs:

$$
\begin{aligned}
\widehat{mc}_t =& \left(\frac{1}{(C_W/Y)(1-\chi)} + \left(\frac{1}{(1-H)\alpha} - 1\right)\right)\hat{y}_t - \frac{\chi}{(C_W/Y)(1-\chi)}\hat{y}_{t-1} \\
&- \frac{1}{(C_W/Y)(1-\chi)}\frac{X^F}{Y}(\hat{x}_t^F - \chi\hat{x}_{t-1}^F) - \frac{1}{\alpha(1-H)}(\hat{v}_t^a + (1-\alpha)\hat{k}_{t-1})
\end{aligned} \tag{B.18}
$$

[1046] Note that the dependence of Γ^E, G^E, G^B, G^N on the respective shock has been dropped for simplicity.

C Appendices to Chapter 5

C.1 Details on the Dataset

Observable	Explanation
Gross Domestic Product	Real GDP series extracted from the Eurostat database 6 October 2015 (series set name: namq_10_gdp)[1047], in Euro, quarterly, seasonally and working day adjusted series; Own adjustments: per capita real GDP calculated by dividing the series by the working population, then made stationary by calculating log-differences, finally demeaned by the sample average.
Private Consumption	Real consumption of private households and non-profit institutions serving households extracted from the Eurostat database 6 October 2015 (series set name: namq_10_gdp)[1048] , in Euro, quarterly, seasonally and working day adjusted series; Own adjustments: per capita real consumption calculated by dividing the series by the working population, then made stationary by calculating log-differences, finally demeaned by the sample average.
Private Investment	Real gross fixed capital formation extracted from the Eurostat database 6 October 2015 (series set name: namq_10_gdp)[1049], in Euro, quarterly, seasonally and working day adjusted series; Own adjustments: per capita real investment calculated by dividing the series by the working population, then made stationary by calculating log-differences, finally demeaned by the sample average.
Hours Worked	Employment A*10 industry breakdowns series extracted from Eurostat 13 October 2015 (series name: namq_10_a10_e)[1050], thousand hours, quarterly, seasonally and working day adjusted series, total employment, all NACE activities; Own adjustments: per capita hours worked calculated by dividing the series by the working population, then made stationary by calculating log-differences, finally demeaned by the sample average.
Loans	Nominal loans to domestic non-banks extracted from Deutsche Bundesbank database 29 September 2015 (series name: BBK01.OU0115)[1051], Euro, monthly, volume at the end of the reporting period; Own adjustments: aggregated to quarterly frequency by taking the average of the quarter, real volume calculated by dividing by the GDP deflator, per capita real loans calculated by dividing the series by the working population; then

[1047] Eurostat (2015b), URL in list of references
[1048] Eurostat (2015d), URL in list of references
[1049] Eurostat (2015a), URL in list of references
[1050] Eurostat (2015c), URL in list of references
[1051] Deutsche Bundesbank (2015c), URL in list of references

	made stationary by calculating log-differences, and finally demeaned by the sample average.
Bank Equity	Nominal bank equity extracted from Deutsche Bundesbank database 29 September 2015 (series name: BBK01.OU0322)[1052], Euro, monthly, volume at the end of the reporting period; Own adjustments: aggregated to quarterly frequency by taking the average of the quarter, real volume calculated by dividing by the GDP deflator, per capita real bank equity calculated by dividing the series by the working population, then made stationary by calculating log-differences, and finally demeaned by the sample average.
Policy Interest Rate	EONIA extracted from ECB DataWarehouse 18 November 2015 (series name: FM.M.U2.EUR.4F.MM.EONIA.HSTA)[1053], % p.a., monthly, period average; Own adjustments: aggregated to quarterly frequency by taking the average of the quarter, then made stationary by calculating absolute differences, and finally demeaned by the sample average.
Return on Entrepreneurial Equity	Nominal yield on bonds outstanding, domestic business, extracted from Deutsche Bundesbank Database 1 October 2015 (series name: BBK01.WU0022)[1054], % p.a., monthly, period average; Own adjustments: aggregated to quarterly frequency by taking the average of the quarter, real volume calculated by dividing by the GDP deflator, then made stationary by calculating absolute differences, and finally demeaned by the sample average.
Inflation	GDP Deflator extracted from the Eurostat database 6 October 2015 (series set name: namq_10_gdp)[1055], Index, 2010=100, quarterly, seasonally and working day adjusted series; Own adjustments: calculated as annualised rate, demeaned by the sample average.
Time Series used for Adjustments	
Working Population	Working Population according to ILO-Concept extracted from Genesis Database operated by the German Statistical Office 6 October 2015 (series code: 13231-0001)[1056], persons, monthly, X-ARIMA 12 trend adjusted series; Own Adjustments: aggregated to quarterly frequency by taking the average of the quarter.

Table C.1: Dataset Information: Data Sources and Adjustments

[1052] Deutsche Bundesbank (2015b), URL in list of references
[1053] European Central Bank (2015b), URL in list of references
[1054] Deutsche Bundesbank (2016f), URL in list of references
[1055] Eurostat (2015e), URL in list of references
[1056] Statistisches Bundesamt (2015a), URL in list of references

C.2 Prior and Posterior Distributions

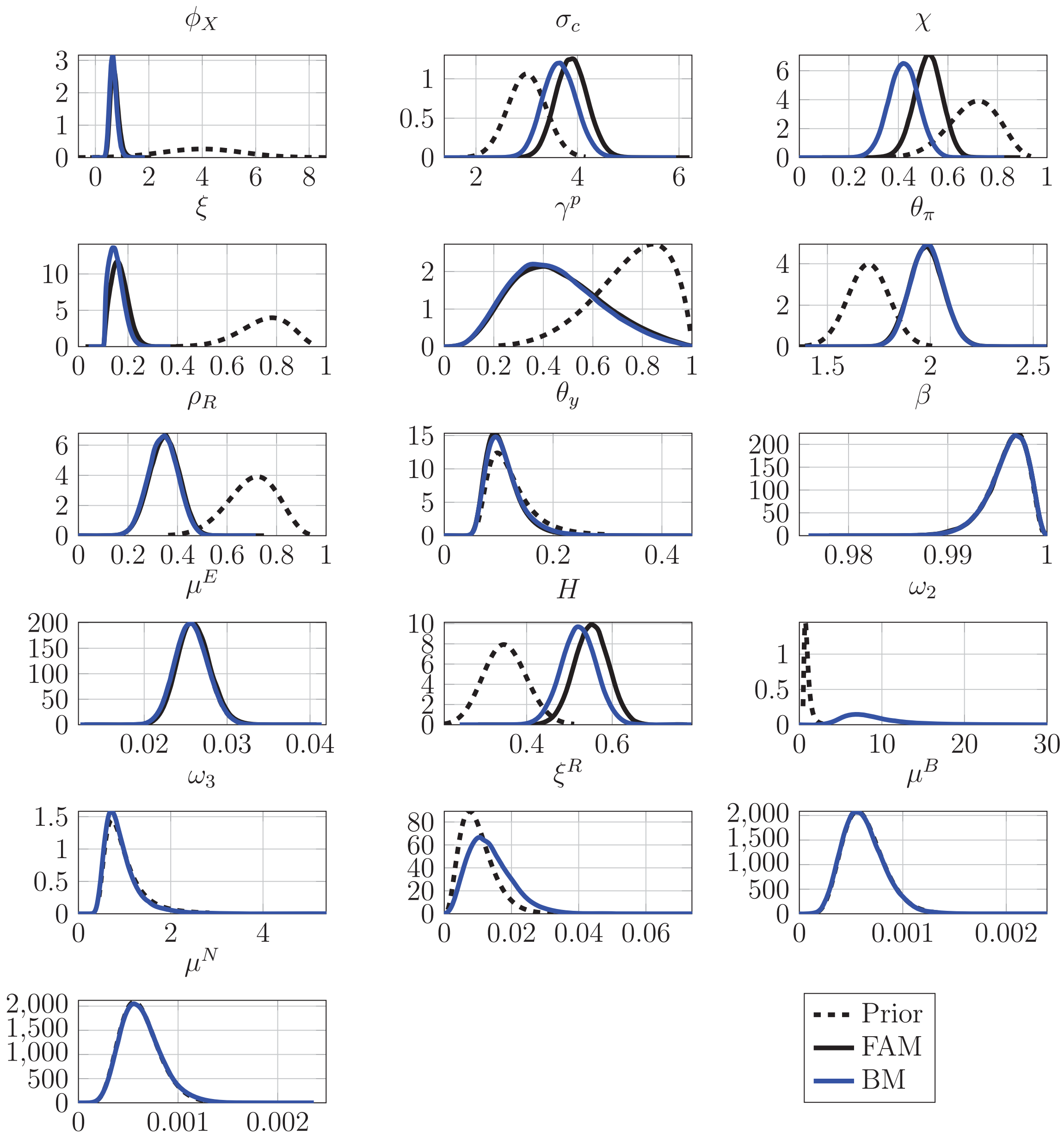

Figure C.1: Prior and Posterior Distributions: Structural Parameters of the Banking (BM) and Financial Accelerator Models (FAM); black dashed line: prior distribution, blue solid line: posterior distribution of the banking model, black solid line: posterior distribution of the financial accelerator model.

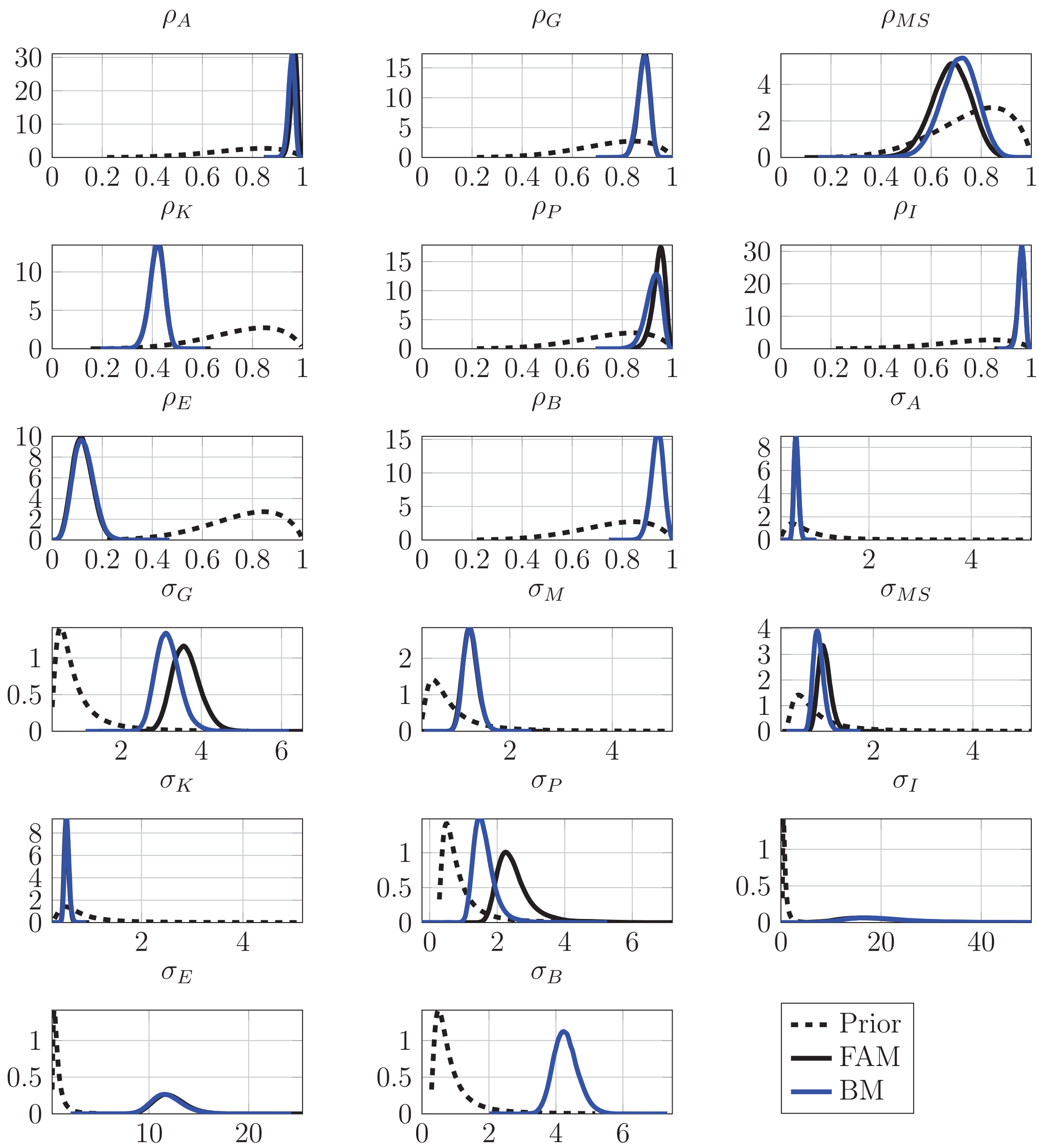

Figure C.2: Prior and Posterior Distributions: Shock Parameters of the Banking (BM) and Financial Accelerator Models (FAM); black dashed line: prior distribution, blue solid line: posterior distribution of the banking model, black solid line: posterior distribution of the financial accelerator model.

C.3 Posterior Estimates of the Banking Model (Reduced Dataset)

As noted in the text, the calibration and prior distributions for the reduced-dataset banking model are the same as for the complete banking model, presented in tables 5.1 to 5.3. σ_B and ρ_B are not included as estimated parameters since the exogenous bank risk shock process Υ^B is not included in the reduced-dataset banking model to align the number of shocks to the number of observable time series. The dataset is the same as for the financial accelerator model. The results presented in table C.2 are similarly based on 200,000 draws of 5 chains. Convergence was checked again by the same means as for the complete banking model.[1057] All tests indicated convergence after the burn-in period.

As can be seen by comparing the entries in table C.2 with the corresponding entries in tables 5.4 and 5.5, the results are overwhelmingly similar. Estimated posterior means generally differ to only a low degree and 90% highest posterior density (HPD) intervals overlap significantly. There are two exceptions to this observation: the posterior estimates of ω_2 and ω_3. The respective 90% HPD intervals overlap only marginally for ω_2. Also, the estimated posterior mean of ω_2 in the complete banking model does not fall in the 90% HPD interval of the reduced-dataset banking model and vice versa. The 90% HPD intervals overlap more widely for ω_3 and it is only the posterior mean of the complete banking model which does not fall into the 90% HPD interval of the reduced-dataset banking model. Given that bank equity is not included in the dataset used for estimating the reduced-dataset banking model, it appears to be the case that this time series is informative on these two parameters. In contrast, the estimates of the other parameters are robust to the smaller dataset.

[1057] See section 5.3

Parameter		Mean	90% HPD	
workers' discount rate	β	0.996	0.993	0.999
consumption habit parameter	χ	0.427	0.331	0.525
Calvo pricing parameter	ξ^p	0.153	0.107	0.193
price indexation rate	γ^p	0.447	0.162	0.728
investment adjustment cost parameter	ϕ_I	0.674	0.448	0.889
Taylor rule parameter	ρ_R	0.359	0.259	0.457
Taylor rule parameter	θ_π	1.981	1.848	2.113
Taylor rule parameter	θ_y	0.108	0.062	0.153
degree of non-separability between consumption and leisure	σ_c	3.616	3.098	4.141
steady-state hours worked	H	0.518	0.453	0.588
(*) minimum reserve ratio	ξ^r	0.009	0.002	0.015
(*) reaction coefficient to equity return	ω_2	2.401	0.776	4.124
(*) reaction coefficient to deposit return	ω_3	0.631	0.378	0.885
entrepreneurial default transaction cost parameter	μ^E	0.026	0.022	0.029
(*) bank default transaction cost parameter	μ^B	0.0006	0.0003	0.0009
(*) governmental transaction cost parameter	μ^N	0.0006	0.0003	0.0010
st. dev. technology shock	σ_A	0.576	0.503	0.648
st. dev. government consumption shock	σ_G	3.226	2.710	3.729
st. dev. monetary policy shock	σ_M	1.209	0.974	1.438
st. dev. mark-up shock	σ_{MS}	0.897	0.731	1.060
st. dev. capital quality shock	σ_K	0.514	0.444	0.583
st. dev. preference shock	σ_P	1.780	1.173	2.387
st. dev. investment adjustment cost shock	σ_I	22.594	9.048	35.339
st. dev. entrepreneurial risk shock	σ_E	12.105	9.480	14.718
(*) st. dev. bank risk shock	σ_B	N/A	N/A	N/A
autocorrelation of Υ^A	ρ_A	0.954	0.933	0.976
autocorrelation of Υ^G	ρ_G	0.884	0.846	0.923
autocorrelation of Υ^{MS}	ρ_{MS}	0.703	0.588	0.824
autocorrelation of Υ^K	ρ_K	0.406	0.358	0.456
autocorrelation of Υ^P	ρ_P	0.934	0.891	0.981
autocorrelation of Υ^I	ρ_I	0.963	0.943	0.984
autocorrelation of Υ^E	ρ_E	0.120	0.055	0.183
(*) autocorrelation of Υ^B	ρ_B	N/A	N/A	N/A

Table C.2: Banking Model (Reduced Dataset): Posterior Estimates. Posterior distribution mean and 90% HPD interval are based on 200,000 draws from the posterior distribution of the MH algorithm. Starred parameters are not relevant in the financial accelerator model.

C.4 Posterior Estimates of the Banking Model (Sensitivity Analysis)

This appendix lists the estimation results of the sensitivity analysis for the prior distributions and time periods. The following assumptions are made:

Asymmetric risk premiums Here, the prior distributions for μ^E, μ^B and μ^N are different from the benchmark prior distributions. The underlying assumption is that the entrepreneurial and bank risk premiums are 0.25% and 0.625% quarterly, respectively. Furthermore, the prior mean for μ^N is increased. This is to check whether the data is really not informative on these transaction cost parameters or whether there is evidence in favour of a symmetric or asymmetric distribution of risk premiums. In addition, some parameter calibrations need to be adjusted. These concern the bank- and entrepreneur-specific shock interval parameters and the parameters governing the distribution between entrepreneurial consumption and net worth. The alternative calibration and prior distributions used for the sensitivity test are displayed in table C.3.

	ξ_E	η_E	E_ψ	B_ψ
Calibrated Value	0.0028	0.9835	0.6949	0.5783

(a) Alternative Parameter Calibration

	μ^E	μ^B	μ^N
Prior Mean	0.0147	0.014	0.20
Prior St.Dev.	0.002	0.002	0.05

(b) Alternative Prior Distribution

Table C.3: Alternative Prior Distributions and Parameter Calibration: Asymmetric Risk Premiums

Equal Friction Size To check whether the results are sensitive to the relative size of the financial friction between entrepreneurs and banks versus the friction between banks and equity-holders, this sensitivity test changes the values of calibrated parameters and prior distributions such that the severity of these two frictions is roughly the same. Thus, both banks and entrepreneurs default with the same probability, the intervals of the bank- and entrepreneur-specific shocks as well as the risk premiums are set to equal values. The values are summarised in table C.4. As discussed before, the transaction cost parameters μ^E and μ^B are tightly linked to the respective risk premium, thus their prior distributions have to be adjusted accordingly. In line with the benchmark prior distributions, the prior distribution of the governmental transaction cost parameter μ^N is set equal to the one for μ^B, to abstract from a discussion about potentially different efficiencies in monitoring.

	ξ_E	η_E	$p(\overline{\psi}^B)$	$\varrho^B = \varrho^E$	$E_\psi = B_\psi$
Calibrated Value	0.0038	0.9805	0.02	0.0175/4	0.5891

(a) Alternative Parameter Calibration

	μ^E	μ^B	μ^N
Prior Mean	0.0197	0.0018	0.0018
Prior St.Dev.	0.002	0.001	0.001

(b) Alternative Prior Distributions

Table C.4: Alternative Prior Distributions and Parameter Calibration: Equal Financial Frictions Size

Alternative Asset Demand Prior The third prior sensitivity test concerns itself with the parameters in workers' asset demand functions, ω_2 and ω_3. As for the other sensitivity tests, all other parameters are set to the benchmark calibration/prior distributions. The prior distributions for ω_2 and ω_3 are summarised in table C.5. Again, both parameters imply that bank deposits and bank equity are substitutes in the deterministic steady state of the banking model. However, in contrast to the benchmark prior distributions, the prior mean here is centred at a lower value, implying a unit-proportional elasticity of volumes with respect to returns. Furthermore, the prior standard deviations are adjusted accordingly.

	ω_2	ω_3
Prior Mean	0.50	0.50
Prior St.Dev.	5.00	5.00

Table C.5: Alternative Prior Distributions: Workers' Asset Demand Parameters

Alternative Time Periods Finally, the sensitivity to different time periods is considered. The prior distributions are the same as for the benchmark banking model in section 5.2.2. The sample period used for the benchmark banking model in section 5.3 is divided into two periods for the sensitivity analysis: in the first exercise, the cut-off point is the change in the monetary regime; in the second exercise, the cut-off point lies before the financial crisis of 2007-8 so as to examine the impact of the crisis period starting with the financial crisis. Hence, table C.7 reports the posterior estimates for the two separate sample periods 1994Q2-1999Q1 (Bundesbank period) and 1999Q2-2015Q2 (ECB period). Table C.8 reports the estimates for the periods 1994Q2-2006Q4 (pre-crisis period) and 2007Q1-2015Q2 (crisis period).

Details on Computation The results in tables C.6 to C.8 are based on 200,000 draws from the posterior distribution after burn-in. Convergence was checked by the same means as for the banking and financial accelerator models, the reader is referred to section 5.3 for details. Note that all convergence checks indicated convergence after the burn-in period.

Parameter	**Asymmetric $\varrho^{E/B}$**			**Equal Friction Size**			**Alternative Asset Demand**		
	Mean	90% HPD		Mean	90% HPD		Mean	90% HPD	
β	0.996	0.993	0.999	0.996	0.993	0.999	0.996	0.993	0.999
χ	0.422	0.326	0.519	0.437	0.337	0.537	0.406	0.309	0.501
ξ^p	0.156	0.107	0.197	0.157	0.108	0.199	0.150	0.107	0.188
γ^p	0.459	0.170	0.749	0.463	0.176	0.755	0.449	0.160	0.730
ϕ_I	0.795	0.522	1.057	0.784	0.525	1.029	0.656	0.448	0.857
ρ_R	0.396	0.299	0.498	0.325	0.229	0.421	0.336	0.241	0.431
θ_π	1.956	1.822	2.091	2.007	1.873	2.137	1.982	1.853	2.116
θ_y	0.109	0.062	0.155	0.120	0.062	0.178	0.109	0.061	0.154
σ_c	3.568	3.038	4.097	3.664	3.143	4.187	3.582	3.061	4.108
H	0.511	0.443	0.580	0.528	0.459	0.597	0.513	0.445	0.579
ξ^r	0.014	0.004	0.025	0.020	0.005	0.034	0.015	0.004	0.026
ω_2	5.747	3.589	7.813	6.216	3.102	9.182	12.672	4.319	21.264
ω_3	0.848	0.438	1.253	1.013	0.438	1.614	0.413	0.120	0.760
μ^E	0.015	0.012	0.018	0.020	0.016	0.023	0.026	0.022	0.029
μ^B	0.0134	0.0103	0.0165	0.0014	0.0003	0.0026	0.0006	0.0003	0.0009
μ^N	0.0862	0.0568	0.1147	0.0019	0.0003	0.0034	0.0006	0.0003	0.0009
σ_A	0.583	0.509	0.658	0.583	0.510	0.658	0.580	0.506	0.652
σ_G	3.765	3.115	4.413	3.257	2.740	3.754	3.144	2.655	3.627
σ_M	1.132	0.905	1.351	1.279	1.044	1.516	1.250	1.015	1.475
σ_{MS}	0.892	0.724	1.055	0.920	0.743	1.094	0.878	0.714	1.035
σ_K	0.536	0.464	0.607	0.659	0.572	0.745	0.528	0.456	0.597
σ_P	1.592	1.131	2.046	1.833	1.194	2.392	1.515	1.056	1.952
σ_I	20.698	8.864	32.610	24.442	10.353	37.350	21.213	10.132	32.206
σ_E	22.354	15.983	28.543	11.019	8.392	13.589	11.826	9.285	14.314
σ_B	4.209	3.635	4.758	4.387	3.776	5.004	4.304	3.692	4.883
ρ_A	0.956	0.936	0.976	0.958	0.939	0.978	0.954	0.933	0.975
ρ_G	0.868	0.829	0.909	0.890	0.854	0.928	0.885	0.846	0.924
ρ_{MS}	0.697	0.578	0.817	0.691	0.573	0.813	0.710	0.596	0.827
ρ_K	0.422	0.372	0.473	0.350	0.301	0.401	0.416	0.369	0.464
ρ_P	0.929	0.885	0.975	0.937	0.894	0.980	0.923	0.875	0.977
ρ_I	0.965	0.946	0.985	0.969	0.953	0.987	0.960	0.941	0.980
ρ_E	0.138	0.067	0.207	0.134	0.064	0.201	0.125	0.059	0.190
ρ_B	0.965	0.937	0.993	0.940	0.902	0.981	0.945	0.907	0.985

Table C.6: Banking Model (Prior Sensitivity): Posterior Estimates. Posterior distribution mean and 90% HPD interval are based on 200,000 draws from the posterior distribution of the MH algorithm.

Parameter	94Q2-99Q1			99Q2-15Q2		
	Mean	90% HPD		Mean	90% HPD	
β	0.996	0.993	0.999	0.996	0.993	0.999
χ	0.731	0.622	0.838	0.380	0.277	0.480
ξ^p	0.379	0.227	0.527	0.196	0.126	0.262
γ^p	0.334	0.095	0.571	0.506	0.204	0.815
ϕ_I	2.943	0.728	4.950	0.860	0.524	1.188
ρ_R	0.907	0.868	0.948	0.343	0.247	0.439
θ_π	1.502	1.301	1.710	2.004	1.866	2.139
θ_y	2.676	1.089	4.368	0.106	0.061	0.150
σ_c	3.036	2.441	3.644	3.477	2.941	4.013
H	0.344	0.267	0.424	0.476	0.401	0.549
ξ^r	0.010	0.002	0.017	0.010	0.002	0.017
ω_2	1.256	0.575	1.953	10.117	3.963	16.281
ω_3	1.612	0.688	2.544	0.907	0.435	1.395
μ^E	0.026	0.023	0.030	0.026	0.023	0.029
μ^B	0.0006	0.0003	0.0009	0.0006	0.0003	0.0009
μ^N	0.0006	0.0003	0.0009	0.0006	0.0003	0.0009
σ_A	0.519	0.378	0.651	0.622	0.531	0.711
σ_G	0.812	0.532	1.094	2.841	2.352	3.340
σ_M	0.326	0.239	0.410	0.938	0.763	1.111
σ_{MS}	1.640	0.702	2.560	0.905	0.717	1.088
σ_K	0.805	0.520	1.073	0.518	0.441	0.596
σ_P	2.241	1.357	3.095	1.530	1.000	2.058
σ_I	1.721	1.097	2.321	19.383	7.041	31.949
σ_E	3.539	2.302	4.691	10.063	7.681	12.341
σ_B	3.874	2.641	5.073	4.548	3.827	5.274
ρ_A	0.847	0.685	0.987	0.953	0.931	0.974
ρ_G	0.994	0.988	0.999	0.881	0.838	0.926
ρ_{MS}	0.431	0.220	0.636	0.728	0.601	0.862
ρ_K	0.477	0.339	0.615	0.503	0.456	0.549
ρ_P	0.632	0.471	0.791	0.939	0.900	0.982
ρ_I	0.278	0.101	0.442	0.964	0.944	0.985
ρ_E	0.902	0.773	0.999	0.160	0.079	0.238
ρ_B	0.803	0.717	0.889	0.932	0.883	0.985

Table C.7: Banking Model (Sensitivity to Time Periods I): Posterior Estimates. Posterior distribution mean and 90% HPD interval are based on 200,000 draws from the posterior distribution of the MH algorithm.

Parameter	94Q2-06Q4			07Q1-15Q2		
	Mean	90% HPD		Mean	90% HPD	
β	0.996	0.993	0.999	0.996	0.993	0.999
χ	0.529	0.423	0.634	0.551	0.433	0.667
ξ^p	0.176	0.111	0.229	0.387	0.278	0.493
γ^p	0.487	0.186	0.782	0.675	0.417	0.958
ϕ_I	1.129	0.598	1.657	0.904	0.435	1.358
ρ_R	0.425	0.317	0.534	0.450	0.347	0.553
θ_π	1.894	1.754	2.029	1.916	1.774	2.059
θ_y	0.139	0.063	0.207	0.123	0.062	0.185
σ_c	3.605	3.058	4.138	3.316	2.749	3.879
H	0.479	0.405	0.552	0.424	0.341	0.505
ξ^r	0.012	0.003	0.021	0.008	0.002	0.015
ω_2	5.769	2.212	9.259	5.496	1.505	9.689
ω_3	0.913	0.439	1.379	0.880	0.438	1.328
μ^E	0.026	0.022	0.029	0.026	0.023	0.029
μ^B	0.0006	0.0003	0.0009	0.0006	0.0003	0.0009
μ^N	0.0006	0.0003	0.0009	0.0006	0.0003	0.0009
σ_A	0.489	0.409	0.568	0.681	0.548	0.816
σ_G	4.044	3.200	4.897	3.354	2.518	4.150
σ_M	1.165	0.888	1.447	0.826	0.624	1.018
σ_{MS}	0.951	0.726	1.175	1.273	0.803	1.732
σ_K	0.536	0.441	0.630	0.514	0.407	0.618
σ_P	1.691	1.096	2.272	1.908	1.125	2.664
σ_I	12.408	3.032	22.353	13.515	3.752	22.903
σ_E	15.870	11.622	19.925	12.516	8.843	16.079
σ_B	4.373	3.566	5.155	4.622	3.569	5.623
ρ_A	0.955	0.916	0.994	0.949	0.917	0.983
ρ_G	0.897	0.860	0.936	0.871	0.806	0.938
ρ_{MS}	0.708	0.560	0.861	0.411	0.217	0.608
ρ_K	0.412	0.344	0.480	0.448	0.383	0.518
ρ_P	0.916	0.857	0.977	0.932	0.886	0.981
ρ_I	0.939	0.898	0.986	0.945	0.913	0.977
ρ_E	0.186	0.095	0.276	0.203	0.099	0.303
ρ_B	0.919	0.866	0.974	0.870	0.788	0.957

Table C.8: Banking Model (Sensitivity to Time Periods II): Posterior Estimates. Posterior distribution mean and 90% HPD interval are based on 200,000 draws from the posterior distribution of the MH algorithm.

D Appendices to Chapter 6

D.1 Comparison of Technology and Monetary Policy Shocks

In section 6.1.3 the relative quantitative effect of monetary policy and technology shocks was compared. The following fig. D.1 reports the simulation evidence on which this assertion is built. Figure D.1 depicts the impulse response function for output, the nominal interest rate and inflation after a monetary policy shock (blue line) and a technology shock (green line). The size of each shock is set to its respective standard deviation, that is the mean of the posterior distribution. The assumptions made for the monetary policy shock carry over to the technology shock. In quarter 1, $\epsilon_A = \sigma_A$, and for all following periods $\epsilon_A = 0$. All other shocks are set to 0.

Evidently, the response of output and the nominal interest rate is larger for the technology shock than the monetary policy shock upon impact. The effect on the nominal interest rate decreases within a few periods to a level similar to the monetary policy shock effect. In contrast, the response of GDP is longer-lasting than the one of the nominal interest rate and GDP deviates from its steady-state level to a larger extent than for the monetary policy shock. However, the response of inflation does not fit either pattern: Here, the monetary policy shock has a larger effect than the technology shock upon impact, and both have a similar quantitative effect afterwards. As noted in the text, these quantitative differences may explain part of the differences in terms of the forecast error variance decomposition (FEVD).

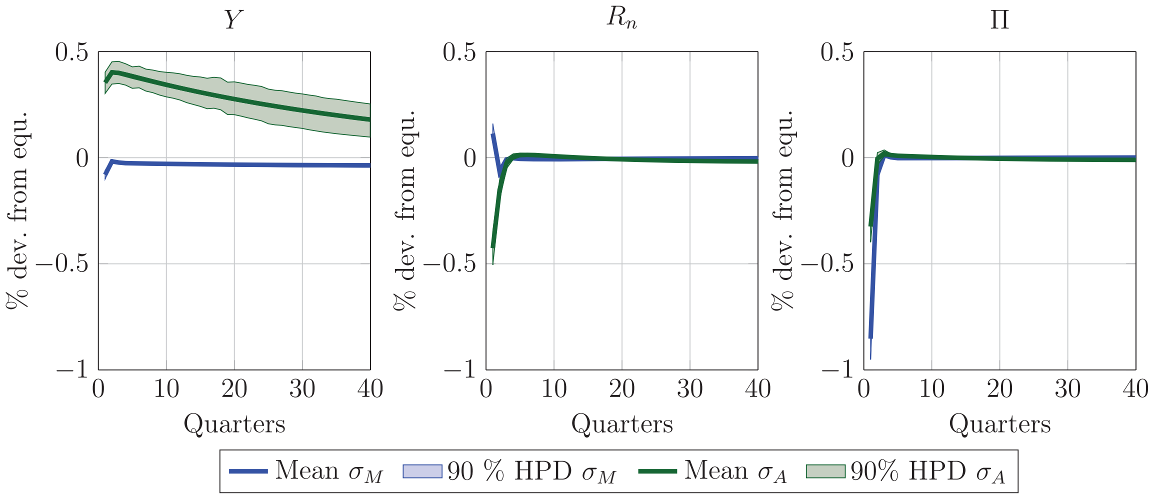

Figure D.1: Comparison of Reactions to Technology and Monetary Policy Shocks for the Banking Model; blue line: monetary policy shock, posterior mean, $\epsilon_{M,1} = \sigma_M$, $\epsilon_{M,s} = 0$, for $s = 2 : \infty$; green line: technology shock, posterior mean, $\epsilon_{A,1} = \sigma_A$, $\epsilon_{A,s} = 0$, for $s = 2 : \infty$, shaded areas indicate 90% HPD intervals; % dev. from equ. denotes percentage deviation from the equilibrium (steady state).

D.2 FEVD for Asymmetric Risk Premiums Prior

In explaining the lower significance of bank risk shocks vis-à-vis entrepreneurial risk shocks, one point to consider is the size of monitoring costs which are incurred after entrepreneurs or banks default, respectively.[1058] The following table D.1 presents the FEVD for the banking model using the parameter vector from the estimation with the asymmetric $\varrho^{E/B}$ prior distribution.[1059] To save space, only the short (s=1) and long term (s=32) for these two shocks of the FEVD are reported. Table D.1 is commented on in the text in section 6.1.3.

		BM benchmark prior		**BM asym. $\varrho^{E/B}$ prior**	
		ϵ_E	ϵ_B	ϵ_E	ϵ_B
s=1	$\hat{y}$	0.144	0.001	0.150	0.012
	$\hat{r}$	0.393	0.002	0.358	0.028
	$\hat{\pi}$	0.393	0.002	0.358	0.028
	$\hat{c}_w$	0.011	0.007	0.013	0.009
	$\hat{\imath}$	0.208	0.005	0.137	0.072
	$\hat{e}$	0.320	0.078	0.272	0.165
	$\hat{b}$	0.244	0.003	0.226	0.031
	$\hat{r}_k$	0.453	0.002	0.376	0.034
s=32	$\hat{y}$	0.012	0.004	0.012	0.022
	$\hat{r}$	0.549	0.002	0.496	0.031
	$\hat{\pi}$	0.407	0.004	0.371	0.041
	$\hat{c}_w$	0.002	0.005	0.002	0.111
	$\hat{\imath}$	0.019	0.010	0.011	0.149
	$\hat{e}$	0.059	0.058	0.040	0.258
	$\hat{b}$	0.053	0.008	0.040	0.145
	$\hat{r}_k$	0.542	0.001	0.470	0.028

Table D.1: FEVD Comparison of Entrepreneurs' and Bank Risk Shocks: Benchmark and Asymmetric Risk Premiums Prior Distributions

D.3 Additional Taylor Curve Results

The text referred to Taylor curves under the assumption that only one shock is present in the banking (BM) and financial accelerator model (FAM) economies. For illustration, the scatter graphs for single shocks are reported in fig. D.2 here. Note that the axis scales are different from figs. 6.5 and 6.6 and that the y-axis is differently scaled for investment and preference shocks (top two panels) than for the other shocks. A clear observation which emerges from fig. D.2 is that different shocks imply different magnitudes of the variances of the output gap, and to a lesser extent, inflation. The relative position of the banking model Taylor curve depends on both the estimated parameter values as well as

[1058] See section 6.1.3

[1059] See table C.6 in section C.4 for the estimation results.

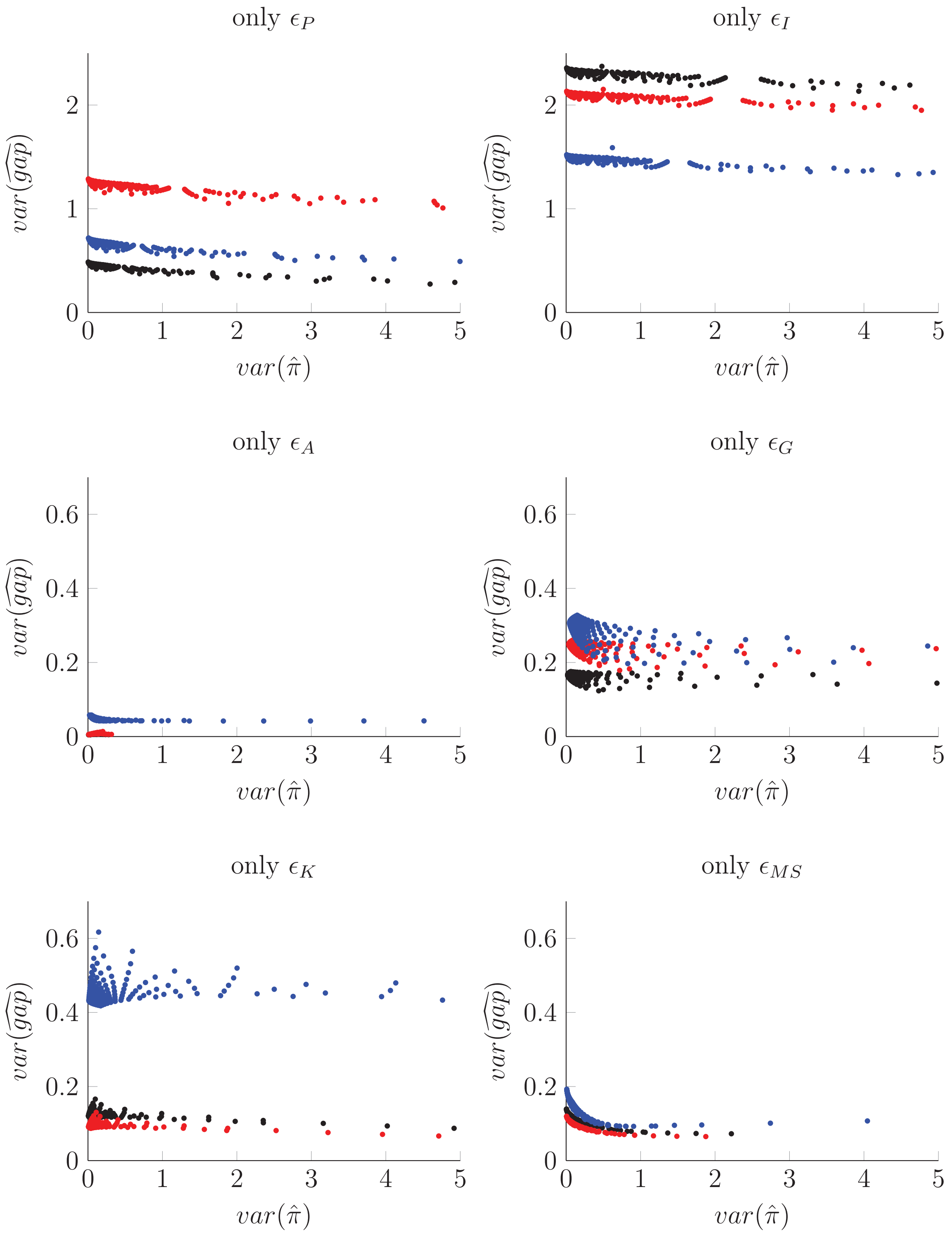

Figure D.2: Single-Shock Taylor Curve Simulations (Graphs 1-6 of 7), see next side for the legend and explanations.

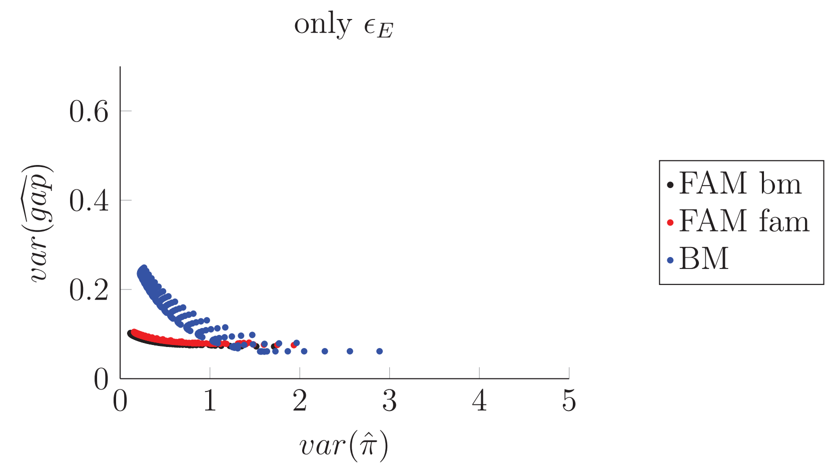

Figure D.2: Single-Shock Taylor Curve Simulations; parameters are set to the posterior mean of the banking model for BM and FAM bm, and to the posterior mean of the financial accelerator model for FAM fam, note that the x and y axes are differently scaled than in figs. 6.5 and 6.6 to focus on the different positions of the Taylor grids for single shocks.

whether the response of the banking model economy to the shock is amplified or dampened with respect to the financial accelerator model. The scatter plots in blue and red show the banking model with parameters set to the banking model posterior mean and the financial accelerator model with the parameters set to the financial accelerator model posterior mean, respectively. The black scatter plot shows the Taylor curve for the financial accelerator model when the parameters are set to the posterior mean of the banking model.

The single-shock Taylor curves for the banking model lie above the ones of the financial accelerator model for technology shocks ϵ_A, entrepreneurial risk shocks ϵ_E, government consumption shocks ϵ_G, capital quality shocks ϵ_K and mark up shocks ϵ_{MS}, irrespective of the parametrization. In line with this result, the responses of investment and GDP to these shocks are amplified in the banking model with respect to the financial accelerator model.[1060] In contrast, for investment adjustment cost shocks ϵ_I and preference shocks ϵ_P, the banking model Taylor curve lies below the financial accelerator model (FAM posterior mean). Also, for ϵ_I shocks, the banking model Taylor curve lies below the ones of either financial accelerator model parametrization.

These results concerning preference and investment adjustment cost shocks can be explained by considering the impulse responses to these shocks. The response of the banking model economy after a preference shock is amplified as compared to the financial accelerator model using the banking model posterior mean parameter vector. Thus, it is plausible that the banking model Taylor curve lies above the corresponding financial

[1060] For technology shocks, the response of inflation and investment is amplified, but the response of GDP is dampened in the long term in the banking model with respect to the financial accelerator model (FAM posterior mean).

accelerator Taylor curve evaluated at the posterior mean of the banking model (FAM bm, black dots). However, the preference shock process is estimated to be stronger initially and more strongly autocorrelated for the financial accelerator model than the banking model. This leads to the response of GDP, investment and net worth to be weaker in the banking model than in the financial accelerator model evaluated at the posterior mean of the financial accelerator model. Therefore, the banking model Taylor curve lies below the financial accelerator model (FAM posterior mean).

Considering investment adjustment cost shocks the explanation is different. The efficiency frontier of the banking model lies below the one of the financial accelerator model irrespective of the parameter values. The impulse response functions show that the reaction to an investment adjustment cost shock is dampened in the banking model, with GDP and investment declining to a smaller extent in the banking model. The reason why investment adjustment cost shocks are muted in the banking model is similar to the mechanism which amplifies monetary policy shocks. The immediate impact of an adjustment cost shock is to reduce investment and increase the price of physical capital by making investment more costly. Due to the friction associated with banks' liability management, the price of capital increases by more, thus increasing entrepreneurial net worth by more in the banking model.[1061] This in turn reduces the external finance premium of entrepreneurs, alleviating the negative initial impact on investment as entrepreneurs' capital demand does not fall as much as in the financial accelerator model. Thus, a dampened impulse response is in line with the banking model Taylor curve showing a better trade-off than the financial accelerator model. Furthermore, the investment adjustment cost process is estimated to be marginally stronger in the banking model. This explains why the Taylor curve of the financial accelerator model with the banking model parameters (black dots) lies above the one of the financial accelerator model with financial accelerator parameters (red dots).

To sum up the previous discussion, for investment adjustment cost shocks different model dynamics in the banking and financial accelerator models are the primary cause. In contrast, for preference shocks stronger shock estimates for the financial accelerator model imply more volatility, even though the dynamics of the financial accelerator model are less volatile than the ones of the banking model. This gives rise to the different positions of the single-shock Taylor curves. There is one further notable feature about shock-specific Taylor curves: The slope of the efficiency frontier of the banking model is significantly altered for the case of entrepreneurial risk shocks only.

[1061] This is in contrast to a monetary policy shock which led to a decrease in the price of physical capital and thus entrepreneurs' net worth, reinforcing the negative effect on investment.

In the aggregate Taylor curves in fig. 6.5 (as well as the other single shock Taylor curves in fig. D.2), the trade-off generally involves small increases in the output gap variance for comparatively large decreases in the inflation variance. In contrast, for the financial-shocks-only banking model, the slope of the Taylor curve changes significantly with respect to the financial accelerator model. The same reduction in terms of inflation variance is related to a marked increase in output gap variance. Particularly interesting is the fact that increasing θ_y, that is the Taylor rule coefficient governing the response to the output gap, does not monotonically decrease output gap variance in the financial-shocks-only banking model. In fact, the output gap variance monotonically increases with θ_y. In contrast, this pattern does not arise when all shocks are present and only to a smaller extent in the financial accelerator model for the case of only entrepreneurial risk shocks. Hence, the additional financial friction induces a generally positive correlation between the reaction of the central bank to the output gap and the variance of the output gap in the case of financial shocks. By reacting to deviations in the output gap, the central bank moves away from its efficiency frontier. Yet, overall, it should be kept in mind that the implied variances of the output gap and inflation due to financial shocks are small compared to, for example, preference or investment adjustment cost shocks.

D.4 Sensitivity Analysis for Macroprudential Parameters

Various sensitivity analyses were conducted in order to test the robustness of the results in section 6.3. The impulse response analysis of section 6.3.3 and the Taylor curve analysis of section 6.3.4 were repeated for varying values of ω_{mpe}, θ_m and τ_M. Also, banks' leverage ratio was used for computing deposit insurance fees instead of banks' default probability. The following paragraphs report the results.

Concerning the endogenous deposit insurance factor, the results are generally robust to varying ω_{mpe}. A countercyclical parametrization of the deposit insurance factor, that is using a negative value for ω_{mpe}, yields the opposite reaction to a monetary policy shock than the procyclical policy: the change in the inflation response is still negligible, but the deviation of GDP from its steady state is larger than in the benchmark banking model. Larger absolute values of ω_{mpe} lead to the respective effect being stronger, that is the GDP response being further amplified with a countercyclical policy, and more dampened with a procyclical policy. However, values above 2 produce counter-intuitive behaviour. Firstly, values for ω_{mpe} above 2.9 but below 4.3 yield unstable equilibria.[1062] Secondly, in contrast to the dampening effect of $\omega_{mpe} = 2$, setting ω_{mpe} equal to 5 leads to a strong amplification with respect to the benchmark banking model. Thirdly, as ω_{mpe} increases further, the response of GDP is still amplified with respect to the benchmark

[1062] This range concerns values on a 0.1 scale.

banking model, but ever more dampened with respect to the response with $\omega_{mpe} = 5$. This behaviour presents another reason for why increasing the responsivity of deposit insurance fees in order to moderate the effects of monetary policy shocks may not be viable.

Concerning the policy trade-off, both the countercyclical and the procyclical parametrization lead to upward shifts in the all-shock Taylor curves. The shift is the stronger, the higher is the absolute value of ω_{mpe}. The results are different when bank risk shocks are excluded. For positive values of ω_{mpe}, the Taylor curve shifts rightwards, with the maximum shift for $\omega_{mpe} = 5$. For values below 5, the higher is ω_{mpe}, the stronger is the rightward shift; for values above 5, the higher is ω_{mpe}, the closer is the Taylor curve to the benchmark position. This mirrors the behaviour of the impulse response functions. For negative values of ω_{mpe}, the position of the Taylor curve tilts negligibly towards higher output gap variances at low inflation variances. The larger is the absolute value of the parameter, the larger is the tilt of the $\epsilon_B = 0$ Taylor curve.

In conclusion, increasing ω_{mpe} increases the absolute effects both in terms of the impulse response function and the policy trade-off, excluding the cases of $\omega_{mpe} \geq 5$. Furthermore, a procyclical deposit insurance factor leads to a dampened response to monetary policy shocks and a worsening of the policy trade-off both with and without bank risk shocks. The countercyclical parametrization yields amplified responses to a monetary policy shock and a deterioration in the policy trade-off for the all-shock case, but a small tilt in the no-bank risk shocks Taylor curve. Yet, overall the differences are marginal. Thus, the evaluation of the particular implementation depends on how the transmission of monetary policy is judged and whether transmission or policy trade-offs weigh larger.

Also, the results are qualitatively unchanged when banks' leverage ratio is used. Yet, the changes in the impulse response functions with respect to the benchmark banking model are much smaller than with banks' default probability. This is due to banks' leverage ratio changing to a much smaller extent than banks' default probability. Also, the Taylor curve anomaly in response to bank risk shocks does not arise for the same reason. The Taylor curves for the countercyclical parametrization show a marginal downward shift of the Taylor curves, while the procyclical parametrization shows a slight upward shift. The shifts are the stronger, the higher is the absolute value of ω_{mpe}.

Turn next to the macroprudential Taylor rule (MTR) and macroprudential credit spread rule (MCS) policies. The sensitivity analysis used a value range for θ_m of 0.5 to 2.5 in 0.5 steps. This is in line with the grid used for θ_y in computing Taylor curves, although more coarse. The range for τ_M is 0.05 to 0.3, where the respective boundaries are given by the values used in Bailliu et al. (2015) (0.05) and Kannan et al. (2012) (0.3).[1063] For the MTR+MCS policy, θ_m was set to 0.25 when looping over τ_M, while τ_M was held constant at 0.15 when changing θ_m.

Regarding the Taylor curve analysis, the results presented in the text also hold for these different parameter values. Furthermore, changes in Taylor curves become larger in absolute size as the parameter values increase. The results concerning impulse response analysis also generally show that increasing parameter values lead to a stronger effect of the macroprudential policy. If a policy with $\theta_m = 0.5$ leads to a dampened response of GDP following a monetary policy shock, that is the deviation of GDP from its steady-state value is smaller in absolute terms than in the benchmark model, then the same macroprudential policy with $\theta_m = 1.0, ..., 2.5$ leads to an even more dampened response of GDP, that is lower absolute deviation from its steady state. Conversely, if macroprudential policy with $\theta_m = 0.5$ leads to an amplified response of GDP compared to the benchmark case, that is a larger absolute deviation from the steady state, then increasing θ_m amplifies the response of GDP even further, that is it increases the absolute deviation from the steady state. This similarly applies to τ_M.

There is one notable exception to this pattern. This concerns the impulse response analysis for the combination of MTR policy (with and without the MCS policy in place) with the loan-to-GDP ratio. For $\theta_m = 0.5$ above pattern still holds. However, as θ_m increases further, the responses of endogenous variables become counterfactual. In fact, real GDP, the nominal policy return and inflation increase long-lastingly with respect to their steady-state values. This is not in line with the monetary transmission mechanism as considered here.

The explanation for this behaviour of the model with high θ_m is linked to the relationship of bank loans, financing costs and the monetary policy rule. Normally, a monetary policy shock induces higher loan demand due to decreasing entrepreneurial net worth. However, as the central bank promises to react very aggressively to changes in the loan-to-GDP ratio, a relatively small increase in loans aggravates the financing situation of entrepreneurs even further, as higher policy rates imply higher marginal financing costs. Anticipating this aggressive stance of the central bank, entrepreneurs actually reduce their loan demand. This can only be achieved by an increase in entrepreneurial net worth since the capital stock in the shock period is fixed at the value before the shock. This, in turn, implies that the real return on and the price of physical capital increase. Thus, the monetary transmission mechanism is turned upside down in this case. The observation that ever higher values of θ_m decrease the quantitative impact arises for the same reasoning: absolute

[1063] See Kannan et al. (2012: 16) and Bailliu et al. (2015: 156) changes in the loan-to-GDP ratio yield an ever more aggressive reaction of the central bank. Since agents anticipate this reaction, the responses of endogenous variables turn out to be less strong. The fact that this peculiarity only arises in this specific case with the loan-to-GDP ratio is due to the size and long duration of the reaction of loans: According to the Taylor rule, as θ_m increases, the central bank eventually reacts more strongly to deviations in the loan-to-GDP ratio than to deviations in inflation. Thus, the link between the MTR policy with the economy leads to the counterfactual reaction to a monetary policy shock.

D.5 Macroprudential Policies and Financial Stability

The main text only touched upon the issue of whether and how macroprudential policies can enhance financial stability in the banking model. This appendix summarises the simulation results on this topic. The implications are discussed in the main text. There are two ways to evaluate whether macroprudential policies enhance financial stability. Firstly, macroprudential policies may counter the accumulation of financial imbalances in terms of reducing volatility. Secondly, macroprudential policies may increase the resilience of the banking model economy to financial shocks.

Financial imbalances are incorporated into the specific macroprudential policies analysed in the banking model. To measure such financial imbalances, three variables are used: lagged loan growth, the loan-to-GDP ratio and the price of physical capital. These three variables are also used here to evaluate whether macroprudential policies enhance financial stability. To this end, the computations for the Taylor curves were modified to show the trade-off between the variance of inflation and the respective financial variable. Using this measure, a macroprudential policy improves on the banking model in terms of financial stability if the same inflation variance is related to a lower variance of the financial variable.[1064] To save space, the results of this experiment are summarised in table D.2.

Column 1 of table D.2 shows the measure of financial (in)stability. Column 2 shows the indicator variable for the MTR and MCS policies, respectively. The following columns 3 to 5 report the movement of the macroprudential 'financial Taylor curve' with respect to the location of the corresponding 'financial Taylor curve' of the benchmark banking model. Finally, columns 6 and 7 report the movement in the 'financial Taylor curve' of the banking model with endogenous deposit insurance factor for two parametrizations. Note that in these latter two columns, the financial Taylor curves were computed without bank

[1064] The reference to inflation is deemed important here because it rules out extreme cases when financial volatilities decrease, but only when inflation variance is unreasonably high. Given the large range of inflation variances in the benchmark experiment, this possibility is not hypothetical.

Measure	Indicator	MTR	MCS	MTR+MCS	ν^{de} ($\epsilon_B = 0$)	
					$\omega_{mpe} = 1$	$\omega_{mpe} = -1$
$var(\hat{b}_t - \hat{b}_{t-1})$	$\hat{b}_t - \hat{b}_{t-1}$	U	U	U		
	$\hat{b}_t - \hat{y}_t$	U	D	D	U	D
	$\hat{q}_t$	U	U	U		
$var(\hat{b}_t - \hat{y}_t)$	$\hat{b}_t - \hat{b}_{t-1}$	U	(T^*)	(T^*)		
	$\hat{b}_t - \hat{y}_t$	U	D	D	U	D
	$\hat{q}_t$	T^*	U	U		
$var(\hat{q}_t)$	$\hat{b}_t - \hat{b}_{t-1}$	(U)	T^{**}	T^{**}		
	$\hat{b}_t - \hat{y}_t$	U	U	U	U	D
	$\hat{q}_t$	T^*	D	D		

Table D.2: Consequences of Macroprudential Policies for Financial Stability

risk shocks. Concerning the abbreviations in the table, 'U' denominates an upward shift with respect to the benchmark banking model, that is the macroprudential policy leads to a higher financial volatility. Conversely, 'D' denotes a downward shift. For both 'D' and 'U', this shift is visible for inflation variance values of less than 20.[1065] In contrast, the term 'T' signifies that the Taylor curve tilts: one star (*) indicates that for low inflation variances, the macroprudential policy yields a lower variance of the financial variable than the benchmark banking model, but not at higher inflation variances. The opposite is true for the case of two stars (**), where the macroprudential banking models yield higher variances of the financial variable for low inflation variances, but lower variances of the financial variable when inflation variance is high.

For the MTR and MCS policy (combinations) there is no simple pattern. Somewhat surprisingly, the use of lagged loan growth as an indicator variable does not improve the inflation-financial imbalance variances trade-off when financial imbalances are measured by lagged loan growth. However, neither the MCS nor the MTR+MCS policies yield a monotone improvement in the trade-off using lagged loan growth as the measure of financial imbalances. For the other two measures of financial imbalances, some policy combinations result in an improvement, an improvement over some value span or a deterioration. Conversely, no single one of these policies leads to a uniform improvement in all three measurements of financial imbalances.[1066] For the endogenous deposit insurance factor the pattern is simpler: if bank risk shocks are included, both parametrizations yield

[1065] Cutting off the curves at an inflation variance of 20 appears reasonable since firstly, this would imply that the central bank regards output gap variance roughly 7 times more important than inflation variance which seems counter-intuitive in this context (see fig. 6.5). Secondly, the objective of this table is to exemplify the difficulties surrounding the measurement of financial instability and not to assess which macroprudential policy is best. Thus, the range is sufficient.

[1066] Note that there are policy combinations which lead to a uniform deterioration in this regard.

a deterioration in the trade-off. This is the reason they are not reported in table D.2. If bank risk shocks are excluded, a procyclical policy leads to a uniform deterioration, while a countercyclical policy leads to a uniform improvement.

Concerning the resilience to financial shocks, there is a wide variety of effects. Mirroring the results in table D.2, some policy combinations lead to amplifying and others to dampening effects with respect to the benchmark banking model.[1067] Also, the effects may be different for the responses of GDP and inflation.[1068] Finally, macroprudential policies may increase the duration for which GDP is displaced from its steady state.[1069] The endogenous deposit insurance factor generally leads to an amplified response, except for the procyclical policy in response to entrepreneurial risk shocks.

Thus, the endogenous deposit insurance factor presents mixed results in terms of enhancing financial stability. Yet, the endogenous deposit insurance factor may instead be judged based on its impact on the government budget. Upon impact of the monetary policy shock, either parametrization leads to an increase in the budget deficit, ceteris paribus.[1070] However, after a few quarters, banks' default probability is close to its steady state value, and so is the endogenous deposit insurance factor and the government budget deficit. A further curiosity arises in the benchmark banking model with endogenous taxes. In this case, the government runs a budget surplus a few quarters after the shock when the deposit insurance factor is exogenous while the budget is balanced in the case of the endogenous deposit insurance factor. If a balanced budget is taken as a goal, then this policy can help achieve it. However, since there are budget surpluses in the benchmark banking model, the endogenous deposit insurance factor may be judged to have a negative impact on the government budget. Either way, above criticisms about the limited characterisation of the government budget in the banking model apply here as well. This reduces the informative value of this experiment.

[1067] An example of the former is the MCS policy with the price of physical capital in response to bank risk shocks. Either policy with the price of physical capital in response to entrepreneurial risk shocks is an example of the latter.

[1068] This occurs for example in response to financial shocks when the MTR policy reacts to the loan-to-GDP ratio.

[1069] This is the case with the MCS policy responding to lagged loan growth after bank risk shocks.

[1070] Since the government is confined to a balanced budget, this deficit is covered by tax increases.

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