Balance Sheet Policies and Financial Stability: Central Banking Reimagined

by

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Dissertation presented for the degree of

Doctor of Philosophy in Economics in the

Faculty of Economic and Management Sciences

at Stellenbosch University

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December 2016

Declaration

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December 2016

Abstract

Balance sheet policies have become the primary policy lever of several central banks in the wake of the international financial crisis. However, with inflated central bank balance sheets, and global economic conditions returning to normal, the future of balance sheet policies needs to be considered. In this thesis I aimed to define a role for balance sheet policies in the monetary policy toolkit, especially with regard to financial stability. First, I developed an explicit definition of balance sheet policies and their channels of transmission to help resolve the confusion clearly visible in the academic literature and popular media. Second, I explored the changing nature of central bank operational frameworks, which identifies several new regimes. Third, I developed a dynamic general equilibrium model that implements supply-side financial frictions and the salient features of balance sheet policies.

My first empirical chapter employed a time-varying parameter vector autoregressive (TVP-VAR) model to establish the nature of the relationship between central bank liabilities and the overnight policy rate. Four countries with different monetary policy regimes were considered. It was found that a clear negative relationship between these variables exists only in the case of one regime, namely the reserve regime. This result indicates that the introduction of new operational frameworks for central banks have challenged the traditional model of monetary policy implementation. The practical implication of the decoupling of interest rates from reserves is that central bank balance sheets potentially can be used alongside conventional interest rate policy.

In the last two chapters of the thesis a dynamic general equilibrium model was developed, equipped with a heterogeneous banking sector, endogenous default and collateralised lending on the part of the central bank. Within this framework, changes along the dimensions of size and composition of the central bank's balance sheet were integrated. Increasing the size in this model significantly contributed to financial stability. However, when used in conjunction with interest rate policy, it could cause conflicting effects. Changes in its composition establish local supply effects, which means that long-term interest rates are depressed, an explicit goal of many asset purchase programmes. Changing the composition has an impact beyond that for the change in size, relaxing borrowing conditions even more than a pure injection of liquidity.

Opsomming

Balansstaatbeleide het ná afloop van die internasionale finansiële krisis die vernaamste beleidshefbome geword van verskeie sentrale banke. As gevolg van vergrote sentrale bank-balansstate en die globale ekonomiese toestande wat teruggekeer het na normaal, moet die toekoms van balansstaatbeleide egter heroorweeg word. In hierdie tesis is my doel om 'n rol te definieer vir balansstaatbeleide in die monetêre gereedskapskis, met spesifieke aandag aan finansiële stabiliteit. Eerstens het ek 'n eksplisiete definisie van balansstaatbeleide en hulle oordragkanale ontwikkel, om sodoende die verwarring te help opklaar wat duidelik sigbaar is in die akademiese literatuur en die populêre media. Tweedens het ek die veranderende aard van die sentrale bank se operasionele raamwerk ondersoek en verskeie nuwe bestelle geïdentifiseer. Derdens het ek 'n dinamiese algemene ekwilibriummodel ontwikkel wat aanbodkant-finansiële wrywings implementeer, tesame met die kenmerkende eienskappe van balansstaatbeleide.

My eerste empiriese studie het 'n tyd-variërende parametervektor-outoregressiewe (TVP-VAR) model gebruik om die aard van die verwantskap tussen sentrale banklaste en die oornagbeleidskoers te bepaal. Vier lande met verskillende monetêre beleidstelsels is oorweeg. Daar is gevind dat 'n duidelike negatiewe verhouding tussen dié veranderlikes net bestaan in die geval van een stelsel, naamlik die reserwestelsel. Dié resultaat dui daarop dat die ingebruikneming van nuwe operasionele raamwerke vir sentrale banke die tradisionele model van monetêre beleidsimplementasie bevraagteken. Die praktiese gevolg daarvan om rentekoerse te ontkoppel van reserwes is dat sentrale bank-balansstate potensieel saam met konvensionele rentekoersbeleide gebruik kan word.

In die laaste twee hoofstukke van die tesis is 'n dinamiese algemene ekwilibriummodel ontwikkel, wat 'n heterogene banksektor insluit, asook endogene wanbetaling en gekollateraliseerde uitleen aan die kant van die sentrale bank. In hierdie raamwerk is veranderings geïntegreer oor die omvang van die grootte en samestelling van die sentrale bank. Indien die omvang van die balansstaat in hierdie model vergroot word, het dit aansienlik bygedra tot finansiële stabiliteit. Wanneer dit egter saam met 'n rentekoersbeleid gebruik word, kan dit teenstrydende gevolge hê. Veranderings in die samestelling het gelei tot plaaslike voorsieningsgevolge, met die gevolg dat langtermynrentekoerse afwaarts gedwing word, wat 'n uitdruklike doel is van baie bate-

verkrygingsprogramme. Die uitwerking van 'n verandering in die samestelling het 'n groter impak getoon as 'n verandering in omvang, en het uitleentoestande selfs meer verslap as 'n suiwer inspuiting van likiditeit.

Acknowledgements

The process of writing a dissertation can be long and arduous. However, there are several people that have made it manageable and ultimately worthwhile.

I would like to thank my supervisor, Prof. Stan du Plessis, who has been an outstanding mentor. His input, since my time as Honours student, has shaped the way in which I approach research. I am grateful to him for allowing me to tap into a vast pool of knowledge on a range of issues, including, but not limited to, this dissertation.

I extend my gratitude to my co-supervisors, Prof. Dave Liu and Dr. Monique Reid. In terms of the more technical aspects of the thesis, Prof Liu has always managed to steer me in the right direction. His calm demeanour in dealing with problems is contagious. Another calming influence during this process has been that of Dr. Reid. She has prevented me from derailing on several occasions, often helping me to retain perspective.

To my mother and father, thank you for unwavering support, emotionally and financially. I hope to pay you back, emotionally at least. To my brother, Wimpie, thank you for enduring my endless discussions and tirades.

To my wife, Milandré, thank you for your understanding. It is difficult to imagine how I would have accomplished this without you. Thank you for giving balance to my life, reminding me that there is more to life than work. I love you very much.

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Acronyms and Abbreviations

ABCP Asset-backed Commercial Paper

ABS Asset-backed Securities

ABSPP Asset-backed Security Purchase Program

ADF Augmented Dickey-Fuller

AIC Akaike Information Criterion

AMLF Asset-backed Commercial Paper Money Market Mutual Fund Liquidity Facility

APF Asset Purchase Facility

APFF Asset Purchase Facility Fund

APP Asset Purchase Program

BAR Banker's Acceptance Rate

BoE Bank of England

BoJ Bank of Japan

BSP Balance Sheet Policy

BVAR Bayesian Vector Autoregression

CAB Current Account Balance

CBI Central Bank Independence

CBPP Covered Bond Purchase Program

CDO Collateralised Debt Obligation

CDS Credit Default Swap

CME Comprehensive Monetary Easing

CP Commercial Paper

CPFF Commercial Paper Funding Facility

CPI Consumer Price Index

DWF Discount Window Facility

DSGE Dynamic Stochastic General Equilibrium

EAPP Extended Asset Purchase Programme

ECB European Central Bank

ECS Enhanced Credit Support

EFSF European Financial Stability Facility

ELTRs Extended Collateral Long-Term Repos

EME Emerging Market Economy

ER Excess Reserves

ESM European Stability Mechanism

FAVAR Factor Augemented Vector Autoregression

Fed United States Federal Reserve

FLS Funds for Lending Scheme

FOMC Federal Reserve Open Market Committee

FRFA Fixed Rate Procedure with Full Allotment

FROs Fixed Rate Operations

FSA Financial Services Agency

GDP Gross Domestic Product

GSEs Government Sponsored Enterprises

GSFF Growth Supporting Funding Facility

HBOS Halifax Bank of Scotland

HM Her Majesty

IMF International Monetary Fund

IOR Interest on Reserves

IOER Interest on Excess Reserves

IP Industrial Production

IRF Impulse Response Function

JGBs Japanese Government Bonds

LBVAR Large Bayesian Vector Autoregression

LIBOR London Interbank Overnight Rate

LTROs Longer-term Refinancing Operations

LTV Loan-to-Value

LSAPs Large-scale Asset Purchase

LVTS Large Value Transfer System

MB Monetary Base

MBS Mortgage-backed Securities

MEP Maturity Extension Program

MMMF Money Market Mutual Fund

MPC Monetary Policy Committee

MROs Main Refinancing Operations

MS-VAR Markov-switching Vector Autoregression

NBR Nonborrowed Reserves

NIBOR Norwegian Interbank Offered Rate

NIRP Negative Interest Rate Policy

OECD Organisation for Economic Co-operation and Development

OLS Ordinary Least Squares

OMOs Open Market Operations

OMT Outright Money Transactions Programme

OMTD Open Market Trading Desk

PBC Portfolio Balance Channel

PDCF Primary Dealer Credit Facility

PSPP Public Sector Purchase Programme

P-VAR Panel Vector Autoregression

QE Quantitative Easing

QEP Quantitative Easing Program

QQE Quantitative and Qualitative Monetary Easing

QQEN QQE with Negative Interest Rates

QVAR Qualitative Vector Autoregression

RBS Royal Bank of Scotland

RRPs Reverse Repurchase Agreements

SA South Africa

SABOR South African Benchmark Overnight Rate

SARB South African Reserve Bank

SBLF Stimulating Bank Lending Facility

SFSOs Special Funds-supplying Operations to Facilitate Corporate Financing

SIC Schwarz Information Criterion

SIV Structured Investment Vehicle

SLS Special Liquidity Scheme

SMF Sterling Monetary Framework

SMP Securities Markets Programme

SPV Special Purpose Vehicle

SVAR Structural Vector Autoregression

TAF Term Auction Facility

TALF Term Asset-backed Securities Loan Facility

TARP Troubled Asset Relief Program

TBR Treasury Bill Rate

TIBOR Tokyo Interbank Overnight Rate

TL Total Liquidity

TLRTOs Targeted Longer-term Refinancing Operations

TSLF Term Securities Lending Facility

TVP-VAR Time-varying Parameter Vector Autoregression

UK United Kingdom

US/A United States of America

VAR Vector Autoregression

VECM Vector Error-correction Model

VLTROs Very Long-term Refinancing Operations

ZLB Zero Lower Bound

ZIRP Zero Interest Rate Policy

Chapter 1

Introduction

> *Over the past twenty years the world's major central banks have been largely successful at bringing inflation under control. While it is premature to suggest that inflation is no longer an issue of great concern, it is quite conceivable that the next battles facing central bankers will lie on a different front.*
>
> — Ben Bernanke and Mark Gertler (2000)

In his 1979 article, entitled *The Anguish of Central Banking*, Arthur Burns lamented the ability of central banks to address the worldwide disease of inflation, despite central bankers having "potent means for fostering stability of the price level" (Burns, 1979). In the years that followed academics, central bankers and policymakers came together to combat this disease, all but reaching a cure. In fact, as argued by Goodfriend (2007b), the progress of monetary policy "is a remarkable success story". However, not all were convinced, and as argued by Galí and Gertler (2007), "despite the recent successes, we cannot be certain without further experience how resilient these frameworks will prove as new kinds of disturbances hit the economy". Caution was warranted, as less than a year later the financial crisis called the contributions of monetary policy into question. The words of Bernanke and Gertler (2000) ring almost prophetic, heralding perhaps another era of anguish for the central banker.

In response to the crisis, central bankers aggressively pursued expansion, with interest rates driven close to zero in many countries. With conventional monetary policy tools exhausted, balance sheets of central banks - previously relegated to regulating the effective overnight policy rate - assumed the role of protagonist in the post-crisis monetary policy narrative. In this chapter I endeavour to explain why balance sheet policies will become an intricate part of the future of monetary policy, especially as it pertains to achieving financial stability. The literature on the topic of central bank balance sheets is vast, with theoretical contributions on different aspects of balance sheet policy spanning back to the end of the Second World War. With such a wealth of research, one might ask what possible contributions are left to be made. This chapter addresses that question, not only identifying a gap in the literature, but also offering suggestions on how one could approach the problem.

1.1 Rationale

In 2007 the United States Federal Reserve held less than $1 trillion worth of assets on its balance sheet. Today that number is in excess of $4.6 trillion (Feroli et al., 2016). During this period the Bank of England purchased assets to the value of £375 billion (Emerson, 2016). The Bank of Japan is expanding the monetary base - which is already at ¥416.5 trillion at the time of writing - at an annual rate of ¥80 trillion (De Michelis and Iacoviello, 2016). Finally, the European Central Bank (ECB) is the latest in a succession of central banks to adopt a quantitative easing (QE) program. The size of the program is unprecedented, with monthly injections of €60 billion (Breuss, 2016). The numbers quoted tell only a part of this story, as the composition of balance sheets has undergone dramatic change, with many central banks allowed purchases of private sector assets beyond their normal operations (Pattipeilohy, 2016).

Owing to the controversy[1] surrounding their implementation, balance sheet policies such as quantitative easing are a topic now familiar to many outside of monetary policy circles. Surprisingly, balance sheet policies are ill-defined in academic research, and more so in the popular media. There exist several conflicts and inconsistencies in the definition of central bank balance sheet policies, which is compounded by the fact that implementation differs across central bank operational frameworks. Unfortunately, this translates into a broad misunderstanding of the purpose and capacity of these policies.

In a general sense, balance sheet policies can perform three actions. First, central banks can use balance sheet expansion to reflect an accommodative monetary policy stance, in conjunction with a commitment to a certain short-term policy rate (Woodford, 2012). In some cases, such as the one in which the nominal short-term policy rate reaches the zero lower bound, balance sheet policy can act as a temporary substitute to traditional monetary policy. Second, they can help prevent the damage caused by sudden sharp movements in international capital flows. Finally, they are capable of improving conditions for financial stability. Research in this thesis is concerned primarily with the implications for financial stability of implementing balance sheet policies. (Pattipeilohy, 2016)

[1]The introduction of QE was perceived as a bailout of the very financial institutions that caused the crisis and exposed central banks to credit risk, in turn threatening their fiscal independence.

While financial stability has always been of great concern to policymakers and scholars alike, it was only in recent years that its import has been elevated to match that of price stability (De Gregorio, 2012). Several policy suggestions, with respect to financial stability, have been proffered to monetary authorities; however, they have not consented to a resolution (Blanchard et al., 2013). The short-term interest rate as the conventional tool of monetary policy is limited in its scope to address financial stability. This is due, in part, to the fact that interest rates are a blunt tool against the buildup of financial imbalances accompanying movements in asset prices and credit aggregates (Bernanke, 2011).

In addition, as stated by the Tinbergen rule, "if the number of policy targets surpasses the number of instruments, then some targets may not be met" (Tinbergen, 1952). In other words, one should not overburden policy tools with too many targets, as this impedes the proper functioning of the instrument concerned. In line with this reasoning, several developed countries have enacted balance sheet operations, by altering the size and composition of their balance sheets, to address dysfunctional markets (Bernanke, 2011).

Most of the empirical research on the topic of balance sheet policies have been directed at financial markets and the broader macroeconomic impact. In particular, there are two broad classifications of empirical studies on this topic. First, there are studies that look at the short-term influence of balance sheet policies implemented around the time of the crisis, specifically the impact on longer-term interest rates and interest rate spreads. Research in this area usually takes the form of event studies, with more recent papers using time-series analysis to determine the effect. Second, research is being done on the macroeconomic effect of these policies, looking at different measures of real activity, such as gross domestic product (GDP), inflation and unemployment among others. For this analysis, there is a large contingent of different models used.

In terms of theoretical developments, there are also several dynamic stochastic general equilibrium (DSGE) models that try to model the specific channels through which balance sheet policies can affect both financial markets and real activity. In particular, there is a collection of models that looks to emulate the large-scale asset purchases (LSAPs) implemented by developed economies. One of the attractive features of these models is their ability to provide a mechanism to evaluate the potential balance sheet policy impact, through country-specific calibration and estimation.

1.2 Problem Statement

Macroeconomic theorists from all research spheres are trying to introduce greater scope for financial markets in their modelling frameworks. In particular, a recent strand of models, which incorporate financial frictions, has been developed with the purpose of replicating the effect of balance sheet operations on the macroeconomy. However, most of the work looks only at the impact on the real economy, with only a small number dealing with financial stability implications. This thesis aims to extend the current generation of dynamic general equilibrium macroeconomic models in a significant way, by allocating a non-trivial role to balance sheet operations in harnessing the objective of financial stability.

This is a significant development, as currently there is limited scope for conventional monetary policy to address financial instability. Macroprudential regulations have been offered to complement monetary policy. However, balance sheet policies could provide another useful tool in the policy arsenals of central banks. With the development of new operational frameworks, it might be possible to incorporate balance sheet policy alongside the traditional monetary policy mechanisms (not only in the case of a liquidity trap).

The purpose of this thesis then is threefold. First, to bring clarity to what is meant by balance sheet policies and also explain how they fit into the monetary policy narrative. Second, to establish the conditions under which balance sheet policy can be used in conjunction with the short-term nominal interest rate (i.e. conventional monetary policy). Third, to build a dynamic general equilibrium model that incorporates a measure of financial stability as well as the different aspects of balance sheet policies. Importantly, this means including all dimensions of balance sheet policy, translating to both changes in the size and composition of the balance sheet of the central bank. Ultimately, I want to determine what the financial stability impact would be of implementing different balance sheet operations.

1.3 Outline and Approach of the Thesis

This dissertation can be divided into four distinct sections, each exploring a different dimension of balance sheet operations. This section delineates the different chapters of the thesis, exploring the central questions in each chapter and the methodological approach used. It also acts as a roadmap for the thesis, providing a general overview of each section and its relative contribution. Also, the results of specific chapters are discussed briefly, with a more in-depth discussion deferred to the individual chapters; ultimately, these are summarised in the conclusion.

1.3.1 Chapter 2, 3, 4: Balance Sheet Policies

A reading of the literature on balance sheet policies quickly reveals that there is a general level of confusion as to what these policies are capable of, the transmission mechanisms at play, the definition of the different types of balance sheet policies and the drawbacks associated with implementing them. The goal of this chapter is to unravel the often abstruse writings on the subject and give a clear idea of what balance sheet policies are, providing clarity as to the different dimensions, against the backdrop of different central bank operational frameworks.

In these three chapters, I present a balance sheet policy narrative through a mixture of chronological and thematic literature reviews. I start the dialogue by referring to the earliest incarnations of balance sheet policies, which entails a survey of the pioneering balance sheet policy actions taken by the Bank of Japan in the early 2000s. This case study provided me with a point of departure from which to commence the search for an appropriate balance sheet policy typology. Properly defined, a typology provides greater clarity to the reader as to the finer details on what constitutes different types of balance sheet policy. Importantly, the typology also provides a platform for the conversation on the proposed transmission channels.

The financial crisis was the catalyst to the large-scale adoption of balance sheet policies in developed and emerging economies. However, each country is distinct in its motivation for employing balance sheet policies, which led me to consider the rationale for adopting them in several countries that have done so. Hence, I tried to identify why they differed in the type of policy implemented. Country-specific scenarios gave me a better idea of the scope of the policy practiced. Once the narrative on balance sheet policies was set, I looked at the empirical evidence as to their efficacy in achieving their stated goals. The review of empirical evidence on balance sheet policies in several developed economies gave me an idea of optimal policy combinations, revealing which policy was most appropriate to use, given certain circumstances. Finally, I identified several of the unforeseen complications encountered with the application of balance sheet policies.

1.3.2 Chapter 5: Liquidity Effect

In this chapter, I look to uncover how monetary policy is implemented internationally. The purpose of this is to discover which operational frameworks will deliver a possible decoupling of a central bank's balance sheet from the policy rate. Decoupling here is the independent movement of the interest rate and central bank balance sheet, providing two distinct monetary policy tools.

The analysis was conducted through several time-series methods, but the utilisation of a time-varying parameter vector autoregressive (TVP-VAR) model was the preferred approach. This approach to VAR modelling is specifically relevant to this topic as I wanted to determine the nature of the relationship between interest rates and central bank liquidity (i.e. reserves), while also considering whether it would be stable over time. An alternative approach that was employed is that of a traditional VAR model. However, this requires a, largely arbitrary, splitting of samples for each country into sub-samples according to identified monetary policy regimes. Even though these regimes can be identified by consulting the relevant literature, the partitioning into sub-samples is subjective. Another method of tracking the time-varying nature of changes in the relationship, namely rolling regressions, was also used.

In particular, I implemented a TVP-VAR model with *stochastic volatility*, as proposed by Primiceri (2005). This model has become widely used to evaluate several crucial macroeconomic questions. The important contribution of this approach is that is allows the researcher to "capture the potential time-varying nature of the underlying structure of the economy in a flexible and robust manner" (Nakajima, 2011). The assumption that VAR coefficients will be constant across changes in monetary policy implementation is not realistic, which was an important reason for adopting the TVP-VAR framework.

In addition, one of the primary concerns of VAR models is that of over-parametrisation (Koop and Korobilis, 2010). Bayesian methods, as utilised in TVP-VAR models, introduce a solution to this problem by relying on shrinkage (i.e. imposing restrictions on parameters and shrinking them to zero). Multivariate time-series models with high multi-dimensionality are particularly difficult to solve, but due to improvements in computational power, this problem has been largely resolved. Through the use of Bayesian priors one can include multiple time-series variables in a sensible way without serious concern about over-parametrisation.

1.3.3 Chapter 6: Model

The workhorse macroeconomic model, utilised by the majority of central banks, is the standard New-Keynesian dynamic stochastic general equilibrium (DSGE) framework. In general, economic theorists have to make assumptions that reduce complex real-world interactions into easily digestible mathematical equations. However, the assumption that financial markets are perfect and complete has come under scrutiny after the recent financial crisis (Roger and Vlcek, 2012).

This assumption implies that agents (and thereby the asset pricing kernel) will not necessarily be affected by government purchases of assets. Agents may perceive balance sheet operations as a reshuffling of assets between the private sector and the central bank (Cúrdia and Woodford, 2011). This assumption originates from the work of Modigliani and Miller (1958), who believed in the irrelevance of the composition of the firm's balance sheet. The problem is that the inclusion of this theorem into modern macroeconomic models limits the scope for financial intermediation; and thereby the transmission of credit market conditions to real economic activity (du Plessis, 2012; de Walque et al., 2010). With hindsight it is palpably clear that the exclusion of the banking sector in analytical macroeconomic models was a mistake. However, the opportunity to correct this error has presented itself.

The dynamic general equilibrium model proposed in this dissertation draws on the work of Goodhart et al. (2006). This piece of work is the culmination of years of research, and several other articles are linked in the model's construction (see, for example, Aspachs et al. (2006a); Tsomocos and Zicchino (2005); Aspachs et al. (2006b); Goodhart and Tsomocos (2006)). One of the most important contributions of their body of work has been the inclusion of a heterogenous and endogenous banking sector.

Goodhart et al. (2006) abstract from the representative agent approach in modelling the banking system. This allows the interaction of banks on the interbank market and thereby the possibility to model the reaction of commercial banks to certain shocks. The failure of banks, or endogenous default as it is referred to by Goodhart et al. (2006), is one of the primary features of this model. Failure is a function of the risk preference of banks in this system, with the riskiest banks being assigned the highest probability of default. These failures are not isolated events in this model and have system-wide implications for the survival of other banks. Some other highlights of the model include a non-trivial role for money, frictions in consumer credit markets and the possibility of the violation of capital requirements (Goodhart et al., 2006). Since the publication of this paper, several authors have adopted it to explore various macroeconomic issues.

The contribution of this chapter to the literature is the introduction of non-trivial balance sheet operations in a DSGE model with financial frictions. Goodhart et al. (2011) incorporate the monetary base into their financial fragility framework and analyse its potential for use as a prudential policy tool. My model builds on these ideas but is different along two dimensions. First, it is set in a dynamic general equilibrium framework, similar to that of de Walque et al. (2010). Second, it includes collateralised lending from the work of Schabert (2015), which is considered to be a less arbitrary method for modeling balance sheet expansion. Alterations to the collateralised lending (haircut) mechanism of Schabert (2015) also allow the possibility of decoupling the balance sheet from the policy rate, in order to see how these policies could operate independently from one another.

1.3.4 Chapter 7: Model with Long-term Bonds

Having established a dynamic general equilibrium model with some attractive aspects, such as financial frictions and balance sheet expansion, the important question became, what would be the effect of changes in the composition of the balance sheet? In particular, what would happen if a portfolio balance effect were introduced, through the purchase of long-term securities?

The post-crisis discourse indicates that the composition of balance sheets matter (du Plessis, 2012). It is, therefore, imperative to determine what changes in the composition of the balance sheet mean for financial stability. Several countries have already broadened their asset portfolio to include several public and private sector securities. I glean from this that central banks have tried to influence the balance sheets of banks in the private sector through the issuing of liabilities, of which central banks are the monopoly suppliers (Brink and Kock, 2009).

Theoretically, employing credit easing transmits to the real economy through the signalling and portfolio balance channels (du Plessis, 2012). The portfolio balance effect reflects how the accumulation of assets by central banks might induce a change in the relative spreads of various assets in financial markets (Tobin, 1969)[2]. The theory is that if the central bank holds large amounts of a particular reserve, it forces private banks to hold less of it and more of other types of assets, referred to as the local supply or scarcity effect[3]. This type of scenario exists only when agents in the private sector are not perfectly indifferent among assets (Cúrdia and Woodford, 2011). Central banks often point to the fact that risk profiles are likely to be different among a selection of assets, which would mean that assets are not always perceived as perfect substitutes (Joyce et al., 2012a).

For this chapter I am interested in the implications of changes in the composition of the balance sheet of the central bank for financial stability. In order to achieve this, one needs to present a model that contains some form of imperfect asset substitutability. In general, there are two modelling approaches. First, there are models that try to impose some type of restriction on intermediation, in the vein of Gertler and Karadi (2011). Central bank intermediation performs the function of financial intermediaries in this setup, which creates the appropriate friction, allowing the central bank to transform illiquid assets on the balance sheets of private investors. Second, we have 'preferred habitat' models, in which a certain class of investors are interested only in investing in a certain segment of the yield curve. Models in this tradition include those of Vayanos and Vila (2009) and Chen et al. (2012a). My approach most closely resembles that of Chen et al. (2012a). The contribution from this chapter entailed incorporating their model of long-term securities into the framework from Chapter 6. This provided the ability to look at

[2]This forms part of the portfolio balance channel and is also known as the asset substitution effect.
[3]This still falls under the portfolio rebalancing mechanism, it is simply a subcategory of the channel.

purchases of long-term securities by central banks.

1.3.5 Chapter 8: Conclusion

In this chapter I summarise the results obtained from the models, identifying the tangible contribution of the thesis to the literature, as well as the potential for practical application. This chapter also allows the space to highlight some shortcomings of my approach and then to briefly discuss plausible research avenues that could stem from this thesis.

Part I

Literature Review

Chapter 2

Balance Sheet Policies I: Early History and Theory

> *The central bank's balance sheet has 'always' been a policy tool, especially in open economies where central banks hold foreign reserves... The use of QE and other unconventional tools in the recent past has just made us study these issues better, learn more about their effects, and so become more confident about using them in the present and in the future.*
>
> — Ricardo Reis in the CFM Survey (2016)

Central banks across the globe have resorted to unconventional monetary policy (UMP), in light of the fact that conventional expansionary interest rate policy alternatives have been exhausted. However, balance sheet policies are not considered all that unconventional. In particular, as illustrated in this chapter, it is the choice of asset markets targeted by central bank purchases that makes a balance sheet policy unconventional (Borio and Disyatat, 2010). In the US, for example, the Federal Reserve Act allows the central bank to buy and sell assets "without regard to maturities but only in open markets" (D'Amico et al., 2012). This implies that the Fed could undergo purchases of long-term government debt without contravening this act, while still staying within the realm of what is considered conventional. However, large-scale asset purchases of private sector securities extend the balance sheet of the bank beyond its 'Treasuries only' protocol[1], moving it into unconventional territory (Woodford, 2012). Even before the current crisis, there were examples where the usage of central bank balance sheets were considered normal.

[1]The central bank is only supposed to carry Treasuries on the asset side of the balance sheet. However, Treasuries can be of different maturities.

2.1 Early Balance Sheet Policy (Post-War Period)

In the broadest, sense balance sheet policies can be viewed as any balance sheet action taken by the central bank that attempts to affect asset market conditions beyond adjusting a short-term interest rate (Borio and Disyatat, 2010). Derivatives of modern balance sheet policy were first implemented in foreign exchange intervention, long before the current financial crisis[2]. The management of exchange rates is not of specific interest to the balance sheet narrative explored in this thesis. Nevertheless, foreign exchange intervention is referenced to demonstrate that the use of balance sheets by central banks, beyond that of interest rate management, preceded the response to the international financial crisis.

These operations of central banks in the post-War period were primarily performed by developing countries in an attempt to exert pressure in an ever-changing exchange rate environment. They can be defined as central bank intervention in the foreign exchange market, the buying/selling of foreign currency to affect the exposure of private agents. Exchange rate policy is especially prominent in emerging Asia, with South Korea, Thailand and China identified as examples of countries that have managed to intervene in foreign exchange markets through sterilised purchases[3] of foreign assets (Borio and Disyatat, 2010). More recently, reserve accumulation (expansion of the central bank's balance sheet) has been a characteristic of developing countries in the aftermath of the 1997-8 Asian financial crisis, in attempts to resist the appreciation of their domestic currencies (Filardo and Grenville, 2012). With that considered, the next section introduces the first part of our discussion on modern central bank balance sheet policy, which was spearheaded by Japan in a concerted effort to avoid deflation.

2.2 The Zero Lower Bound (1990s)

2.2.1 The Lost Decade and the Liquidity Trap

Balance sheet measures were thrust into the spotlight during the 1990s, owing to the derailment of the Japanese economy following a period of rapidly increasing prosperity. Japan's 'lost decade' refers to the prolonged economic slump experienced since the early 1990s. A dissection of the slowdown identified several causal factors: a protracted period of overly accommodative

[2]*Exchange rate policy* is one of the least mentioned balance sheet policies (Borio and Disyatat, 2010).

[3]The central bank might intervene in the foreign exchange market by purchasing local currency, through the sale of foreign exchange reserves; that, in this case, cause an appreciation. However, this reduces money supply, which could be deflationary. In order to sterilise these purchases, the central bank can conduct open market operations to increase the money supply.

monetary policy; a banking crisis (on the back of non-performing loans); and an asset-price bubble collapse (Ito and Mishkin, 2006)[4]. During this decade, specifically in the period between 1992 and 2002, the Japanese real economy grew at a meagre rate, slightly above 1% on average (Ueda, 2005)[5]. In 1995, in response to anaemic growth and budding deflation, the Bank of Japan (BoJ) brought interest rates close to the zero lower bound (ZLB)[6]. Despite the expansionary efforts of the monetary authority, three large Japanese banks[7] failed due to sustained capital losses and, in concert with the Asian financial crisis of 1998, this heralded the start of deflation[8] (Ito and Mishkin, 2006). This called for a reduction of the interest rate to the ZLB and ignited fears that a "liquidity trap" might emerge (Okina and Shiratsuka, 2004).

As first mentioned by Keynes (1936) and later formalised by Hicks (1937), once the nominal policy rate reaches a level close to zero, the central bank might find itself in a liquidity trap; this is defined as a low interest rate environment in which liquidity injections are rendered ineffective because money and bonds have become perfect substitutes. Traditional Keynesian thinking on monetary policy[9] accepts that, once in a liquidity trap, the central bank becomes impotent with respect to its ability to stimulate economic activity[10] (Hicks, 1937).

Japanese central bankers grappled with the potential loss of their primary policy lever and the possibility of chronic deflation. However, as argued by Krugman (1998) at the time, the conclusion that central banks are powerless at the ZLB is far from categorical. He proved, using an IS-LM framework, that a sustained increase in "outside money"[11] at the ZLB can have an inflationary impact on the economy, increasing both the general price level and output (Krugman, 1998). In order for this increase to be effective, the central bank is required to commit to future increases in the monetary base (Krugman, 2000). In other words, public expectation needs to be guided by the actions of the central bank, in order for the expansionary policy to work when interest rates have hit the ZLB (Bernanke, 1999).

[4]For a good review of the events that led to this downturn, see the article by Ito and Mishkin (2006).

[5]It should be noted that during this period, population growth was declining, which translates into a better overall picture of growth in per capita terms (Economist, 2008).

[6]The term zero lower bound has become a bit of a misnomer with recent developments of negative nominal interest being implemented in several central banks (Feroli et al., 2016). However, I have kept the term as it reflects the discussion at the time. In addition, it should be noted that in several instances during the discussion of the financial crisis that I refer to ZLB, but it could be that the interest rate is 10-30 basis points above this. In a practical sense, this is considered an effective ZLB by the market participants (Gerlach and Lewis, 2010).

[7]These banks were Hokkaido Takushoku, Long-term Credit, and Nippon Credit.

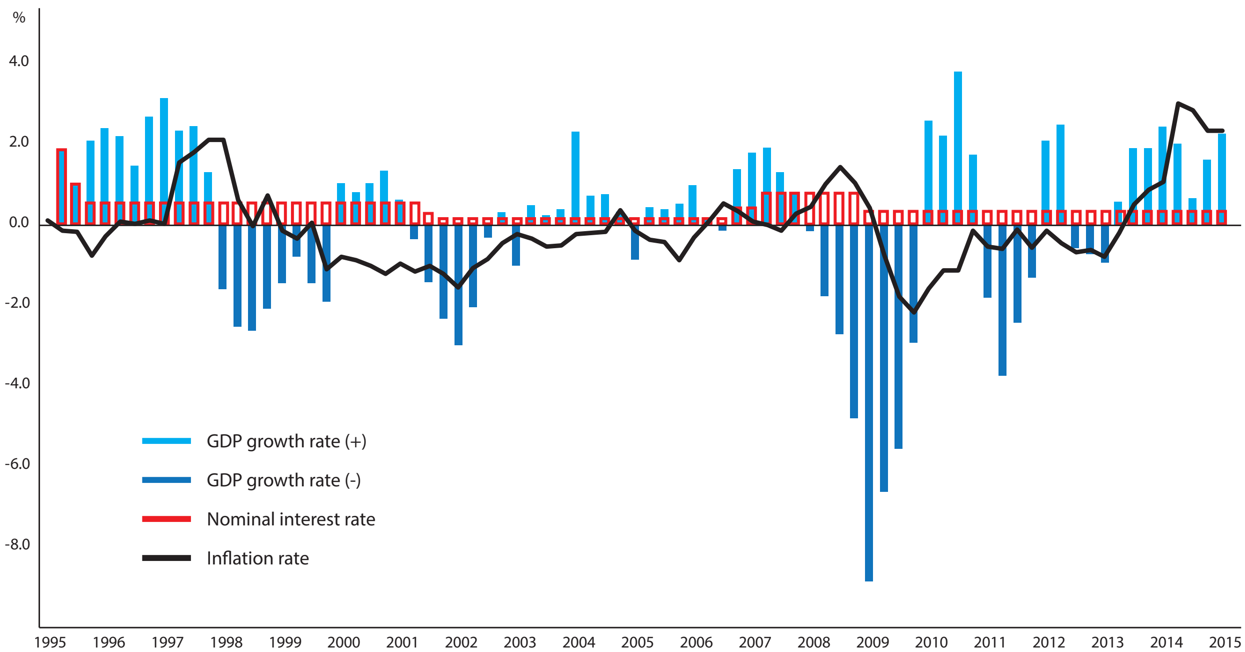
[8]In other words, this is a negative rate of inflation. Usually, this is considered a troubling economic position, as agents in the economy defer consumption and investment, causing economic growth to stall indefinitely.

[9]This type of thinking emphasises the belief that the only instrument available to the central bank is its control over the short-term policy rate, usually described with the use of an IS-LM type of model.

[10]This is thought of as the Keynesian challenge of monetary policy, whereby the claim is that monetary policy is ineffective at combating recessions ("pushing on a string").

[11]Outside money is money without corresponding liability.

Figure 2.1: Japanese growth, inflation and interest rates



Source: Bank of Japan

2.3 ZIRP and QEP in Japan (1999 - 2006)

2.3.1 Zero Interest Rate Policy (1999 - 2000)

The BoJ implemented several nonstandard monetary policy measures in an attempt to spur economic growth and avoid deflation, in line with the policy recommendations made by Krugman (1998). In 1999, in the wake of the currency crises experienced by many South-East Asian economies, the BoJ adopted a zero interest rate policy (ZIRP), with a commitment to keeping the uncollateralised call rate at a level of zero "until deflationary concerns are dispelled"[12]. Implementing such a policy is supposed to shape public interest rate expectations, indicating the 'easy' stance of monetary policy. Achieving success with this measure requires transparency and continued communication on the side of the central bank (Woodford, 2012).

In 2000, the BoJ believed the Japanese economy to be in recovery, with forecasts of the consumer price index (CPI) indicating the possibility of at least zero percent inflation (Momma and Kobayakawa, 2014). Despite protestation from academics and private sector economists, the central bank reneged on their zero rate commitment at the first signs of growth, and increased the call rate by 25 basis points (Ito and Mishkin, 2006). However, economic conditions rapidly

[12]As stated by Governor Hayami at a press conference on April 13, 1999. This is known as a conditional (state-dependent) commitment, and is one of the first examples of forward guidance - albeit rather weak in its implementation

worsened in 2001 with the burst of the global ICT bubble[13], and the BoJ reversed their rate increase with the declaration that ZIRP would continue until the "inflation rate becomes stably above zero" (Ito and Mishkin, 2006). Reneging on the zero rate commitment severely damaged the credibility of the bank for several years afterwards [14]. The next section considers the repercussions of the BoJ's decision and the eventual usage of QE in an attempt to change public perception of their resolve to combat deflation.

2.3.2 The Quantitative Easing Program (2001 - 2006)

Having blemished their reputation, the BoJ adopted a quantitative easing program (QEP) in March 2001 to complement their renewed ZIRP, trying to bolster their expansionary commitment. Quantitative easing (QE) as utilised by the BoJ primarily entailed providing reserves in excess of those needed to keep the interest rate at the ZLB[15]. This approach to monetary easing was supported by several academics, such as Krugman (1998), Meltzer (1998) and McKinnon and Ohno (1997). However, there were dissidents who believed that this type of policy would have fiscal implications, with the central bank exposed to unwanted investment risk in potentially volatile asset markets (Fujiki et al., 2001). This issue is becoming increasingly important as central banks across the world extend their balance sheets to include a wider range of securities. It also raises the issue of central bank independence, which is discussed at the end of the chapter. In addition, there are concerns that the balance sheet expansion will be ineffective and ultimately lead to high levels of inflation.

A simple definition of quantitative easing is an increase in the size of the central bank's balance sheet. In the case of Japan, this translated into switching of the policy instrument from the short-term interest rate to the current account balance (CAB)[16](Ito and Mishkin, 2006). The BoJ framed its approach as a three-pronged attack. First, it set a target for current account balances in a stepwise fashion, starting with ¥5 trillion[17] in 2001 and steadily increasing this over four years to between ¥30 and ¥35 trillion (Momma and Kobayakawa, 2014). This amounts to increasing base money in the economy with the target of supplying the economy with a surplus of liquidity.

[13]Refers to a speculative bubble that formed as the result of a sudden increase in equity values of Internet-based companies. It is also known as the dotcom bubble.

[14]The paper by Ito and Mishkin (2006) discusses the market behaviour during this period, which points to the loss of confidence in the central bank's ability to conduct policy.

[15]In Chapter 5 on the liquidity effect, I discuss the mechanism by which open market operations determine the interest rate.

[16]This refers to the commercial bank balances held at the central bank and should not be confused with the current account on the balance of payments.

[17]Which is in excess of the required balances of ¥4 trillion, providing the name 'excess reserve targeting'.

Second, as a corollary to the first arm, the central bank committed to providing liquidity in excess of the banks' reserve requirement, to keep expectations on the short-term interest rate fixed at zero. Under this commitment the BoJ also made clear the conditions under which ZIRP would be lifted (Momma and Kobayakawa, 2014). The specific condition in this case was achieving a positive inflation rate and maintaining it for a prolonged period. Third, the purchase of long-term Japanese government bonds (JGBs) was conducted gradually; monthly outright acquisitions started at ¥400 billion in August 2001, and eventually reached a level of ¥1200 billion in October 2002 (Ito and Mishkin, 2006). This third prong still operated under the guise of quantitative easing, as the asset purchases were not sterilised[18] by concomitant sales of short-term debt, a topic that is covered in more detail in the section on balance sheet typologies.

In addition to quantitative easing, from 2003 to 2006 the BoJ temporarily implemented credit easing through intervention in asset markets; this entailed changing the composition (asset side) of the central bank's balance sheet by buying asset-backed securities (ABS). The BoJ made it clear that this intervention was done in the spirit of financial market stabilisation and should not be considered under the banner of monetary policy. In general, the reason the BoJ implemented credit easing was to depress long-term interest rates and thereby encourage interest-sensitive economic activity[19]. In 2006 the BoJ, believing that inflation was sufficiently entrenched, announced its plan to terminate unconventional policy arrangements (Shiratsuka, 2010). A successful exit from QE relied on clear communication of the policy stance of the BoJ. In this period, the intentions of the BoJ were made clear to stakeholders, with the specific goal of preparing financial institutions for the withdrawal of liquidity.

2.3.3 Shaping Market Expectations: Hayami vs Fukui

At this point it is necessary to make a distinction between policy conducted under Governors Hayami (1998 - 2003) and Fukui (2003 - 2008). Before 1998, at the start of Hayami's term, policymakers had little practical experience in dealing with a liquidity trap (apart from the Great Depression). During that period, the first round of quantitative easing was implemented and appeared largely to be ineffective. The problem was the policymakers' failure to signal the nature of their policy commitment and in so doing to disarm deflation (Ito and Mishkin, 2006). It has been argued that this was because QE was conveyed as a temporary measure,

[18]Sterilised in the context of balance sheet policy usually refers to actions by the central bank that counteract a cash injection resulting from asset purchases (Woodford, 2012). In the case of Operation Twist, for example, an increase in long-term Treasuries was met with a decrease in short-duration debt; which is a 'cash-neutral' operation. Alternative strategies implemented by central banks to sterilise purchases are the use of term deposit facilities and reverse repurchase agreements (Ihrig and Meade, 2015).

[19]This mechanism is discussed in more detail in the next chapter.

without proper support from a tentative administration. The credibility of the bank was harmed under Governor Hayami, as market participants were not always certain of the direction policy would take. Indeed, as pointed out by Ito and Mishkin (2006), Hayami constantly changed his position without providing the proposed mechanism of operation.

In 2003, when Governor Fukui was appointed, he immediately changed the message portrayed by the central bank, by ratcheting up quantitative easing measures to reinforce the claims of an expansionary policy commitment (Ito and Mishkin, 2006). Communication strategies were significantly more transparent under the leadership of Fukui. The necessary conditions for an exit from the ZIRP were explicitly stated. The change in rhetoric was found immediately to have an impact on the recovery of the financial sector, with a more protracted rebound of real variables (Ito and Mishkin, 2006). Forward guidance under Fukui was more successful because announcements left little room for interpretation as to the position of the bank, with the commitment of the bank being linked to actual and not forecasted values of CPI (Momma and Kobayakawa, 2014).

Empirical evidence suggests that QE under Fukui was effective in establishing market expectations on future short-term interest rates, and ultimately on the long-term rates (Ugai, 2007). The most profound impact of the change in rhetoric was on the financial markets and the state of the banking sector, with the real economy showing only slow signs of recovery, which suggested that the blockage in transmission was between nonfinancial and financial sectors (Ito and Mishkin, 2006). Up until this point, it was not necessary to be specific about balance sheet policies, as the types implemented in Japan before the financial crisis were sufficiently simple, fitting easily into broad classifications. However, as we delve deeper into what balance sheet policies encompass, it might be useful to have an appropriate typology toolkit.

2.4 Making Sense of Balance Sheet Typologies

The Japanese experiment generated a discussion on the role of monetary policy in a deflationary environment. In what follows, I discuss some of the most important theoretical contributions on the topic. These contributions were used to answer questions posed during the financial crisis in 2008. The implications of central banks being constrained by the ZLB is highlighted in the academic works of authors such as Reifschneider and Williams (2000), Blinder (2000), Clouse et al. (2003), Svensson (2003), Orphanides and Wieland (2000), Eggerston and Woodford (2003) and the seminal article by Bernanke et al. (2004). In general, there are several instruments available to the central bank once the interest rate reaches the ZLB, most of which were implemented in the case of Japan, with varying degrees of success.

In the literature there are several classifications of balance sheet policy tools beyond interest rate policy. Bernanke et al. (2004) first identified three plausible policy tools to use once the ZLB is reached: (i) the management of public expectations on the course of interest rates, through communication strategies; (ii) changes in the size of the central bank balance sheet; and (iii) changes in the composition of the central bank balance sheet.

Woodford (2012) aggregates these tools into two streams, namely forward guidance and balance sheet policies. I am primarily interested in the latter, which entails changes in the size (quantitative easing) and composition (credit easing) of the central bank balance sheet. A more detailed taxonomy proposed on these balance sheet policies is that of Borio and Disyatat (2010), which is discussed in Chapter 2.4.2.1.

2.4.1 Expectations/Forward Guidance

Among the first authors in the modern literature to consider seriously the consequences of a deflationary trap, is Krugman (1998, 2000). He contends that the appropriate solution to a deflationary environment is to manage expectations, something that was poorly implemented in the early years of the Japanese deflation. Several authors in the literature, such as Eggerston and Woodford (2003), Svensson (2003), and Auerbach and Obstfeld (2005) agree that this is the best strategy to employ in order to escape a liquidity trap. Central banks in this predicament need to convince markets that they will commit to a higher rate of inflation in the future, allowing expectations to form around the objective of persistently easy monetary policy. Krugman (1998) suggests that the central bank set a high inflation target[20] over the medium term in order to stabilise expectations.

Krugman's suggestion was met with resistance, as a high inflation target is at odds with the idea of price stability. The work by Eggerston and Woodford (2003) points out that once the economy emerges from the deflationary environment, a time-inconsistency problem would emerge. Given the central bank mandate to maintain price stability, the policymaker would be admonished for aiming for a high inflation target; Krugman (1998) refers to this as committing to "being irresponsible". In other words, owing to time-inconsistency, the public would expect the central bank to renege on its high inflation rate commitment and the economy would fail to move from its deflationary environment.

The Japanese experiment can be understood as an example of such time-inconsistency. When faced with a slightly positive inflation rate, the central bank increased the call rate above the ZLB, claiming that financial markets had stabilised. This action severely damaged the credibility

[20]Krugman (1998) suggests a medium-run target of 4% for fifteen years

of the monetary authority, and when the economy moved back into a deflationary environment, the newly appointed Governor had to look to unconventional policy in conjunction with a policy rate commitment to boost economic growth and avoid deflation. The Japanese example shows that sometimes announcing the target is not enough to pin down expectations. In order to increase the credibility of its commitment, the central bank might have to combine elements of balance sheet policy with an inflation target, which is referred to in the more modern literature as forward guidance (Woodford, 2012).

2.4.2 Changes in Size and Composition

Central banks were created with the unique ability to issue bank reserves, making them the monopoly supplier of bank money in the economy (Goodhart, 1988). These liabilities of the central bank can be generated freely, without cost or limit. It is important to remember that, as Lord Cobbald reputedly said, the "Central Bank is a bank, not a study group" (Goodhart, 2011, p. 146). Central banks are responsible for the provision of liquidity to the banking system, which acts as liquidity insurance that filters through to households and firms via commercial banks (Tucker, 2014). In this regard, post-war monetary policy was initially concerned with the management of the central bank's balance sheet (Friedman, 1964). In recent years, the focus has shifted to guidance of the nominal short-term policy rate. However, as argued by du Plessis (2012), "determining the level of a policy interest rate is not a necessary function of the central bank". The international financial crisis has refocused the attention of central bankers of balance sheet policies as part of the monetary policy toolkit.

There are several typologies of balance sheet policy, depending on the source being consulted. In the most general sense, balance sheet policies operate along the dimensions of size and composition. Increases in the size of the balance sheet usually mean "open market operations on short-term government debt, outright purchase of long-term bonds (or equities), or through unsterilized purchases of foreign currency" (Ito and Mishkin, 2006). However, quantitative easing has become synonymous with the expansion of the central bank balance sheet (particularly the monetary base) without changing the composition of assets. Quantitative easing in this sense entails the purchasing of assets by the central bank, leaving the type of assets on their portfolio unchanged, while increasing reserve liabilities on the other side of the balance sheet (Lenza et al., 2012). Some authors, such as Woodford (2012), refer to this as 'pure' quantitative easing, while Reis (2009) calls it quantitative policy. Cúrdia and Woodford (2011) refer to this as reserve-supply policy, which is the choice of reserves in the system. In essence, these are open market operations where central bank liabilities (reserves) are traded in return for Treasury securities.

Credit/qualitative easing is generally perceived as balance sheet management aimed at altering the composition of the central bank's balance sheet (Cúrdia and Woodford, 2011). In this setting, the size of the balance sheet remains the same but the underlying portfolio of assets changes from conventional assets held to include a variety of 'unconventional' assets, ranging from long-term government debt to private sector securities (Lenza et al., 2012). One central banker, that was adamant about the distinction between quantitative and credit easing, is Bernanke (2009). He argues that,

> *The Federal Reserve's approach to supporting credit markets is conceptually distinct from quantitative easing (QE), the policy approach used by the Bank of Japan from 2001 to 2006. Our approach - which could be described as 'credit easing' (CE) - resembles quantitative easing in one respect: It involves an expansion of the central bank's balance sheet. However, in a pure QE regime, the focus of policy is the quantity of bank reserves, which are liabilities of the central bank; the composition of loans and securities on the asset side of the central bank's balance sheet is incidental.*

This typology is quite broad and is sometimes an inaccurate representation of policy intent; in other words, it does not always encapsulate the nuance of specific policy actions. My discussion of the balance sheet policies used during the financial crisis requires a more precise classification. As we will see, changes in the composition of the balance sheet of the central bank often accompany increases in size, if purchases are unsterilised. It becomes increasingly difficult to map the textbook view of changes in size and composition onto policy actions taken during the financial crisis (Lenza et al., 2012).

2.4.2.1 A More Precise Typology

A more granular classification is probably better suited to the identification of different balance sheet policies. I use the typology of Borio and Disyatat (2010) who have a four-fold classification that includes exchange rate policy, quasi-debt management policy, credit policy and bank reserves policy. This typology is summarised by Figure 2.2.

First, *exchange rate policy*, which is briefly described in the first section of this chapter, is not considered further. Second, *quasi-debt management policy* entails central bank intervention in the market for public sector debt. Policy in this sphere operates mainly on the composition of private sector balance sheets, with the aim of altering the composition of government securities held in the hands of private agents. In general, the aim is to alter the yield curve on Treasury securities. Policy in this vein could translate into interest rate risk for the central bank as it take on riskier long-term government debt.

Figure 2.2: Typology of balance sheet policies

		Impact on private sector balance sheets		
		Change in net FX exposure	Change in the composition of claims on the public sector	Change in profile of claims on private sector and /or composition of claims on public vs private sector
Market targeted	Foreign exchange	★		
	Public debt		⬚	
	Private credit			✪
	Bank reserves			

Exchange rate policy (★); Quasi-debt management policy (⬚); Credit policy (✪)
Bank reserves policy (shaded area)

Source: Borio and Disyatat (2010)

Third, *credit policy* refers to targeted purchases of private assets in specific markets in order to affect private sector balance sheets. During the financial crisis, this type of policy was employed to "enhance market liquidity, reduce risk spreads, promote new issuance, and increase private access to credit" (Meier, 2009). Credit policy often exposes the central bank to credit risk on private sector claims, an issue that is covered in more depth in the discussion on the measures used in the financial crisis. Finally, *bank reserves policy* requires increasing liabilities, by setting a specific target for bank reserves, independently from what happens on the asset side of the central bank balance sheet.

Quantitative easing, for example, in the case of Japan (2001 - 2006), in this taxonomy is seen as a combination of bank reserves policy and forward guidance (Borio and Disyatat, 2010). There are also elements of quasi-debt management policy, with the purchase of long-term Japanese government bonds, in the latter part of the QE program.

Defining QE as merely an increase in the size of the balance sheet loses some of the nuance involved; however, such simplifications will sometimes be made to facilitate model construction. It is important to understand not only the general classification, but also the channels of policy transmission, in order to comprehend why policy actions are performed. In the following section I discuss some of the most important transmission channels for balance sheet policies.

2.5 Transmission Channels

Up to this point, I have abstained from discussing the transmission mechanism, but the balance sheet policies used by the central bank during the crisis rely on an understanding of transmission channels (Krishnamurthy and Vissing-Jorgensen, 2011). In this section I discuss, in greater detail, the transmission channels through which balance sheet policies - specifically quasi-debt management and credit policies - are thought to affect financial markets and a broader range of macroeconomic indicators. In particular, they are thought to have three direct effects, through: (i) asset yields/prices; (ii) money market rates; and (iii) market confidence/expectations, as depicted in Figure 2.3 (Cova and Ferrero, 2015).

There are diverging theories on the channels through which balance sheet policies are transmitted to the broader economy. However, there is some consensus that there are two primary channels: the signalling channel and the portfolio balance channel, with several plausible subchannels (Bernanke et al., 2004; Borio and Disyatat, 2010). It should be noted that this classification is not exhaustive and includes primarily the main channels of transmission as well as some relevant subchannels. Only the relevant channels are discussed here, as there are several taxonomies in the literature, with differing levels of complexity. Figure 2.3, which is adapted from Cova and Ferrero (2015), is provided to give a summary of potential transmission channels and effects.

2.5.1 Portfolio Balance Channel

The most natural setting for balance sheet policies when the interest rate has reached the ZLB is the portfolio balance channel. Several policymakers such as Bernanke (2009), Yellen (2011), and Bean (2011) specifically mention this channel in conducting large-scale asset purchases during the recent crisis. The portfolio balance effect refers to the ability of the central bank to affect term, risk, and liquidity premiums (i.e. overall yields) through open market operations (Bernanke et al., 2004). More simply stated, it describes "how the purchase of a given asset pushes up the price of that asset and its substitutes" (Krishnamurthy et al., 2014). A large part of modern research on balance sheet policies focuses on this channel, with a rich vein of literature dating back to the late 1950s. It is important to mention that the portfolio balance channel (PBC) itself is multidimensional, with a further subdivision normally entailing a discussion on the scarcity and duration risk channels (D'Amico et al., 2012). These mechanisms are individually explored.

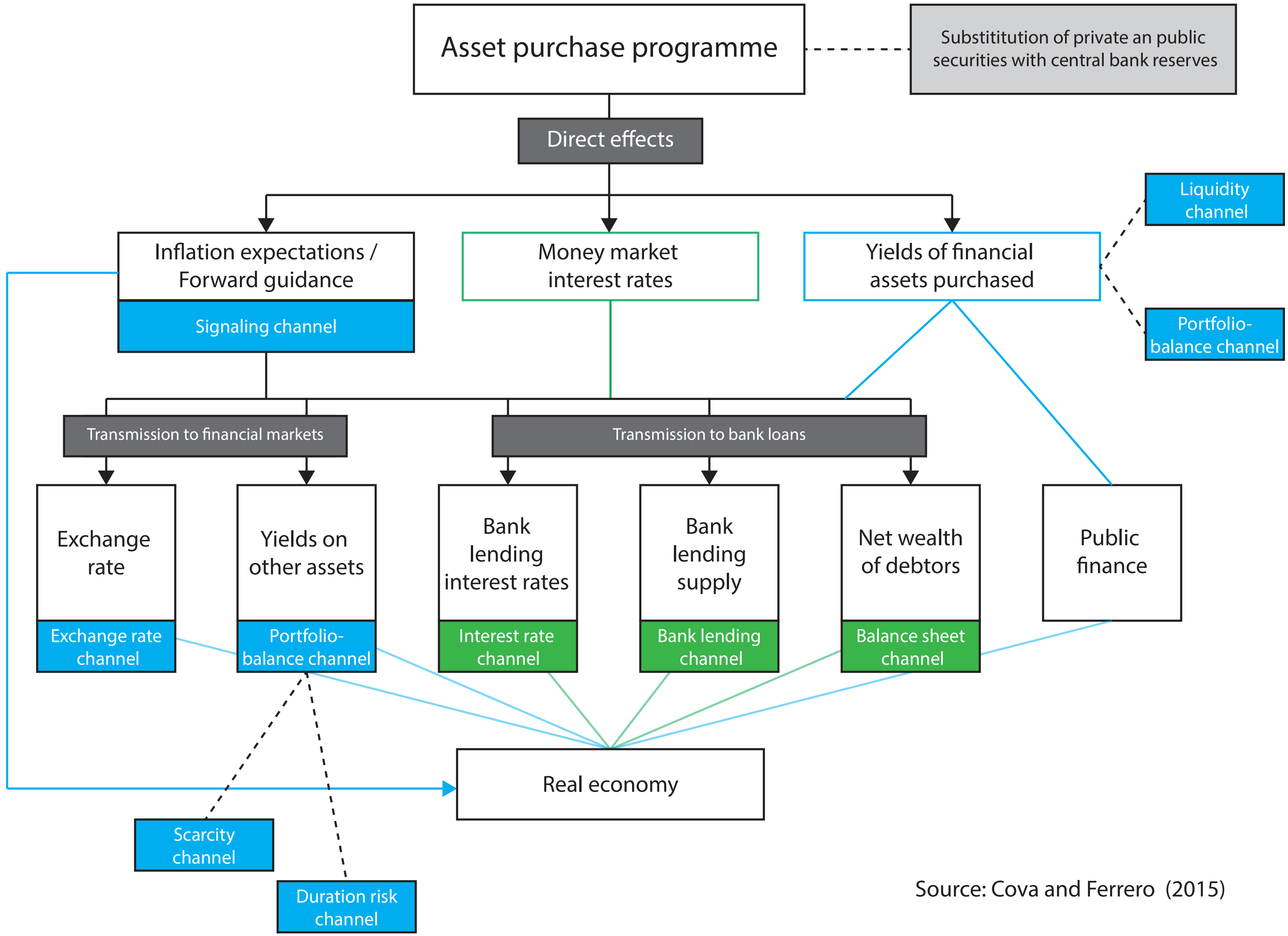


Figure 2.3: Transmission channels of balance sheet policies

2.5.1.1 History of the Portfolio Balance Channel

The literature on the portfolio balance channel originates largely from the discussion surrounding the Fed's 'bills only' policy, which it adopted in 1953. Within the confines of the Federal Reserve Accord, the central bank could conduct open market operations only through the trading of short-term Treasury securities (D'Amico et al., 2012). The logic, as presented in Riefler (1958), was that the central bank could steer expectations on the long-term interest rates through its control over the path of the short-term rate. This meant that movements in the short-term rate would transmit through the interest rate structure, by its influence on market expectations, to steer the long-term rate, all without intervention in long-term markets. This is referred to as the expectations hypothesis of the term structure of interest rates, which is normally depicted using a yield curve[21] (Thornton and Guidolin, 2008).

Criticism on the exploitable link between short- and long-term asset markets emerged in the academic literature, with an early critique of the bills-only approach provided in the work of Culbertson (1957), Conard (1959), and Ascheim (1961). The Kennedy administration was supportive of this assessment of the bills-only policy and ratified Operation Twist in 1961 in order to affect the term structure of interest rates, which entailed increasing the amount of long-term securities on the balance sheet of the central bank. In principal, this policy to change the composition of the central bank balance sheet was aimed at decreasing the long-term rate by increasing the supply of long-term bonds relative to short-term bonds (D'Amico et al., 2012). Control over the long-term rate was considered important, as aggregate demand is influenced by more than just the short-term interest rate, which is pointed out by both Keynesians (Tobin, 1969) and monetarists (Brunner and Meltzer, 1973; Friedman and Schwartz, 1982)[22]. This approach is juxtaposed by the current quasi-debt management strategy followed by central banks to depress long-term Treasury rates[23].

2.5.1.2 Preferred Habitat / Scarcity Channel

Although Operation Twist was initially judged to be largely ineffective[24], it acted as a catalyst for the further development of a theoretical literature on the term structure of interest rates. In particular, it inspired Culbertson (1957) and Modigliani and Sutch (1966) to establish the

[21]A yield curve reflects the relationship between bonds with similar ratings but different maturities (Strohsal, 2013). It is usually upward sloping, as longer maturity bonds are supposed to have a higher yield.

[22]The idea that several asset yields should be taken into consideration is at the heart of the monetarist transmission mechanism.

[23]It is easy to observe the heritage of the newly implemented LSAPs in the US, with the maturity extension program accompanying QE2 also referred to as Operation Twist.

[24]Initial studies showed an insignificant affect on long-term rates. However, a recent article by Swanson (2011) shows that an event-study approach reveals a significant reduction in long-duration security yields.

"preferred habitat" approach. This is a market segmentation theory that points to the fact that investor clienteles might have a preference for assets of a specific maturity, and that the "interest rate for a given maturity is influenced by demand and supply shocks local to that maturity" (Vayanos and Vila, 2009). Notably, this establishes a positive correlation between asset yields and the relative supply of long-term securities[25] (Strohsal, 2013).

It is generally accepted that generating portfolio balance effects relies on imperfect asset substitutability[26]. As stated by Bernanke and Reinhart (2004), "if the liquidity or risk characteristics of securities differ, so that investors do not treat all securities as perfect substitutes, then changes in relative demands by a large purchaser have the potential to alter relative security prices". Under the assumption that assets are imperfect substitutes, Tobin (1961, 1969) was among the first to illustrate that a large buyer, such as the central bank, could alter the supply of assets - with different maturities or liquidity - and thereby plausibly influence asset yield patterns. In this narrative the purchase of securities by the central bank will increase the amount of one asset relative to others in the private sector portfolio. In response to these open market operations, the public will rebalance their portfolio to include more of the scarce (often riskier) assets, which raises their price and lowers their yield; this is often referred to as the scarcity / local supply channel (Bernanke et al., 2004).

Initial discussions on imperfect asset substitutability and the related portfolio balance effects centred on the ability of the central bank to affect long-term asset yields through the scarcity channel. This mechanism relies on the fact that there are limits to quantities of a certain asset that investors can buy (Dai et al., 2013). In fact, as mentioned, this was the idea behind Operation Twist in the 1960s, which entailed a change in composition of the balance sheet in order to affect term structures. Quasi-debt management and credit policy[27] relies on imperfect asset substitutability in order to work; with securities of different maturities and risk profiles treated as imperfect substitutes (Borio and Disyatat, 2010). Theoretically, there are several reasons why assets are not perfect substitutes, with the most frequently cited justification being related to investor maturity preference and the pricing of duration risk (Joyce et al., 2012a)[28].

In the preferred habitat model investors have specific preferences for assets of a certain maturity (segment of the yield curve / investment horizon), such as the preference of pension funds to invest in longer-dated securities (D'Amico et al., 2012). Purchases by the central bank in this model matter for bond yields, as private sector agents will try to rebalance their portfolios

[25] There are some caveats, with the magnitude of the correlation dependent on the risk aversion of arbitrageurs.

[26] Some of the most prominent early contributions in the work on imperfect asset substitutability can be found in the work of Friedman (1956) and Tobin (1961, 1969).

[27] Primarily changes in the composition of the balance sheet of the central bank

[28] The introduction of transaction costs, capital constraints, and other financial frictions could in combination generate this result (Bernanke et al., 2004).

once open market operations have been performed on specific market segments (D'Amico et al., 2012). This is illustrated in the general equilibrium models of Andres et al. (2004), Vayanos and Vila (2009), Harrison (2012), and Chen et al. (2012a). All these papers feature a preferred habitat approach and construct a segmented market model with imperfect asset substitution.

Generally, these models have two types of agents: I refer to them as preferred habitat investors and arbitrageurs, as stipulated in Vayanos and Vila (2009)[29]. Preferred habitat investors are inclined to purchase securities of a certain maturity[30], while arbitrageurs are not limited to a particular investment horizon. The model of Andres et al. (2004) puts the ideas of Tobin (1969) into a general equilibrium setting, modelling preferred habitat investors who are interested only in marketable, long-term fixed-income securities (D'Amico et al., 2012). With this, they try to capture the idea that changes in the relative supply of assets can generate price changes.

Targeted purchases of assets of certain maturities can create shortages in that market segment which cannot be resolved completely through asset substitution. This creates a scarcity in these assets, which forces market prices to change. Some refer to this as the safety premium (asset scarcity) channel, as described by Krishnamurthy and Vissing-Jorgensen (2011)[31]. Evidence is provided by Krishnamurthy and Vissing-Jorgensen (2011) that in a preferred habitat environment which operates only in the space of safe assets, the presence of investors in long-term safe assets lowers the yield on those assets[32]. Investors in this setting are willing to pay a safety premium for assets with a low default risk.

The model of Andres et al. (2004) highlights the importance of the heterogeneity of agents in establishing imperfect asset substitutability. However, in this model the possibility exists that arbitrageurs can eliminate the trades made by long-term bond investors, which would yield an irrelevance result. In their work Vayanos and Vila (2009), try to elicit portfolio balance effects by making the arbitrageurs risk averse[33]. Risk aversion, or even capital constraints on arbitrageurs, could limit arbitrage in these markets so that asset prices are indicative of segmented investor valuations (IMF, 2013).

[29] Andres et al. (2004) refers to them as restricted and unrestricted households, but the idea is the same. In his model the restricted household (preferred habitat investor) is only allowed to purchase long-term securities, while the unrestricted household (arbitrageur) has access to both short- and long-term assets.

[30] Normally long-term safe assets with zero risk for default, such as those invested in by pension funds (Krishnamurthy and Vissing-Jorgensen, 2011).

[31] The asset scarcity channel pertains only to liquid, safe assets, such as Treasury bonds.

[32] Empirical evidence is discussed in more detail in Chapter 4.

[33] An alternative would be to place a credit constraint on investors, as in (Gertler and Karadi, 2011)

2.5.1.3 Duration Risk Channel

In the model presented by Vayanos and Vila (2009) there is another portfolio balance mechanism at play, besides the scarcity effect, called the duration risk channel, also emphasised by Gagnon et al. (2011). Fixed income assets like long-term government bonds usually carry a term premium, as they are susceptible to future movements in the interest rate (Bowdler and Radia, 2013). The uncertainty associated with longer term securities is called duration risk. Intervention by the central bank in long-term asset markets, for example, changes the duration risk.

If the central bank were to purchase a large quantity of long-term bonds in a specific market segment, it would decrease duration risk (making the investors' portfolios safer) by removing a portion of long-term securities and thereby reducing long-term yields. Importantly, this effect flattens the entire yield curve (spread between long- and short-maturity bond yields), instead of just the segment where purchases were made, as in the scarcity channel (Krishnamurthy and Vissing-Jorgensen, 2011). This duration risk channel was thought to be of great importance during the recent financial crisis. The model of Chen et al. (2012a) is an extension of the work of Vayanos and Vila (2009) and attempts to develop a DSGE model of the large-scale asset purchase programs of the US. They found that the programs achieved the greatest success in reducing risk premia; or, in other words, operating through the duration risk channel.

2.5.1.4 Reserve- vs Supply-induced Portfolio Balance Effects

As first pointed out by Bernanke and Reinhart (2004), as well as later argued by Woodford (2012), a 'pure' form of quantitative easing exists, whereby the change in the size of the central bank balance sheet only entails a shift in reserves. In a recent paper Christensen and Krogstrup (2016) make a distinction between reserve- and supply-induced portfolio balance effects. The supply-induced portfolio balance channel is the one usually stressed, whereby the relative change in assets supply results in a change in the price of close substitutes.

However, there might also be a reserve-induced portfolio balance channel that reflects the effect from 'pure' quantitative easing, where an increase in reserves will increase a broad range of asset prices. In particular, the idea is that this reserve-induced channel might impact on long-term yields. According to Christensen and Krogstrup (2016) the reserve-induced portfolio balance effect can only be identified with "a substantial increase in the amount of central bank reserves, [which] is achieved without acquiring any long-lived securities or close substitutes thereof". This channel is thought to exist because of one special property of reserves, they can only be held by eligible banks.

Using a specific case study of the Swiss National Bank, they are able to identify the overall impact from the reserve-induced portfolio balance channel. They find that it contributes significantly to decreasing the yield on long-term rates, without impacting on long-term Swiss bonds or their close substitutes. It is then argued that this reserve-induced channel might have played a substantial role in driving down long-term rates in the the QE programs implemented by the US, UK, ECB and Japan in recent years.

As originally argued in Bernanke and Reinhart (2004) and later reiterated by Kandrac and Schlusche (2015) and Christensen and Krogstrup (2016), increases in reserves can have an impact on the broader economy beyond changing the relative supply of assets. Little research has been performed on this component of the portfolio balance channel. However, with central banks across the globe significantly increasing reserves in the last decade, more research will try and determine the position of reserves in the range of transmission channels.

2.5.1.5 The Irrelevance Result and the Portfolio Balance Channel

During the 1970s and 1980s the expectations theory was the prevailing doctrine on long-term interest rate determination (D'Amico et al., 2012). In fact, in this period few researchers and policymakers were convinced about the relevance of balance sheet policies along the portfolio balance channel. While the expectations hypothesis was instrumental in guiding beliefs about the term structure of the interest rate, the work of Wallace (1981) contributed significantly to the exclusion of the portfolio balance channel from formal economic models. He postulates that open market operations - in an economy with complete markets, where government bonds of a certain maturity are exchanged for assets of different maturity - have no real economic effect, often referred to as the irrelevance result or Wallace neutrality[34].

Naturally, a prime example of where agents are thought to be indifferent among options is at the ZLB. Once this bound is reached and the central bank decides to intervene through a purchase of short-term bonds, the market will react by balancing its portfolio toward money holdings (Krugman, 1998; Svensson, 1999). In this setting the central bank asset purchases have no impact on the real economy because both assets are largely risk free and bear no interest.

Owing to the irrelevance result (and the dominance of the expectations hypothesis), the portfolio balance mechanism has been largely missing from modern New-Keynesian macroeconomic models. Asset pricing in the traditional New-Keynesian model, see Woodford (2003), is usually framed in terms of two assets, money and bond holdings. In the case of consumers being indifferent between holding money versus bonds, agents consider the assets to be perfect substitutes at the ZLB (Bowdler and Radia, 2013). This explanation, which is similar to that of

[34] Sargent and Smith (1987) corroborate the message of Wallace (1981).

the Ricardian equivalence or Modigliani-Miller theorem, hinges on the fact that private sector agents will internalise the asset acquisitions of the central bank (Bean et al., 2010).

The model of Eggerston and Woodford (2003) formalises the irrelevance result in a general equilibrium setting with the nominal interest rate at the ZLB, proving that in frictionless financial markets, balance sheet actions are ineffective. Operations are considered even neutral in the exchange of reserves for longer-term securities (Chen et al., 2012a). In the absence of frictions, assets purchased by the central bank are equivalent to reserves, implying no policy impact. However, there is little practical support for this result (Bean et al., 2010).

In a response to criticism of their earlier work, Cúrdia and Woodford (2010) developed a model that considers the potential of a central bank balance sheet as a policy tool. This model is similar to that of Eggerston and Woodford (2003) but includes vital credit frictions that generate the desired non-neutrality in credit policy. In terms of the typology of Borio and Disyatat (2010), credit policy can work when supply-side frictions are imposed; however, there is no role for quasi-debt management in this model.

2.5.2 Signalling Channel

One of the most important tools at the disposal of the central bank is its ability to shape the expectations of market participants (Bernanke and Reinhart, 2004). The signalling channel is the primary channel through which monetary policy is thought to affect the longer-term interest rates when assets are perfect substitutes (D'Amico et al., 2012; Joyce et al., 2014). Asset purchases by the central bank, as argued by Eggerston and Woodford (2003) , could lower long-term bond yields if they serve as a commitment device to keep the short-run policy rate lower in future[35]. In other words, they reveal information that changes market expectations about key factors that determine the asset's price. These factors include "expectations regarding the future course of policy, relative scarcities of different assets or their risk and liquidity profiles" (Borio and Disyatat, 2010).

Clouse et al. (2003) argue that if the central bank purchased a large number of long-term bonds and then raised the short-term rate, it would expose itself to capital losses on the assets purchased. Financial market participants might view these purchases as a credible commitment not to deviate from its easy monetary policy stance; that is, if they believe that these losses enter into the central bank's objective function (Bowdler and Radia, 2013). Interestingly, signalling affects all bond rates, since the lower yield on Treasury securities is thought to affect all rates in the market via the expectations hypothesis (as previously discussed) (Krishnamurthy and

[35]This might mean keeping the rate below what is prescribed by an interest rate rule, such as the Taylor rule.

Vissing-Jorgensen, 2011). Empirical evidence on the signalling channel is given in Chapter 4.

2.5.3 Liquidity Channel

A potential third channel is called the liquidity channel and is mostly applicable when financial markets are dysfunctional (Bowdler and Radia, 2013). In this channel the central bank purchases long-term illiquid securities and issues reserves, with reserves being more liquid than long-term securities. Distressed financial markets generally result in a decrease in wholesale funding, which leaves many firms liquidity constrained. Central bank asset purchases when financial market functioning is impaired can increase investor liquidity and reduce the liquidity premia (Krishnamurthy and Vissing-Jorgensen, 2011). This means that yields on the most liquid assets will increase, relative to other assets. During the crisis other plausible transmission channels were suggested, but at the moment there is no consensus over their inclusion in a larger typology. These channels are described as they are encountered throughout the rest of the thesis.

2.6 Chapter Conclusion

In this chapter I discussed the various dimensions of balance sheet policy. The primary contribution of this chapter, as with most literature reviews, is to aggregate relevant passages in the literature in such manner as to construct a coherent narrative. First, I provided an historical account on the use of balance sheet policies, with specific reference to the case of Japan. Operating under threat of deflation, with conventional policy tools exhausted, encouraged Japanese authorities to experiment with new monetary policy instruments. Not only did this provide a training ground for the development of their quantitative easing program, it motivated research on a topic long-forgotten.

In retrospect, the Japanese experience provided invaluable preparation in dealing with the global collapse. In response to the crisis, several central banks had no choice but to relinquish the usage of their nominal overnight interest rate as policy tool, quickly shifting policy responsibility to their balance sheets. For example, once the zero lower bound was reached in the US, large-scale asset purchases and establishment of liquidity facilities were expeditiously carried out. The rapidity of response might have been slowed if it were not for the lessons learnt in Japan.

While it is widely understood that during the crisis central banks used their balance sheets to restore order to dysfunctional financial markets - and more broadly the monetary transmission mechanism - the nature of these policies and their implementation is often severely misunderstood. Correcting confusion with respect to balance sheet policy implementation and channels of transmission was a central objective of this review. In order to facilitate understanding, balance sheet policies were codified in terms of both broad and narrow typologies. In the broad sense, balance sheet policies are conducted along the dimensions of size and composition, while the narrow typology captures greater nuance with reference to asset classes affected by operations. Precise definition is important, as future discussion on the channels of transmission rely on a narrow understanding of balance sheet policies.

Chapter 3

Balance Sheet Policies II: Financial Crisis and Policy Response

The most difficult subjects can be explained to the most slow-witted man if he has not formed any idea of them already; but the simplest thing cannot be made clear to the most intelligent man if he is firmly persuaded that he knows already, without a shadow of a doubt, what is laid before him.

— Leo Tolstoy (1894)

In the years preceding the global financial crisis it was argued that the *science* of monetary policy was starting to develop, owing to contributions of "rigorous theory and empirical work" (Mishkin, 2007). A consensus had been reached. The success of inflation targeting meant that "monetary policy could sustain low inflation with low unemployment on average, and with infrequent, mild recessions" (Goodfriend, 2007b). The last decade has proven that the consensus might have been premature, with declarations of monetary policy as science quickly quashed. What was previously thought to be certain, was perhaps a case of academic hubris.

3.1 The Financial Crisis (2007 - 2008)

The initial deflation diagnosis in Japan caused lively debate in the academic community as to the possibility of its incidence in other industrialised nations (Eggerston and Woodford, 2003). With interest rates already low in many developed countries in response to low inflation and slowed economic growth in the industrialised world, the possibility of a binding constraint on interest rate policy became a sobering reality. This was particularly true in the case of the USA, with concerns over deflation being resurrected with the recession in 2001.

An extensive literature emanated from this discourse, revealing potential policy predicaments and complementary solutions. Naturally, one of the concerns with a liquidity trap is that real interest rates will be too high to stimulate economic activity[1]. Several strategies were proposed as alternatives when short-term interest rate policy is constrained by the lower bound. An examination of the literature shows that, in order to combat this deflationary trap, an appropriate communication strategy, often in conjunction with nonstandard policy measures, is a suitable cure (Bernanke et al., 2004)[2]. The biggest challenge, then, faced by central banks (especially those who suffer from a lack of credibility) is to convince the public that they are willing to commit to a sustained future expansionary policy. However, central bankers and academic economists, under the influence of the overwhelming success of the much-lauded New Neoclassical synthesis in monetary policy, have lost interest in the topic of deflationary traps (Goodfriend, 1997; Woodford, 2003).

3.1.1 Flexible Inflation Targeting

After the initial rush of research on Japan, economists considered the idea of deflation as no more than a passing theoretical curiosity (Woodford, 2012). Progress in terms of monetary theory instilled a confidence that even in advanced economies with low rates of inflation and interest, the ZLB would not plausibly be reached (Orphanides and Wieland, 2000). This false sense of security came from the apparent success of monetary policy in taming inflation (in terms of its level and variability) during the period known as the Great Moderation. This period, between the mid-1980s and 2007, was characterised by decreased business cycle volatility and low and stable inflation in most of the developed world. Apparent advances in theory, corroborated by empirical evidence, led researchers and policymakers to state that monetary policy had ventured into the territory of being called a science[3] (Clarida et al., 1999; Mishkin, 2007; Galí and Gertler, 2007; Goodfriend, 2007a; Taylor, 2007b).

It was believed that the focus of monetary policy in controlling inflation, by managing expectations of future policy rates (and thereby the long-term rate), made these advances possible (Svensson, 2003). In other words, optimal monetary policy was centred around the concept of a flexible inflation targeting regime with a symmetric target[4]. Under such a system, deflation

[1]This is if we calculate real interest rates to be the sum of the nominal and inflation rates, as specified by Fisher (1930).

[2]This strategy was referred to by Svensson (2003) as a foolproof way of escaping from a liquidity trap.

[3]In fact, the famous 1999 article by Clarida, Gali and Gertler is called *The Science of Monetary Policy: A New Keynesian Perspective*. The idea of the economist as a scientist is challenged in the article by Mankiw (2006), who likens economists more to problem-solving engineers.

[4]According to the flexible inflation targeting framework, optimal monetary policy steers to a constant long-run

could be avoided. Generally, a nominal anchor has two important features that could help in avoiding deflation. First, an inflation targeting regime was believed to have better fixed the expectations of the market on the nominal anchor, in the process helping to avoid deflation (Woodford, 2003). Once again, for this strategy to be successful, communication on the part of the central bank is crucial. A commitment to a nominal anchor removes policy flexibility, improving the accountability and transparency of the policy.

Second, as argued by Ahearne et al. (2002), modern economies in a low-inflation environment faced with a negative shock could apply an aggressive reduction in the policy rate and thereby avoid the liquidity trap. Research by Harrigan and Kuttner (2004) on optimal monetary policy in Japan, using a Taylor rule, revealed that a credible nominal anchor (specifically an inflation target) would have guided their policy formulation so as to avoid the situation. Academics and government officials alike agreed that the economic slump of Japan in the 1990s was poorly handled by policymakers, in that the BoJ did not react swiftly and aggressively enough in the years preceding the deflationary spiral to prevent it (Ito and Mishkin, 2006). As stated by the previous BoJ Governor, "the low growth in Japan following the bursting of a bubble was often simply interpreted as a unique episode caused by a failure to implement bold policy measures in a prompt manner" (Shirakawa, 2013).

Empirical evidence presented by Bernanke and Gertler (2000), Jinushi et al. (2000), McCallum (2003), and Taylor (2001) indicates that policy was too tight after 1992 and that the policy rate should have been reduced much earlier. Studies on the efficacy of policy were focused on policy rate rules and the credibility that these rules afford (Blanchard, 2011). In particular, optimal monetary policy during this period was conducted with a focus on Taylor rules. In this setting, the optimal level of the short-term interest rate was determined by the distance from the output and inflation gaps (Taylor, 1999). Central banks before the crisis paid great attention to output gaps and inflation expectations, often neglecting issues of financial instability and the formation of asset bubbles (Shirakawa, 2013).

3.1.1.1 Inflation Targeting and Financial Stability

> *A monetary regime that produces aggregate price stability will, as a by-product, tend to promote stability of the financial system.*
>
> — Claudio Borio and Philip Lowe (2002)

Historically, policymakers were concerned with both price and financial stability. In fact, as argued by Goodhart (1988), central banks were initially created to prevent financial crises and

average rate of inflation. Fluctuations in the short-run are tolerated in order for policy to affect real activity, but inflation should not move away from the established long-run level for too long (Woodford, 2012) bank failures that resulted from the "free banking" systems. However, there are several reasons why discussions on the central bank's role in achieving financial stability have been muted.

First, the financial sector risk was not taken into account in determining the appropriate stance of monetary policy, as central banking was too narrowly focused on price stability (Borio, 2011). It is argued that the capacity of the central bank to combat asset price movements and the build-up of financial instability with conventional policy tools is limited (Woodford, 2010). The magnitude of the change in the nominal short-term interest rate might have to be quite large to combat asset price movements. This might be detrimental, as it could derail the inflation objective. For example, in their seminal article Bernanke and Gertler (2001), argue that monetary policy should be concerned only about factors that could plausibly influence inflation projections[5]. In their study they found that the central bank gains relatively little from responding to asset price movements, and it should consider asset price fluctuations only in its capacity to affect the forecast of inflation, referred to as the "benign neglect" approach. In addition, the increase in the interest rate might impact asset classes beyond the one where a bubble is developing (Woodford, 2010). This means that perhaps targeted instruments, such as macroprudential regulation, would be more appropriate.

In fact, after the financial crisis there was a resurgence in the literature on the interaction of monetary policy and financial stability. In an article by Smets (2014), he argues that "price stability has proven not to be a sufficient condition for financial stability and lack of financial stability can have large negative feedback effects on price stability". In his article he calls for macroprudential regulation to run complementary to monetary policy in dealing with the buildup of financial imbalances. Monetary policy should be able to lean again the wind in the short-run, coordinated with macroprudential policy, while focusing on price stability in the medium-term (Smets, 2014).

Second, measurement of the build-up of risk has been problematic. For example, it has proven almost impossible to identify asset price 'bubbles'[6] until they have burst. Without a proper method for identifying bubbles, it is not considered worthwhile for the central bank to try and lean against asset price increases through contractionary policy. This has led academics and policymakers alike to suggest mopping up after the bubble has burst. However, as evidenced by the recent crisis, this might prove too costly. On the other hand, one thing gained from the crisis is that the overvaluation of an asset and the accompanying drop in price is not always the issue that needs to be addressed. The important consideration is the development of systemic risk that poses a threat to the health of the overall financial system, in other words, the joint failure of systemically important financial institutions. In this sense there have been significant

[5]Before the financial crisis, this was referred to as the Jackson Hole Consensus.
[6]A situation in which the price of an asset exceeds its fundamental value.

improvements in the measurement of risk to financial stability (Woodford, 2010).

Third, central banks generally adhere to the principal of one instrument for one target, often referred to as the Tinbergen principle. Relying on only the policy rate as the tool of monetary policy means that central banks have no power to navigate the financial stability space. One tool for two goals creates “conceptual and practical” confusion as to the ultimate objective, with communication becoming increasingly difficult (Svensson, 2012). Finally, regulation was thought to complement monetary policy and thereby take care of financial stability concerns, with microprudential regulation acting the as key policy tool. However, once the crisis had hit, this idea surrounding the tools available to the monetary authority with respect to financial stability changed dramatically, bringing the balance sheet of the central bank into contention (Blanchard, 2011).

3.1.2 Tension Before the Collapse (2007)

In early 2007 there were signs of an impending financial crisis, stemming from turmoil in the sub-prime mortgage market in the USA. Housing and credit bubbles had formed due to several factors, with a low interest environment in the US, the increasing use of structured finance, and deficient financial regulation considered proximate causes. This section is not an in-depth discussion on the most likely causes and mechanisms underlying the crisis; it is simply an overview of the relevant contributing factors. Giving a detailed account of the financial crisis is a difficult endeavour; as Gary Gorton (2012) puts it, “the wave of research on the crisis has already exceeded any single reader’s capacity, with the pace of new work only making it harder”. In fact, in a report to Congress in 2010 to explain the origin of the financial crisis, Mark Jickling (2010) identified 26 potential causes. Undoubtedly the list of causes has grown since then, and a discussion on each potential contribution is unfeasible.

3.1.2.1 Low Policy Rate Environment

The low policy rates of the early 2000s in the US were the result of historically low inflation during the Great Moderation and an active attempt by the Fed to dispel deflationary concerns in the wake of the mild 2001 recession[7]. In fact, Taylor (2007a) argues that rates were significantly lower than prescribed by rule-based optimal monetary policy mechanisms, such as the Taylor rule. Such an environment could plausibly induce a risk-taking attitude of investors in several ways, which Borio and Zhu (2012) call the “risk-taking channel” of monetary policy.

[7] After the bursting of the dotcom bubble.

Conventionally, when yields on safe assets are low, investors substitute toward higher-yielding risky assets, a phenomenon that was recorded in the build-up to the crisis, described as a "search-for-yield" (Rajan, 2005; Shirakawa, 2013). This was compounded by the fact that perceived risk was at an all-time low during the Great Moderation, as suggested by several measures of implied volatility (Bean et al., 2010). In addition, as argued by Adrian and Shin (2008) and Adrian et al. (2010a), the increase in the price of risky assets improves the balance sheet position of financial intermediaries[8] and encourages them to take on more debt (either through the extension of loans or the acquisition of securities), which in turn fuels further asset price increases. This effect is amplified by the pro-cyclical capital requirements of the Basel II accord. Over time, owing to the limited number of 'safe borrowers' in an economy and the depressed interest margins of commercial and investment banks, increased loan provision translates into increased funding of risky projects, inducing a leverage cycle (Bean et al., 2010).

3.1.2.2 Securitisation

In order to frame better the context of the incentive structure faced by financial institutions, it is important to discuss the topic of securitisation and the introduction of structured financial instruments. In a low interest rate environment, where financial institutions were in a search-for-yield, they were incentivised to create structured financial instruments to boost profitability. Financial engineering allowed the transformation of a group of illiquid and possibly risky assets (such as mortgages) into an apparently low-risk security, through a process called securitisation (du Plessis, 2011).

3.1.2.2.1 Definition and History Traditionally, banks needed to fund loans issued to borrowers through the collection of deposits. Modern banking has grown significantly in terms of the sources of funding available, which now "include bond financing, commercial paper financing, and repurchase agreement (repo) funding" (Bord and Santos, 2012). A vitally important change in the lending structure of banks is the shift from the originate-to-hold model of lending to the originate-to-distribute framework (du Plessis, 2011). In the originate-to-hold model, loans are kept on the balance sheet of the originator, which provides an incentive to control the quality of the loan. The benefit of this model, as discussed in Ramakrishnan and Thakor (1984), Diamond (1984) and Holmstrom and Tirole (1993), is that banks are able to monitor borrower activity. With the originate-to-distribute model, "loans are pooled, tranched, and then resold via securitization" (Brunnermeier, 2009). Modern banks, therefore, are more concerned with convincing potential investors of the quality of the loans underlying the asset pledged

[8] Commercial banks are looking to retain constant leverage ratios, but investment banks do not mind increased leverage in a boom period.

(du Plessis, 2011)[9]. Credit ratings agencies helped to bridge the information gap between investors and financial institutions selling bundled cash flows.

According to Andersen et al. (2013), "[s]ecuritization means selling securities whose principal and interest payments are exclusively linked to a pool of legally segregated, specified, cash flows (promised loan payments) owned by a special purpose vehicle (SPV)[10]". In this setting, an SPV (i.e. the issuer) buys the rights to the cash flow of the pooled assets from an authorised loan originator (Gorton, 2015). Securities formed from the pooling of assets are referred to as asset-backed securities (ABS). After being packaged and assigned credit ratings[11], these ABS are sold in capital markets to fund the purchase of the loan portfolio (Andersen et al., 2013).

In the US this process led to the creation of mortgage-backed securities (MBS), which entailed collecting mortgages and bundling them into a security. Initially, securitisation of this type was performed only by government sponsored enterprises (GSEs), such as Fannie Mae and Freddie Mac. Due to the potential credit risk borne by these GSEs, the approval of mortgage loans was subject to a set of guidelines. Mortgage loans that fell within a prudent set of parameters were referred to as standard conforming loans (du Plessis, 2011).

The restrictions on loan eligibility were not politically popular, as the inability to qualify for conventional mortgages excluded a large portion of the population. In response, new mortgage classes, such as Alt-A and sub-prime mortgages were created, which allowed those with poor credit histories to be considered for loans (Taylor, 2008). The lowering of lending standards was considered largely to be a political initiative intended to increase homeownership among low-income households (Wallison, 2009). Due to their risky nature, interest rates on nonprime loans are significantly higher than the rate on prime loans (Acharya and Richardson, 2012).

One of the major contributing factors to the sweeping defaults and foreclosures of 2007 and 2008 was that a substantial proportion of subprime mortgage loans had adjustable rates, which were unwittingly structured in such a way as to create systemic risk. Adjustable rates meant that loans were offered at a fixed rate for a short period (a teaser rate), usually for the first two to three years, after which the rate floated at a variable rate with an additional premium (Acharya and Richardson, 2012). Financial institutions understood that a rate increase would result in either defaulting or refinancing for many clients. However, as long as the underlying asset price was increasing, borrowers could use capital gained from the appreciation as collateral to refinance their homes[12] (Gorton, 2008). With this mechanism in place, the probability of

[9]Investors need to be convinced, as banks are off-loading the risk associated with these loans onto investors.

[10]SPVs in this context are legal entities created to fund a large pool of assets, by buying the right to cash flows from financial intermediaries.

[11]Interestingly, securities created in the process of securitisation are considered 'credit enhanced', which means that the rating is higher than the underlying asset pool (i.e. unsecured debt from the originator)

[12]Interestingly, refinancing of existing mortgages formed the bulk of origination in the sub-prime mortgage

systemic default seemed remote.

3.1.2.2.2 MBS and Derivatives Along with adjustable rate mortgages and the reliance on appreciating house prices, the type of securitisation performed before the crisis also significantly contributed to systemic risk, as it "eroded loan quality" and caused a "lack of transparency about the quality of the loans" (Jaffee et al., 2009). Usually, the issuer of the security divides it into tranches, and each tranche is assigned a specific credit rating. AAA-rated, senior tranches were considered the safest investment by credit rating agencies[13]. Ratings were based on both the individual probability of default (i.e idiosyncratic risk), as well as on the correlation of default across all securities in the pool (i.e systematic risk) (Gorton, 2010). Market participants looking for low-risk, stable investments - such as pension funds - looked to the safer senior tranches, while riskier investors purchased securities from the lower-rated and higher-yielding tranches.

The most basic form of MBS is referred to as 'pass-through'. A pass-through security is usually created by pooling a selection of assets and then allowing the sale of shares or participation certificates, allowing access to the pool. Shareholders then are passed through a pro-rata portion of the cash flow generated by the pool (Andersen et al., 2013). However, in order to generate an even greater selection of investment products, several mortgage derivatives were created. Among the most popular derivatives were the collateralised debt obligations (CDOs)[14].

The complexity and lack of transparency generated by securitisation is not fully appreciated until one delves into the topic of CDOs. Cash flow generated from the different tranches of MBS was often further segmented into structured asset-backed securities called CDOs, with sub-prime mortgages (i.e. the debt obligation) offered as collateral. While the structure of CDOs can be explained in different ways, I follow the layout of Gorton (2008) and Jaffee et al. (2009).

First, CDOs are divided into high-grade, mezzanine and equity levels. The majority (more than 95 per cent) of the cash flow from the top three tranches of MBS (AAA, AA, A) was directed at senior high-grade CDOs (Jaffee et al., 2009). Mezzanine CDOs are usually formed from the middle, riskier tranches of the MBS. Equity CDOs are formed from the bottom tranche and are considered junk bonds, or "toxic waste" (Brunnermeier, 2009). In this setup the high-grade CDOs get paid first in the case of a default, with mezzanine paid next and the equity tranche paid only after the others receive payment[15].

market (Bhardwaj and Sengupta, 2008).

[13]Tranches range from the safe senior level to risky junk bonds, with the yield increasing as you move to the riskier tranches.

[14]While it is rather confusing, a CDO is still considered an MBS.

[15]Referred to as a waterfall structure, where the benefits go to the top first and then flow down.

Second, adding another level of complexity, both the high-grade and mezzanine levels are portioned into discrete tranches, with different ratings of default risk assigned to each tranche (Acharya and Richardson, 2012). The equity tranche is usually held by the issuing bank, in order to monitor borrowing activity (Brunnermeier, 2009). On average, the more senior levels are divided into six or seven tranches. Effectively, this means that within the mezzanine CDO, which is formed from riskier MBS tranches, it is possible to create an AAA-rated MBS. With increased demand for AAA-rated securities, this type of financial engineering was encouraged. Third, the middle portion (normally AA and A rated securities) of mezzanine CDOs were often repackaged as CDO^2, which also delivered a significant portion of AAA-rated securities (Jaffee et al., 2009). As revealed during the crisis, correctly assigning risk to these structured securities is exceedingly difficult.

A lack of transparency, and a belief in the financial engineering[16] underlying the creation of CDOs led credit rating agencies to incorrectly assign inherently risky assets the highest possible credit ratings. This was, in part, because agencies believed the potential for large-scale default was improbable[17] (du Plessis, 2011). Needless to say, ratings agencies underestimated the risk associated with these securities and their derivatives, which became evident when delinquencies started to increase in response to a turn in the housing market in 2006 (Ashcraft and Schuermann, 2008). Unfortunately, many securities firms held large quantities of these opaque assets on their balance sheets[18].

3.1.2.2.3 Credit Default Swaps Security buyers could also try and protect their potentially risky investments by purchasing a credit default swap (CDS) contract. With a credit default swap, the seller of a CDS contract asks the protection buyer to pay a nominal fee (credit swap premium) to assume the credit risk associated with a security[19]. In the case that a negative credit event - such as a default - occurs, the seller of the CDS contract needs to pay the principal and interest on the referenced obligation, while the buyer delivers either the referenced asset or a settlement worth the market value of the bond (Acharya et al., 2012).

Before the crisis, CDSs were quite popular for insuring against the credit risk associated with CDOs and other MBS. In fact, the CDS market was one of the most rapidly growing markets before the crisis. In 1998 the notional amount of outstanding CDS contracts was about $180 billion, expanding to a high of $62 trillion in 2007 (Acharya et al., 2012). According to data

[16]Market participants believed that the Gaussian Copula formula used was representing risk probabilities accurately.

[17]Credit rating agencies were also incentivised to assign high ratings. If they did not abide, financial institutions would simply move their business to another agency.

[18]Usually the purchases of these assets are financed through repurchase agreements with commercial banks (Adrian and Shin, 2010)

[19]This fee payment occurs periodically until the maturity of the CDS.

from the Bank for International Settlements (BIS), the current size of the market is around $12 trillion. The size of this market meant that in the case of a large-scale default, it might not be possible for the sellers of CDS risk contracts to meet their obligations. In this subsection some of the most important components of securitisation are detailed. What follows is a discussion on how these elements contributed to financial intermediation in the shadow banking system.

3.1.2.3 Shadow Banking System

Initially, the term shadow bank, which was coined by Paul McCulley in 2007, referred to "risky off-balance-sheet vehicles hatched by banks to sell loans repackaged as bonds" (Economist, 2016). However, shadow banking in its current incarnation has taken on a different meaning. There are multiple definitions on what constitutes the shadow banking system. Broadly speaking, as stated by Bernanke (2012),

> *Shadow banking, as usually defined, comprises a diverse set of institutions and markets that, collectively, carry out traditional banking functions - but do so outside, or in ways only loosely linked to, the traditional system of regulated depository institutions*.

The primary function of the shadow banking system involves maturity transformation, in which "'opaque, risky, long-term assets" are converted into short-term liabilities (Adrian et al., 2010b; Chan, 2012). In the chain of financial intermediation, purchases of MBS and CDOs by financial institutions, through off-balance-sheet structured investment vehicles (SIVs) and conduits, are usually financed through repurchase agreements with commercial banks. Lending by the commercial bank, in turn, is funded through issuing short-term liabilities. Financial commercial paper (CP) is a popular form of short-term paper offered by these banks (Adrian and Shin, 2010). Buyers of these liabilities include money-market mutual funds (MMMFs), often with household savers as shareholders.

Credit intermediation from shadow banking activities grew to equal that of commercial banks (i.e. traditional depository institutions) in the years before the crisis (Bernanke, 2013). Securitised portfolios were considered a source of collateral for funding under the shadow banking system. In addition, abiding by the Basel II accords, banks had to fulfil a certain capital adequacy ratio, with the safest tranches of ABS requiring less capital. During that time the economy became reliant on seemingly low-cost shadow banking activities to supply short-term liquidity. These activities were facilitated by the use of off-balance-sheet vehicles.

3.1.2.3.1 Off-Balance-Sheet Activity As a point of clarification, structured investment vehicles (SIVs) and asset-backed commercial paper (ABCP) conduits are types of special purpose vehicles. These vehicles allow institutions to remove debt from corporate balance sheets, which reduces the exposure of their balance sheet to risk, often making them appear safer then they actually are. SPVs are legal entities that are created with one specific goal in mind. Earlier in the chapter I discussed SPVs that are involved in the process of securitisation, creating investment vehicles such as CDOs, CDSs and MBS. Securitised debt in this form is not kept on the balance sheet of the bank. Whereas the SPVs in securitisation are fully mechanical/robotic in their function, SIVs and ABCP conduits are actively managed companies. For example, the function of SIVs is to sell short-duration bonds, such as commercial paper, to MMMFs, which generates funds that are used to purchase long-duration securities - such as ABS - with high credit ratings (Gorton and Metrick, 2010).

SPVs were first mentioned in the process of securitisation, with operations being conducted off the balance sheets of banks. There are several benefits associated with conducting business in this manner. First, securitisation avoids the potential for bankruptcy[20]. SPVs are constructed in such a way as to make the possibility of bankruptcy - voluntary or involuntary - sufficiently small (Gorton and Metrick, 2010). Second, off-balance-sheet securitisation is not subject to regulatory capital requirements, which affords them access to relatively cheap debt financing. Third, structures are put into place to avoid adverse selection[21]. Some of the prominent features incorporated to eliminate adverse selection are eligibility criteria and warranties on the loans, as well as the maintenance of an equity position in the security by the originator (Gorton and Metrick, 2010). Finally, transparency is inherent in an SPV, with its portfolio being completely known (i.e. full disclosure is provided in terms of its balance sheet).

3.1.2.3.2 Leverage The increase in off-balance-sheet activity effectively allowed many financial institutions to avoid capital requirements. However, this also entailed an almost unrestricted increase in leverage. The ratio of assets to capital (equity) on a bank's balance sheet is known as leverage. When debt is in excess of equity, a bank is considered highly geared/leveraged (Adrian and Shin, 2010). In other words, increases in debt financing relative to capital financing increase the leverage. Equity is more costly to generate than debt, with servicing costs on debt being tax-deductible (Ingves, 2014). Firms that finance assets with debt, as opposed to equity, also improve their return on equity. This can be seen by the fact that leverage, in terms of financial institutions, is considered to be pro-cyclical, which means a "strongly positive relationship between changes in total assets and changes in leverage" (Adrian and Shin, 2010). Leverage is key to credit provision as it decreases financing costs for firms, as long as earnings

[20]The paper by Klee and Butler (2002) provides a comprehensive account of how SPVs are structured in order to avoid bankruptcy.

[21]In this setting, adverse selection might occur because loan originators have more information as to the quality of the loans selected for the portfolio purchased by the SPV.

exceed borrowing costs. However, the downside to excessive leveraging is that it can amplify liquidity spirals, as explained in the last part of this section.

While banks were already highly geared, the on-balance-sheet activities were regulated. One of the primary reasons why shadow banking grew so explosively is the fact that it was not prone to the same regulatory oversight as traditional banks. In particular, the creation of off-balance-sheet investment vehicles allowed banks to effectively circumvent risk-based capital adequacy ratios. This allowed these institutions to become highly leveraged off their balance sheets, while still conforming to regulatory capital requirements.

3.1.2.3.3 Regulation In the years leading up to the crisis, Alan Greenspan purposefully attempted to deregulate markets in the US, with the belief that they would be able to self-regulate. In this narrative, financial firms are the best equipped to regulate their own actions, with government regulation seen as cumbersome and inefficient (Born, 2011). The self interest of market participants would rule out excess, with tremendous amounts of government resources needed to perform this action effectively, possibly without improving the final outcome. In addition, several mechanisms were put into place by financial institutions to prevent excessive risk-taking. For example, balance sheets with securitised assets were considered healthy, as they contained assets with high credit ratings and therefore relatively low capital requirements (Bernanke, 2012). The creditworthiness of counterparties is based on the health of the balance sheet, which according to credit rating agencies and insurance companies, was considered safe (Gorton, 2014).

An emphasis on deregulation helped the largely unregulated shadow banking sector to rapidly evolve to match the size of the traditional banking sector. Several of these unsupervised financial institutions, outside of the commercial banks, achieved the same level of systemic importance (Born, 2011). The size of these institutions, linked with reduced regulation, had several important implications that contributed to the crisis.

First, there was limited regulatory oversight on the risk-taking behaviour and risk management strategies in the shadow banking system. While there was a degree of market discipline imposed by market participants, it did not halt the development of systemic risk (Bernanke, 2012). In addition, the fact that there was no statutory authority limited the information available with regard to underlying risk.

Second, regulation focused mainly on microprudential supervision, which meant that authorities were concerned only with the safety of individual financial institutions (i.e. idiosyncratic risk) (Adrian et al., 2010b). After the crisis, macroprudential policy, which is directed at systemic risk, became the focal point. Interestingly, before the crisis, in many advanced economies, governments did not even have the authority to "limit systemic risks that could result from the collective behaviour of financial institutions and markets" (Bernanke, 2012). Not only did this contribute to the build-up of risk, but also to the ability of policymakers to combat it.

Finally, the procyclical nature of the Basel II accords, with capital requirements becoming easier to satisfy with the rise in asset prices, helped to fuel the asset market bubble (Goodhart et al., 2010). This allowed banks to increase their leverage in good times and, unfortunately, made it more difficult for them to maintain the requirement in times when credit was tight. In general, the booming economy led most financial institutions to hold less capital than they needed, with the potential for loss amplified in the case of a bust (Gorton, 2014).

In addition to the incentivised gearing through regulation, the central bank also contributed by creating moral hazard through its capacity as lender-of-last-resort (Gorton, 2010). Market participants were under the impression that once a crisis emerges, they would be considered too-big-to-fail. This belief was institutionalised, in part, from the Bagehot principle, in which the central bank is obligated to assist financial institutions regarded as systemically important. 'Bagehot's dictum', as summarised by Tucker (2009), is that "to avert panic, central banks should lend early and freely (i.e., without limit) to solvent firms, against good collateral, and at 'high rates'".

3.1.2.4 Housing Market Collapse

At the start of 2007, house prices were on a downward trajectory, accompanied by a wave of foreclosures, as teaser rates on adjustable-rate mortgages came to an end. Sweeping defaults raised the question as to the values of a wide range of mortgage-related securities. Private sector agents found it increasingly difficult to determine their own risk exposure, especially when it came to off-balance-sheet investment vehicles (Bernanke, 2012). This section describes the amplifying factors that transformed the turmoil in the housing market into a full-blown financial crisis. Brunnermeier (2009) identifies four crucial amplification mechanisms. However, only the first two are relevant to our discussion.

First, a negative shock to asset prices could severely impact the balance sheets of borrowers. Highly leveraged investors facing a decline in asset prices could potentially trigger a *loss spiral*. This is best explained by an example, as in Brunnermeier (2009). Let us consider investors who purchase assets to the value of $\$100$ million with a haircut of 10%. In order for the investors to purchase these assets, they need to put up $\$10$ million of their own capital, while funding the rest with debt. In this case, the leverage ratio is calculated at 10. Suppose a shock to the economy causes the asset price to decline, which leaves the market value of the investors' assets at $\$95$ million. In this case, the decrease in the value of the assets has caused the investors' capital to decline, from $10 million to $5 million.

The loss in capital experienced by the investors mean that they must reduce their asset position in the market, in order to retain the same leverage ratio. In this case, the bank has only sufficient capital to hold $50 million worth of assets. The investors are now forced to sell $45 million worth of assets in order to achieve this position. However, the sale of these assets further depresses the price, which leads to an iterative process of asset sales and price reductions. In this example haircuts are kept constant but in the case of the crisis a *margin spiral* also emerged. During periods of financial distress, borrowers tend to increase haircuts, which means that investors need to offer up more capital to purchase assets. This intensifies the effects of the loss spiral. Together the loss and margin spiral form what is referred to by Brunnermeier and Pedersen (2009) as a "liquidity spiral".

Losses experienced were concentrated "disproportionately at key nodes of the financial system, notably highly leveraged banks, broker-dealers, and securitisation vehicles" (Bernanke, 2012). Due to high leverage, the losses quickly consumed the capital of these institutions, leaving them only debt and causing broad-scale insolvency. Following this there was an attempt to deleverage, but due to the inability to sell mortgage related securities in repo markets, this prompted sales into illiquid markets. Fire sales of assets outside of the housing market ensued as banks scrambled for liquidity in order to meet the capital requirements of the Basel II accord (du Plessis, 2011). Sales decreased prices on assets sold, which further weakened balance sheets. Rapid asset sales further promoted the unwillingness to lend, as counterparties exposed to toxic assets were considered desperate.

Second, shocks to the economy can operate through the lending channel (Brunnermeier, 2009). The balance sheets of borrowers form only one side of the equation. Supply-side constraints generate shortages in liquidity, which means that lenders might not be able to meet demand, even if borrowers are solvent. Lenders with limited amounts of capital might start to hoard liquidity in a precautionary manner, in fear of worsening financial conditions. Uncertainty as to the asset positions of other intermediaries made these banks hold on to their assets.

This behaviour could be explained with reference to the repo market. As previously discussed, this is the link in the financial intermediation chain whereby financial institutions convert their long-term illiquid assets into short-term debt with commercial banks. In order to obtain short-term funding, financial firms offer their mortgage securities as collateral. A halt in the process of intermediation resulted from uncertainty as to the quality of assets offered as collateral. In other words, liquidity from the interbank markets was drying up as commercial banks were becoming increasingly unwilling to provide liquidity, in the fear that they would not see repayment (Acharya and Richardson, 2012). Commercial banks responded by increasing the haircut requirements on collateral. This effectively shut many financial institutions out of the wholesale market, as they were unable to transform their illiquid securities into short-term debt. Trust in the ability of counterparties to meet their obligations was broken (du Plessis, 2011).

The trend of asset price increases precipitating a crisis is a familiar one, as according to the work of Reinhart and Rogoff (2009), most of the economic crises of the past two centuries have been preceded by rapid credit expansion and the accompanying creation and collapse of bubbles. In other words, asset price increases and excessive risk-taking created distorted incentives for banks and accelerated credit expansion and overall leverage to abnormal levels (Adrian and Shin, 2011). In conjunction with lax regulations and information problems in assessing the underlying value of asset-backed securities, this created the perfect storm for a financial crisis. Eventually, the realisation dawned that even with inflation targeting, the focus on price stability is not a guarantee against financial instability (Borio, 2011).

3.1.3 Creating Liquidity Facilities (2007)

During 2007 the Federal Reserve responded to the credit crunch by cutting the policy rate incrementally on several occasions, in order to stimulate activity. The extent of the crisis was not known at this time, but owing to the experience of Japan, it was crucial for the central bank to be aggressive in its approach to easing (Ahearne et al., 2002). Credit ratings agencies placed several securities backed by subprime mortgages on credit watch, while various financial institutions (in the US and abroad) started reducing their exposure to MBS.

Once the Fed realised that dysfunctional financial market conditions were not improving, it further decreased the policy rate in the hope that it could avoid a recession. However, pressure in the financial market did not abate, and liquidity shortages on the interbank funding market became commonplace, with large spikes in the LIBOR-OIS[22] spread, referred to as "illiquidity waves" (Sengupta and Tam, 2008)[23]. A widening of the bid-ask interest rate spread generally means that collateralised borrowing is constrained (Dicecio and Gascon, 2008).

In order to address the widening spread between the overnight and interbank rates[24], the Fed introduced a variety of liquidity facilities. This credit policy was meant to operate primarily through the liquidity channel, providing liquidity to distressed financial institutions (Sack,

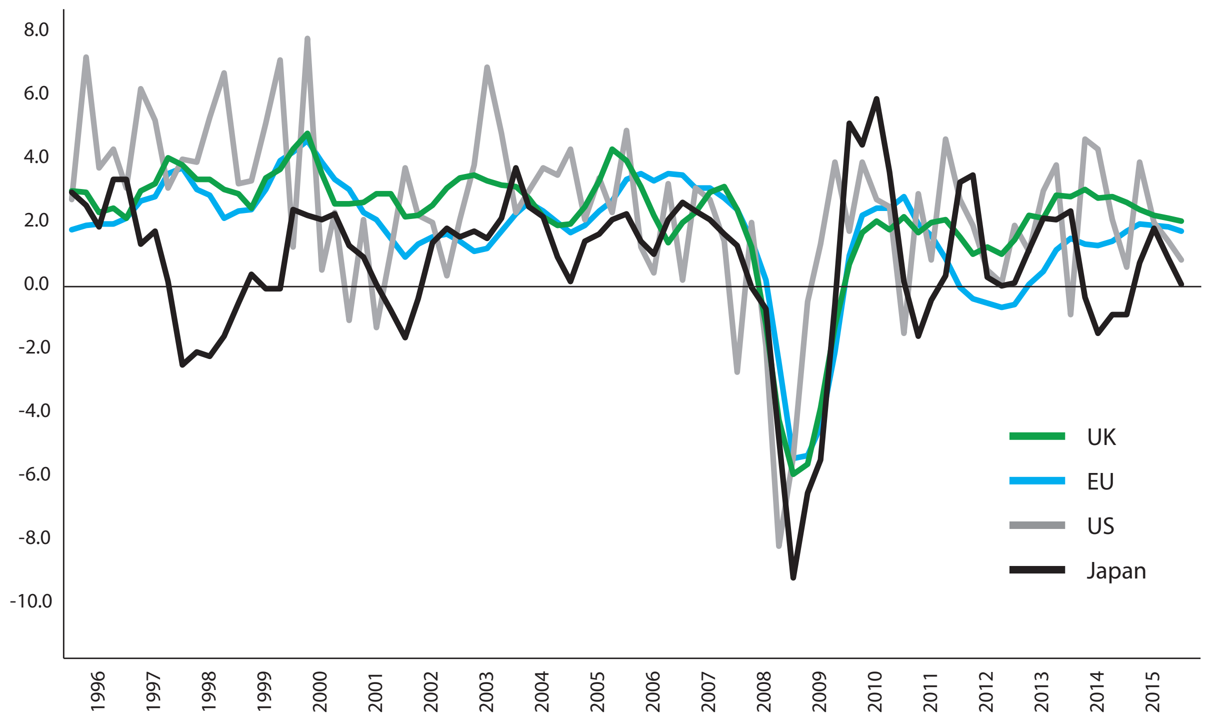
[22]Bid-ask interest rate spreads.

[23]Several significant events contributed to these illiquidity waves. These include the emergency funding to UK mortgage lender Northern Rock (85 bp), several writedowns by large American investment banks such as UBS and Lehman Brothers (108 bp), and the eventual sale of Bear Sterns to JP Morgan Chase in March of 2008 (83 bp). However, by far the largest increase in spread came from the failure of Lehman Brothers in October 2008; a massive 365 basis points.

[24]Usually of maturities beyond the short overnight rate. Indicative of a liquidity premium.

2009). The first in the long line of broad-based liquidity facilities created by the Fed was the Term Auction Facility (TAF) for depository institutions, which was established in December 2007[25]. At roughly the same time, similar actions were undertaken by other central banks, such as the Bank of Canada, BoE and ECB[26]. The TAF is considered the first implementation of the central bank balance sheet. It can be filed under a change in the composition of the balance sheet[27]; this is a sterilised operation whereby assets and liabilities on the balance sheet are increased in equal amounts.

Figure 3.1: Real GDP growth of four countries



Source: Bank of Japan; St Louis Federal Reserve Bank; European Central Bank; Bank of England

3.1.4 The Collapse of Lehman Brothers (2008)

In 2008 the housing bubble burst, with the decrease in housing prices resulting in increased delinquencies and foreclosures (Bernanke, 2008). Mortgage markets experienced a significant downturn, and financial institutions exposed to these markets were heavily affected, suffering

[25]This facility was similar to the normal discount window, but it was anonymous. This avoided the stigma attached with going to the discount window; which is one of the reasons that the interbank market liquidity dried up in the first place (Wheelock, 2008).

[26]Swap lines were also established with ECB and Swiss National Bank, in order to improve global credit flow.

[27]Considered a type of 'credit easing', as defined by Bernanke et al. (2004), or 'credit policy' as defined by Borio and Disyatat (2010)

losses in terms of capital and liquidity (Labonte, 2015). Affected institutions became increasingly reluctant to extend loans of any type to consumers and firms, which had a particularly severe impact on residential construction (Bean et al., 2010). The extent of the impact was exemplified by the fact that even two GSEs, Fannie Mae and Freddie Mac, needed massive intervention (Bernanke, 2009).

In order to improve credit conditions, the central bank reduced the policy rate even further, as seen in Figure 3.2. In March 2008, with funding markets' liquidity constrained, the Federal Reserve started a securities lending program[28], called the Term Securities Lending Facility (TSLF). This program entails the swap of Treasury securities for other eligible securities, which is essentially a change in the composition of the balance sheet of the central bank. This facility is different than the TAF in that it includes a wider range of eligible securities, including several forms of agency debt and MBS (Dicecio and Gascon, 2008).

Finally, in addition to the TAF and TSLF, the Fed introduced the Primary Dealer Credit Facility (PDCF), an initiative that was initially different from the TSLF in that it accepted an even broader range of investment-grade securities as collateral. At this point in the crisis narrative, the balance sheet measures used were not considered strictly unconventional. These measures entailed an increase in the range of eligible collateral and counterparties, but purchases were highly collateralised and considered within the normal purview of central bank operations (Bean et al., 2010).

The US experienced the largest share of the turmoil, with many crucial financial players becoming heavily distressed and highly geared. Heavy involvement in the securitisation of mortgage-backed securities meant that investment bank Bear Sterns would be sold to JP Morgan Chase at a fraction[29] of its pre-crisis market value, a deal brokered by the New York Fed, which also provided the necessary term financing (Bernanke, 2009). In addition, several firms that werelinked to mortgage markets, such as the large savings and loan association IndyMac[30], started to collapse. Even the support provided to Fannie Mae and Freddie Mac was not sufficient, and they had to be taken into conservatorship, with the Treasury providing massive liquidity injections (Bernanke, 2009).

Fears of a systemic collapse was on the cards with continued liquidity frictions in the wholesale market and increasing risk premia. Unfortunately, the position of Lehman Brothers (one of the largest players in the US shadow banking system) was unsalvageable; despite efforts on the part of monetary and fiscal authorities, they filed for bankruptcy in September 2008. This bankruptcy

[28]Started in unison with several other G-10 central banks.

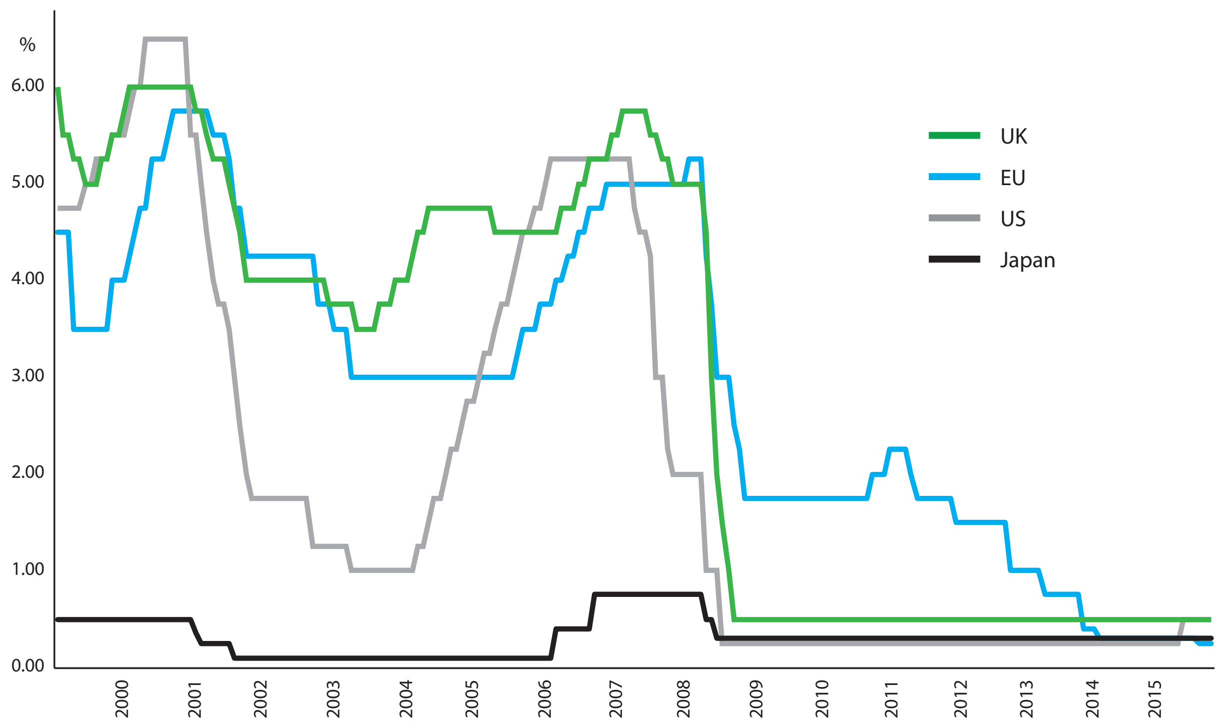
[29]Their value dropped from more than $133 per share to below $2 per share after the crisis. The intervention of the Fed meant that Bear Sterns would be acquired for a more reasonable $10 per share.

[30]Independent National Mortgage Corporation.

raised concerns for the solvency of other financial institutions with similar asset profiles, such as the insurance company AIG[31] (which was eventually bailed out at the cost of $85 billion) and investment bank Merrill Lynch (which was acquired by the Bank of America). In a strategic move to avoid further default, large investment firms Morgan Stanley and Goldman Sachs were approved to become bank holding companies, with direct access to the term lending facilities of the Fed. At this point, market participants had lost faith in highly leveraged financial institutions to meet their obligations, and coordination failures emerged (Falagiarda and Saia, 2013).

Shock waves from this event were felt across the globe, and policymakers started to comprehend the magnitude of the crisis. Central banks worldwide realised that if key institutions were allowed to fail, it would have a catastrophic impact on financial markets. Monetary and fiscal authorities across the globe started implementing expansionary policy measures, specifically with the goal of providing liquidity to financial institutions. As interest rates started circling the ZLB in December 2008, monetary authorities realised that they would have to provide stimulus through balance sheet policies (Labonte, 2015).

Figure 3.2: Short-term policy rates of four countries



Source: Bank of Japan; St Louis Federal Reserve Bank; European Central Bank; Bank of England

[31]Heavily invested in CDS. Default triggered the repayment on all the CDS contracts extended. This was simply too much to bear.

3.2 Four Balance Sheet Stories (2008 - 2016)

The fall of Lehman Brothers was the catalyst that escalated balance sheet operations by central banks across the globe. This section chronicles different liquidity management strategies implemented by four influential central banks, namely the Fed, ECB, BoE and BoJ. It is important to gain some perspective on the balance sheet policies used by different countries, in order to determine whether there are some common trends. The goal of this section is to highlight the policies that have been used most widely and that have enjoyed the greatest longevity and success. This section is complemented by the next chapter, where the empirical evidence on the stated balance sheet policies implemented are discussed. Figure 3.3, Figure 3.4, Figure 3.5 and Figure 3.6 represent the different balance sheets of the four countries discussed. In addition, each figure contains country-specific timelines of the events mentioned in the section.

3.2.1 USA: The Federal Reserve

3.2.1.1 Liquidity Facilities

In most developed countries, banks can deposit or withdraw liquidity in the primary market, with the central bank, or in the secondary/interbank market (Catalão-Lopes, 2010). Open market operations[32] conducted with the central bank are secure, while the liquidity traded between banks carries some risk. A number of different facilities were established in order to quell fears over a pending recession and the potential collapse of secondary markets. Credit intermediation in the modern era increasingly is performed in financial markets, as only commercial banks have access to the relatively inexpensive funding provided in the federal funds market (Bernanke, 2009). The Fed was one of the first central banks to enact liquidity facilities to provide relief to struggling financial institutions and repair dysfunctional markets.

In the immediate aftermath of the collapse, the Fed created the Asset-Backed Commercial Paper (ABCP) Money Market Mutual Fund Liquidity Facility (AMLF), which was guaranteed by the Treasury (Fawley and Neely, 2013). The amelioration in short-term funding markets, especially that of commercial paper, was not realised. The Reserve Primary Fund, a large money market fund, had heavy investment exposure to Lehman Brothers, with the default causing its net asset value to drop below $1, which is referred to as ‘breaking the buck’. As a result, there was a flight to quality, from high-yielding prime money market funds toward those that held Treasuries (safe government securities) only (Adrian et al., 2011). In an effort to avoid a bank run in

[32] Also those conducted with standing facilities

money markets, the Fed established the Commercial Paper Funding Facility (CPFF), purchasing high-quality commercial paper (Fawley and Neely, 2013).

The failure of commercial paper funding translates into increased difficulties in meeting the credit needs of businesses and households, for institutions outside of the Fed's discount window. This liquidity facility extended the discount window to all issuers of commercial paper. Liquidity facilities like these provide backstop funding in dysfunctional markets. Increased liquidity, through the so-called liquidity channel, provides assurance to both the issuer of the commercial paper and the investor that short-term debt obligations will be met, but does not guarantee the solvency of firms (Adrian et al., 2011).

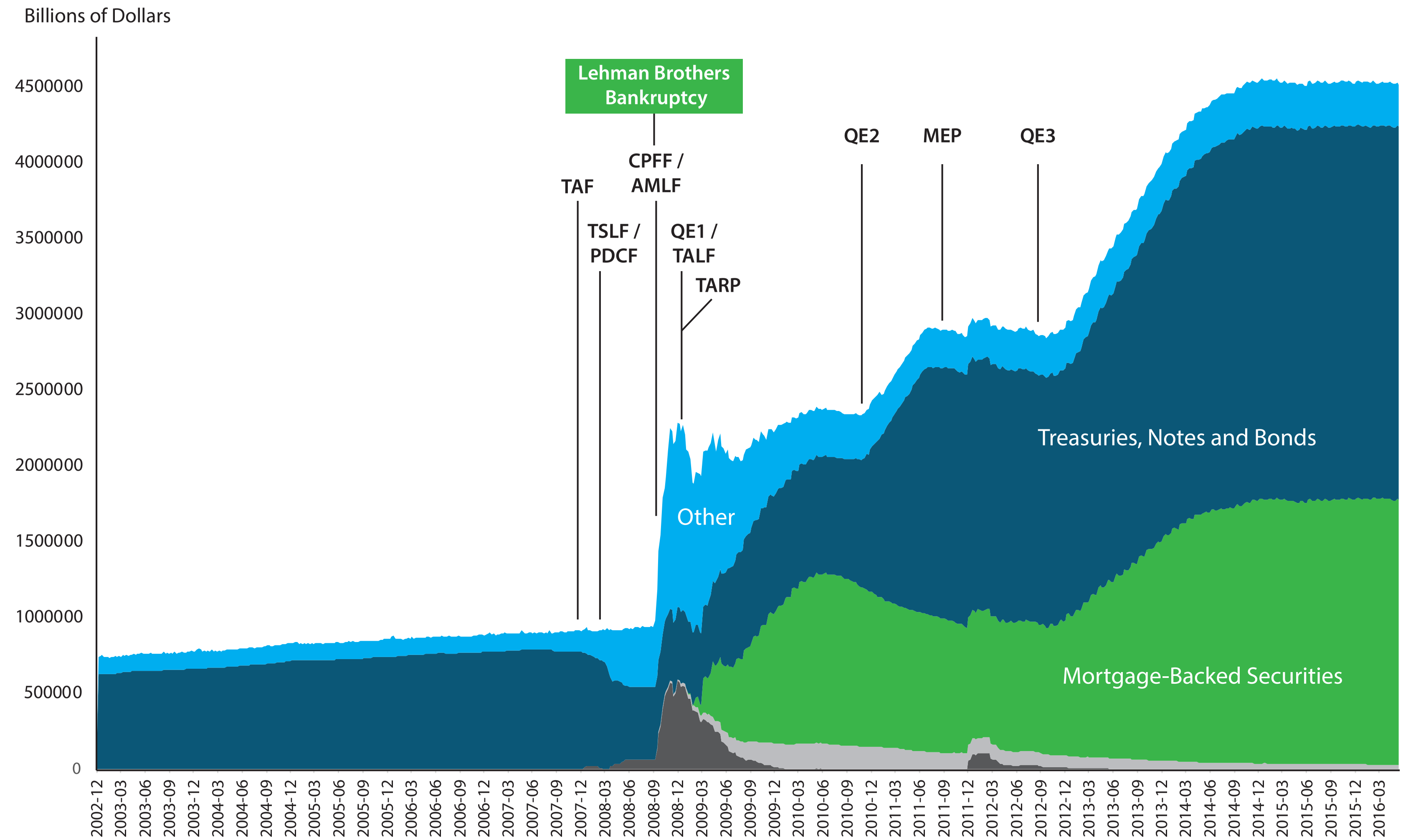
The establishment of these facilities entailed an increase in the size as well as a change in composition of the balance sheet of the central bank, and could have had potential fiscal consequences[33]. Creating these types of facilities was the first among many steps by the Fed that moved it out of the territory of conventional easing, as it entailed the purchase of assets that could expose the central bank to credit risk. In other words, these actions heralded the start of credit policy in the US, with the intention of targeting specific market segments in purchasing private sector assets (Bernanke, 2009). In addition, these were also the first unsterilised purchases, indicating an extraordinary expansion of the balance sheet (Fawley and Neely, 2013)

3.2.1.2 QE1

After allowing Lehman Brothers to fail, the Fed realised that other large investment banks were credit constrained and afforded them the opportunity to borrow at the discount window, giving them a direct credit line to the central bank (Bernanke, 2009). However, the credit extended through various liquidity facilities and the extension of lender-of-last-resort services to a wider range of counterparties was not enough to turn the tide (Fawley and Neely, 2013). Even after establishing liquidity facilities in order to combat rapidly deteriorating conditions in short-term funding markets, the Federal Reserve could not independently reverse the fortune of financial markets, and as a recourse it solicited fiscal cooperation. In other words, the Fed was pressed to coordinate its efforts with the Treasury. In early October Congress passed the Emergency Economic Stabilisation Act, which established the Troubled Asset Relief Program (TARP) to the value of $700 billion, in aid of financial stabilisation (Bernanke, 2009). The objective of this stimulus was to clear toxic assets from the balance sheets of financial institutions, in order to avoid over-leveraging and potential fire sales.

[33] Concerns were raised over the fiscal independence of the central bank.

Figure 3.3: Assets on the balance sheet of the Fed



Source: St Louis Federal Reserve Bank

Having reduced the federal funds rate close to the zero lower bound (0.25 %), the Federal Reserve believed that to further stimulate economic activity, it would have to utilise another tool in its policy arsenal, namely unsterilised purchases of government sponsored enterprise (GSE) debt and mortgage-backed securities (MBS) to the total of $600 billion (Gagnon et al., 2011). This first round of quantitative easing or large-scale asset purchases (LSAPs), referred to as QE1, was implemented on the 25th of November 2008. In addition to this initial purchase, in March 2009 the Fed increased QE1 purchases, which consisted mostly of GSE debt ($100 billion), MBS ($750 billion) and long-term Treasury bonds ($300 billion). The total assets purchased in QE1 cumulated to a value of more than $1.75 trillion (Fawley and Neely, 2013).

The housing market and related institutions were the primary target of these policy actions, with more than 80% of total purchases being related to the housing credit market (Fawley and Neely, 2013). In terms of the transmission channel, the Fed was looking towards the portfolio balance channel to reduce term premia on long-term assets, a channel that was explicitly mentioned by Bernanke (2009). It utilised both credit policy (GSE and MBS) and quasi-debt management (long-term securities) to achieve this goal. Importantly, even though the quantity of bank reserves increased in these operations, they did not constitute 'pure' quantitative easing, as it wasn't the explicit target of the central bank (Borio and Disyatat, 2010)[34]. The last part of this section contains a discusses on the empirical evidence of the efficacy of the different programs employed.

3.2.1.2.1 TALF At the same time that QE1 was implemented, the central bank created the Term Asset-Backed Securities Loan Facility (TALF), which is a loan program that entices investors to purchase AAA-rated commercial MBS. This facility was the last in the line of the Fed's special liquidity facilities (Sack, 2010). It differed from most of the other liquidity facilities[35] in that it looked to provide support for market-based credit intermediation, rather than providing liquidity to commercial banks. It was specifically aimed at reviving securitised credit markets, opening up securitisation channels and thereby improving the "availability and affordability of credit for households and small businesses" (Bernanke, 2009). Two features that were unique to this facility were that TALF loans were non-recourse[36] and of longer maturities (Sack, 2010). In addition, TALF was available to a wide array of counterparties, thereby increasing the reach of the program.

[34]This point was emphasised by Bernanke (2009) who refers to QE along the lines of credit than quantitative easing.

[35]It differs in structure from the TAF, TSLF, PDCF and AMLF, but shares some similarities with the CPFF.

[36]Collateral can be provided to the Fed; they do not have to repay the loan if the value of the collateral falls.

3.2.1.3 QE2

Financial market turmoil subsided toward the latter part of 2010, with asset prices rising and private sector balance sheets being bolstered (Edmonds et al., 2010). However, despite the magnitude of expansionary fiscal and monetary policy, unemployment remained persistently high and disinflation continued unabated (Yellen, 2014). As emphasised by policymakers, the stagnating economic situation warranted a second round of easing in November 2010, to improve economic performance and quell some deflationary concerns (Fawley and Neely, 2013).

The second round of quantitative easing was different from the first in that the Fed looked only to purchase $600 billion in long-term Treasury debt, with purchases occurring in monthly instalments of $75 billion. In other words, the central bank was following a quasi-debt management strategy, with the goal of working through the scarcity channel to influence long-term security yields (Borio and Disyatat, 2010). In particular, the Fed wanted to push up prices and thereby drive down yields on long-term Treasury bonds, which in theory, would work to increase inflation expectations (Yellen, 2014). In addition, policymakers committed to keeping the federal funds rate close to the ZLB, enacting a forward guidance strategy.

3.2.1.3.1 Operation Twist In September 2011 there were concerns that a double-dip recession was looming, with growth still slow and signs of distress in global financial markets. Amelioration called for another round of easing but, instead of further outright purchases of securities, the central bank experimented with maturity transformations similar to those of Operation Twist in 1961. On 21 September, in what was officially called the Maturity Extension Program and Reinvestment Policy, the Fed sold $400 billion in short-term securities with a matching purchase of long-term securities (Fawley and Neely, 2013). With this policy the central bank attempted to 'twist' the yield curve, by reducing long-term rates relative to short-term ones.

The implementation of this quasi-debt management strategy was different than before in that it took place without expansion of the monetary base, entailing only a change in composition of the assets on the balance sheet. In other words, the revived Operation Twist differs from QE2 in that liabilities (reserves) increased with the purchase of long-term assets during QE2, while there was no increase in liabilities in the MEP, but rather a change in the type of assets held by the central bank (Fawley and Neely, 2013). Operation Twist was extended in June 2012 with another $267 billion worth of long-term government securities purchased to "make broader financial conditions more accommodative"[37].

[37] Quoted from the Federal Reserve Press Release on the 20th of June 2012.

3.2.1.4 QE3

Policy efforts to reduce persistently high unemployment rates were considered partially successful. However, the labour market remained sluggish,[38] featuring a significant unemployment gap. The third round of quantitative easing was aimed directly at improving economic conditions, with a specific focus on reinvigorating the labour market (Fawley and Neely, 2013). Purchases of MBS were made on a monthly basis, to the tune of $40 billion. In addition, the central bank reinvested principal payments of MBS, which accounted for another $45 billion dollar monthly injection into long-term treasury securities. This translated into an increase in holdings amounting to $85 billion per month (Yellen, 2013). This initiative is similar to QE1 in the variety of assets purchased, but distinctly different with regard to the communication of assets purchased (Fischer, 2015a).

QE3 entailed a more open-ended structure, citing no total amount of assets that would be purchased, but rather a commitment to continue purchasing assets at regular intervals until labour market conditions improved. At first, the condition for exiting this commitment was vague, with the FOMC relaying a scenario in which there was "significant improvement" in labour market conditions (Yellen, 2015). At a later stage, it was announced that the pace at which purchases were to be conducted would be data dependent; in particular, they were looking toward conducting purchases until the unemployment rate went below a certain threshold (in this case it was 6.5%)[39].

3.2.1.4.1 Tapering On 22 May 2013, Ben Bernanke revealed that the pace of asset purchases might start slowing before the end of the year if labour market conditions continued to improve. It was projected that a reduction in the unemployment rate below the suggested threshold would possibly be achieved in 2014. Shortly after Bernanke's statement, financial markets reeled at the thought of a potential taper. Further distortions in economic conditions were felt outside the borders of the US, specifically in developing countries, with large capital outflows emanating from these countries[40].

Taking note of the strong adverse reaction to the tapering announcement, the Fed made it clear on 18 September 2013 that it did not have any immediate plans to reduce the asset purchase programs. This alleviated some of the pressure following the initial suggestion of winding down QE3, with emerging markets enjoying the greatest relief (Kumar and Barua, 2013). The eventual start of the taper took place on 18 December 2013, with purchases down from $85 to

[38] The housing market was also depressed during this period, but the focus of QE3 was on improvements in the labour market position.

[39] This target was announced at the FOMC.

[40] This is an issue I discuss in the concluding chapter of the thesis.

$75 billion dollars a month. At this time, the Federal Reserve Open Market Committee (FOMC) also announced that QE3 would be tapered at a suggested rate of $10 billion at each successive meeting, outlining a complete winding down of the purchasing program by October 2014.

3.2.1.5 Normalising Monetary Policy

Since the start of the financial crisis, the central bank accumulated a large portfolio of long-term securities[41], with the federal funds rate being close to the ZLB for more than six years (Yellen, 2015). At the start of 2015, with the US economy showing signs of recovery, questions as to the normalisation of monetary policy and a potential increase of the short-term policy rate came to the fore. As discussed previously, if policy is too accommodative for too long, it could create an environment where excessive risk-taking takes hold. Some interest rate rules that take both unemployment and output gaps into account had already necessitated increases in the policy rate. However, the reading of these rules depends on the definitions of historical inflation and natural rates of employment (Yellen, 2015). The experience of Japan has taught policymakers not to be too hasty in coming out from under the ZLB.

The "conditions for liftoff", as Stanley Fischer (2015b) puts it, are sufficient improvements in the labour market[42] and confidence in the fact that inflation will move to the 2% objective in the medium term. In December 2015 the Fed increased the federal funds rate by 25 basis points, which marked the first increase in the policy rate in a seven-year period where it was kept near the ZLB (Yellen, 2016). One of the newfound challenges faced by the central bank is conducting monetary policy with an elevated balance sheet. Owing to the size of the balance sheet[43], traditional repurchase agreements will fall by the wayside and normalised monetary policy will entail setting of the interest on excess reserves (a mechanism discussed in both Chapter 4 and 5).

In addition to the interest on excess reserves, the Fed will also be conducting overnight reverse repurchase agreements, with a wide range of eligible counterparties[44]. This overnight facility will create a soft floor on money market rates. These issues will be discussed in more detail in the last part of Chapter 4, where I consider the possible drawbacks of implementing balance sheet policies. In the next section I look at the policy response of the ECB to the financial crisis.

[41] Current assets are at $4.5 trillion, up from $900 billion before the crisis.
[42] To the point where full employment is reached, as stated by Yellen (2015).
[43] With more than $3 trillion in excess reserves.
[44] At this point it includes money market funds, depository institutions, broker dealers and government sponsored enterprises (Fischer, 2015a).

3.2.2 EU: European Central Bank

3.2.2.1 The European Banking System

In order to appreciate fully the policy response of the European Central Bank (ECB), it is necessary to set the stage as to the position of Euro area banks before the crisis, as their structure differs in significant ways from the US economy. Several systemic balance sheet vulnerabilities were present in the EU before the crisis. European banks have increasingly developed a reliance on wholesale funding, but not to the extent of the US (Pill and Reichlin, 2014). In the years leading up to the crisis, approximately 30% of external funding for firms originated from financial markets in the EU, while in the US this figure was closer to 70% (Trichet, 2009; Cour-Thimann and Winkler, 2012). Naturally, the development of other sources of external credit meant that the ratio of loans to traditional deposits started to decline (Giannone et al., 2012).

In addition to an increased dependence on external market-based funding, banks started to use newly developed financial instruments and processes. In particular, European banks started to use off-balance-sheet vehicles, securitisation and several structured financial products (Pill and Reichlin, 2014). Several European bank balance sheets were also contaminated with asset-backed securities that originated in the US, but fortunately exposure was limited. Despite all these concerns, the structure of the European economy was still largely bank-based (Cour-Thimann and Winkler, 2012). In fact, it was postulated by Padoa-Schioppa (2004), before the crisis, that the Eurosystem would be able to survive a run on secondary markets, as its funding originated mostly from primary markets.

Outside of the exposure to flighty assets, the EU had its own unique problems to deal with. Importantly, the cross-border exposure of banks to wholesale funding had increased significantly since the inception of the monetary union. Supervision at the national level meant that retail markets remained segmented, but cross-border funding markets became more active, with increased financial integration (Pill and Reichlin, 2014). In particular, larger economies with slow and steady growth found opportunities to finance the demand for credit in smaller developing nations (González-Páramo, 2011). Unfortunately, this meant that imbalances on the current and financial accounts of many Euro area countries were exacerbated; this was a large contributor to the sovereign debt crisis.

Successful financial integration resulted in a narrowing of spreads in the sovereign bond market[45], which would usually be indicative of a decrease in the market's pricing of sovereign

[45] At one point before the crisis the spreads were what Cour-Thimann and Winkler (2012) refer to as, "quasi nill" among the sovereigns of the Euro area.

risk (Ehrmann et al., 2010). However, it is thought that the compression of the spread could have been due to the involvement of the ECB, with their mandate providing an inherent guarantee against the failure of a sovereign entity (which further promoted risk-taking and moral hazard) (Pill and Reichlin, 2014). Taking this structure into consideration, I provide an overview of the traditional format of monetary policy implementation and the manner in which the central bank amended its approach to address mounting concerns.

3.2.2.2 Monetary Policy Implementation at the ECB

In contrast to the fixed-rate open market operations of the Fed, monetary policy at the ECB is usually conducted through refinancing operations in an auctioning process. In this setup the ECB sets a liquidity cap, and the lowest bids are accepted, which is referred to as the variable-rate tender procedure (Cour-Thimann and Winkler, 2012). In June 2000 the ECB switched from fixed- to variable-rate tenders, in response to overbidding in the fixed-rate system[46] (Catalão-Lopes, 2010).

In general, the ECB offers two types of collateralised lending options, differentiated by maturity. Main refinancing operations (MROs) are the primary mode of policy conduct; they have a maturity of one week and are auctioned weekly. More recently, the bank introduced the longer term refinancing operations (LTROs), which at first were presented with a maturity of three months; these are auctioned once a month (Vogel, 2016)[47]. In the months before the collapse of Lehman Brothers, the ECB tried to address building pressure by introducing reductions in the MRO interest rate[48]. It became evident that policy rate cuts were not going to provide the necessary stimulus in constrained credit markets, which prompted the ECB to implement several liquidity management measures[49]. These measures formed part of the first phase of the policy response of the ECB, namely the Enhanced Credit Support program, which is be discussed subsequently.

In terms of the ECB policy response to the crisis and the surrounding fallout, four phases are identified[50]. First, liquidity management operations started as early as 13 months before the collapse of Lehman Brothers, in September 2008. The demise of this institution heralded

[46]This system was not with full allotment.

[47]Practically, the ECB also uses fine-tuning operations (FTOs) with the objective of steering interest rates toward the policy rate target.

[48]They also varied the interest rate corridor, initially decreasing it from 200 basis points to 100 basis points.

[49]They correspond with the label of exceptional liquidity provision as classified in the typology of unconventional policies by Szczerbowicz (2015). Unconventional policies here fall under the banner of either exceptional liquidity provision or asset purchases. In the typology of Borio and Disyatat (2010), exceptional liquidity provision is classified under credit policy.

[50]These coincide somewhat with those identified in Cour-Thimann and Winkler (2012) and Pill and Reichlin (2014).

the start of the global financial crisis and heightened the intensity of management required, which involved several alterations and additions. This approach is referred to by Trichet (2009) as enhanced credit support (ECS). Second, an equally important event for the Euro area is the sovereign debt crisis that started in May 2010, specifically as a result of developments in the Greek economy. This phase also included the resurgence of the debt crisis, with several other member states experiencing similar difficulties to that of Greece, in June of 2011. Third, the current ECB president, Mario Draghi, famously stated that the ECB was committed to do "whatever it takes" to salvage the Euro. Finally, the last phase is considered the one in which quantitative easing measures were adopted, in January of 2015.

3.2.2.3 Phase 1: Enhanced Credit Support

Financial distress in the Eurozone following the Lehman Brothers episode was exhibited in the widening of several interest rate spreads, such as the Eurbor-OIS spread[51] (Fawley and Neely, 2013). The widening of spreads was indicative of the increased counterparty risk, emanating from the uncertainty with respect to the health of the balance sheets of financial institutions. The interbank market in the case of the ECB extends beyond several borders and therefore segmentation becomes an important issue. Counterparties in this setting may find it difficult to participate in the interbank market, based on the "perceived riskiness of their sovereign" (González-Páramo, 2011). Despite initial liquidity provisions, the volume of interbank lending remained lacklustre "because of mounting insolvency and liquidity risks exacerbated by asymmetric information" (Rodríguez and Carrasco, 2014).

In May 2009 the ECB formulated their actions with regard to liquidity management, in the form of the ECS program. The goal was to provide liquidity to the banking sector and remedy the lack of counterparty confidence. As mentioned before, the banking sector was becoming more reliant on wholesale funding. However, the ratio of loans to traditional deposits (leveraging) had not reached the level of the US, with the traditional banking sector still playing an important role in the extension of credit. Therefore, to address dysfunctional markets, the ECB opted to target the banking sector aggressively with the ECS program. According to Trichet (2009), "enhanced credit support constitutes the special and primarily bank-based measures that are being taken to enhance the flow of credit above and beyond what could be achieved through policy interest rate reductions alone".

[51] Spread between a secured (Eurbor) and unsecured (OIS) money market rate. Indicates the premium that agents are willing to pay for security; a safety premium.

3.2.2.3.1 Five cornerstones Jean-Claude Trichet, who was president of the ECB at the time, identified five policy cornerstones of the ECS program (Trichet, 2009). First, in early 2008 the ECB introduced the Fixed Rate Procedure with Full Allotment (FRFA) program. The FRFA gave commercial banks access to unlimited amounts of liquidity against eligible collateral at the main refinancing rate, provided they were financially sound (González-Páramo, 2011). This often-overlooked policy shift is considered by several ECB central bankers[52] to be the most significant liquidity management operation conducted to retain the health of the financial sector. Liquidity risk generated by elevated lending rates in interbank markets posed a threat to many financial institutions. Liquidity provision under this strategy aimed to facilitate interbank lending and, by extension, increase the availability of credit to households and firms (Falagiarda et al., 2015).

Lorenzo Bini Smaghi[53] refers to the FRFA as "endogenous credit easing", in that banks can meet all their liquidity needs, with peak demand before the crisis reaching €95 billion (Rodríguez and Carrasco, 2014). In this setup the ECB sets the MRO refinancing rate, and interbank market rates are variable (determined by supply and demand) (Catalão-Lopes, 2010). Fluctuations in the quantity demanded reflects market sentiment, with high liquidity demand indicative of the strain in interbank lending[54]. In addition to the mere provision of liquidity, this mechanism works by providing liquidity more cheaply than the market price; which in turn drives down money market rates (González-Páramo, 2011). Immediately following the collapse, banks began to overbid in terms of price of the MROs, in an attempt to secure liquidity. Overbidding pressure prompted the ECB to discontinue traditional refinancing operations of all maturities (MROs and LTROs) and replace them with fixed-rate tenders (Szczerbowicz, 2015). However, this resulted in severe overbidding on the amount of liquidity, as there was no associated penalty[55].

Second, in addition to the FRFA, supplementary LTROs with a six-month maturity were instituted before the crisis, with the first round met with a fourfold oversubscription of bids, and €442 billion was eventually supplied (Trichet, 2009; Darracq-Paries and De Santis, 2015). In June 2009 12-month LTROs were created to cater for commercial bank preferences for assets of longer maturities (Fawley and Neely, 2013)[56]. This can help address maturity mismatches where banks are looking for investments in longer-term bonds, but only finding funding in the shortest end of the market. It reduces the uncertainty involved in laying out investment strategies. Policy is designed with the expectation that banks will use long-term credit to fund

[52]Such as Trichet (2009) and González-Páramo (2011)

[53]Member of the Executive Board of the ECB from 2005 until 2011.

[54]Which would also show in interest rate spreads, with the spread between secure/unsecure assets widening.

[55]Importantly, some of the excess liquidity went into Eurozone debt securities, which exacerbated the problems presented in the debt crisis. This overbidding was also the reason why the ECB initially switched to variable rate tenders in 2000.

[56]The first auction closes with more than 1000 bidders, indicating increasing demand for LTROs

long-term asset investment, rather than supply short-term liquidity.

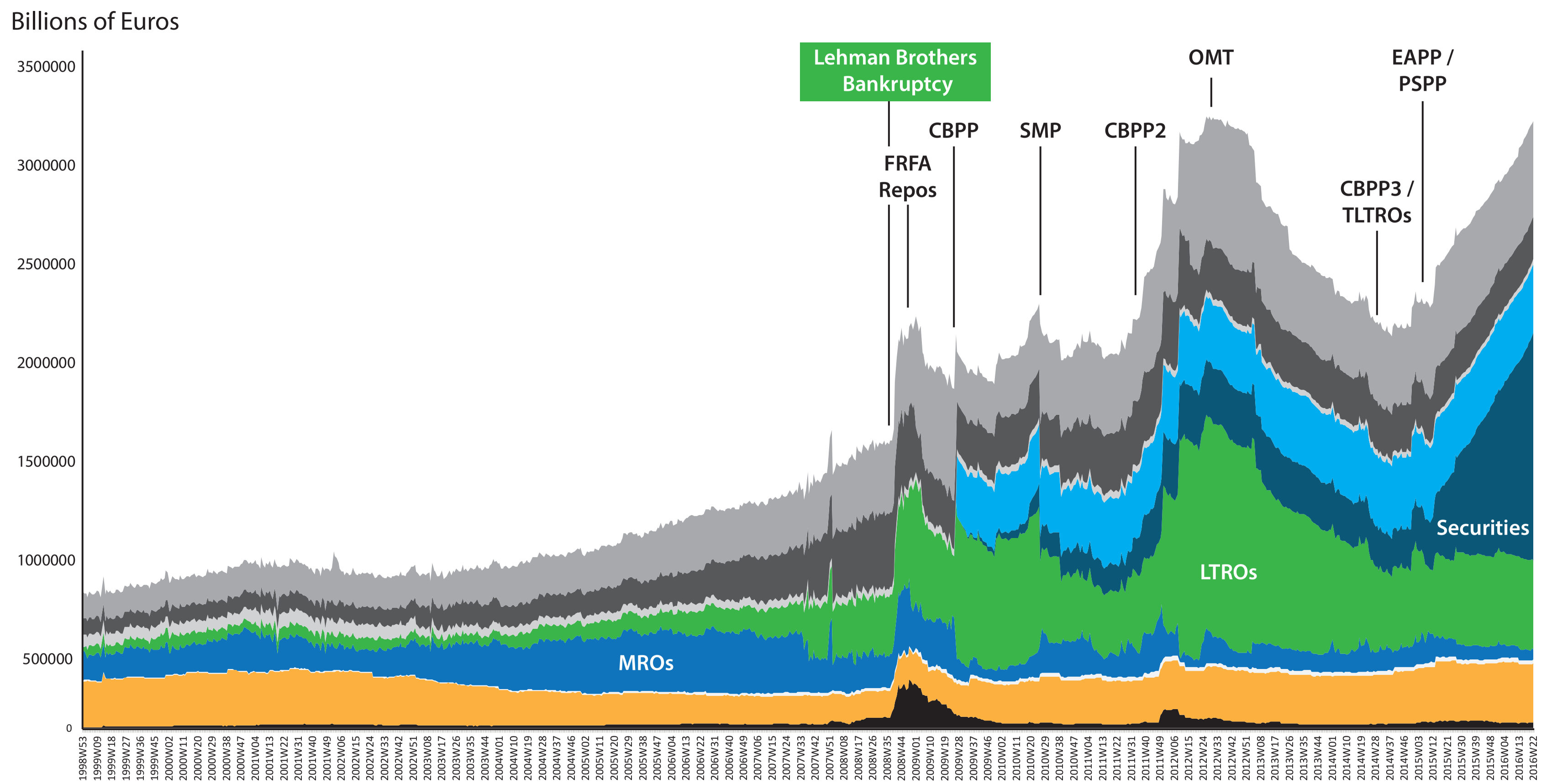
Third, the list of assets eligible for collateral was extended by lowering the ratings threshold. Allowing a wider range of collateral affords banks the opportunity to refinance a larger portion of their balance sheet [57] (Cour-Thimann and Winkler, 2012). Previously illiquid assets can now be transformed, potentially preventing liquidity shortages in secondary markets. In addition to the type of collateral, there is an increase in the number of counterparties that can take part in the refinancing operations (Trichet, 2009). Fourth, international swap lines allow financial institutions to address foreign currency funding (Falagiarda et al., 2015). Cooperation among central banks is key in this respect.

Finally, the Covered Bond Purchase Program (CBPP) was created, with these purchases being the ECB's first foray into asset purchases (Falagiarda et al., 2015). The first round of covered bond purchases, called CBPP1, amounted to €60 billion and took place between July 2009 and July 2010. A supplementary round of purchases, CBPP2, took place between November 2011 and October 2012. However, the number purchased was almost negligible during this round, amounting to less than €17 billion in total (González-Páramo, 2011). Trichet (2009) states clearly that covered bond purchases were not considered quantitative easing, as they would not result in an expansion of the ECB's balance sheet. He believed that there would be an "automatic sterilisation", with a simultaneous reduction in purchases of LTROs. However, according to the data, the balance sheet of the bank did not remain unaltered, and expanded by 30% in the most acute phase of the crisis, which indicates that sterilisation was not complete (Rodríguez and Carrasco, 2014).

In comparison with the Fed, the ECB was a latecomer to the asset purchase party, as QE1 was already well under way during this time. This was because the US had to respond more swiftly, as financial institutions were exposed directly to mortgage markets: they had greater flexibility in the economy[58], and the funding structure revolved around money markets for funding, as opposed to the more traditional banking sector (Trichet, 2009). The reason for implementing CBPP hinged on two factors. First, it allowed the opportunity to address maturity mismatches between assets and liabilities (Trichet, 2009). Second, covered bonds markets are important and these securities are different from most asset-backed securities in several ways. They are a form of recourse debt, whereby the bond holders can collect from the issuer of the bond and are entitled to the underlying collateral pool. In addition, underlying collateral is held on the consolidated balance sheet of the bond issuer, similar in spirit to originate-and-hold mortgages in the US (Fawley and Neely, 2013).

[57] In July 2009 eligible securities totalled €12.2 trillion.
[58] The labour market in particular is more responsive in the US.

Figure 3.4: Assets on the balance sheet of the ECB



Source: European Central Bank

3.2.2.4 Phase 2: Sovereign Debt Crisis

In October 2009 it was revealed that Greece had been misreporting statistics with respect to their debt. This deception meant that interbank lending to Greek banks dried up, which raised concerns over Greek solvency (Pill and Reichlin, 2014). Uncertainty surrounding the fiscal position of the country translated into a sharp decline in the demand for Greek government bonds and, as a result, sovereign spreads widened against several countries in the Eurosystem. The possibility of sovereign debt default was on the cards as the economy struggled to find funding to meet debt payments. This was problematic for the ECB, as default would have meant an exit from the Euro area, which in turn could have spread to other countries in a similar fiscal position, such as Ireland, Portugal, Spain and Italy (Cour-Thimann and Winkler, 2012). In addition, the portfolios of several countries, such as Germany and France, were heavily exposed to Greek debt.

This sovereign debt crisis spurred a fire-sale on several Euro area government bonds. In order to contain the crisis and avoid financial contagion, several emergency facilities were created. The adjustment program consisted of bilateral loans from Eurosystem countries (European Commission) and support from the International Monetary Fund (IMF) [59] (Pill and Reichlin, 2014). Despite these attempts to boost sovereign solvency, interest in Greek debt remained stale. In the face of mounting pressure, the ECB was forced to act[60] and provided ancillary support through the creation of the Securities Markets Programme (SMP), injecting liquidity into dysfunctional markets through the purchase of sovereign bonds in secondary markets[61] (Szczerbowicz, 2015). SMP is considered a sterilised purchase program[62] and did not expand the balance sheet of the bank, which classifies it as credit policy (Fawley and Neely, 2013). Communication under this purchase program was limited, with no details on the bonds purchased, counterparties or length of the scheme made available to the public (Szczerbowicz, 2015).

The ECB justified the SMP on the grounds that it would restore the functioning of the monetary policy transmission mechanism and relieve tension in sovereign debt markets (Falagiarda et al., 2015). In practice, they were preventing a Greek default, by aggressively removing debt from the market. More importantly, the ECB brokered debt restructuring for private debt holders (Pill and Reichlin, 2014). However, this was a symptomatic treatment and public finance remained a topic for concern throughout the Eurosystem. Contagion had spread to Ireland in 2010 and

[59] This was later formalised in the form of the European Financial Stability Facility (EFSF) and European Stability Mechanism (ESM).

[60] The European Commision, IMF and ECB form part of what is referred to as the “troika”, three institutions that aided in preventing default in the Eurozone.

[61] The ECB is prohibited from purchasing sovereign debt in primary markets through Treaty provisions.

[62] Purchases were sterilised through ‘Fixed Term Deposits’ (Rodríguez and Carrasco, 2014).

Portugal in 2011, which meant that the ECB had to step in as a lender-of-last-resort for these sovereigns. Within the SMP, the ECB spent a total of €219.5 billion on Euro zone government bonds, but this was not spent according to paid-in capital; rather, it focused only on vulnerable countries, and thereby, spread the risk (Szczerbowicz, 2015). Shortly after the effective bailout of Greece, Ireland and Portugal, there was a discussion as to the fiscal health of the Italian and Spanish economies. The ECB had enough funds at its disposal to assist some of the smaller member states, but the default of large countries like Italy and Spain would have been far beyond the reach of the monetary authority.

3.2.2.5 Phase 3: 'Whatever it Takes'

At the start of the financial crisis, the ECB highlighted the fact that nonstandard policies were temporary, only to be used as long as they were considered necessary. However, by late 2011 fears of a sovereign debt crisis were reignited, as the solvency of Italy and Spain was considered. Sovereign bond prices plummeted and significantly altered the balance sheet positions of several banks in the Euro area (Cour-Thimann and Winkler, 2012). The widening of sovereign yield spreads reflected the fact that market participants believed economies could potentially be leaving the monetary union. In order to preserve the union, unconventional policies became a more permanent fixture in the ECB's policy toolkit (Falagiarda et al., 2015). Mario Draghi's (current president of the ECB) first response was to reinstate the SMP, which had been dormant since the bailout of Portugal in early 2011(Pill and Reichlin, 2014). In addition, he announced the creation of 36-month LTROs, as well as the second round of covered bond purchases (as mentioned before) (Cour-Thimann and Winkler, 2012). The LTROs were specifically aimed at sovereign debt, providing liquidity over the medium term.

Talks arose about the exit of certain countries from the monetary union and the ensuing reversibility of the Euro. In response, in July 2012, Draghi famously stated that the central bank would do "whatever it takes to save the Euro". The ECB followed through on the commitment with the announcement of the Outright Money Transactions program in September 2012 (Pill and Reichlin, 2014). Under this scheme, which officially replaced the SMP, the ECB agreed to intervene in secondary sovereign bond markets if this became necessary.

The OMT differed from the SMP in several ways. First, an important improvement on the SMP was that purchases of sovereign debt in the secondary market[63] would be conditional, with the ECB buying debt only once countries had accepted and met the conditions for structural and fiscal reform set by the European Commission, ECB and IMF (often referred to as the "Troika")

[63] The ECB is prohibited from purchasing debt directly from governments, and needs to purchase debt from investors.

(Fawley and Neely, 2013). Second, the ECB was more transparent about communicating its purchase strategies and there would be no “ex ante quantitative limits” on the purchases once conditions had been met (Cour-Thimann and Winkler, 2012). Third, the focus of the OMT was on shorter-term bonds, whereas the SMP focused on longer-term securities (Szczerbowicz, 2015).

Similar to the function of the SMP, the OMT was established to improve the functioning of the monetary policy transmission mechanism. The OMT is considered to be credit policy, with purchases sterilised similarly to those of the SMP. Interestingly, the OMT has, to date, not been used. However, it was considered successful in that it acted as an insurance mechanism against redenomination risk, signalling the commitment of the bank to prevent the exit of struggling member states (Pill and Reichlin, 2014). In fact, the mere announcement of the OMT reduced risk premia and brought sovereign spreads closer to one another (Szczerbowicz, 2015). Focusing more on communication with the general public seems to be part of a new strategy employed by the ECB.

3.2.2.6 Phase 4: A New Framework

Deflationary pressure became of particular concern with the steady decline of inflation since the start of 2012. The ECB, under the guidance of Mario Draghi, developed a multifaceted strategy to boost economic growth in what can be considered a new framework[64]. This framework is similar to that implemented in other central banks and combines forward guidance with credit and quantitative easing. Forward guidance, which forms an important part of this new framework, made its first appearance in July 2013, when the ECB made it clear that rates were going to remain low for an extended period of time (Falagiarda et al., 2015). By May 2014 the deposit rate, the lower bound on the policy rate, had dipped below the ZLB, and interbank rates followed suit. However, even negative rates failed to reignite interbank activity and spur economic growth (Valiante, 2015). In response, the ECB unveiled its credit easing package in June 2014, which was mostly an extension of measures implemented in the ECS program. The package consisted of targeted LTROs, an Asset Backed Security Purchase Program (ABSPP) and another round of covered bond purchases, CBPP3 (Falagiarda et al., 2015).

Targeted LTROs are a new loan facility that is intended to encourage banks to extend credit to the private sector by reducing financing costs (Blot et al., 2015). These 48-month TLTROs are supposed to provide banks access to a source of low-interest-rate funding for the following four years. The ECB hoped that these would entice banks to lend to the real economy. They

[64]Can be considered new in the sense that it moved outside its single mandate to focus on price stability. Now considers economic growth as well.

are specifically aimed at small to medium-sized nonfinancial firms (Szczerbowicz, 2015). They differ from previous LTROs in that the amount a bank can acquire is provisioned on the amount of loans extended to the nonfinancial private sector in the Euro area (Blot et al., 2015). However, these TLTROs did not have an immediate impact on the economy, which provided an incentive for the ECB to enact a more rapid-acting mechanism, namely a private asset purchase program.

ABS purchases and CBPP3 were meant to supplement the TLRTOs. They were meant as a direct intervention in secondary bond markets, purchasing the securities of European firms and residential real estate loans to affect long-term bond yields. At this point the asset purchases were still sterilised and limited to private sector debt. However, in 2015 the central bank announced an extension of the program, called the Extended Asset Purchase Programme (EAPP) that would signal the movement to quantitative easing. The ECB claimed that it was merely expanding an existing program of asset purchases, but under the EAPP, unsterilised purchases were added, moving from the passive management of liquidity demand to a more active intervention (Breuss, 2016).

In March 2015 the ECB announced, as part of the EAPP, the Public Sector Purchase Programme (PSPP), the first instance of QE in the Euro area. This program diverged from previous attempts in two distinct ways. First, it would start purchasing bonds issued by "Euro area central governments, agencies and the European institutions", which meant intervention in primary markets for sovereign debt (Falagiarda et al., 2015). Second, the scale of the program was unprecedented, with liquidity provided by the ECB under the EAPP amounting to €50 billion a month[65], with a conditional commitment to keep it in place until inflation met the mandated medium-term objective (around 2%) (Breuss, 2016). This was estimated to be at the end of March 2017, with a total of €1500 billion bought in total. This program was met with significant resistance, as it was felt that it contradicts the conventions of the EU Treaty, blurring the line between fiscal and monetary policy. PSPPs were distributed according to paid-in capital, to avoid them being just a redistribution of risk between member states (Krampf, 2016). The next section looks at at how balance sheet policies were implemented in the United Kingdom.

3.2.3 UK: Bank of England

Balance sheet policy implemented in the UK is not significantly different from that of the US. Policy comprised the creation of several liquidity insurance facilities and successive rounds of quantitative easing. The timeline of implementation of rescue efforts by the Bank of England (BoE) is also relatively in line with that of the Fed's actions. Before introducing the measures used during the financial crisis, it is worth looking at how the BoE conducts monetary policy

[65]Of purchases, 88% are sovereign bonds, and 12% are the bonds of supra-national institutions.

under normal circumstances, as it settled on a new monetary framework in the build-up to the crisis.

3.2.3.1 Sterling Monetary Framework

The BoE revised its operational framework for monetary policy in 2006. Management of the balance sheet was now coordinated under the Sterling Monetary Framework (SMF). This new system revolves around the use of reserves, standing facilities and open market operations. It has all the qualities of a reserve regime[66] whereby banks decide on how many reserves to hold, which means liquidity issue is demand determined (Cross et al., 2010).

In contrast with the single mandate of several other central banks in developed economies, the BoE has an explicit dual mandate, with two objectives specified under its new operating framework (Joyce et al., 2012a). The first of these is the pursuit and maintenance of the CPI inflation target in the medium run, which is set at 2%. In normal times this is achieved through setting the policy rate. Second, the BoE is tasked with reducing the cost of disruptions to the functioning of commercial banks, which is done through the provision of liquidity insurance (Cross et al., 2010). Taking into consideration the objectives of this framework, I consider the actions taken by the BoE to abide by its mandate.

3.2.3.2 Initial Response

The spill-over from the crisis significantly affected the UK economy, with real activity slowing and financial market mechanisms being broken. However, the pressure from failing financial markets was felt in the UK even before the Lehman Brothers bankruptcy. Northern Rock, a British bank, asked the BoE for liquidity support in September 2007. However, in February 2008 Northern Rock was nationalised in order to save it from a run on the bank[67]. At the height of the crisis, several large UK banks, such as Halifax Bank of Scotland (HBOS) and Royal Bank of Scotland (RBS), were found to be highly leveraged and dependent on wholesale funding. Large-scale intervention was required to save these struggling institutions, with HBOS getting acquired by Lloyds TSB with the aid of public capital. Lending conditions deteriorated, with solvency concerns about these large financial firms.

As a result of the evidence on policy implementation from the Japanese experience, the BoE reacted quickly to provide monetary policy support (Joyce and Woods, 2011). As a first line

[66] These monetary policy regime characteristics are defined in the second chapter of the thesis

[67] This is a situation under which depositors wish to withdraw their deposits. It could result from coordination failure, as in the Diamond and Dybvig result.

of defence, interest rates were radically reduced from 5.75% in July 2007 to 0.5% in March 2009[68], as seen in Figure 3.2. In addition to interest rates cuts, several liquidity facilities were created and amended during this time. Similar to the liquidity facilities in other countries, those of the BoE were targeted at specific markets. In December 2007 the BoE announced a change to its existing three-month repo open market operations[69], with an extension on the range of assets viable as collateral to include AAA-rated MBS and covered bonds (Cross et al., 2010). These newly formed longer-term open market operations (OMOs) were referred to as extended collateral long-term repos (ELTRs) and were initially offered at monthly auctions of £10 billion.

The BoE also formed two liquidity insurance schemes to provide liquidity to the banking sector, namely the Special Liquidity Scheme (SLS) and the Discount Window Facility (DWF). The SLS and DWF are off-balance-sheet collateral-swap initiatives that allow banks to swap high-quality illiquid securities (such as MBS) for UK treasury bills (Cross et al., 2010). Under these programmes the banks pay a fee according to the quality of the asset offered for the swap arrangement, in order to prevent opportunistic behaviour. Finally, as a result of tension arising in US markets, the BoE engaged in temporary foreign currency swap lines with the Fed, to meet dollar-denominated obligations.

3.2.3.3 Asset Purchase Facility

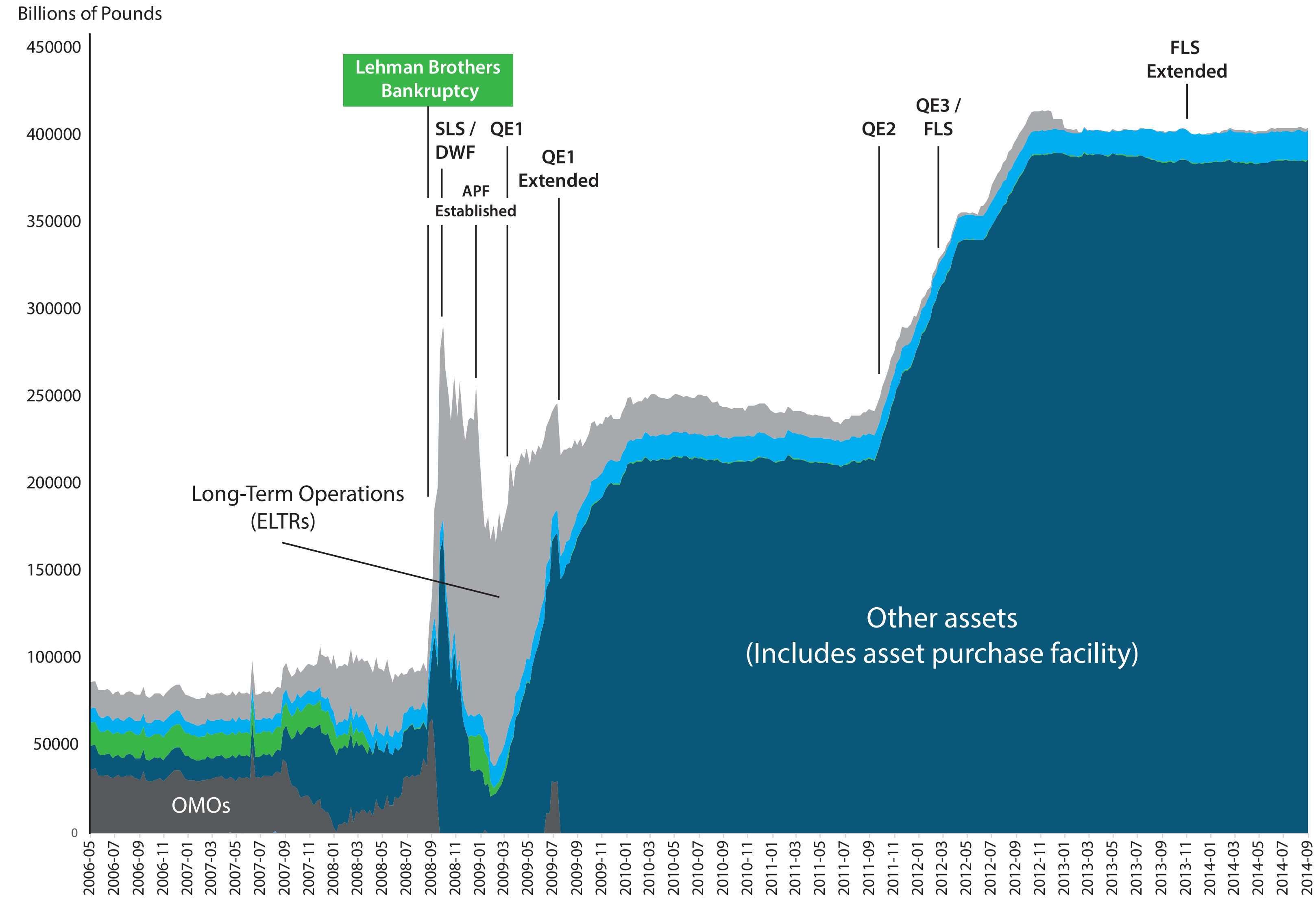
In January 2009 Her Majesty's (HM) Treasury announced the creation of the Asset Purchase Facility (APF). Operations were conducted through a limited company called the Asset Purchase Facility Fund (APFF), a legal entity that is fully under the control of the BoE (Joyce et al., 2012a). HM Treasury conducted both credit and quantitative easing through this fund. At first, the BoE was authorised to conduct purchases of up to £50 billion worth of high-quality private sector assets; however, private asset holdings reached a peak of only £3 billion. This credit easing was meant to increase the availability of corporate credit. Easing was justified on the grounds of the lender-of-last-resort function of the bank, as espoused by Bagehot. Purchases were sterilised[70] through sales of short-term gilts, which means this is a pure credit policy (Fawley and Neely, 2013). These liquidity provisions are considered similar to those conducted by the Fed under their CPFF program.

[68]Which is effectively the ZLB for the bank

[69]The BoE introduce longer-term repos (3, 6, 9 and 12 month) in 2006; similar in operation to the LTROs of the ECB

[70]In other words, for every asset purchased, short-term gilts were sold to offset the increase in the size of the balance sheet.

Figure 3.5: Assets on the balance sheet of the BoE



Source: Bank of England

3.2.3.4 QE1

Despite aggressive easing the BoE felt that it would not be able to meet its mandated medium-term goal of 2% CPI inflation. The second operation under the APF was performed in March 2009 with the bank's explicit quantitative easing program to help achieve their policy objective. More specifically, the bank adopted a combination of bank reserves policy and quasi-debt management policy, increasing the size of the balance sheet through the purchase of £200 billion of assets[71] in the first round of easing. UK government bonds (gilts) of varying maturity (mostly from 5 to 25 years) formed the majority of the purchases (Steeley, 2015).

Quantitative easing as implemented by the BoE was intended as a liquidity injection to induce spending in the economy, in order to generate an inflationary effect (Joyce and Woods, 2011). Purchases[72] were financed by reserves, which translated into a fourfold increase in the monetary base from March to November 2009 (Cross et al., 2010). The backing by central bank money meant that this now was considered part of monetary policy. Since reserves in excess of voluntary targets were being issued, and the policy rate was near the ZLB, the SMP ceased its normal functioning. Policy was being conducted based on the size of the program, similar to that of Japan under QEP. Purchases continued until February 2010, when the MPC decided not to further increase the size of the balance sheet (Steeley, 2015).

At the same time as the first round of QE, the BoE implemented several changes to their ELTRs, with an increase in the amount available for auction, as well as inclusion of securities backed by mortgage assets and corporate bonds. These credit easing operations reached a peak of £180 billion in January 2009 (Cross et al., 2010).

3.2.3.5 QE2/3

Two years after the first round of QE the second round was started. In October 2011, the BoE conducted a further £75 billion worth of purchases. It was considered a necessary measure to keep inflation in line with its mandate. This increase occurred parallel to fears of a sovereign debt crisis in the Euro area. By May 2012 the second round came to an end, with a total of £125 billion purchased; bringing the total of QE to £325 billion (Steeley, 2015). The third round of QE quickly followed the second, due to a contraction of GDP between the last quarter of 2011 and the first quarter of 2012. Purchases under QE totalled £375 billion by July 2012 (Fawley and Neely, 2013).

In order to improve lending conditions the BoE and HM Treasury constructed the Funds

[71] Initially set at £75 billion, but later expanded.
[72] Loans to the fund.

for Lending Scheme (FLS). This scheme shares many similarities with the TLTRO program implemented by the ECB, and is thought to be the inspiration for that policy initiative. One of the differences between the FLS and TLTROs is that the BoE is able to coordinate its efforts with the Treasury in order to avoid significant losses, whereas the ECB has no single centralised Treasury (Steeley, 2015). Next, I look at the most recent monetary policy developments.

3.2.3.6 Current Policy Stance

British monetary authorities have not had reason to implement large-scale changes to their balance sheet since QE3. Data from the first quarter of 2016 puts inflation at 0.5%, which is not close enough to the 2% target. However, the price level is expected to increase over the next year, as uncharacteristically low food and energy prices start to unwind. Economic growth has been positive, but modest. Forecasts by the BoE predict a slowdown toward the end of the year, in response to mounting pressure from the recent EU referendum result (Bank of England, 2016). In light of this evidence, the members of the MPC (May 2016) have voted to keep interest rates unchanged at 0.5% and the QE purchase limit at £375 billion (Emerson, 2016).

3.2.4 Japan: Bank of Japan

We have already covered the pre-crisis history of the BoJ's balance sheet policy. This section looks at the policy approach of the BoJ in the last decade, namely 2007 to 2016. The Japanese economy had just started to recover before the start of the crisis, but fortunately some of the policy tools had been tested before, so policymakers had some notion of how to approach macroeconomic shocks.

3.2.4.1 Japanese Banking System

The Japanese economy showed signs of recovery following its slump in the early part of the new millennium. In response, the BoJ started to unwind some of its unconventional measures, with quantitative easing coming to an end in 2006 (Kuttner, 2014). However, the financial crisis of 2008 resulted in a large negative shock, slowing economic growth significantly (Takahashi, 2013). Interestingly, the response of the BoJ in terms of financial markets was modest compared with other central banks, with unconventional policy not being adopted at first[73]. The primary reason is that Japanese banks and financial firms were not heavily invested in US mortgages

[73] In fact, the central bank has been criticised for the fact that it did not adopt aggressive unconventional measures in response to the unfolding of the crisis.

or structured financial products, such as credit default swaps. In other words, they did not have toxic assets on their balance sheets. This was due, in part, to reform in the banking sector following the banking crisis of the 1990s (Vollmer and Bebenroth, 2012). Japanese banks were focused on traditional banking activities, instead of the dissemination of securitised financial products. In addition, liabilities were mostly financed though the deposit base, with only 10% of financing derived from wholesale markets (Vollmer and Bebenroth, 2012).

Spreads on unsecured interbank markets remained relatively stable in the wake of the fall of Lehman Brothers, especially in comparison with other countries. The Tokyo interbank market rate (TIBOR), for example, showed little volatility. Transmission of the crisis was primarily through international capital movements, with the position on the capital, current and financial accounts deteriorating during this period (Vollmer and Bebenroth, 2012). This indicates that the crisis affected the economy through decreased exports, showing the reduced global demand and appreciation of the yen[74], rather than contagion in the financial markets (Takahashi, 2013). Capital outflows translated into a sharp decrease in the Nikkei stock index, translating into a decrease in the asset values of Japanese banks, which hold a substantial portion of their high-quality capital in stocks (Vollmer and Bebenroth, 2012). Despite the limited impact on the Japanese banking system, the economy experienced a sharp decline in growth, registering one of the greatest falls in GDP among OECD countries, as seen in Figure 3.1.

3.2.4.2 Initial Policy Response

The BoJ and the Financial Services Agency (FSA) started to react to the movements in the financial markets in September of 2008. In line with the path of other central banks, the BoJ implemented reductions to the prevailing policy rate in order to stimulate activity. In addition to the rate cuts, several measures were implemented to prevent further financial market distress. First, the BoJ agreed to swap lines with the Fed[75], in order to satisfy the increasing liquidity demand for US Dollars (Vollmer and Bebenroth, 2012). Second, in October 2008 the BoJ suspended the "sale of stocks purchased from financial institutions on the stock exchange"[76]. The motive for the suspension was to create space to monitor market developments. Third, changes were made to the securities lending facility. Usually, this facility allows repurchase agreements on JGBs, but in October 2008 the list of eligible collateral for repurchase operations was increased[77]. This also heralded the return to JGB purchases, which last occurred in 2002

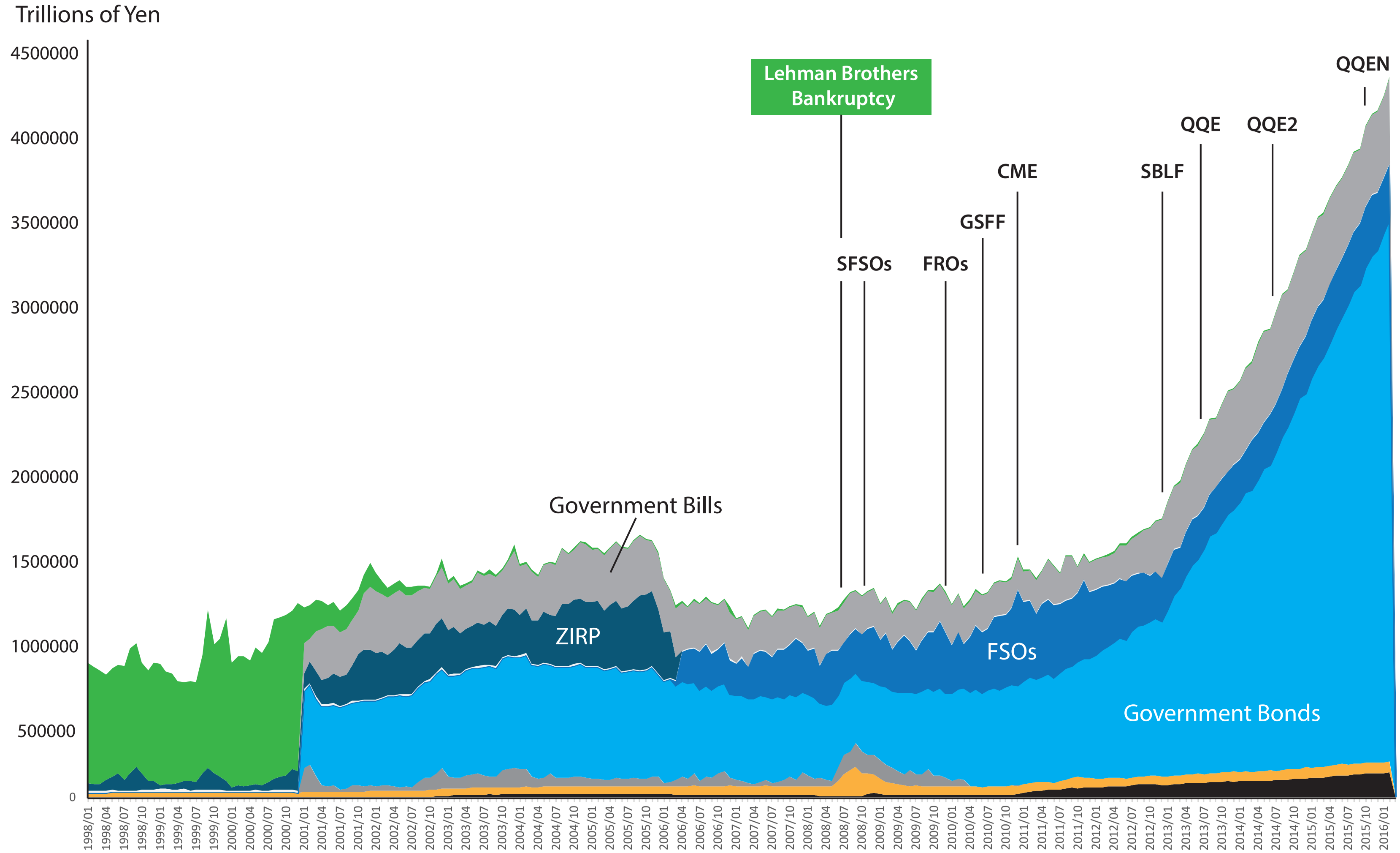
[74]Appreciation of the yen occurred because the monetary base in Europe and the US was increasing at a faster rate than that of Japan. In addition, the yen was thought to be a less risky currency, as can be seen by looking at volatility indices, which meant a further appreciation in the currency (Takahashi, 2013).

[75]Fixed-rate auctions were conducted, with full allotment.

[76]Taken from a statement released by the BoJ on the 14th of October 2008.

[77]The list now included floating rate JGBs, inflation-indexed JGBs and longer term 30 year JGBs.

Figure 3.6: Assets on the balance sheet of the BoJ



Source: Bank of Japan

(Fawley and Neely, 2013).

Fourth, the BoJ showed interest in facilitating corporate financing, which was supported by the creation of a new credit facility called the "Special Funds-Supplying Operations to Facilitate Corporate Financing", which here will be called the SFSOs. Institutions are allowed unlimited 3-month loans at the uncollateralised call rate using this facility, which is similar to the FRFA of the ECB (Vollmer and Bebenroth, 2012). The facility involved an expansion of the balance sheet of the bank and constituted quantitative easing (Fawley and Neely, 2013). In addition to the loan provision of this facility, the BoJ announced temporary purchases of commercial paper and corporate bonds, a form of credit easing. The downside of these purchases was the exposure to credit risk. The initial response of the BoJ was a combination of the credit easing imposed by the US and the elastic supply of loans applied by the ECB. In general, the Japanese and ECB focus appeared to be more on the banking sector, as opposed to the bond market focus of the US (Fawley and Neely, 2013).

By the end of 2008 the BoJ started to use its newly established 'complementary deposit facility', which provided interest on excess reserves[78] at a fixed rate, similar to the deposit facilities found in the Eurozone since 1999, and introduced in the US in 2008. This facility creates a floor on the uncollateralised call rate and pays interest on reserves held at the central bank. Toward the end of 2009 and the start of 2010 the BoJ decided to retire some of its temporary stability initiatives and replaced SFSOs with fixed rate operations (FROs) (Vollmer and Bebenroth, 2012). The newly introduced policy differed in that loans were not provided in an unlimited amount, with an initial amount of ¥10 trillion in 3-month maturities being allocated[79] (Fawley and Neely, 2013). In addition, under FROs a wider range of eligible collateral was accepted.

In April 2010, with the economy still experiencing slow economic growth, the BoJ proposed an initiative to boost growth through the provision of funds to financial institutions. By June 2010 the final details of the Growth Supporting Funding Facility (GSFF) were presented. Under this program eligible institutions were to submit proposals for one-year loans, with a possible extension to four years (Ueda, 2013). The quantity of loans under this framework was limited to ¥3 trillion. This program was extended in June 2011, with ¥500 billion worth of credit being made available. Inflation persisted close to zero per cent, and in September 2012 the BoJ increased the credit available from ¥3.5 to ¥5.5 trillion (Shirakawa, 2013).

[78]Interest rate was 0.1% in December 2008.
[79]This was later extended to ¥20 trillion worth of 3-month maturity loans and ¥10 trillion of 6-month maturities.

3.2.4.3 Comprehensive Monetary Easing

The initial efforts of the BoJ were quite mild and, as a result, in October 2010 the Japanese economy was still struggling to recover from the financial crisis. In order to remain transparent regarding its policy approach, the BoJ announced a more aggressive three-pronged comprehensive monetary easing program (Kuttner, 2014). This program marked the first attempt of the BoJ at large-scale usage of its balance sheet to rectify market conditions. First, it entailed lowering of the uncollateralised overnight call rate, such that it was back to the ZLB (Vollmer and Bebenroth, 2012). Second, clarification was provided for the conditions under which the bank would exit its ZIRP program. Third, it involved the introduction of the Asset Purchase Program (APP).

The APP consists of both credit and quasi-debt management policies, with private and public assets purchased (Kuttner, 2014). However, the focus was primarily on private sector securities[80], in order to reduce the spread between private and sovereign debt yields (Takahashi, 2013). With this program, the bank focused on reducing risk instead of term premia, similar in style to QE1 in the US. In the period from October 2011 to December 2012, additional purchases were made under the program, this time with more of a focus on the purchases of long-term government bonds. The problem with the APP was that it was quite small compared with the equivalents other countries. This seemed to indicate a lack of commitment on the side of the BoJ to implement an aggressive easing program (Kuttner, 2014).

As witnessed by the data on GDP in 2012, it seemed that the measures implemented by the BoJ were somewhat successful in promoting growth. However, the third quarter of 2012 was met by a contraction in growth, which prompted further policy action. Purchases under the APP were once again attempted, with ¥11 trillion worth of public and private assets purchased. In addition, a new framework was created to further promote lending. This new facility is called the Stimulating Bank Lending Facility (SBLF). In December 2012 Shinzo Abe became Prime Minister and announced an economic stimulus package in response to poor growth; this approach is often referred to as 'Abenomics' (Haidar and Hoshi, 2015). Three arrows are stipulated under this policy framework. The arrows of this package are flexible fiscal policy, bold monetary policy and structural reform. This plan gave rise to a shift in the thinking on monetary policy implementation (Fukuda, 2015).

[80] Such as commercial paper (CP), asset-backed commercial paper (ABCP), corporate bonds, exchange-traded funds (ETFs) and Japan real estate investment trusts (J-REITs) (Kuttner, 2014).

3.2.4.4 Quantitative and Qualitative Monetary Easing

In March 2013 the BoJ appointed a new Governor, Haruhiko Kuroda, who was sympathetic to the goals of the incumbent government and critical of the passive approach followed by the BoJ in the past (Haidar and Hoshi, 2015). Similarly to Mario Draghi, the new central bank Governor indicated his resolve in ending chronic deflation and spurring economic growth (Takahashi, 2013). A new, more radical set of easing measures was suggested to replace the CME program. In April 2013 the BoJ introduced the Quantitative and Qualitative Monetary Easing (QQE) program. It entails some strong commitments on the part of the BoJ, with Prime Minister Shinzo Abe referring to the shift in monetary policy as a regime change (Kuttner, 2014). First, the bank announced an explicit inflation target of 2%, with the idea of reaching this within two years. This is aimed at changing the public's deflationary mindset (Takahashi, 2013). Second, it announced quantitative easing in the form of open-ended expansion of the monetary base to aid in achieving the stated inflation target. Initially, a total of about ¥60-70 trillion per year was set; this was to replace the APP (Haidar and Hoshi, 2015). This expansionary policy commitment also generates the expectation of a higher rate of inflation.

Third, as a qualitative measure, the bank would conduct purchases of longer-term securities, in an attempt to increase the duration of bonds held on the banks portfolio (Kuttner, 2014). This marked the first time that the BoJ used credit easing to lower long-term rates. The balance sheet of the bank has grown significantly since the adoption of QQE, with most of the purchases coming from long-term JGBs. Purchases under the QQE program were increased to ¥80 trillion annually in October 2014, with the goal of increasing inflation more rapidly; this amendment is often referred to as QQE2. Under these expansions, the balance sheet of the bank has almost doubled in size (De Michelis and Iacoviello, 2016).

3.2.4.5 Negative Interest Rates

In January 2016, amid declining oil prices and depressed growth of emerging market economies, the BoJ announced that in order to meet its price stability target it was going to make an amendment to the QQE program so as to include negative nominal interest rates (De Michelis and Iacoviello, 2016). Adopting negative rates is not entirely new, and has been used before by central banks in Europe, Switzerland, Denmark and Sweden (Bech and Malkhozov, 2016). QQE with negative interest rates (QQEN) operates along three dimensions. Under this designation there are three tiers to the policy rate, with a positive, zero and negative rate applied to different portions on the current accounts of the financial institutions that interact with the BoJ. A positive rate is applied to existing balances with the BoJ, while the zero rate is applied to required asset holdings (De Michelis and Iacoviello, 2016). The negative interest rate is then applied to the balance of the current account in excess of the previously mentioned accounts. Thus far, the NIRP has been met with criticism and a disappointing response from financial markets, with an increase in the deflationary mindset.

3.3 Chapter Conclusion

This chapter framed the narrative of events surrounding the financial crisis and the policy response of key central banks to the global collapse. My approach was chronological, as it agrees with the development, razing and rebuilding phases associated with the crisis. The buildup of financial imbalances in the US as a result of 'ultra-loose' monetary policy, formation of a housing price bubble, deregulation of financial markets, growth in securitisation and an increasing reliance on shadow banking activities for credit provision, culminated into a perfect storm. The housing market collapse triggered a large-scale macroeconomic response that quickly spread beyond US borders. This chapter not only recounted these events, but considered the attempts to rebuild once the initial shock receded. The reactions by central banks were mixed and largely based on the exposure to the US financial markets. In the case of the United States the response was swift and of great consequence, while other countries were afforded the opportunity to be more measured in their attempts. The next chapter looks to evaluate whether policy responses were correct, with empirical evidence provided as to their success.

Chapter 4

Balance Sheet Policies III: Empirical Evidence and Policy Consequences

> *An economist is a man who, when he finds something works in practice, wonders if it works in theory.*
>
> — Walter Heller (1979)

In his last public interview as Federal Reserve Chairman, Ben Bernanke, quipped that "the problem with QE is that it works in practice but it doesn't work in theory" (Saft, 2014). In order to determine whether QE does indeed work in practice, this chapter is dedicated to a discussion on the empirical evidence as to the efficacy of balance sheet policies. In addition, the potential side effects from implementing such policies will be fleshed out.

4.1 Empirical Evidence

Following the discussion on balance sheet policies, I verify, through an analysis of the empirical evidence, the practical application of the implemented policies. The literature in this regard draws primarily on event studies[1] and econometric analyses of episodes surrounding the most recent financial crisis[2]. I will divide the discussion thematically, looking at the impact of these policies on different dimensions of the economy.

[1] This approach looks at a specific event, such as an announcement of a QE program. Researchers then consider movement in a variable of interest immediately following the event (Martin and Milas, 2013).

[2] The reason being that balance sheet policies were in full force during this time. We have limited exposure to these measures in the rest of the post-war period, as they remained mostly in the realm of theory (except for the Operation Twist experiment in the USA during the 1960's under the Kennedy administration).

Generally, we believe that central banks expand their balance sheets during periods when the policy has reached the ZLB (Woodford, 2012). The earliest form of quantitative easing was implemented by Japan, under its quantitative easing program (QEP). After the financial crisis, this unconventional measure was implemented by several advanced economies. The most prominent examples have been that of the US and UK, which to date have expanded their balance sheets by the largest amounts in relative terms (Gambacorta et al., 2014).

4.1.1 QEP in Japan

I begin my analysis by looking at the success of the Japanese QEP, which was the earliest example of a 'pure' quantitative easing program[3]. Expanding the supply of bank reserves in this case was done to supplant the use of the policy rate in conducting monetary policy, since the policy rate had reached the ZLB (Gambacorta et al., 2014). Increasing the size is similar in nature to a reduction in the policy rate, having the common goal of stimulating economic growth through. As suggested by quantity theorists, with this approach one would readily be able to see increases in nominal spending (Bernoth et al., 2015). The pressing question is whether this policy has generated the predicted effect in practice.

Econometric analysis of the Japanese policy experiment in the early part of the millennium indicate that it was rather ineffective in impacting the real economy (Ugai, 2007). Exploration of the economic aggregates reveals that this policy had limited impact. In spite of the monetary expansion, economic growth (and nominal expenditure) remained persistently low. More importantly, deflation appeared to be unaffected. The Japanese economy slowly started to recover toward 2006, quite long after the initiation of the program. However, further evaluation reveals that although the policy might have been unsuccessful in generating real activity, it might have been effective in shaping expectations as to the future path of the policy rate, shown by longer-term interest rates decreasing throughout the early part of the 2000s.

This might be explained in part by the change in rhetoric of the central bank with regard to policy communication. Under the QEP, the credible commitment from policymakers to ZIRP comes from the fact that they are eliminating the possibility of increasing the policy rate in future (without first decreasing the excess reserves in the economy). This could mean that eventually the promise of the central bank to keep rates low was transmitted through the expectations channel, from short- to longer-term rates (Woodford, 2012). After the crisis the BoJ moved away from simply using quantitative targets for reserves with their CME program, signalling that they did not have much confidence in QEP.

[3]Woodford (2012) defines 'pure' QE as a change in the size of the balance sheet of the bank without any accompanying compositional changes.

4.1.2 LSAPs in the US

After the collapse of Lehman Brothers, the Fed was the first to undertake increases in its monetary base. Large-scale asset purchase programs were a combination of quantitative and credit easing, with unsterilised purchases of both private and public securities. QE implemented by the Fed differed dramatically from the QEP of Japan, both in terms of magnitude and rhetoric. There was a clear communication strategy, with the goal of lowering expectations with respect to the future policy rate (Gagnon et al., 2011).

The literature on the effects of QE can be divided broadly into two categories. The first is the research that aims to look at the short-run policy impact, mainly through the effect on asset yields. Research in this category is mostly characterised by event studies, although attempts have been made to quantify effects through time-series analysis. These studies usually utilise high-frequency data, capturing the immediate effect of announcements[4] concerning QE programs on financial variables (Meinusch and Tillmann, 2015). The second is a longer-term look at the impact of QE on the broader macroeconomy. Initial evidence on aggregate nominal expenditure shows little to support the idea that QE had an immediate impact on the real economy. In the case of the US, the size of the balance sheet was almost quadrupled in the first four years after the crisis, with only a modest increase in the growth of nominal GDP (Woodford, 2012). However, the stated short-term objective of QE was to reduce market yields of long-term bonds, which would then eventually translate into increased availability of credit to firms and households (Woodford, 2012).

4.1.2.1 Effect on Long-term Security Yields

Econometric proof as to the existence of a reduction in long-term rates (flattening of the yield curve) through LSAPs[5] has been easy to come by, but proper identification of the transmission channels has been more difficult (Krishnamurthy and Vissing-Jorgensen, 2011). Modelling the complete transmission mechanism through which long-term rates operate has proven difficult, as the mechanism is poorly understood. Generally, the effect of central bank asset purchases on longer-term asset yields can be thought to affect two elements: a risk premium of some kind and the average short-term interest rate expected over the term to maturity (Gagnon et al., 2011)[6]. With the portfolio balance channel, asset purchases look to affect long-term interest

[4]Once point of contention in these studies is the length of the event "windows". They normally range anywhere from 30 minutes to 3 days. A short window may perhaps miss some of the market reaction, while a longer window could include market effects unrelated to the announcement.

[5]Especially in the earlier rounds of QE, when the announcements were a complete surprise to market participants

[6]As an example, in the purchase of long-term government bonds, the two components of the decomposition are the term premium and average short-term interest rate over the maturity of the bond (known as the risk-neutral

rates through their impact on risk premia. Purchases of assets with long durations are swapped for bank reserves, to affect the relative supply of long-term assets and, thereby, the asset yield. According to a statement by the Fed Chairman at the time, Ben Bernanke, the Fed intended for LSAPs to work through the portfolio balance channel (Bauer and Rudebusch, 2014). In the case of the signalling channel, the mechanism works by changing expectations about the future of the short-term rate (Christensen and Krogstrup, 2015).

Several event studies, such as those by Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), D'Amico et al. (2012), Glick and Leduc (2012), Rosa (2012), and Neely (2015), have determined that the Fed was successful in reducing long-term rates through its spectrum of QE initiatives. Combining time-series and event-study methodologies, the study by Gagnon et al. (2011) is among the earliest to try and capture the portfolio balance effects of QE1. The identification strategy in the event-study methodology relies on the fact that announcements were a surprise to market participants. Immediate shifts in asset prices following these announcements show the true pass-through to bond yields, as opposed to the effect of anticipated monetary policy (Rogers et al., 2014).

Using the Kim-Wright term-structure model and event-study methods, the study of Gagnon et al. (2011) reveals that positive QE announcements cause significant reductions in the long-term interest rates of several securities. In particular, they found that the 10-year Treasury term premium dropped significantly in response to QE1 announcements, with the response of longer-term interest rates on MBS and agency debt showing an even stronger reaction[7]. They assert that while asset purchases were effective at lowering risk premia, they failed to shape expectations as to the future of the short-term policy rate (Gagnon et al., 2011). Emphasis is placed on the portfolio balance channel while reducing the role for a signalling channel. The results of Gagnon et al. (2011) are reinforced by the term-structure estimates of Hamilton and Wu (2012), who find a large and significant portfolio balance effect in a preferred habitat model, similar to that of Vayanos and Vila (2009).

Findings provided by the event study of Krishnamurthy and Vissing-Jorgensen (2011) suggest that the portfolio balance channel[8] is the most important driver of the reduction in long-term rates, but that the signalling and liquidity channels also contribute significantly[9]. Empirical evidence provided by Woodford (2012) indicates that there is a strong signalling channel component. In fact, Bauer and Rudebusch (2014) contest the claim of Gagnon et al. (2011) that the signalling channel is unimportant, citing concerns over small-sample bias in their term-structure model. Their revision of the model of Gagnon et al. (2011) aims to correct for

rate) (Bauer and Rudebusch, 2014).

[7]This is not surprising considering that QE1 focused primarily on purchases of these securities

[8]Although they refer to it as the safety channel

[9]The liquidity channel does not appear significant in QE2.

bias and statistical uncertainty. Estimates from this revised process illustrate the extent to which the signalling channel was understated in previous attempts. The paper by Gagnon et al. (2011) only credits about 30% of the movement of long-term rates to the signalling channel, while Bauer and Rudebusch (2014) identifies the value to be between 30% and 65%.

4.1.2.2 Effect on the Real Economy

While some models focused on the short run impact on asset yields, others tried to determine what impact QE has had in the longer-run on the real economy. During the crisis the policy rate reached the ZLB, which meant that economies had to switch to LSAPs. It is important therefore to verify whether these programs that supplant the traditional policy tool would be able to spur economic growth and prevent deflation (Baumeister and Benati, 2013). Several econometric methods have been used in this pursuit, such as SVARs, TVP-VARs, Markov-switching VARs (MS-VAR), large Bayesian VARs (LBVAR), FAVARs and panel VARs (P-VAR) (Bork, 2015). Unfortunately, the small sample size has made these evaluations difficult to accept.

Preliminary results of a counterfactual constructed by Chung et al. (2012) reveal that without the policy intervention, the economy would have experienced decreased growth and inflation, in addition to increased unemployment. Similar results were reached with the DSGE models of Del Negro et al. (2013) and Chen et al. (2012a), which incorporate the effect of LSAPs on the broader macroeconomy.

Baumeister and Benati (2013) used a TVP-VAR to measure the impact of a 60 basis point increase in the 10-year term spread, which results in 0.9% lower GDP, 1 percentage point lower inflation and the unemployment rate increased by 0.75 percentage points (Baumeister and Benati, 2013). In order to determine whether output and price levels react to LSAPs in the US, Weale and Wieladek (2014) used a BVAR model with several different identification specifications. In this setup they found a positive and significant effect on the real economy resulting from an asset purchase shock, with a 0.36% increase in real GDP and 0.38% increase in CPI from the purchase of a government bond worth 1% of nominal GDP (Weale and Wieladek, 2014).

Another approach is that of Meinusch and Tillmann (2015), who used a Qual VAR (QVAR) model, in which they found that QE had been effective in stimulating real activity. With a similar result, Bork (2015) found a significant impact on the real economy resulting from the LSAPs using a dynamic factor model. He found that "industrial production, capacity utilization, inflation, and employment have significantly positive responses, and unemployment is significantly reduced" once an unconventional policy shock is applied (Bork, 2015). In addition, in the case of a counterfactual, Bork (2015) found that a significant downturn in the economy was avoided by the asset purchases.

4.1.3 QE in the UK

Once the traditional monetary policy route was exhausted, the BoE used QE to promote growth, and FLS to inject liquidity and address dysfunctional financial markets; this most closely resembled the strategy followed by the US (Churm et al., 2015). Similar studies were performed, with the results resembling those of the US. Policies were primarily differentiated by the size of the programs implemented, with the QE of the BoE being much smaller in comparison to that of the US. Programs looked at in this section, as used in the UK, are QE and FLS. Studies are grouped according to their impact on the economy.

4.1.3.1 Effect on Long-term Security Yields

In a similar fashion to that of the research for the US, event studies were first used to attempt measuring the short-term effect of gilt purchases on the yield spreads in the UK economy. Relative to research on the unconventional measures of the Fed and ECB, studies on the policy actions of the BoE are limited. Important contributions in this literature include Meier (2009), Meaning and Zhu (2011), Joyce et al. (2012b), Breedon et al. (2012) and Churm et al. (2015), with most of the research focusing on the first phase of quantitative easing. Research performed on the UK economy is largely comparable to that of the US in terms of methodology.

Casual empirical observation reveals that the range of credit facilities and quantitative easing mechanisms put into play in 2009 resulted in increasing asset prices as well as significant decreases in the yields of both government and corporate bonds (Joyce et al., 2012b). Early studies that estimate the immediate impact on financial markets, through an event-study approach, are those of Meier (2009), Joyce et al. (2012a) and Meaning and Zhu (2011). Using counterfactual analysis (constructing scenarios in which policy did not occur), Meier (2009) found that initial QE announcements resulted in a reduction of gilt yields by between 35 and 60 basis points. In the work of Joyce et al. (2012a), they found that longer-term gilt yields fell by at least 100 basis points in total for the period 2009 - 2010, with a similar narrowing in corporate bond yields.

In utilising the event-study methodology there is a general disagreement in the literature about the exact approach to follow. However, most studies agree that QE contributed to the lowering of yields, as was the case for the US, especially with regard to longer-term securities. In addition, there is a consensus that the portfolio balance channel, which is sometimes decomposed into local supply and scarcity effects, is the primary channel of operation (Joyce et al., 2012b). Increased transparency with respect to QE policy changes in the UK has meant it has become increasingly difficult to identify the impact of announcements on bond yield spreads (Mclaren et al., 2014). Event studies, in particular, rely on the surprise component of policy announcements. Widely anticipated policy announcements dampen market reactions, which has led some research to show a decrease in the ability of purchases to affect asset prices (Churm et al., 2015). More recent studies, such as those of Butt et al. (2012), Mclaren et al. (2014) and Churm et al. (2015), attempt to evaluate the relative impact of the QE2 program, looking specifically at the financial market impact of this policy.

In terms of the effect on broad money aggregates, Butt et al. (2012) found that the effect has been largely the same over time, with transmission channels being the primary difference. Using a principal components model and counterfactual analysis, Churm et al. (2015) found that even though there was a significant reduction in gilt yields with QE2 across medium- to longer-term gilts, the registered impact across all yields was substantially lower than found during QE1. Mclaren et al. (2014) believe that an explanation for the decreased impact of QE2 is the decrease in contribution from the signalling channel. In their study they found that the local supply effect (an element of the portfolio balance channel) is similar over time, between 40% and 60% of changes in asset yields, suggesting that other transmission channels are responsible for the change.

In addition to estimating the impact of QE2 on asset yields, the article by Churm et al. (2015) looks at the newly developed FLS. In particular, they are interested in the scheme's influence on marginal funding costs, similar to the study of Kapetanios et al. (2012). The conclusion reached by Churm et al. (2015) is that the introduction of FLS resulted in a drop in bank wholesale funding spreads.

4.1.3.2 Effect on the Real Economy

There is a dearth of literature on the broader macroeconomic implications of asset purchase programs in the UK. Kapetanios et al. (2012) use a variety of models, such as BVAR, MS-VAR and TVP-SVAR, to determine the real economy impact of the QE programs. Empirical results suggest that the programs that were implemented greatly improved economic conditions, and that in their absence GDP and inflation would have been much lower, perhaps even reaching negative values. Conservative estimates of the positive effect on real GDP puts it at 1.5%, while inflation rose by at least 1.25% as the result of QE. Similar estimates are found in the work of Baumeister and Benati (2013).

In their paper Weale and Wieladek (2014) impose an asset purchase shock in a BVAR framework, worth 1% of nominal GDP, to determine the effect on the real economy, which delivered a 0.18% increase in real GDP and 0.3% increase in CPI. Also utilising a BVAR model, Churm et al. (2015) conducted an out-of-sample forecast to determine how the landscape of the UK economy would have differed if QE had not been implemented. An assumption was made, based on event-study evidence that the stimulus reduced spreads by up to 45 basis points. In other words, the counterfactual scenario assumed that QE2 reduced the yield spread by 45 basis points. Stimulating the economy through asset purchases was found to have the equivalent impact of reducing the policy rate by between 1.5% and 3%, which roughly increased nominal GDP by 0.6% over one year and inflation by between 0.25 and 0.6 percentage points. Churm et al. (2015) also studied the impact of a lower marginal funding cost, as the result of FLS. They found that the impact of the scheme is similar to that of QE2, with a 0.8% increase in GDP growth and a 0.6 percentage point increase in inflation, after a year from the start of the policy.

4.1.4 LTROs, SMP, OMT and PSPP in Europe

The ECB also implemented liquidity injections and asset purchases throughout the crisis, but these were mostly sterilised operations and did not increase the size of the balance sheet. The first instance of expansion of the balance sheet was through the Public Sector Purchase Programme, which was implemented in 2015. Unfortunately, due to the fact that this program was announced only quite recently, there is little relevant research on the topic, with the work of Altavilla et al. (2015) being the only published research on the topic. However, there are several studies that look at the financial market impact of the ECB's policy initiatives. Usually, these studies look at one of three markets, namely, money markets, covered bond markets and sovereign bond markets (Szczerbowicz, 2015).

Early attempts by the ECB to rectify the position of failing financial markets were focused primarily on LTROs. The impact of these exceptional liquidity provisions on interbank lending was studied through basic regression analysis in the work of Abbassi and Linzert (2012), (Angelini et al., 2011) and Brunetti et al. (2011). From these studies the general consensus is that the introduction of a range of LTROs did not contribute significantly to reducing relevant money market spreads. In other words, this policy avenue was not particularly useful in combating financial market instability.

Of particular importance is the liquidity provided under the 3-year LTROs[10], which Carpinelli and Crosignani (2015) refers to as the "largest liquidity injection ever conducted", totaling $1.37 trillion to 800 banks. They show that these liquidity injections positively affected Italian credit supply.In a similar study Andrade et al. (2015) found that these LTROs positively impacted credit extension in France. In addition, García Posada and Marchetti (2015) argues that VLTROs increased loan supply in Spain. Szczerbowicz (2015) found that only 3-year LTROs

[10]These are also known as very long-term refinancing operations (VLTROs) (García Posada and Marchetti, 2015).

(in combination with ZIRP) contributed to removing some of the tension in stressed interbank markets, which is consistent with the result of Darracq-Paries and De Santis (2015).

Lenza et al. (2012) consider the macroeconomic effects of unconventional policies implemented during the period of enhanced credit support, before the creation of the SMP. Using a large BVAR model to construct a counterfactual, they determined that facilities created under ECS (specifically looking at FRFA) helped to reduce money market spreads, which translates into improved financial market health (Lenza et al., 2012). In addition, the ECS operated in much the same way as conventional monetary policy, by increasing industrial production by 2% and decreasing the unemployment rate by 0.6 percentage points. The BVAR analyses of Giannone et al. (2011) and Baumeister and Benati (2013) corroborate the evidence that policy intervention supported market functioning by reducing money market spreads, thereby restoring the transmission mechanism of monetary policy, which helped to increase real activity across the Eurozone.

Asset purchase strategies of the ECB during the sovereign debt crisis were subject to fierce academic and policy debate. The overwhelming majority of papers turned to the evaluation of the sovereign bond market impact of policies implemented, specifically focusing on SMP and OMT. In general, these papers looked toward the effect on asset yield spreads and the volatility associated with yields (Eser and Schwaab, 2016). Importantly, the ECB intervened in failing secondary sovereign debt markets, which had broader implications for the Euro area as a whole. I first evaluate the impact of the SMP and then the OMT (which later replaced the SMP).

The SMP was considered a temporary initiative to help stabilise the Euro economies and prevent the collapse of the monetary union. The language used by the ECB described measures that were used to restore the transmission mechanism of monetary policy (Eser and Schwaab, 2016). SMP, unlike QE in the UK and US, was not intended to be a replacement for the short-term overnight interest rate. In other words, it was meant to normalise the movement of sovereign bond yields, not to be an accommodative monetary policy. As a result, studies rarely consider the broader macroeconomic implications of the program, as it was not intended to boost growth or deter deflation (Szczerbowicz, 2015).

According to several studies, the initial announcement of the SMP and OMT had a powerful effect on sovereign bond yields, with the program acting as a commitment to save the monetary union. Sovereign bond spreads for the Eurozone periphery narrowed significantly following the announcements, as documented by Pattipeilohy et al. (2013), Krishnamurthy et al. (2014), Ghysels et al. (2014), Pooter et al. (2015), Acharya et al. (2015) and Falagiarda and Reitz (2015). However, it is argued by Eser and Schwaab (2016) that the announcement effect was not the primary driver, with actual bond purchases being more impactful in terms of lowering yield spreads and yield volatilities of sovereign bonds.

Using a panel regression, the 'impact identification'[11] strategy performed by Eser and Schwaab (2016) on daily data reveals that bond purchases by the ECB under SMP decreased 5-year bond yields across a range of countries most affected by the sovereign debt crisis[12]. In general, the SMP appears to have had a stronger impact on the shorter end of the yield curve. Szczerbowicz (2015) used internal ECB data and found that purchases within the SMP and OMT had significantly lowered covered bond and sovereign yield spreads.

According to Eser and Schwaab (2016), SMP operated through three primary channels. First, reduction of liquidity risk premia through the lender-of-last resort function of the ECB. Second, local supply effect, whereby reducing supply in a specific market increases price on that asset and lowers the yield. Third, the default risk, which is reduced trough country specific asset purchases to help avoid sovereign debt default. Interestingly, since the SMP was temporary in nature, and did not contain any information as to the policy stance of the ECB, we do not expect any signalling effect from these purchases (Krishnamurthy et al., 2014). In the work of Krishnamurthy et al. (2014), they found that the dominant channels through which sovereign bond yields were affected by the SMP and the OMT were through default risk and sovereign bond segmentation (local supply) effects.

More recently, the work of Altavilla et al. (2015) looked at the impact of the Asset Purchase Program. The APP contains the PSPP as one of its policy arms, with the PSPP being the first true instance of unsterilised balance sheet expansion implemented by the ECB. They found that this APP resulted in a sizeable reduction in yields across a wide range of assets. In addition, these effects seem to intensify with an increase in the maturity and riskiness of the targeted asset. Estimates of the yield impact delivered an average reduction of 30 to 50 basis points on bonds with a 10-year maturity. Driffill (2016) found that APP resulted in the reduction of 10-year government bond yields in troubled economies, reducing differentials between countries of the Euro area.

A comprehensive event study by Falagiarda and Reitz (2015) looked at spillovers to Central and Eastern Europe from the range of nonstandard policy measures implemented by the ECB since 2007, including the newly formed APP. They found a strong announcement effect emanating from the SMP, while the OMT and PSPP had a limited impact. They identify the primary channels of transmission for nonstandard policies as the portfolio balance, signalling and confidence (redenomination risk) channels (Falagiarda and Reitz, 2015).

[11]This exploits both cross-sectional and time series components of the data. Yields might have risen in many of the countries in the sample due the announcement, however, using this strategy we are concerned only with relative movements.

[12]These countries include Greece, Italy, Spain, Portugal and Ireland.

4.1.5 CME and QQE in Japan

I end the balance sheet policies narrative with the empirical evidence supplied on the Japanese economy. Since the adoption of the QEP in 2001, several other central banks have emulated the strategy, incorporating unconventional policy measures as part of their policy toolkit. Evidence as to the efficacy of nonstandard policies implemented is becoming more abundant. As previously stated, most of the research has been on the LSAPs of the US. However, the introduction of CME and especially QQE has garnered the attention of several international researchers.

4.1.5.1 Effect on Long-term Security Yields

As in the other sections on empirical evidence, most of the research has been conducted to determine the short-term financial market impact of asset purchases. Schenkelberg and Watzka (2013) found that QE under CME resulted in a reduction of long-term interest rates, in a similar manner to that of LSAPs in the US. Transitory increases in output and inflation were also observed with this SVAR approach. Rogers et al. (2014) examine the effect of several nonstandard policy announcements on asset prices, with policy shocks resulting in a reduction of 10-year JGBs and corporate bond yields. Although this was not necessarily the intended effect from asset purchases, with the BoJ explicitly stating that it wanted to affect the real economy, specifically inflation.

Interestingly, the study of Ugai, Hiroshi (2015) points out that the signalling channel was important in the dissemination of the effect of CME, but this channel does not appear to be important under QQE. In particular, QQE caused a sharp depreciation of the yen, which is thought to operate through the portfolio balance channel. The yield of longer maturity JGBs declined with the introduction of QQE, but this reduction did not filter through to corporate bond yields (Ugai, Hiroshi, 2015). The study of Hausman and Wieland (2015) also found that the yen experienced a strong depreciation under Abenomics, as well as an increase in Japanese stock prices.

4.1.5.2 Effect on the Real Economy

One of the stated objectives of Abenomics has been to reach an inflation target of 2% in the space of two years (De Michelis and Iacoviello, 2016). This target was not reached, but inflation has turned positive for the first time in 15 years, indicating that it has been somewhat successful. In their paper, Hausman and Wieland (2015) show that the approach of the BoJ with Abenomics was successful in providing a small increase to output, but inflation remains well below the intended target. However, they believe that the cost of the program is justified. Matsuki et al. (2015) showed, using an MS-VAR, that expansion of the balance sheet resulted in lowering short-term market rates and increasing inflation. De Michelis and Iacoviello (2016) used both VAR and DSGE analyses to conclude that the nonstandard policies implemented by the BoJ have been effective in the battle to overcome deflation; however, due to credibility concerns, the BoJ has not reached its intended target. Bolder measures are required if real activity is to be bolstered and deflation defeated (De Michelis and Iacoviello, 2016).

4.2 Other Implications of Using Balance Sheet Policies

Balance sheet policies were undoubtedly crucial policy instruments during and after the financial crisis. Nonetheless, all remedies have side effects; it is simply the severity that differs. Concerns over unintended consequences of balance sheet policies were first voiced with the initial rounds of QEP in Japan. However, due to the unprecedented scale and pervasive usage of balance sheet policies after the financial crisis, concerns over the potential ramifications have been amplified. Some of the potential adverse consequences include international spillover effects, loss of central bank independence, the creation of moral hazard, permanently inflated balance sheets (no exit strategy), inflation and the depreciation of currency. These potential consequences are discussed in this section, with a focus on the primary disadvantages recorded from recent policy experiments.

4.2.1 Central Bank Independence

British economist David Ricardo wrote in 1824 that governments should never be entrusted with the power to issue paper money, as this would ultimately lead to inappropriate servicing of public debt. His solution was to establish an independent monetary authority not subject to political influence. In fact, the central bank should “never, on any pretence, lend money to Government, nor be in the slightest degree under its control or influence” (Ricardo, 1888). In the rest of this section I aim to show that political intervention in the process of money creation could severely affect the functioning of the monetary transmission mechanism, potentially causing inflation to become unmanageable.

4.2.1.1 Types of Central Bank Independence

There are different concepts of central bank independence. Two broad classifications emerge from the literature. First, independence of objective, or goal independence, allows an organisation to determine which objectives to pursue, without input from political authorities (Ćorić and Cvrlje, 2009). Central banks do not generally have goal independence, as this would encourage opportunistic behaviour and lacks accountability, allowing the monetary authority to restructure goals so as to allow deviations from predetermined objectives[13].

Second, one of the attractive features of the modern central bank is that it is free to achieve its mandate without regard for political agenda, using whichever instrument it chooses (Bernanke, 2010). Being able to use the tools of monetary policy to achieve stated goals without interference is at the heart of what is called instrument (or operational) independence.

Instrument independence is a multidimensional concept. The ability to pursue policy objectives requires the central bank to have political, technical and financial independence. Political independence means that central banks do not receive assistance or take instruction from government bodies in pursuit of their stated goals. Technical independence refers to the ability of the central bank to use monetary policy tools as they see fit. In addition, they are not allowed to use these tools for goals outside of their mandate, such as the monetizing of government debt. Finally, financial independence means that the central bank has to have control over its own balance sheet, with a budget separate from that of the government (Buiter, 2009).

4.2.1.2 Motivation for Central Bank Independence

There are several reasons government needs to be seperated from the monetary authority. First, political intervention in the operations of the central bank can potentially damage the credibility of the monetary authority. While the central bank might be committed to a low inflation target, the fiscal authority could cause a deviation from this objective by using policy to pursue higher growth. Political authorities, as argued by (Orphanides, 2008), are tempted to seek inflationary conditions, with a potential trade-off in the short-run between an immediately realised increase in economic activity and higher inflation down the line[14]. Policymakers have a vested interest in creating jobs and boosting economic growth in the present, even at the risk of increasing inflation in the future, especially during election years (Corsetti and Dedola, 2013).

[13]Interestingly, the Fed has a limited form of goal independence, vaguely assigned the dual mandate of achieving maximum employment and price stability. The Fed has much room to move in its interpretation of maximum employment (Ćorić and Cvrlje, 2009).

[14]This relationship is depicted by the Phillips curve, which illustrates the potential for a short run trade-off between inflation and employment. Taylor (1998) categorises this relationship as one of the five things we know for sure about economics.

Public policymakers who systematically push the economy beyond its productive capacity could plausibly set in motion a spiral of increasing inflation and inflation expectations, without an associated improvement in real economic conditions (Bernanke, 2010). In other words, inflating the economy to achieve higher output will only end up causing higher inflation, without any gain in economic activity in the longer-run[15]. The disadvantages of deviating from a stated policy objective are well recorded, both theoretically and empirically. A wealth of knowledge gained from the 'time-inconsistency' discourse advises monetary authorities to abide by their mandate[16].

Second, a fiscal authority with control over the central bank may attempt to print money to service a budget deficit (Bernanke, 2010). Monetisation of debt through the printing of money by the government eventually leads to high levels of inflation and volatility in the economy. Politicians might run budget deficits and accumulate debt with the idea that future governments will carry the cost, or perhaps that debt can be reduced through inflation (Orphanides, 2008). The only way in which the government could retain control over money creation is if the public trusted it not to pursue growth objectives to the detriment of price stability. However, in lieu of this trust of the public, it would be better to designate the role of price stability to an independent organisation (Orphanides, 2008).

4.2.1.3 The Role of Central Bank Independence

The discussion on the effectiveness of monetary policy in combating inflation intensified during the 1970s. This period was characterised by high levels of inflation and low economic growth, referred to as stagflation. Researchers, policymakers and the public wanted an explanation as to the sudden impotence of monetary policy with regard to lowering inflation and boosting economic growth. It was a commonly held Keynesian belief that increasing inflation on the part of the monetary authority would reduce unemployment[17]. However, inflation persisted in conjunction with deteriorating real macroeconomic performance, despite central bank intervention (Berger and Kißmer, 2013).

It was in response to these events that the literature on time-inconsistency and rational expectations emanated[18]. Arguments originally developed by Friedman (1968), Lucas (1976) and Kydland and Prescott (1977) were later confirmed by Barro and Gordon (1983), who found

[15]The reason for this is that private agents with rational expectations anticipate attempts to exploit the relationship and adjust inflation expectations upward, arguments originally made by Thomas Sargent and Robert Lucas

[16]Notable contributions are that of Kydland and Prescott (1977), Calvo (1978) and Barro and Gordon (1983).

[17]Known as the Phillips curve trade-off, which was first suggested by Phillips (1958) and later popularised by Samuelson and Solow (1960).

[18]Although it is a fascinating literature, it is not worthwhile delineating all the relevant arguments in this section.

that monetary authorities were, in fact, setting inflation targets too high, pushing economies beyond their natural levels of output. This caused inflation to increase without the resulting growth benefits. The agreed-upon cure was to implement a price stability objective for the central bank, which now had instrument independence. This episode is remarkable in that academic research was effective in bringing about changes to monetary policy practice that resulted in a new consensus on how policy should be conducted.

The new consensus assigned central banks the mandate of achieving price stability. As highlighted by theory, achieving this goal depends heavily on central bank independence, transparency and accountability (Bernanke, 2010). Inflation targeting, through adopting the inflation rate as a nominal anchor, greatly decreased inflation and output volatility. Empirical evidence supports the idea that central bank independence is key to achieving desired inflation outcomes[19]. It is therefore not surprising that dissidents of unconventional policy measures identify the potential loss of central bank independence as too costly to ignore.

4.2.1.4 Balance Sheet Policies and Central Bank Independence

Balance sheet policies immediately raise concerns about the independence of the central bank. I identify two broad streams of argument made in the literature about the impact of unconventional monetary policy on central bank independence. There is some overlap between these categories, but they are largely distinct from each other. First, there are discussions about the budgetary independence of central banks with the introduction of asset purchases. Second, a large literature has formed on the portfolio management of assets purchased by central banks after the crisis. In the next section, I discuss some suggestions made to quell these fears.

4.2.1.4.1 Budgetary Independence In the previous section, it was established that instrument independence is vital in achieving price stability. However, with the start of the crisis, it is not the loss of the freedom to use the tools of monetary policy that is mourned[20]; instead, budgetary or financial independence has become the focus of discussion[21]. In normal times, central banks have a certain structure to their balance sheet. Liabilities consist primarily of currency and reserves, while the asset side contains Treasury securities (Dudley, 2013). As the central bank did not hold private sector assets, there was no credit risk on the portfolio. It is possible for the central bank to hold long-term government bonds, which implies some interest

[19] The related literature includes, but is not limited to, Grilli et al. (1991), Cukierman et al. (1992), Summers and Alesina (1993) and Cukierman et al. (2002).

[20] Sometimes referred to as technical independence. The central bank still has technical independence, even when the policy rate reaches the ZLB.

[21] According to certain definitions, financial independence forms part of operational independence.

rate risk. However, as these long-term bonds are usually held to maturity, it eliminated much of the associated risk (Dudley, 2013). Notably, central banks typically secure some degree of profit, which they then remit to the Treasury.

Unconventional monetary policy can have fiscal consequences. Large-scale asset purchases and maturity transformations could plausibly be unfavourable for the central bank's asset risk profile, and the level of profits remitted to the Treasury (Rossi, 2013). This is of particular relevance if central banks wish to intervene in financial markets outside of the traditional banking sector (Goodfriend, 2007a). Purchases of private sector assets (such as MBS) and long-term government securities result in the central bank adopting the risk associated with the asset.

Broadly speaking, two types of risk are created, credit risk and interest rate risk. First, credit risk is considered the most damaging, as the central bank has little control over private asset markets. Purchases of these private sector securities expose the central bank to the volatility of the associated markets. Second, increasing long-term debt translates into greater interest rate risk. Normally, these assets would be generating income for the central bank, as has been the case in most countries. This means that the government receives seignorage revenue from these investments, as illustrated in the case of the US in Figure 4.1. However, if long-term interest rates increase, or money market investments turn sour, there could be a cessation of the stream of seignorage revenue.

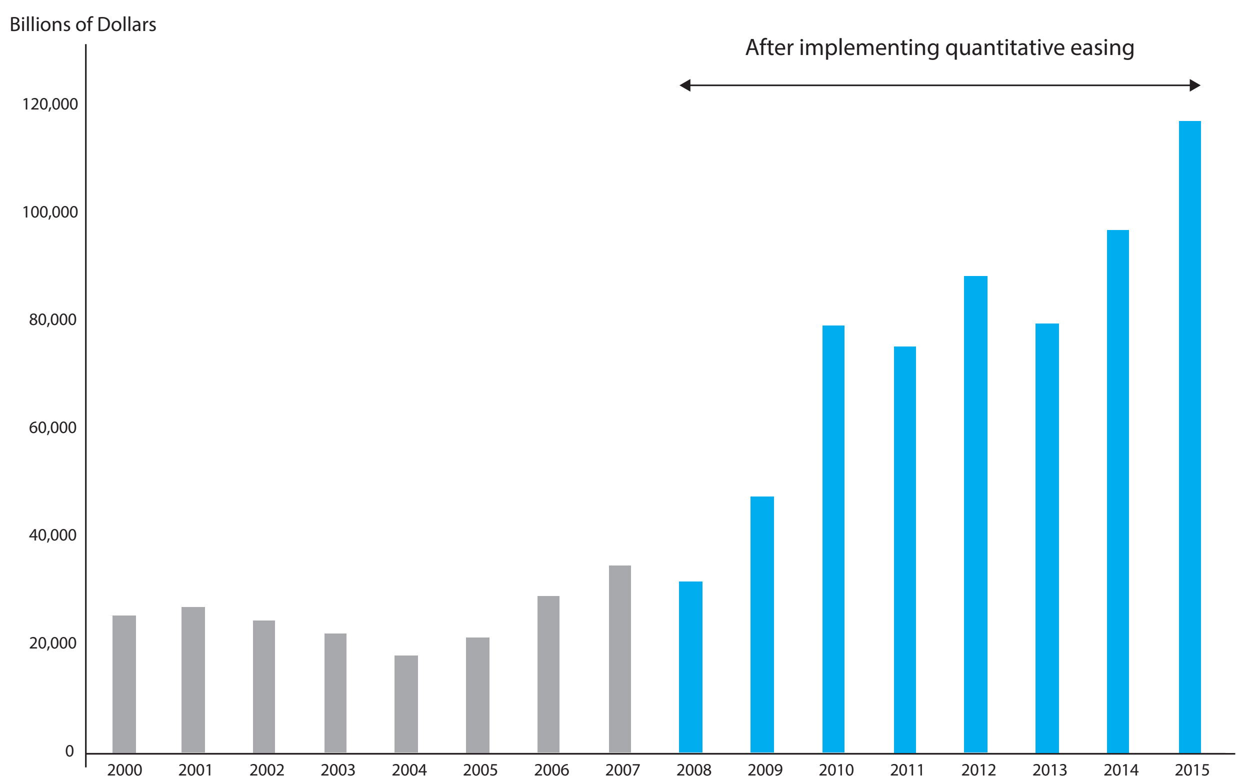
Earnings from these securities could also be negative (creating a budget deficit), which means the central bank could experience losses. Increasing interest on reserves, as in the US, makes this situation even worse, as interest needs to be paid on this debt (Dudley, 2013). Small, temporary, losses experienced by the central bank should not, however, be a cause for concern, as the burden could be shifted by increasing remittances at a later stage when the central bank becomes profitable again (Del Negro and Sims, 2015). However, in the case of the recent crisis, the sheer size of asset purchase programs amplified the potential budget risk. If losses are large, the bank might not be able to retain control over its balance sheet.

One of the most hotly debated topics at the moment, is whether central banks should be allowed fiscal support when the "system's net worth at market value is negative" (Del Negro and Sims, 2015). In order fully to appreciate this discussion, a distinction needs to be made between fiscal support and fiscal backing. Fiscal support is defined as the "commitment by the treasury to recapitalize the central bank if necessary". Fiscal backing, however, refers to the behaviour of the fiscal authority to 'back' the inflation target set by the central bank, making sure inflation is guided primarily through monetary policy (Reis, 2015). Fiscal backing is coordinated behaviour that cannot be managed by the central bank on its own (Del Negro and Sims, 2015). As illustrated in the literature, for the price level to be uniquely determined, fiscal authorities need to limit their interference in monetary policy affairs (Woodford, 2003).

Fiscal backing does not imply fiscal support, and vice versa. At the moment few countries have fiscal support when it comes to making losses from investments in private credit markets. Some central banks, like the BoE, are indemnified fully by the Treasury against any loss occurring from their unconventional monetary policy spending, while other central banks have constructed charters to deal with negative dividends (Reis, 2015).

However, if the central bank receives no recapitalisation, this might influence its ability to conduct policy. If the government does not tolerate losses, then the central bank cannot guarantee price stability (Goodfriend, 2014). Without the support, the central bank would try to influence inflation in order to devalue its stock of outstanding debt, which means perhaps allowing more inflation than needed (Belke and Polleit, 2010). Seignorage revenue generated (i.e. printing money) could settle their debt, but at the cost of inflation, which means that they are not pursuing their policy objective. This option can cause severe reputational damage; potentially undermining established trust in the ability of the central bank to achieve its policy objective.

Figure 4.1: Remittances from the Fed to the US Treasury



Source: Annual report of the Federal Reserve Board of Governors

4.2.1.4.2 Asset Management and Moral Hazard During the financial crisis, several lending facilities were created by central banks, often in close coordination with fiscal authorities. The financial institutions selected to receive credit were based on apparent need. However, because of the coordination with government agencies, this opened up the possibility that the selection of market intervention could have a political agenda (Bordo, 2010). One concern is that in the pursuit of this seignorage revenue, the government could perhaps try to influence the investment decision of the central bank, potentially forcing it to contradict its mandate (Del Negro and Sims, 2015).

While the goal of most central banks, which adopted nonstandard policies, has been to persuade private banks to lend, it has unearthed another interesting problem. Intervention in credit markets can create unnecessary speculation and associated volatility in asset markets (Plosser, 2009). Influencing asset prices and credit allocation also gives the central bank a lot of power. In practice this has allowed the central bank to behave like a large investor in specific market segments, managing a relatively large portfolio of assets that affects market activity. Unfortunately, this makes it the target of political pressure, opening it up to lobby groups.

The ability to intervene in specific market segments also creates moral hazard, allowing institutions to believe that they will be bailed out at the first sign of distress, inherently promoting even riskier behaviour. As I have mentioned in my discussion on the crisis, one of the reasons the financial agents engaged in risky behaviour is that they believed banking institutions to be of such systemic importance that they would not be allowed to fail. The central bank's lender-of-last-resort function, for example, institutionalises this idea, stating that struggling financial institutions need to be provided support. In addition, if the central bank is responsible for banking supervision, then it will need to use taxpayer money to fund the strategic resolution of these institutions (Rossi, 2013).

4.2.1.5 Suggestions

Several suggestions have been put forward as to how one could resolve issues on central bank independence. In general, central banks need to be transparent when it comes to the link between the fiscal and monetary authority, showing that a coordinated effort is taking place. It is essential that the objectives of policies be explained in detail, in order to leave no doubt about the policy direction. One solution, as mentioned before, is for governments to provide fiscal support (indemnifying losses) in the unlikely event of central bank budget deficits. This could be done through the creation of an institution that absorbs losses, such as in the case of the BoE.

Another suggestion is that of Bernanke (2010), who believes that the same independence should be extended to unconventional policies as that enjoyed by the conventional monetary policy measures. In other words, one would try to remove the influence of government when it comes to nonstandard policies; for example, assigning the central bank some financial stability objective to reach using unconventional tools, without interference from the fiscal authorities.

Finally, there is a proposal for the delineation of fiscal and monetary authorities in handling the assets of the balance sheet of the central bank. Non-treasury securities can form part of the fiscal budget, while the central bank is left with Treasuries on its balance sheet. This resolves some of the issues over the exit strategy and its interaction with price stability (Plosser, 2009). With that, I now move to the topic of exit strategies with respect to unconventional monetary policy.

4.2.2 Exit Strategies

Assets on the balance sheet of the Federal Reserve have grown by more than 5 times in the last nine years, from a value of $869 billion in August of 2007 to $4.6 trillion in July 2016. While growth was not quite as aggressive in the majority of developed countries, there have been significant expansions. A fourfold increase of the assets for both the Bank of England and the Bank of Japan have been recorded, while the Swiss National Bank has experienced an increase in the size of its balance sheet from "20% of nominal GDP to more than 80% of nominal GDP" (Ihrig and Meade, 2015). Economic growth and increased inflation in countries with bloated balance sheets has raised the question as to how these economies will return to the usage of their conventional policy instruments. In fact, these pressures have forced the Fed to exit from its LSAPs, implementing a normalisation program in October 2014.

4.2.2.1 The New Normal

Economic recovery might initiate a process in which commercial banks start lending out their reserves, which means credit conditions might become excessively easy, impacting broader monetary aggregates and perhaps increasing inflation (Peersman, 2014). Two broad strategic approaches have been proposed[22] to deal with the exit from balance sheet measures. The first strategy entails selling off financial assets that were purchased during the crisis and thereby flushing the economy with liquidity. The second entails the maintenance of reserves at their current level (or perhaps slightly below), while increasing the policy rate through the usage of interest on reserves.

[22] There are technically more approaches, but they generally tend to fall within these two categories.

4.2.2.1.1 Shrinking the Balance Sheet [23] In order to pursue price stability and conventional monetary policy instruments, central banks will have to consider the possibility of withdrawing liquidity extended during the crisis. In other words, they will want to return to a 'normal' balance sheet, before regaining control over their policy instrument. Historically, the size of the Fed's balance sheet, for example, is around 6% of GDP, as opposed to the current 26% (Ihrig and Meade, 2015). Rapid reduction in the size of the balance sheet to return to these relatively low pre-crisis levels seems improbable and unrealistic, given how long it took to accumulate these assets (Kliesen, 2013). However, as discussed in the previous section, if the size of the balance sheet remains significantly elevated, the increase in the interest rate could hold problems with regard to remittances to the Treasury (Kliesen, 2013).

Furthermore, reducing the assets on the balance sheet is usually relatively straightforward, with the central bank conducting open market operations, trading Treasuries for reserves. However, in an attempt to remove toxic assets from the balance sheets of financial institutions, several central banks have traded illiquid assets for Treasuries. This has changed the composition of central banks' balance sheets to include a large volume of risky assets, such as MBS. If the market is not ready to accept the return of these assets, it might distort financial market functioning. Exiting from unconventional policies could lead to capital gains or losses, depending on the relative value of the securities sold (Bernanke, 2010). In the case of the Fed, they have suggested holding MBS and related securities until maturity. However, this significantly increases the time taken to normalise the balance sheet, with the average maturity of the Fed's asset portfolio calculated to be around 10.4 years (Williamson, 2015).

Clear communication with respect to exit strategy is important if central banks want to reduce their 'footprint' in money markets (Frost et al., 2015). Distortions could arise in certain market segments if the central bank intervenes for too long. Continued provision of liquidity to certain sectors translates into an increased role in financial intermediation on the part of the central bank, which could potentially "reshape the financial industry over time in ways that are difficult to anticipate in advance" (Ihrig and Meade, 2015). The possibility of cheap money without the possibility of an exit in that segment of the market may result in private sector agents staying away, preventing a return to normal in those markets (Plosser, 2009).

4.2.2.1.2 Interest on Excess Reserves (IOER) Due to the increase in the liabilities of the central bank, commensurate with the increase in assets, this translates to an increase in the monetary base. As Milton Friedman (1963) argues, if "high powered" (i.e monetary base) is permanently elevated, it will eventually lead to a higher price level[24]. In such a case the central

[23]The original idea was to call this section "Honey, I Shrunk the Balance Sheet!" Cooler heads prevailed.
[24]A phrase often used to describe this situation, is that "too many dollars chase after too few goods"

bank is tasked with eliminating excess liquidity or faces the consequence of increased inflation expectations (Peersman, 2014). However, using interest on reserves could potentially dampen the effects associated with increased liabilities, as banks will store some of their reserves with the central bank. Although implementing interest on reserves appears to be a new idea, it could be viewed as a reformulation of the 'Friedman rule', which tries to eliminate social inefficiencies associated with positive nominal interest rates (Friedman, 1969).

This rule, concerning the optimum quantity of money, is often interpreted to mean that the nominal interest rate should be set to zero at all times. However, the efficiency condition of the Friedman rule seeks to eliminate the interest rate differential between the opportunity cost of holding money and the cost of creating additional money (Chari, 2010). Applying this rule when interest paid on reserves is not factored into the equation means that the nominal interest rate needs to be set to zero, because the central bank creates money in a virtually costless manner. In the case where the bank can pay interest on reserves the efficiency condition adapts to allow for a positive nominal interest rate equal to the interest on reserves to be set (Cúrdia and Woodford, 2011). In other words, it is through interest on reserves that the policy rate can be increased (through a *de facto* increase of the interest rate floor), without having to draw down the central bank balance sheet (Woodford, 2012). In the case where central banks do not pay interest on reserves, they might need to unwind their balance sheet completely before they can conduct increases in the short-run nominal policy rate.

One concern raised about the usage of interest on reserves is that central banks and financial markets alike have no experience with it. Communicating policy objectives might be difficult and lead to uncertainty, which could generate volatility in the stock of reserves (Chari, 2010). In addition, while paying interest on reserves allows the central bank to change the level of reserves independently from the interest rate[25], these changes outside of interest rate movements might be misinterpreted by financial institutions as signalling a certain stance of policy that contradicts the movement in the conventional instrument (Chari, 2010).

In addition to the outright sales of financial assets, as previously discussed, there are a few more ways in which central banks can avoid the potential volatility involved with issuing interest on excess reserves. However, I discuss only the two most popular options[26]. First, mopping up excess liquidity could be done by establishing a depository institution at the central bank that allows customers access to term deposits. Financial institutions would then be able to trade their interest-bearing reserves for more attractively priced deposits that are held at the

[25] See the discussion on the decoupling principle in Chapter 5.

[26] Besides the two options discussed, central banks could increase the reserve requirement, which forces banks to hold a portion of their reserves as deposits (Labonte, 2015). Central banks could also adopt term reverse purchase agreements, which are a longer term version of the overnight reverse repos discussed in this section (Ihrig and Meade, 2015).

central bank for different agreed-upon periods of time (i.e. three months, six months, and so forth). This would mean that the central bank offers a service whereby it transforms reserves into short-term deposits (Chari, 2010). As deposits are held at the bank for longer time periods, this would avoid the volatility associated with interest paid on reserves. However, this strategy carries the potential for interest rate and rollover risk.

Second, reverse repurchase agreements (RRPs)[27] as supplementary tool has been suggested (Frost et al., 2015). These RRPs are similar to normal open market operations, but instead of injecting liquidity into the economy through the purchase of Treasuries (or other assets), the central bank withdraws reserves through the sale of assets on its balance sheet (Labonte, 2015). However, the creation of a RRP facility that allows (potentially unlimited) access to safe, short-term assets carries some risks. In the short run, a potential drawback is that during periods of financial stress there might be a large movement to purchase central bank securities (a flight to quality), shifting liquidity away from financial and nonfinancial institutions and thereby crowding out private spending (Ihrig and Meade, 2015). In the longer run, a large RRP facility poses the same problem as that of normal unwinding of the balance sheet, with the central bank potentially exerting influence on market segments, if the liquidity withdrawal is great enough[28].

This solution seems to have gained some traction in the US. In 2014 the Fed announced that, as part of their normalisation approach, they would engage in these RRPs once the interest rate was increased[29]. With the interest rate increase in December 2015, the Fed started full-scale implementation of RRP agreements as part of its Policy Normalization Principles and Plans (Ihrig and Meade, 2015). The next section discusses, in more detail, the approach of the Fed, with specific reference to RRPs.

4.2.2.2 Normalisation at the Fed

Interest paid on reserves is a crucial component in both corridor and floor regimes, but the discussion on its usage has only taken hold that the Fed has adopted it as part of its normalisation

[27]Repurchase agreements can be viewed as collateralised loans. It is an agreement between two parties to purchase and then repurchase assets at a specific price and date. Calculating the difference in price between the sale and resale determines the interest rate (cost) of the transaction (Labonte, 2015).

[28]There is disagreement in the literature about the influence exerted on financial markets as a result of Fed intervention. It is argued that if markets are not highly segmented that the relative contribution of the Fed's purchases will be a drop in the ocean, with economic activity in asset markets being too great for the central bank to make a difference. However, if market segmentation is significant, the central bank might be able to influence that segment. However, there is little consensus in the literature as to the degree of market segmentation, with precise definitions difficult to obtain (Chen et al., 2012a).

[29]In fact, RRPs were first suggested to the FOMC in July 2013 and have been used in an experimental fashion since September 2013, with several variations of overnight RRP operations conducted to determine the effect on short-term interest rates (Frost et al., 2015).

strategy. While the Fed has legally been able to implement the policy tool since 2008, it has not been fully utilised. It is only recently, in 2014, that the FOMC indicated that this would be key to monetary policy normalisation, utilising it as an interest rate floor to accompany the increase in the policy rate (Ihrig and Meade, 2015). In addition, the Fed has introduced supplementary tools, such as reverse repurchase agreements to introduce greater control over the federal funds rate (Frost et al., 2015).

4.2.2.2.1 Reverse Repurchase Agreements One part of the conversation that has not been fleshed out until now, is the mechanism and design of the reverse repurchase agreement. The rest of this section is devoted to explaining its qualities and potential uses. As stated before, RRPs are a lending agreement between the central bank and a relevant counterparty. However, there are key differences between RRPs used currently by the Fed and the repurchase agreements conducted before the crisis (Ihrig and Meade, 2015).

First, overnight RRPs are offered at an "offering rate" announced by the central bank before agreements are structured. Eligible counterparties have time to decide - by comparing this rate to comparable market rates - whether they would like to bid. Initially the Fed accepted a fixed-rate, full-allotment structure (similar to that of the ECB) on these RRPs, but this was replaced by the fixed-rate capped-allotment structure (Frost et al., 2015). With FRFA, the amount of liquidity withdrawn is only limited by the size of the assets on the balance sheet of the central bank. However, this carries the risk, as previously stated, of a flight to quality in times of financial stress. This led the Fed to the auction model, where a cap is placed on how much an individual institution can bid, as well as on the overall size of the operation (Ihrig and Meade, 2015). At the time of writing the individual cap was set at $30 billion, while the aggregate limit was $300 billion[30].

Second, one of the observed anomalies in adopting the IOER framework was that the effective overnight federal funds rate often moved below the IOER, as seen in Figure 4.3. In theory this is not supposed to be possible, as in a perfectly competitive market without bank balance sheet costs, any difference between the money market rate and the IOER is subject to arbitrage (Anderson and Huther, 2016). While many nonbank institutions (thought of as lenders / suppliers of reserves) such as money market funds and government-sponsored enterprises, are "statutorily prohibited from earning IOER", it was believed that arbitrage profits generated would be enough to steer market rates toward the IOER (Anderson and Huther, 2016). This means that depository institutions (the borrowers of reserves) with access to IOER would borrow funds from nonbanks and then deposit them at the central bank to make a profit. This process would lift the short-term market rates to equalise the IOER.

[30] The results of the bids can be found at http://www.newyorkfed.org/markets/omo/dmm/temp.cfm.

It appears that depository institutions are subject to several frictions[31] that have prevented arbitrage from being complete. In this setting, nonbanks awash with excess liquidity were willing to deposit their funds with depository institutions at a level below the IOER (Armenter and Lester, 2015). For arbitrage to occur, depository institutions must expand their balance sheets to accommodate the increase in reserves, which carries certain procedural fees and costs[32]. As stated by Potter (2015), balance sheet expansion created "frictions that have made IOER act more like a magnet that pulls up short-term interest rates than a firm floor beneath them".

The Fed established an RRP facility in order to "supplement the magnetic pull of changes in the IOER rate" (Potter, 2015). One of the unique properties of the RRPs is that the central bank can decide which institutions are eligible to take part in these operations. Potentially included in this set of market participants are nonbanks[33] that are active in short-term money markets. In this sense, the eligible counterparties for RRPs can exceed those that can hold IOERs.

This widening of counterparties is useful, because the central bank can now set the interest rate on RRPs for financial and nonfinancial institutions without access to IOER. Setting the RRP slightly below the IOER allows the Fed to purchase reserves from nonbanks, and removes the incentive to lend funds to other market participants at below the rate they receive at the Fed (Ihrig and Meade, 2015). Nonbanks prefer to deal with the central bank, as this is a riskless secured loan, as opposed to the unsecured loans in over-the-counter markets (Rosengren, 2016). Setting the overnight RRP interest rate and then accepting reserves from eligible counterparties should help increase competitiveness in money markets and thereby firm the floor beneath the federal funds target (Ihrig and Meade, 2015). In principal, market participants in the federal funds market will not have any incentive to lend below the overnight RRP, which means it acts as a supplement to the IOER in controlling the federal funds rate (Frost et al., 2015).

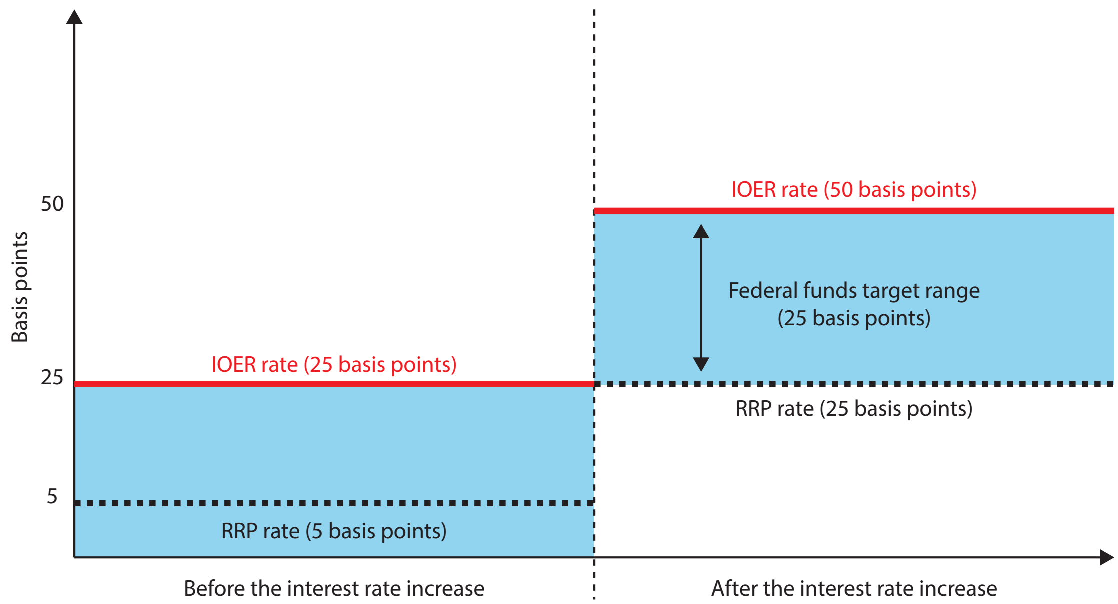
Testing done at the Fed as to the effectiveness of RRPs has yielded positive results. In particular, overnight RRPs have been effective in firming the short-term interest rate floor. One of the design features which I haven't mentioned is the potential to control the band between RRPs and the IOER, which helps keep the federal funds rate under control. This is best explained with an example, which is demonstrated in the next section.

[31] These frictions include balance sheet costs associated with accepting deposits and credit limits on cash lenders. See the discussion in Martin et al. (2013), Potter (2015) and Armenter and Lester (2015). In an attempt to formally show this behaviour, the paper by Armenter and Lester (2015) construct a model in which markets are not perfectly competitive, with depository institutions subject to search frictions.

[32] Fees payable to the Federal Deposit Insurance Corporation (FDIC) based on total assets net equity, liquidity requirements and costs associated with increasing bank capital and (Frost et al., 2015). In addition with Basel III there are likely to be leverage ratios and further inclusion of rules from the Fed

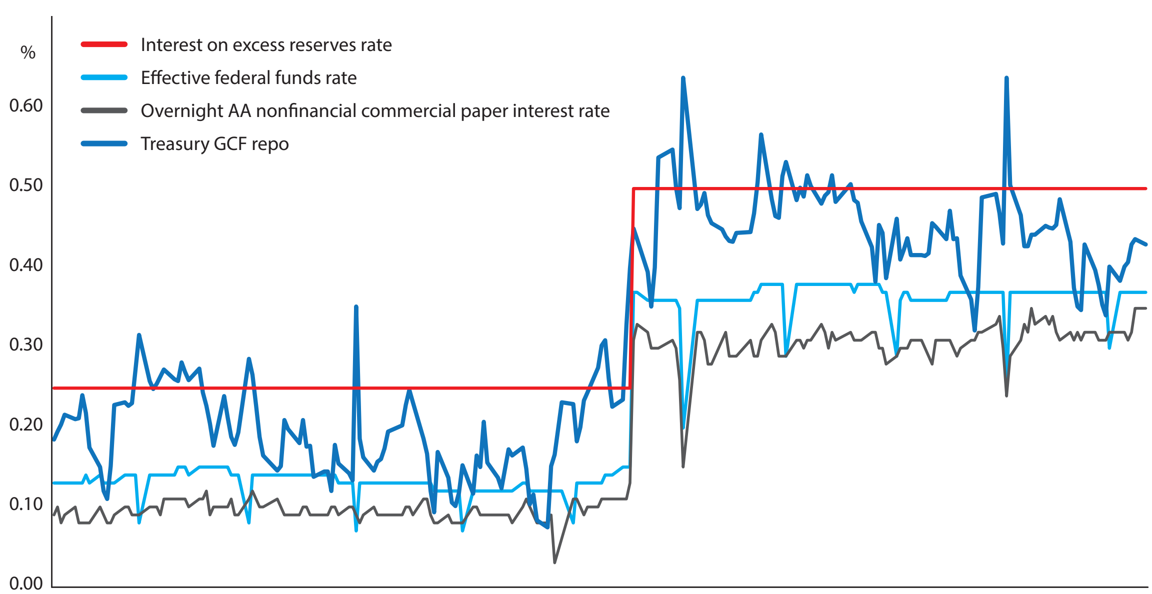
[33] The Fed currently has 164 counterparties for RRPs. These include primary dealers, banks, money market funds and government sponsored enterprises (Frost et al., 2015). A list of counterparties is provided at `www.ny.frb.org/markets/expanded_counterparties.html`

Figure 4.2: The Fed's exit strategy



Source: Ihreg (2015)
IOER = Interest on excess reserves; RRP = Reverse repurchase agreements

Figure 4.3: Interest on excess reserves and selected overnight interest rates



Source: St Louis Federal Reserve Bank

4.2.2.2.2 Practical Example In order to provide a practical example and expand on the mechanisms used, this section provides a look at how the Fed has implemented its normalisation strategy. In 2015 the economic outlook - in terms of employment, output and inflation - had improved to such an extent that the Federal Open Market Committee decided it was time to implement monetary tightening, through an increase of the federal funds rate by 25 basis points[34]. In addition, a band of 25 basis points was established around the target. As indicated in Figure 4.2, the hybrid regime of the Fed now has the following properties.

First, the interest on excess reserves, which is currently set at 25 basis points above zero, forms a soft floor on the policy rate. Second, the federal funds rate target is set at the top of the target band, equal to the IOER. Third, the introduction of the overnight reverse repurchase rate at 25 basis points below the IOER. With this setup, one expects the effective federal funds rate, and other short-term markets, to be contained within the band established as the result of arbitrage (Ihrig and Meade, 2015).

From the data representation in Figure 4.3 one can see this realised. The overnight nonfinancial commercial paper interest rate provides an idea of the interest rates on nonfinancial firms without access to the IOER facilities of the central bank. For these nonfinancial firms the market rate is close to the RRP rate. On the other hand, the Treasury general collateral financing (GCF) repo rate represents a market related interest rate that takes only a few nonbank institutions into account. This rate better reflects the notion that market rates move in line with the IOER rate, as opposed to the narrative suggested by the effective federal funds rate.

There are several undesirable effects from policy normalisation. In terms of the domestic economy, unwinding of the balance sheet and using tools like RRPs can lead to an increased footprint in financial markets, disrupting financial intermediation. However, policymakers should not only be concerned with secondary effects in their own markets; they should consider that policies implemented and disbanded could have potential international spillovers. The next section discusses the potential impact that policy initiatives can have on the rest of the world.

4.2.3 International Spillover Effects

The explosive growth of the balance sheets of advanced economies has led to a rapid increase in global liquidity (Tillmann, 2016). Owing to the increasing interconnectedness of global economies a significant portion of this liquidity spilled over to emerging markets. The magnitude of the liquidity shock leads one to believe that these spillover effects could be potentially severe. Brazil's president, Dilma Rousseff, referred to the expansionary policies of advanced economies as creating a "monetary tsunami"[35]. Although some emerging economies have profited from these unconventional policies, the reality is that it leaves a large portion of them exposed to

[34] The targeted federal funds rate is provided at http://www.federalreserve.gov/monetarypolicy/openmarket.html

[35] Which is also the title of the article by Fratzscher et al. (2012).

market volatility and current account reversals. Spillovers from balance sheet policies have been a source of lively debate between researchers and policymakers, and in this section I frame some of the pertinent arguments.

While many countries have experienced a substantial boom in economic activity as the result of these policy actions, it has often come at the cost of severe disruptions to several key markets. Financial markets, in particular, are prone to distortion as a consequence of increased risk taking on the part of both foreign and domestic investors. This is illustrated by the portfolio balance channel where purchases of long-duration securities cause a substitution toward higher yielding assets. The search-for-yield by investors from developed economies often leads them to direct their capital flows to emerging markets, where returns are relatively higher (Banerjee and Basu, 2015).

Inflows of capital typically are welcomed, in moderation. However, large inflows can be quite volatile and create temporary stock market booms[36]. In addition, they tend to drive up prices of certain assets artificially, leading to asset bubbles and lower yields in the affected countries (Morais et al., 2015). As a result, looser financial conditions in the country receiving capital flows can develop, which promotes risk seeking by domestic investors (Lavigne et al., 2014).

It has been argued that the exchange rate channel also has an important role to play (Park et al., 2015). Capital outflows could cause a depreciation in the currency of the country implementing the policy. This could improve the competitiveness of the advanced economy by making its exports relatively cheaper. On the other hand, asset purchases would mean greater demand for emerging market products, potentially offsetting the effect of the appreciation (Lavigne et al., 2014). The next section provides an overview of the empirical evidence from studies on international spillovers.

4.2.3.1 Empirical Evidence

The idea of spillovers across financial markets is not a new one. The literature on monetary spillovers is present in the work of David Hume in 1742, while early modelling of these phenomena dates back to the contributions of Fleming (1962) and Mundell (1963). The reason for the intense study of spillovers and capital flows is their ability to generate crises. Since the Second World War, there have been several crises that have been initiated by strong capital inflows and then accompanied by sudden reversals. Examples of these are the tequila crisis in Mexico in 1994-95, the East Asian financial crisis in 1997, the Russian default in 1998,

[36] In an interesting quote by Reinhart and Reinhart (2008), they state that "bonanzas are no blessing for advanced or emerging market economies. In the case of the latter, capital inflow bonanzas are associated with a higher likelihood of economic crises (debt defaults, banking, inflation and currency crashes)".

the Argentine crisis in 2001 and the South American economic crisis of 2002 (Powell, 2013). However, empirical research on the topic of international spillovers in the case of the recent financial crisis is still limited. Researchers have been able to determine that the magnitude and speed at which the policies of advanced economies are being transmitted to emerging markets is unprecedented, with the relative impact of channels of transmission not known (Ghosh and Saggar, 2016)[37].

At this stage almost all of the studies focus on the cross-border impact of the US large-scale asset purchases. Two strands of research on the effects of QE have emerged. First, a literature has developed on studying the impact of the announcement of QE by utilising high frequency data; this usually entails the use of event study methodology. Second, several studies consider the broader macroeconomic impact of QE with monthly and quarterly data. Econometric techniques are normally variants of the VAR methodology, and are often applied to panel data. I discuss the empirical evidence from each strand in turn.

4.2.3.1.1 High-Frequency Data Using intraday data on futures prices Glick and Leduc (2013) identify the surprise component from the announcement of QE, and found that it caused a significant depreciation of the US dollar in relation to other major currencies. They argue, however, that the effect is not dissimilar to that of a conventional monetary policy shock of equal size. However, in a later study, Glick and Leduc (2014) amend their result, using a new approach to identifying policy surprises. They found that monetary easing through balance sheet expansion has roughly three times the impact as that of an equivalent interest rate shock[38]. In other words, balance sheet policy has more "bang per policy surprise on the value of the dollar" than previously (Glick and Leduc, 2014).

Fratzscher et al. (2013) look at the impact of QE1 and QE2 (as implemented by the Fed) on international financial markets, looking specifically at the effect on interest and exchange rates. A unique dataset of high-frequency portfolio flows allowed them to track capital injections across a wide range of countries. They found that QE1 caused an appreciation of US currency, with large-scale withdrawals of capital from emerging markets, which resulted in increased equity and bond prices in the US. However, QE2 seemingly caused a depreciation of the US dollar and an outflow of capital to EMEs.

Bauer and Neely (2014) make use of event studies and dynamic term-structure models to evaluate the contribution of the signalling and portfolio balance channels in affecting international

[37]By this, I mean that the relative strength of the channels is not known. The effect of the spillover could be positive or negative depending on which effect dominates. Some of the relevant channels are the exchange rate channel, the domestic demand channel and foreign financial conditions.

[38]Naturally, this is a comparison to the period before the ZLB was reached, as that was when the last shock was applied to conventional policy instruments.

bond yields. They found that the relative impact on bond yields from LSAPs is similar to the movement experienced as a result of conventional monetary policy surprises. Neely (2015) looked at the impact of QE in developed economies, focusing on the cross-border financial market impact. He used an event-study approach in conjunction with a portfolio balance model and found a substantial impact on international markets, decreasing yield spreads across all countries considered. In a similar vein, the work of Rogers et al. (2014) focused on the effect of unconventional policies on asset prices (using daily and intradaily data) in a selection of developed economies. They found that there are significant, but asymmetric, cross-country spillovers where the "effects of US monetary policy shocks on non-US yields are larger than the other way round" (Rogers et al., 2014).

4.2.3.1.2 Lower-Frequency and Panel Data Chen et al. (2012b) used a global VAR to determine the financial market impact of QE. They found that QE increased global asset prices across a wide range of assets, such as sovereign and corporate bond yields. According to this study, emerging markets, in particular, experienced increased capital flows, greater credit extension and inflationary pressure. Lim et al. (2014) used a panel model for capital flows. They found significant spillover effects to developing countries through the portfolio balance, signalling and liquidity channels from the US LSAP programs. Bowman et al. (2015) used a VAR, and their results indicate that the effect of QE has not outsized that of normal monetary easing. In order to determine the relative contribution of quantitative easing, Alpanda and Kabaca (2015) developed a two-country DSGE model. They found that the effect of QE is larger than that from conventional monetary policy, with increased asset prices in the rest of the world.

A newly released article by Tillmann (2016) tries to quantify the effect of QE on emerging market economies. He sets up a Qual VAR[39], that inputs information from QE announcements into a traditional VAR setting. Tillmann (2016) finds that QE has significantly impacted emerging economies, specifically along the dimensions of "capital flows, exchange rates, equity prices and bond prices". Using a global VECM, Chen et al. (2015) also found that QE significantly affected emerging markets, contributing to the overheating, but also recovery, of several economies after the financial crisis. They believe that unintended international spillovers from balance sheet policies could be an important source of global financial instability in future, which leads us to our discussion on tapering.

[39] As first utilised in Dueker (2005).

4.2.3.2 Tapering

In my discussion on exit strategies, the idea of unwinding balance sheet measures was investigated. Recently, concerns have been vocalised, by emerging market economies such as India, Turkey, Brazil, Indonesia and South Africa, about the phasing out of these balance sheet measures (Tillmann, 2016). As evidenced by the 'taper tantrum' of 2013, balance sheet policies can have a large effect on international markets in highly globalised markets (Aizenman et al., 2014). As a result of this announcement, sovereign yields in many emerging market economies increased, stock market indices registered large drops, and currencies depreciated (Bowman et al., 2015). In addition, sharp reversals of capital flows were recorded in several Asian and Latin American countries (Nechio, 2014).

Contractionary policy in advanced economies, which signals the transition to higher global rates, could mean a more pervasive reversal of capital flows (Mishra et al., 2014). Reversals could have a substantial impact on emerging markets, causing sudden stops when capital returns to advanced economies. While external factors are important for spillover effects, one also has to consider internal domestic macroeconomic fundamentals[40] (Nechio, 2014). Although it is possible for countries with strong fundamentals to be affected by spillovers, the general consensus is that those countries have a greater tendency to weather volatile capital movements, as agreed by Ahmed and Zlate (2013), Aizenman et al. (2014), Sahay et al. (2014), Rai and Suchanek (2014) and Basu et al. (2014).

Conflicting evidence is reported with respect to the effect of tapering on countries with 'deeper' financial markets. Eichengreen and Gupta (2015) argue that countries with greater 'financial depth' are exposed to large capital movements, due to the relative ease with which flows can be injected and withdrawn. On the other hand, Aizenman et al. (2014) find that countries with more sophisticated financial markets were better positioned. They attribute this, in part, to the fact that these countries normally have stricter macroprudential policies with respect to capital flows.

The lesson one can draw from this is that in order to overcome problems of the exit from balance sheet expansion, there needs to be greater international monetary policy coordination. Advanced economies need to communicate their exit strategies clearly, to prevent market overreaction. Emerging markets can insulate themselves from shocks, by adhering to stricter macroprudential rules with regard to credit flows. In addition, weaker economies need to improve the position of their fiscal and current accounts, as having stronger fundamentals could provide a buffer against the greatest shocks to capital flow.

[40]Usually determined by the health of the fiscal and current account.

4.3 Chapter Conclusion

As frequently mentioned, the financial crisis was a widespread disaster that resulted in an untold disruption of the world economy. Befitting the size of this event, authorities responded with policy actions of an unprecedented magnitude. Owing to the degree of monetary intervention, it seems prudent to reflect on these policy actions. Academic discussion as to the potential policy impact and transmission is a useful starting point, but it needs to be consolidated with appropriate empirical evidence. Success of policies implemented, and the proposed channels of transmission, are presented in this chapter. The consensus is that balance sheet policies were successful in avoiding even larger disturbances to economic activity, and in some cases restored function to failing markets. There is still disagreement as to the specific channels through which balance sheet policies operated, but their overall success is consented.

From this discussion it is evident that the usage of central bank balance sheets will become the norm in many advanced economies experiencing financial distress. Adopting these policies when financial markets are dysfunctional, and traditional policy tools have outgrown their usefulness, is easy to motivate and considered a necessary evil. However, it uncertain to what extent these measures will be used in normal times. Concerning normal times, the last part is a discussion on the broader implications, such as international spillovers and central bank independence. Most importantly it includes a discussion on how policy is to move forward with inflated balance sheets.

In a recent article Ihrig and Meade (2015) state that the new implementation of monetary policy with interest on excess reserves and reverse repurchase agreements, as implemented by the Fed, means that the way we understand and teach economics to future generations will fundamentally change. The next chapter takes a look at the textbook narrative of monetary policy implementation and how it could possibly change to reflect future developments.

Part II

Empirical Work and Model Construction

Chapter 5

Liquidity Effect

> *Following the on-going financial crisis, central banks are now probably on the verge of a further, fourth, epoch, though the achievement of a new consensus on their appropriate behaviour and operations may well be as messy and confused as in the two previous interregnums.*
>
> — Charles Goodhart (2011)

In his paper on the changing role of central banks, Goodhart (2011) identifies three stable epochs of central banking, with the most recent, third epoch, dating from the 1980s to 2007. The anguish of central bankers was unmistakable in the interregnum before this epoch (Burns, 1979). Despite access to powerful tools of monetary policy, and a willingness to use them, central bankers could not contain the persistent inflation of the 1970s. Fortunately, this inspired cooperation on the part of academic researchers and policymakers alike, bringing about a period of sustained price and output stability. The position of central banks during the 1970s can then be juxtaposed with the current interregnum. Given this setting, one can ask, will a new epoch require a similar paradigm shift? In this chapter I consider such a shift in thinking about monetary policy, highlighting important changes to the conventional operational frameworks of central banks.

5.1 Introduction

Monetary policy, post Bretton Woods, saw the emergence of the short-term interest rate as the primary policy instrument. However, in the wake of the financial crisis, balance sheets have, again, become part the monetary policy toolkit, now empowered to perform more than an automated role in policymaking. The present-day incarnation of balance sheet policy differs in character, though, from historically used balance sheet mechanisms. We now observe that under certain monetary policy regimes, balance sheet policies operate independently from movements in the central bank policy rate[1]. The independence of these monetary policy tools contests the conventional wisdom on the role of central bank balance sheets in policymaking (Borio and Disyatat, 2010). One of the implications is that balance sheets potentially could be used to extend the policy reach of central banks to promote financial stability.

To appreciate fully the changing role of balance sheets in policymaking one needs to look at the history of monetary policy implementation. Since the Second World War there has been a significant evolution in the way monetary policy is conducted. During this period central banks adopted several operational frameworks. Monetarism, which was dominant in monetary policy implementation from the early 1970s to the late 1980s, emphasised the ability of central banks to exert tight control over the money supply. This gave rise to use of several quantitative concepts[2] as preferred operational targets in this era. Operational targets of monetary policy[3] refer to some class of economic variable that the central bank can control using its monetary policy tools. Central banks utilise three tools toward this end, namely, reserve requirements, standing facilities and open market operations (Bindseil, 2004).

This monetarist view coincides with the textbook model of monetary policy implementation, which largely is shaped by the experience of the United States (US). According to this view, central banks actively practice their influence over the money supply in order to pursue their intermediate target[4] and ultimately economic objectives (Keister et al., 2008). However, since the early 1980s central banks have shifted their focus away from quantitative targets toward a short-term interest rate[5].

This textbook narrative underlines the fundamental link between the balance sheets of central banks and monetary policy (Keister et al., 2008). In this framework, central banks can use

[1]This comment might appear vague or even inaccurate for the first time reader on the topic, but the conditions under which this occurs will be identified further on in the text.

[2]Such as the monetary base, reserves of banks, total volume of open market operations, non-borrowed reserves, excess reserves, free reserves and borrowed reserves (Bindseil, 2004).

[3]We know that “there are essentially three main types of operational targets: (i) a short-term interest rate (pre-1914, and post 1990 the dominating type of operational target, and in between also playing at least implicitly an important role). (ii) A quantitative, reserve related concept - officially in the US the operational target in the period 1920-1983. (iii) A foreign exchange rate, for central banks which peg their own currency strictly to a foreign one” (Bindseil, 2005).

[4]According to Bindseil (2004) an “intermediate target is an economic variable that the central bank can control with a reasonable time lag and with a relative degree of precision, and which is in a relatively stable or at least predictable relationship with the final target of monetary policy, of which the intermediate target is a leading indicator”.

[5]Some central banks, such as the Bank of England have never adopted quantitative targets and have always relied on the use of a short-term interbank rate (Bindseil, 2004).

the available monetary policy tools, generally open market operations, to make the short-term market interest rates effective. These operations entail a change in the level of reserves[6] to bring about changes in the interest rate (Disyatat, 2008; Kahn, 2010). The negative causal relationship between central bank reserves and the short-term interest rate is known as the "liquidity effect" (Kopchak, 2011).

A substantial body of empirical work has sought to identify a clear and stable link between several components of central bank balance sheets and key policy interest rates (Friedman and Kuttner, 2010). The results have been mixed. Some authors have found significant liquidity effects for the US economy in the 1980s and early 1990s [7]. However, when the analysis is extended beyond this timeframe one finds that the relationship fades. This has important implications for the understanding of how monetary policy implementation works in the 21st century. Theoretical models of monetary policy implementation stress the negative relationship that exists between liquidity and interest rates, but in modern central bank practice, we do not necessarily see clear evidence of this.

Several explanations have been posited to explain the disappearance of this liquidity effect in recent years. The implementation of new operational frameworks at central banks is often the reason that is put forward for the fading out of this effect. It has been suggested that because of innovations in conducting of monetary policy that interest rates and reserves have been decoupled, which means that various levels of reserves can exist for a given interest rate. The independent movement of these policy targets has been referred to as the "decoupling principle" (Borio and Disyatat, 2010). This has far-reaching implications for the future conduct of monetary policy, as it provides the central bank a new tool with which to pursue additional economic objectives.

The objective of this chapter is to establish the empirical validity of the decoupling principle by analysing the relationship between short-term nominal interest rates and selected central bank balance sheet variables in four countries, each with different operational frameworks. Several empirical methods were used in order to assess the nature of the liquidity effect in the selected sample of countries. First, a simple rolling regression was used to illustrate the potential liquidity effect in each country over time. Second, an identified VAR was used to determine the effect of a shock to different quantity concepts on the relevant policy interest rate for different subsamples. Third, a time-varying parameter VAR (TVP-VAR) with stochastic volatility was constructed, which combines the time-varying properties of the rolling regression and the structural nature of a VAR analysis.

[6] Reserves take the form of both bank deposits and vault cash held at the central bank.
[7] Studies primarily have focused on the United States.

The chapter is structured as follows. Chapter 5.2 contains a literature review on the liquidity effect. This review provides a context for the rest of the discussion in the chapter. Chapter 5.3 provides a discussion on the different operational frameworks of modern central banks. This section also endeavours to undertake a descriptive analysis of the decoupling principle in the sample of countries. Chapter 5.4 provides empirical evidence of the decoupling principle. Chapter 5.5 concludes.

5.2 The Liquidity Effect

According to the traditional/textbook view of monetary policy implementation, central banks conduct open market operations[8] in order to steer the short-term market interest rates toward the bank's policy interest rate target (Friedman and Kuttner, 2010; Ihrig and Meade, 2015). The mechanism underlying monetary policy conduct within this framework is often illustrated with the aid of a graph, as in Figure 5.1. The explanation turns on the interaction of a negatively sloped money demand curve, m_t^d, with a perfectly inelastic money supply curve, m_t^s. The money supply curve is vertical because the central bank is a monopoly supplier of money or reserves (Ihrig and Meade, 2015). In this model m_t is the log of nominal money, d indicates demand and s, supply. These money demand and supply functions are usually expressed analytically, in addition to the graphical presentation. The following money demand and supply relations, similar to those found in Pagan and Robertson (1995), will prove useful for exposition. These equations are:

$$m_t^d = \alpha_1 + \alpha_2 r_t + \varepsilon_t^d \tag{5.1}$$

$$m_t^s = \beta_1 + \beta_2 r_t + \varepsilon_t^s \tag{5.2}$$

where r is a short-term non-negative nominal interest rate and ε_t^d and ε_t^d are mutually uncorrelated demand and supply shocks. In equilibrium, $m_t^d = m_t^s$. Shifting either the m_t^s or m_t^d curves within this framework will bring about changes in the level of the interest rate and/or level of money in the economy. One could ask, what would happen in the case where $\beta_1 \uparrow \Rightarrow m^s \uparrow$ (i.e. expansionary monetary policy)? An increase in β_1 would result in a decrease in r_t if $\alpha_2 < 0$ and $\beta_2 \leq -\alpha_2$ because $dr/d\beta_1 = (\alpha_2 - \beta_2)^{-1}$. It is established that $\alpha_2 < 0$ as m_t^d is downward sloping and it is assumed that $\beta_2 = 0$, which means that m_t^s is perfectly inelastic[9]. The changes

[8]This is achieved by buying or selling reserves/quantity aggregates to depository institutions (i.e. expansion or contraction of the money supply)

[9]The shape of the supply curve in this model is assumed to be vertical, although some Post-Keynesian authors have suggested that a horizontal supply curve is more realistic.

induced are illustrated in Figure 5.1; one can see that increasing the money supply[10] drives down the nominal interest rate[11]. The negative response of the interest rate to an increase in the money supply is referred to as the "liquidity effect" (Friedman, 1972)[12]. Because central banks retain a monopoly over the supply of outside money, the existence of this effect allows them to tightly control the short-term interest rate through adjustments in m_t^s.

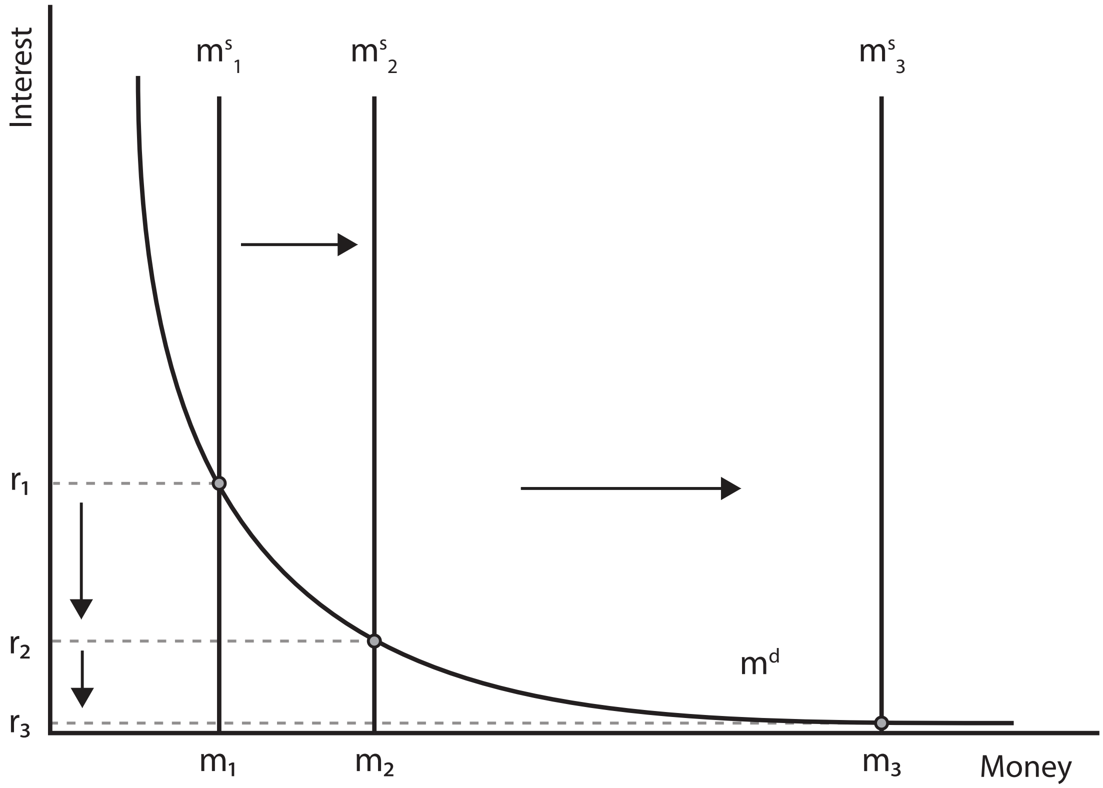


Figure 5.1: This figure presents expansionary monetary policy in the traditional model of central bank interest rate setting. Changes in the m^s curve cause a move along the m^d curve. A rightward shift in m^s increases the quantity of money and depresses the level of the nominal non-negative short-term interest rate

The negative relationship between m_t^d and r_t is a crucial component in this monetary policy narrative, and has resulted in a substantial body of work to investigate the empirical validity of the claim (Friedman and Kuttner, 2010). Some of the earliest attempts to capture this negative relationship were unsuccessful (Litterman and Weiss, 1984; Sims, 1986; Mishkin,

[10]Shifting the m_t^s curve to the right

[11]Once the demand for money reaches the elastic portion of the curve, changes in the money supply will not bring about significant changes in the interest rate. This is normally referred to in the literature as a "liquidity trap" (Hicks, 1937)

[12]Friedman (1968) described this mechanism in his famous presidential address: "Let the Fed set out to keep interest rates down. How will it try to do so? By buying securities. This raises their prices and lowers their yields. In the process, it also increases the quantity of reserves available to banks, hence the amount of bank credit, and, ultimately the total quantity of money. That is why central bankers in particular, and the financial community more broadly, generally believe that an increase in the quantity of money tends to lower interest rates".

1986). However, several articles (Reichenstein, 1987; Thornton, 1988; Sims, 1992; Leeper and Gordon, 1992; Gali, 1992; Bernanke and Blinder, 1992; Christiano and Eichenbaum, 1992), provide evidence of a link between short-term interest rates and several monetary aggregates, in particular the monetary base, M1 and M2[13]. Leeper and Gordon (1992) had a large impact on the liquidity effect discourse. They found a statistically significant liquidity effect, but it was highly dependent on the subsample used. In addition, the size of the innovation in money aggregates required to induce a change in the interest rate was implausibly large. This failure to provide robust and economically significant estimates of the liquidity effect is referred to as the "liquidity puzzle"[14] (Leeper and Gordon, 1992).

Several authors have argued that the fragility of Leeper and Gordon (1992)'s results were due to incorrect model specification - specifically, the use of monetary aggregates as explanatory variables. Christiano et al. (1994) argue that bank reserves could serve as a more appropriate independent variable. They constructed a vector autoregressive (VAR) model[15] and estimated the response of the short-term interest rate to shocks on non-borrowed bank reserves[16]. With this model, they established a significant and persistent liquidity effect. This outcome led Gordon and Leeper (1994), among others, to reconsider their estimation method and variable specification, and they now include a measure of reserves in their model identification. Consequently, they found strong evidence for a liquidity effect. Pagan and Robertson (1994) tried to evaluate the econometric methods used to obtain these results and found that due to improperly motivated identification strategies, evidence from these studies is weak at best. They devote the majority of their analysis and criticism to the article of Gordon and Leeper (1994).

The conflicting evidence in the literature led Strongin (1995) to examine the operational procedures of the US Federal Reserve. Strongin (1995) found that the lion's share of changes to the supply of reserves are made to prevent the market rate from deviating too far from the policy rate. These actions taken by the central bank are known as liquidity management operations[17]. In other words, it was becoming more difficult to isolate the exogenous policy actions of the Federal Reserve, and central banks in general, as the fine-tuning of liquidity management

[13]The monetary base is defined as the sum of vault cash, currency in circulation and the reserves deposited by private banks with the central bank (Bindseil, 2005).

[14]There are four 'puzzles' in empirical macroeconomics. In other words, situations in which the data does not fit the underlying theory. The four puzzles are, the price, liquidity, exchange rate and forward discount bias puzzle (Vinayagathasan, 2014).

[15]This is the standard method used for estimating the magnitude and significance of the liquidity effect in the literature.

[16]Non-borrowed reserves are equal to total reserves minus borrowed reserves, where borrowed reserves are loans/credit extended to depository institutions (which is normally located on the asset side of the central bank's balance sheet).

[17]These operations entail the provision and withdrawal of liquidity available to private banks. Repurchase and reverse repurchase agreements traditionally are conducted to alter liquidity levels.

operations became more frequent and efficient. Strongin's (1995) strategy to identify supply shocks entailed constructing a new reserve measure. He generated this variable by dividing non-borrowed reserves by total reserves. Redefining the independent variable in this fashion revealed a significant and persistent liquidity effect (Strongin, 1995). Bernanke and Mihov (1998) extended the model of Strongin (1995) to allow for different operating procedures. They present a preferred just-identified biweekly model and found a highly significant liquidity effect.

During the mid-1990s various central banks moved away from "quantity-based operating procedures, toward a focus on explicit interest rate targets" (Friedman and Kuttner, 2010). This change meant that the policy interest rate would no longer be endogenously determined through exogenous movements in the supply of reserves. Instead, central banks would rely on the announcement of an explicit policy interest rate and a credible commitment to maintaining it. The introduction of new monetary policy regimes whittled down the remaining evidence of the liquidity effect. The only line of research to yield any significant liquidity effect during the late 1990s was that of James Hamilton (1996; 1997; 1998), who advocated the use of high-frequency data.

Hamilton contributes to the literature by applying an unanticipated shock to the forecasting error of the Federal Reserve, instead of the actual level of reserves, on the last day of the maintenance period[18]. The choice of a forecasting error as an explanatory variable starts at the level of liquidity management operations. These operations entail making reserves available each day for depositing institutions. The amount of reserves needed is unknown, so the central bank attempts to forecast the demand for reserves. Deviations from this forecast, the forecast error, are supposed to alter the position of the economy along the demand for money, m_t^d, curve (i.e. supplying more/less than required in the market shifts the short-term market interest rate). Applying shocks to this variable replicates the liquidity effect. However, to affect a quantifiable movement in the interest rate required a tremendous shock to the level of reserves (which left some to question the economic significance of the result).

Thornton (2005; 2006; 2010) provides a critique on the work of Hamilton. He agrees with the finding of a liquidity effect, using data at a daily frequency, but emphasises that the effect is "statistically significant but quantitatively unimportant" (Thornton, 2006). These findings are reinforced by the work of Carpenter and Demiralp (2006a,b), who used a methodology similar to that of Hamilton (1997), estimating the liquidity effect with high-frequency data. The effect is significant but trivial, with a 1 billion dollar shock to non-borrowed reserves on the

[18]The maintenance period is a timeframe during which depository institutions must maintain a specified level of funds.

final day of the maintenance period delivering a 3.5 basis point movement in the interest rate (Carpenter and Demiralp, 2006b). This indicates that "the change in balances necessary for even a 25-basis point change in the funds rate would lead to implausibly large open market operations" (Carpenter and Demiralp, 2006b).

The most recent strand of liquidity effect literature acknowledges the decrease of the effect over time. Judson and Klee (2010) indicate, for example, that the liquidity effect has "attenuated considerably with time". They test their hypothesis by looking at high-frequency data in a sample ranging from 1995 to 2007. They posit that successive changes in policy practice, especially in the 1990s, have resulted in the disappearance of the observed liquidity effect.

Several other viewpoints are considered as to why this effect has decreased. Kopchak (2011) makes the argument, similar to the one advocated by Strongin (1995), that the difficulty in isolating the exogenous policy actions of the Federal Reserve, and central banks in general, has increased with time, as fine-tuning of liquidity management operations becomes more frequent and efficient. Furthermore, the forecasting ability of central banks has improved greatly with the introduction of modern account monitoring technology (Judson and Klee, 2010). Another argument is that the liquidity effect may have waned in developed economies because of the growing importance of non-bank lending institutions in the setting of market interest rates. This evolution has been facilitated by the "relaxation of legal and regulatory restrictions" in financial markets (Friedman and Kuttner, 2010). Innovations in the financial sector certainly have a role to play in the ongoing liquidity puzzle. However, it seems that the main contribution comes from the changes in monetary policy implementation.

Finally, the liquidity effect may have disappeared because of the shift in monetary policy implementation toward the announcement of a target policy rate. According to Guthrie and Wright (2000) the central bank announcement of a certain policy rate, rather than open market operations, is responsible for the conducting of monetary policy. They refer to these announcements as "open mouth operations". Borio (1997) reaches a similar conclusion about the importance of policy signals, in a study conducted on monetary policy implementation in industrialised countries. A verbalised credible commitment by central banks to counter any deviations from the policy rate focuses the expectations of financial actors around the specified target. In this way market rates may change without any liquidity operations ever taking place (Borio, 1997). The vital point in this discussion is that it appears that in recent years, changes in reserves have played an increasingly insignificant role in the implementation of monetary policy. The discussion in the next section provides insight into some of the operational frameworks that are currently used. Four countries, each with a different operational framework, are considered.

5.3 Changes in Monetary Policy Implementation

The discussion in the preceding section has alluded to the changing nature of monetary policy in the post-war era. This section provides some additional background information as well as a context for the discussion of the most popular operating procedures that central banks currently employ. During the 1950s through to the late 1960s, traditional Keynesianism dominated the policy space. However, the 1970s saw the rise of monetarism and with it the targeting of monetary aggregates by several central banks. A monetary target was the obvious choice for monetarists, as the tools of monetary policy enable central banks to "determine the total amount of money in existence or to alter that amount" (Friedman, 1959, p. 24). This meant adopting a precise level of reserve/money quantity as the operational target for the central bank, with the intermediate target being a monetary aggregate, for example M1. The money multiplier was at the heart of the transmission mechanism by which an adjustment in a reserve or money quantity would bring about changes in a specified monetary aggregate (Bindseil, 2004). By controlling this monetary aggregate, the central bank could exert pressure on inflation and other key economic indicators.

In the early 1980s, several central banks adopted a new operational target, a short-term policy interest rate. The shift toward a new policy instrument paradigm was heavily influenced by William Poole's (1970) seminal work on the instrument problem[19]. Poole utilised a stochastic IS-LM model to illustrate that the policy interest rate was the superior policy instrument with which to negate the impact of a large shock to the monetary sector (Poole, 1970). In the wake of this paper, three dominant monetary policy regimes emerged[20]. These regimes all use the announcement of the policy rate as the primary policy tool (Guthrie and Wright, 2000). The main difference between regimes is the mechanism by which interest rates are made effective. These regimes are discussed next, in turn.

In the traditional model of monetary policy, as propounded in Chapter 5.2, interest rates are determined endogenously through manipulation of the money/reserve supply. However, since the early 1990s, central bank operations have been approached in a slightly different manner. Two broad/stylised operational frameworks emerged. First, the reserve regime, which retains some of the components of the traditional model. The reserve regime relies on the use of reserve requirements (which usually must be met on an average basis over a specified maintenance period) and a publicly announced policy rate (Whitesell, 2006). Either this policy rate or the rate that the central bank charges can then be targeted (Brink and Kock, 2009).

[19]Poole should be referring to operational targets, as neither the interest rate nor money/reserve quantities are policy instruments. This has been the source of much confusion in the literature.

[20]The three regimes of monetary policy implementation are the reserve, corridor and floor regimes

In the case of a policy target, the central bank determines the level that it would like the overnight rate to be, based on prevailing economic conditions, and it then uses liquidity management operations to steer the rate toward this target. According to Ennis and Keister (2008), "central banks aim to adjust the total supply of reserve balances so that it equals demand at exactly the target rate of interest". This requires an estimation of the demand for reserves[21]. Errors in forecasting demand are thought to lead to movements away from the target rate. If central banks are not able to consistently hit the target, the credibility of the communication mechanism of the bank is questioned (Ennis and Keister, 2008). In the case where the rate is the one that the central bank charges, the central bank creates a "shortage of bank reserves in the money market through levying a cash reserve requirement and draining liquidity through open-market operations, and then refinances the shortage by lending funds to banks at its policy interest rate" (Brink and Kock, 2009). This approach is usually followed by developing countries with less active interbank markets.

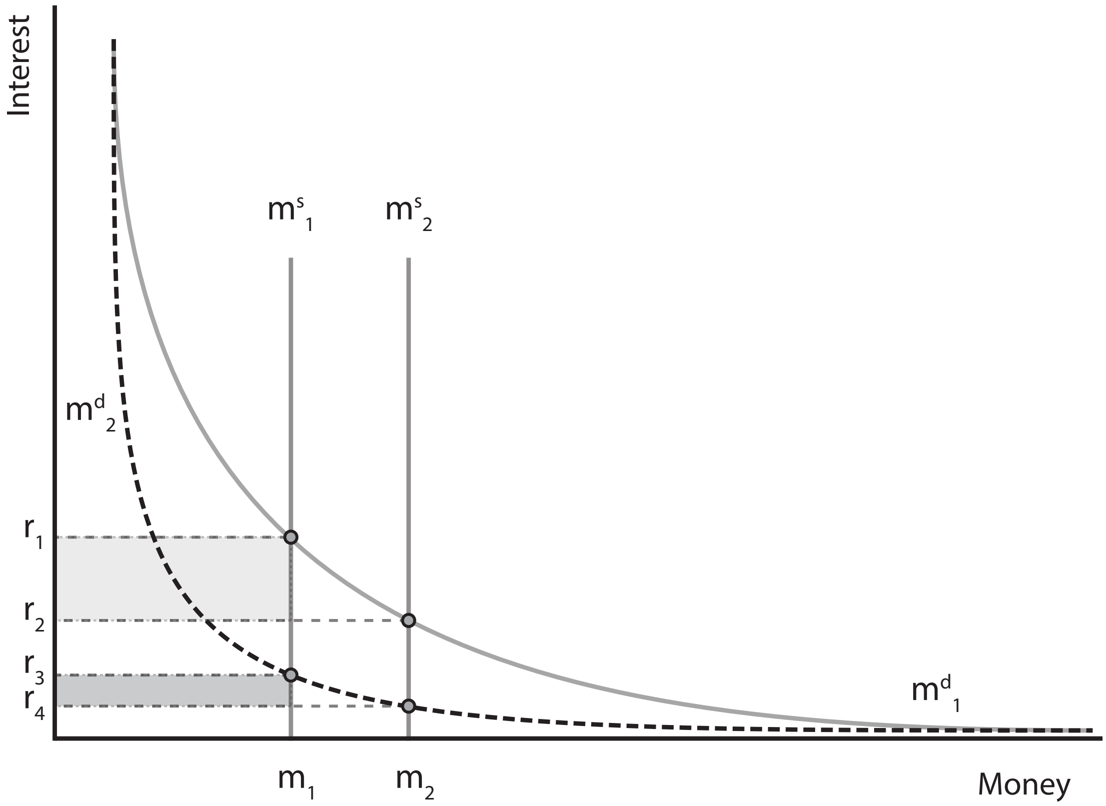
Second, some advanced economies employ a corridor or floor interest rate regime. In this regime the central banks often use interest rate targets. The most noticeable difference between corridor/floor and reserve regimes is the use of standing facilities. Some reserve regimes may employ a penalty rate or overnight lending facilities that act as an upper bound to the interest rate. However, in corridor and floor regimes, interest is paid on reserves through a deposit facility. This means that there is a lower bound placed on the interest rate. The mechanics of both these regimes is described in Chapter 5.3.1 and Chapter 5.3.2, respectively.

5.3.1 Reserve Regimes

Reserve regimes rely on the use of a reserve requirement and liquidity management operations to make the announced interest rate effective. The reserve requirement is usually greater than the working (settlement) balances of private banks (Borio, 1997). The reserve regime, in comparison with corridor/floor regimes, most closely resembles the traditional framework of monetary policy implementation, where "changes in reserve supply systematically result in movements in the relevant interest rate" (Friedman and Kuttner, 2010). However, liquidity management operations in this regime play a purely "technical and supportive role" and they "neither impinge upon, nor contain any information relevant to, the overall stance of policy" (Borio and Disyatat, 2010). The question is whether the market for bank reserves is insulated from these operations. This is emphasised by Borio and Disyatat (2010) as one of the

[21] One of the sources of demand, apart from reasons of statutory compliance (i.e. the reserve requirement), is the usage of reserves to facilitate large inter-bank settlements (Brink and Kock, 2009).

Figure 5.2: Elastic money demand



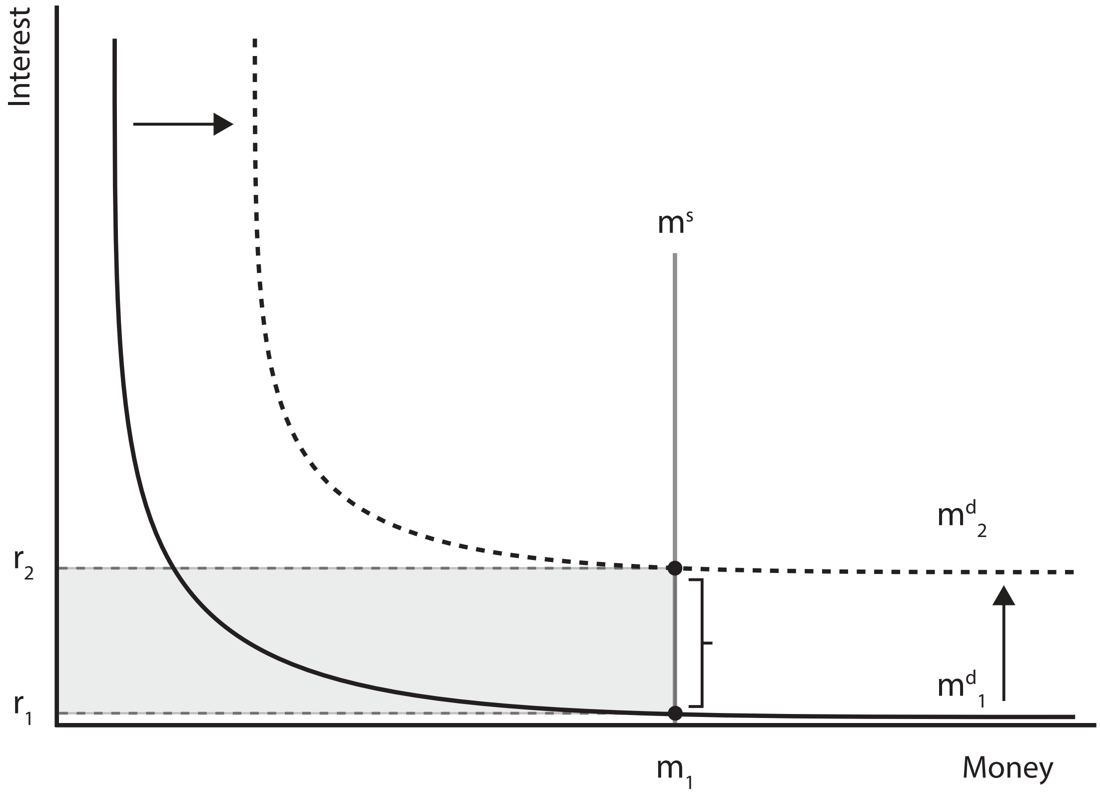
preconditions for decoupling the interest rate from the level of reserves. Central banks need to "engage in offsetting transactions that 'sterilise' the impact of the operations on the amount of reserve balances" (Borio and Disyatat, 2010)[22]. When the market for reserves is insulated from the interest rate, two changes to the traditional framework seem plausible.

First, central banks are either operating on the (almost) perfectly elastic or inelastic portion of the m_t^d curve and the argument in favour of negative interest rate elasticity becomes tenable (Friedman and Kuttner, 2010). Figure 5.2 depicts this alteration, demonstrating the inability of reserve changes to induce proportional shifts in the interest rate once m_t^d becomes sufficiently horizontal. Essentially, interest rates are unresponsive to changes in reserves, as found in the liquidity effect literature for the USA.

Second, substantial interest rate changes do not necessarily require any movement in the supply of reserves. The announcement of the policy interest rate allows central banks to set their rate (or target) instantaneously and precludes the use reserves to shift the interest rate. In Figure 5.3 the entire m^d schedule shifts outward in response to the announcement of a higher policy rate.

[22]Another way to decouple would be to ensure that changing reserve holdings have no impact on the policy rate. This would be achieved by, for example, implementing a policy rate floor, which will be discussed in Chapter 5.3.2

Figure 5.3: The announcement effect



Private banks react to the policy stance signal of the central bank. Woodford (2000) argues that "there need not be a stable relation between this overnight interest rate and the size of the monetary base in order for the central bank to effectively control overnight interest rates". This notion that interest rate movements happen regardless of the level of reserves is referred to as the anticipation or announcement effect (Carpenter and Demiralp, 2006a; Fullwiler, 2008).

The reserve regime has been quite popular with developing countries and a selection of advanced economies. In the sections to follow there is an historical overview of the monetary policy landscape of my sample of countries. In terms of reserve regimes, I will be looking at two case studies, South Africa (SA) and the United States of America (USA)[23], whereas Canada and Norway can be broadly categorised as countries that employ remuneration on reserves. This historical approach serves two purposes. First, it provides a context for my empirical analysis, which facilitates a richer interpretation of the results. Second, the vector autoregression analysis in Chapter 5.4.3 requires a logical demarcation of subsamples, which is elicited from the country-specific narratives.

[23]It should be noted that the operational framework of the US changed to a hybrid system in 2008, with the advent of the financial crisis.

5.3.1.1 South Africa

South Africa has had several monetary policy regimes since the Second World War. The Commission of Inquiry into the Monetary System and Monetary Policy in South Africa (aka the De Kock Commission Report) identified five distinctive monetary policy phases between 1945 and 1985. The first three phases occured between 1945 and 1965. The fourth phase, from 1965 to 1981, was characterised by the "use of direct monetary control measures" (Mollentze, 2000). Aron and Muellbauer (2007), in their classification of South African monetary policy regimes, refer to the period from 1960 to 1981 as a liquid asset ratio-based system, which entailed quantitative controls on interest rates and credit. In this regime "commercial banks held particular assets defined as 'liquid' as a specified minimum proportion of deposits" (Naraidoo and Gupta, 2010).

This regime was in place till the early 1980s and was replaced by the cash reserves-based system in 1985 (Gidlow, 1995). This period corresponds to the fifth phase identified by the De Kock Commission, the transition to a more market-related monetary policy regime. Mollentze (2000) states that the "monetary authorities deliberately started to pursue a policy of allowing interest rates to vary more readily as the forces of demand and supply changed in the market". In this regime the intermediate target was flexible monetary aggregate ranges, based on a broad definition of money (M3). The operational framework remained intact until 1998; however, there was a significant philosophical change in the focus of the central bank with the appointment of Dr CL Stals as governor in 1989.

Since 1998 the South African Reserve Bank (SARB) has followed a reserve regime with an announced policy rate charged on overnight lending. The repurchase rate (i.e. repo rate) is the SARB's operational target (Brink and Kock, 2009). This rate is made effective through the creation of a shortage in the money market. This process starts with the daily reserve requirement imposed on private commercial banks. All loans extended by the SARB to these depository institutions, to meet their liquidity requirement, are refinanced at the repo rate[24].

The SARB can easily maintain this shortage in the market for reserves as it is the monopoly supplier of its own liabilities. Several tools, such as reverse repurchase agreements and debentures, are at the disposal of the SARB for this goal. An increase (decrease) in central bank liabilities (assets) would be associated with an increase in the money market shortage (i.e. the draining of liquidity). Brink and Kock (2009) have the following to say on this,

[24]Which is determined by the Monetary Policy Committee (MPC).

> *Any transaction between the banking sector and the central bank that results in a credit entry into a bank's account at the central bank, results in a creation of new money-market liquidity which, if no further transactions are undertaken, increases the bank's reserve balances with the central bank (i.e. increases the monetary base)*.

An important distinction needs to be made between the different types of liabilities found on central bank balance sheets. The unwinding of the central bank's balance sheet is not entirely under the control of the SARB. According to Disyatat (2008), the "precision of their control depends largely on the degree with which the autonomous factors can be anticipated by the operation desk on a daily basis". Therefore, control relies on the balance of passive/autonomous[25] and active/non-autonomous[26] liquidity management.

The liabilities side of the balance sheet can generally be divided into these two broad categories. If one considers the case of South Africa, the autonomous factors include the notes and coins in circulation and deposits by banks at the SARB. On the other hand, SARB debentures and reverse repurchase agreements are considered non-autonomous and under the full control of the central bank (Brink and Kock, 2009). In South Africa, the relative contribution of non-autonomous factors (i.e. open market operations) has been on the decline, with government deposits[27] becoming a significant component since 1998 (Brink and Kock, 2009). Non-monetary elements now comprise more than 60 per cent of liabilities.

My empirical models, in Chapter 5.4, explore the dimensions of the relationship between non-borrowed reserves[28] and a relevant short-term interest rate. In the textbook model of monetary policy implementation, one would expect a clear and stable negative relationship between the level of non-borrowed reserves and the repo rate. Short-term interest rates, such as the bank rate, are usually "influenced by changes in the supply of non-borrowed cash reserves" (Schoombee, 1996).

5.3.1.2 USA

The Federal Reserve is, in all eventuality, the most extensively studied central bank in the world. Several comprehensive works, for example, Friedman and Schwartz (1963) and Meltzer

[25]Factors that central banks retain no control over.

[26]Factors that central banks actively manage.

[27]These deposits are semi-autonomous.

[28]Non-borrowed reserves generally are calculated as total reserves minus borrowed reserves. Borrowed reserves are found on the asset side of the balance sheet, normally referred to as loans, borrowing, liquidity provided, etc. In the case of South Africa borrowed reserves were defined as the total liquidity provided (i.e. money market shortage).

(2010), map out the entire history of the Fed in meticulous detail. The focus of the world on the practice of the Fed has led many central banks to adopt policies that are closely aligned. It is therefore interesting to look at the different operational frameworks and targets that the Fed has utilised in the post-war era[29]. Romer and Romer (2004) posit the theory that fundamental changes in policy have been the result of changes in the outlook of policymakers carrying out that policy. They found that the objective of Fed chairpersons largely has remained the same, but the methods employed to reach their intended targets have been clearly distinguishable.

An appropriate way then to differentiate between monetary policy regimes in the US is by considering the different terms of each chairperson. In fact, several papers that try to empirically identify monetary policy regime switching in the US found that changes in policy outlook coincide with changes of the incumbent chairperson (Sims and Zha, 2006; Bae et al., 2011). There have been seven Federal Reserve Chairpersons since the 2nd of April, 1951, when William McChesney Martin, Jr. took office (Romer and Romer, 2004). The official position of the Fed during the Martin era was one of 'free reserves targeting', where free reserves are equal to the difference between excess and borrowed reserves (Bindseil, 2004). Several monetary policy instruments were used actively in this era, including frequent changes in reserve requirements, open market operations and the discount rate.

In February of 1970, Arthur Burns was inaugurated (Romer and Romer, 2004). The Burns era also opened with a quantitative operational target, the reserves on private deposits. The intermediate target, M1 growth, was achieved by altering the reserve position of the Fed. Burns acknowledged the importance of the federal funds rate in the implementation of monetary policy. In the second half of the decade, the funds rate was constrained to a narrow band[30] and became the implicit operational target of the Fed (Meulendyke, 1988).

Paul Volcker became the chairperson of the Board of Governors in October 1979. He was tasked with the ostensibly insurmountable objective of overcoming double-digit inflation. In order to combat the high and persistent inflation episode of the 1970s[31], Volcker adopted an aggressive contractionary policy stance. For Volcker, this meant taking a monetarist approach, substituting away from interest rate targeting to non-borrowed reserves as operational target (Meulendyke, 1988; Bindseil, 2004). In 1983, the Fed changed their operational target once again, to borrowed reserves coupled with a five per cent band around the federal funds rate.

Alan Greenspan, who became chairperson in August 1987, was probably the most influential central banker in history. Greenspan continued to use the operational targets of the Volcker era

[29] Especially after 1951, when the Fed gained its independence from the government with the Federal Reserve Accord.

[30] Movements from this band were corrected through market intervention.

[31] Also known as the Great Inflation.

until 1990. Afterwards, a gradual movement toward a federal funds target was undertaken. By 1994 the process was completed, and a federal funds rate target was explicitly announced after each Federal Open Market Committee (FOMC) meeting (Bindseil, 2004). Ben Bernanke, who became chairperson in February 2006, adopted a hybrid regime in 2008 with the advent of the financial crisis. The most recent chairperson, is Janet Yellen, who took office in February 2014. During her term, the Fed increased the federal funds rate in December 2015. This was the first rate increase since 2006.

The mechanics of implementation are highly similar to those of the South African case. The primary difference is in the setting of the short-term interest rate. In the case of the Fed, the FOMC announces a target for the federal funds rate and instructs the Open Market Trading Desk (OMTD) at the New York Federal Reserve to carry out market operations to achieve the target rate. The OMTD conducts the operations by "estimating the quantity of reserves that will be demanded given the FOMC's target federal funds rate and supplying the reserves required to meet that demand at the target federal funds rate" (Kahn, 2010). Forecasting demand is not a precise science, and deviations from the forecast result in volatility of the effective federal funds rate.

5.3.2 Corridor, Floor and Hybrid Regimes

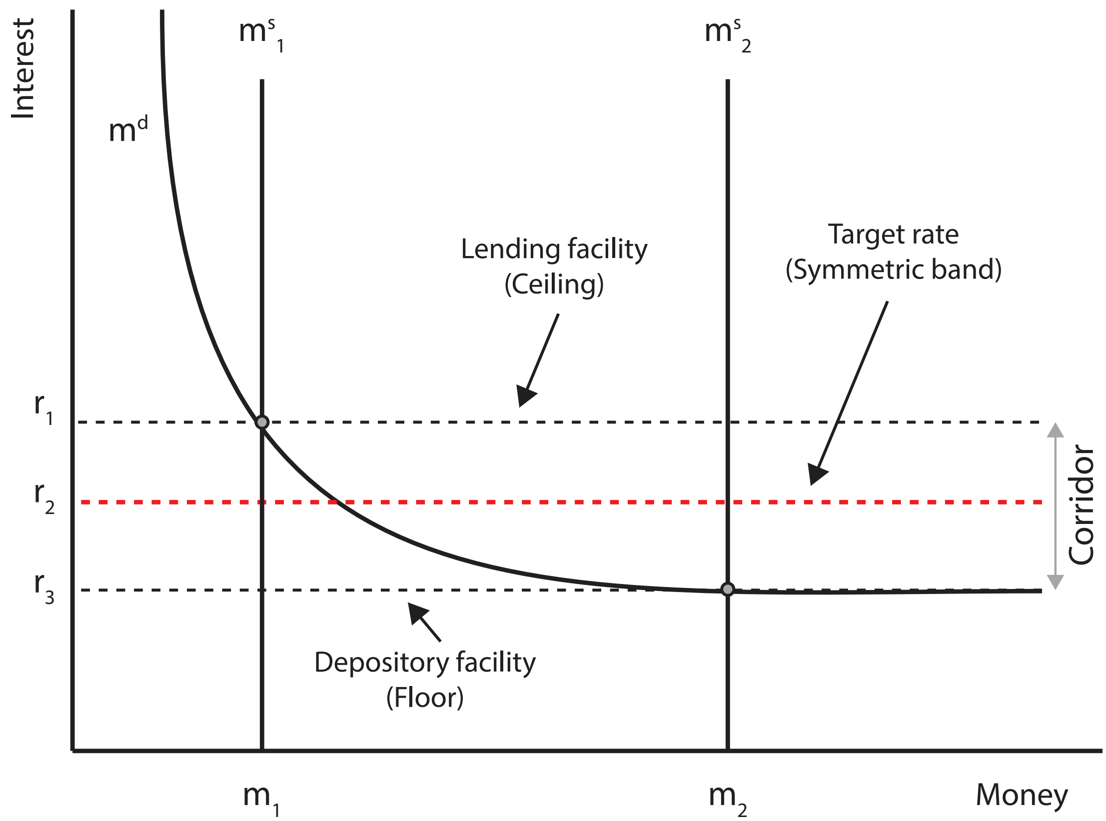
Corridor and floor regimes do not require the levying of reserve requirements to make the targeted interest rate effective; standing facilities are used instead [32]. Most central banks have a lending facility and could establish an interest rate ceiling. This interest rate charged on the lending facility, set above the target rate, imposes a "penalty on depository institutions that borrow from the central bank rather than in the interbank market" (Kahn, 2010). However, in a corridor regime, the standing facilities provide both a ceiling and floor to the target interest rate. The floor, which is established under the target rate in a corridor system, is a depository facility where private banks can deposit reserves and receive a fixed rate of interest on these deposits (Keister et al., 2008). The spread between the ceiling and floor rates is usually narrow and is called the "interest rate channel, tunnel or corridor" (Whitesell, 2006).

Both the upper and lower interest rate limits are presented in Figure 5.4. In a symmetric channel/corridor regime, the target will be set in the middle of the deposit and lending facility. In other words, the upper and lower limits form a symmetric band around the target rate. This is often referred to as a pure corridor regime, and is implemented by countries like Canada and

[32]For the purpose of this paper, a corridor or floor regime with a reserve requirement is referred to as a hybrid regime

Sweden. In this regime the aim of the central bank is to "keep total reserves in the banking system at zero, or marginally higher than zero" (Syrstad, 2012). Figure 5.5 is a graphical representation of the corridor system in Canada. This corridor system has been in place since 1995, to avoid excess interest rate volatility. The Bank of Canada was forced to move temporarily to a floor system between 2009 and 2011.

Figure 5.4: Corridor/floor system of monetary policy implementation



The floor regime differs from the corridor system in two distinct ways. First, the deposit rate is set equal to, instead of below, the central bank's target rate (Keister et al., 2008). Second, the reserve supply is chosen to intersect the flat portion of the demand curve depicted in Figure 5.4. In other words "the central bank must provide the banking system with so much liquidity that the overnight rate approaches the central bank's deposit rate" (Bernhardsen et al., 2010). Norway and New Zealand are examples of countries that have implemented such a regime. Figure 5.6 provides a look at the Norwegian floor system. As stated in Chapter 5.3.1, one of the conditions for decoupling is that changes in reserve holdings have no impact on the policy rate, as per the floor regime.

Several authors (Goodfriend, 2002; Keister et al., 2008; Borio and Disyatat, 2010; Bowman et al., 2010; Kahn, 2010; Lavoie, 2010; Ireland, 2012) have suggested that under floor regimes the 'decoupling principle' is most readily observable. Goodfriend (2002) was the first explicitly to formulate this hypothesis. He believes that under a floor regime the central bank could potentially target any quantity of reserves, as long as liquidity is in excess of the amount required to keep the policy rate equal to the interest paid on reserves. To maintain this floor regime, the central bank has to satiate the banking system with reserves at all times. In this setting the policy rate is theoretically controlled by the level of interest on reserves (Kopchak, 2011). Following the recent decision by the Fed to impose interest on reserves, Keister et al. (2008) claim the central bank "has 'divorced' the quantity of money from the interest rate target and, hence, from monetary policy". This divorce leaves the central bank two independent policy instruments, namely the policy rate and the quantity of reserves. Ireland (2012), for example, believes that under a floor regime, "the traditional short-run liquidity effect, associating a monetary policy tightening with higher interest rates brought about through a reduction in the supply of reserves, vanishes".

In reserve regimes, depository institutions are required to hold non interest-bearing reserves, which represent an opportunity cost to these banks (Kahn, 2010). The distortion created by this tax on reserves was highlighted by Friedman (1959), who argued for the payment of interest on reserve balances at the market rate. Friedman believed that "central-bank reserves are a valuable transactions medium" and that "they should be made available in elastic supply and not taxed" (Kashyap and Stein, 2012). This entails remunerating private banks for reserve balances held at the central bank. The opportunity cost of holding money is also a central concept in the Friedman rule for the optimum quantity of money, which advocates setting the nominal interest rate to zero to address the distortion (Friedman, 1968; Cúrdia and Woodford, 2011).

Several developed nations find themselves utilising a combination of interest on reserves and a modified non-negative Friedman rule (especially since the financial crisis). This combination of interest rate floor and reserve requirement forms part of what is considered a hybrid regime[33]. In the case of the US after 2008, for example, where interest rates were driven to the floor of the interest rate corridor, the system resembles an application of a non-negative Friedman rule[34]. Pure corridor and floor regimes are not subject to these drawbacks as only settlement (working) balances are held by private banks (Borio, 1997).

[33]Countries with a corridor system and reserve requirement are also referred to as hybrid regimes

[34]This discussion is further explored in the previous, where I discuss the exit strategy currently implemented by the Fed

5.3.2.1 Canada

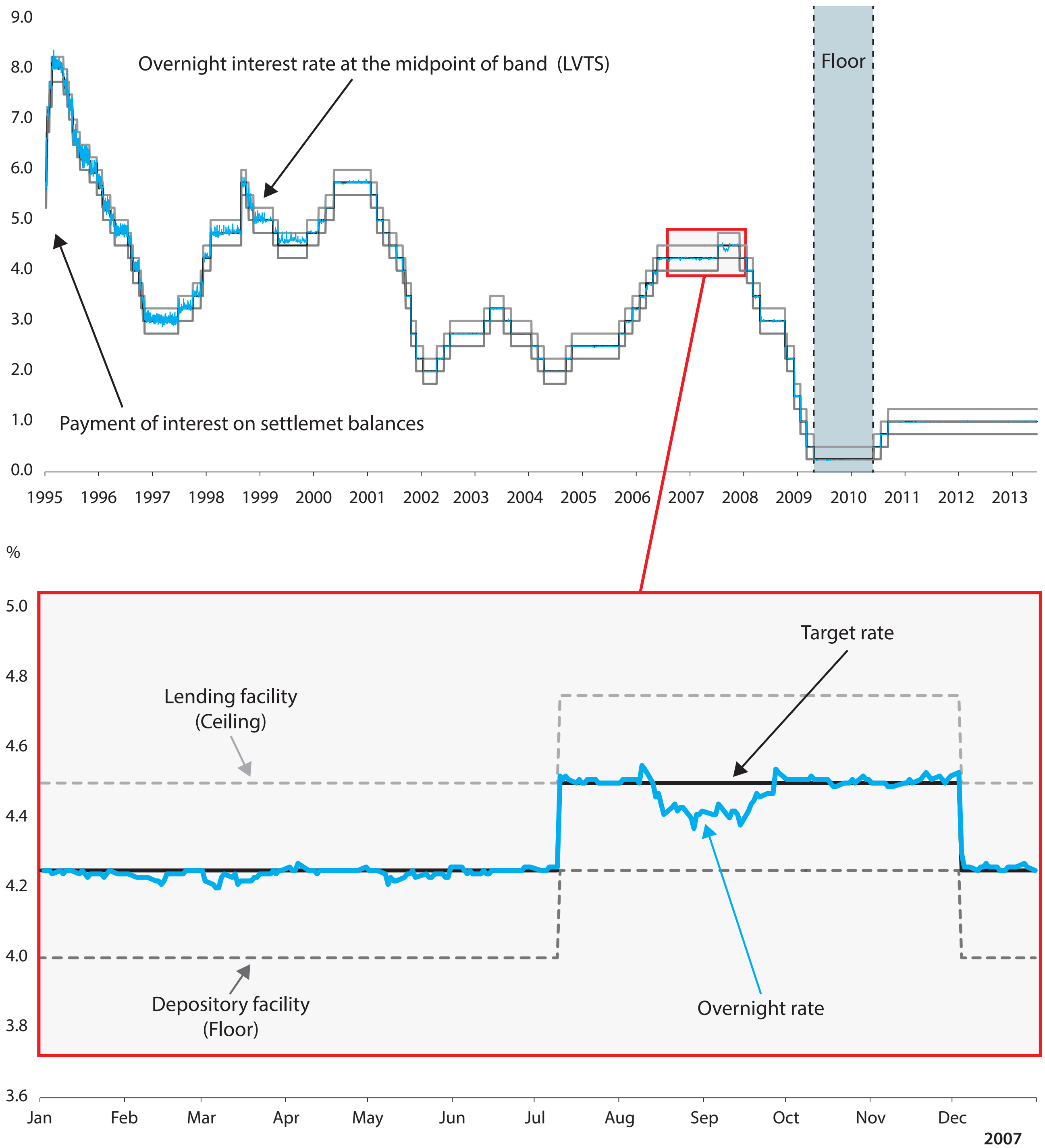
The Bank of Canada's operating framework has been relatively stable since the 1950s. Monetary policy has been implemented through the conventional method of manipulating the supply of reserves (or settlement cash in the case of Canada) to influence the overnight cost of financing (Armour et al., 1996). However, a few deviations from a focus on short-term interest rates as an operational target have been recorded. These departures normally are prompted by prevailing economic conditions, driven by volatility in the exchange rate. Seeing that Canada is a commodity-rich small open economy, it is subject to abrupt movements in the exchange rate. A floating exchange rate regime was implemented between 1950 and 1962. During this period the bank rate was floating[35] and the bank exercised control over mandated bank reserves to perform open market operations (Laidler et al., 2010).

The Canadian dollar came under pressure during the late 1950s, which instigated a futile attempt at foreign exchange intervention. In 1962, and up until 1970, the Bank of Canada relinquished its monetary policy independence in order to maintain an exchange rate peg to the US dollar. In the late 1960s a "surge in demand for Canadian exports accentuated the rising trend in the Canada/US-dollar real exchange rate, and the classic tension between incompatible goals for the exchange rate and the domestic economy became overwhelming" (Laidler et al., 2010). Canada's third monetary policy regime was enacted in 1970 with the floating of the exchange rate.

The oil-price shocks of the 1970s brought elevated inflation, along with reduced economic activity. The Bank of Canada responded by adopting "monetary gradualism" (Lange, 2010). This 'monetary gradualism' meant that the central bank was "committed to effect a gradual reduction in the mean and the variance of the growth rate of the money supply (Ml) and to maintain it thereafter at a low and stable level to establish a low and steady rate of inflation in the long run" (Fortin, 1979). Policy decisions were linked closely to the monetary policy position of the Fed at the time, which tried to establish control over monetary aggregates, and from 1979 to 1982, "the conduct of policy was complicated by shocks to M1 demand, erratic U.S. monetary policy and volatility of the exchange rate" (Armour et al., 1996).

As a result of these developments, money growth targeting was abandoned in 1982 (Laidler, 1999). Growth of M1 was still used as an indicator variable after 1982, but it lost its place as part of the formal operating framework of the central bank. In the period from 1982 until the adoption of an inflation targeting regime in 1991, it was believed that the Bank of Canada

[35] It was set at 25 basis points above the average yield on three-month treasury bills at the Federal government's weekly auction.



Source: Bank of Canada

Figure 5.5: Canadian corridor system of monetary policy implementation

piggybacked on US policy and had an implicit exchange rate target (Bordo and Redish, 2006). The year 1982 also heralded the return of active short-term interest rate management to control inflation (Dib, 2002).

The 1990s are of special interest in the conduct of monetary policy in Canada. Some highlights include the introduction of inflation targeting, in 1991; the phasing out of reserve requirements, in 1992-1994; the shifting from the Bank rate to the "target for the overnight rate", in 1994; the introduction of the Large Value Transfer System (LVTS), in 1999; and fixed dates for announcing policy decisions, in 2000 (Bordo and Redish, 2006). In 1994 the bank introduced the payment of interest on settlement balances, the final component of its symmetric corridor operating system[36]. Standing facilities for overdrafts and deposits formed a 50 basis-point operating band for the overnight rate. In 1999, with the advent of the LVTS, the target for the overnight financing rate was defined as the midpoint of the band, to reduce volatility in interest rate movements. Important changes in operating procedures during the 1990s are shown in Figure 5.5.

5.3.2.2 Norway

Monetary policy implementation in Norway following the Second World War was characterised by a belief in the ability of the central authority to fine-tune the economy through coordinating its available instruments. Policies were conducted in a similar fashion to those of the several other countries under the Bretton Woods fixed exchange rate system, before the tumultuous events of the Great Inflation. The breakdown of Bretton Woods, in 1973, meant a floating exchange rate for the Norges Bank. Supply side shocks in the 1970s pushed inflation levels beyond the control of the monetary authorities, and the economy entered a price/wage spiral. Several exchange rate interventions (devaluations of the krone) were enacted, but this could not sufficiently bolster economic growth (Gjedrem, 2001). The high levels of inflation that accompanied the economic downturn indicated that monetary policy was not functioning effectively. The realisation dawned that a new policy framework needed to be adopted. In 1985 the Norges Bank gained greater independence through legislation, and subsequently, in 1986, the Bank established a fixed exchange rate as nominal anchor (Svensson et al., 2002).

The crisis in the European Monetary System in 1992 "revealed the built-in weaknesses of a fixed exchange rate regime in a world of free capital flows and deep financial markets" (Gjedrem, 2001). Because of the crisis the Norges Bank was forced to move back to a floating exchange rate regime. The exchange rate operated in a narrow band following the crisis, but in 1996

[36]The Bank rate forms the ceiling in this corridor system, 25 basis points above the target overnight rate.

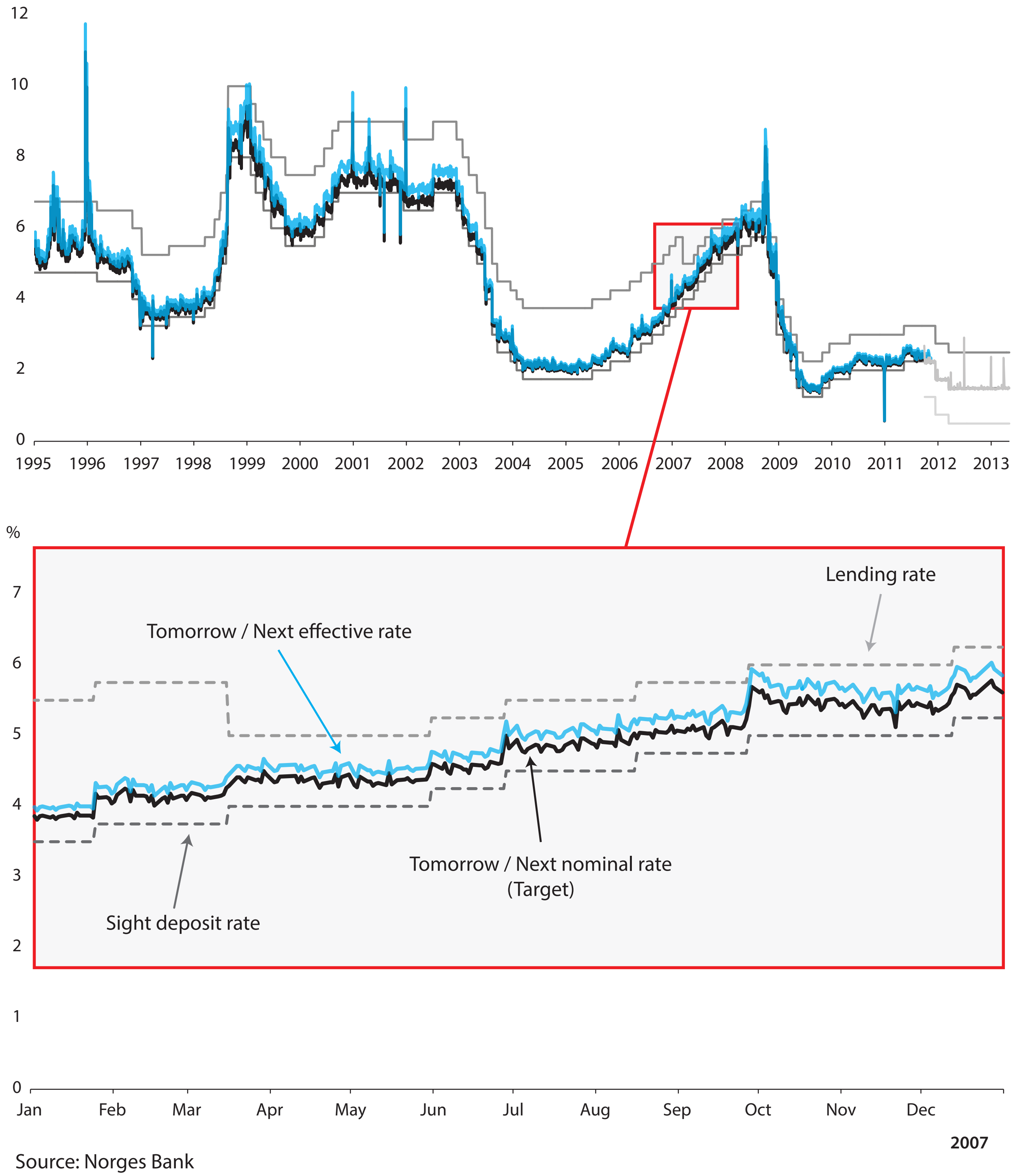


Figure 5.6: Norwegian floor system of monetary policy implementation

exchange rate volatility increased precipitously. This episode proved that fine-tuning operations were, to a certain extent, ineffectual in the case of Norway. The Norges Bank realised that in order to maintain a stable exchange rate it would need to stabilise inflation through the management of price expectations. Consequently, in March of 2001, Norway turned to inflation targeting.

The adoption of inflation targeting does not translate into the use of open market operations. The policy rates used by the Norges bank are those of its standing facilities. Two interest rates are of importance here, the interest rate on sight deposits (i.e. the deposit rate) and the interest rate on overnight loans (i.e the lending rate). These two rates form a corridor for the shortest money market rates. The Norges Bank supplies enough liquidity to the banking system to ensure that the "sight deposit rate is the banking system's marginal rate and the key policy rate in the Bank's conduct of monetary policy" (Olivei, 2002). This is the essence of the floor system, in which the target rate equals the rate charged at the deposit facility. Figure 5.5 illustrates this floor system. Since October 2011 the Norges bank has introduced a new component to the floor system, called a reserve quota. Under this regime, the central bank provides only a limited quantity of liquidity (quota) at the deposit rate. Deposits made in excess of this amount receive a lower rate of interest.

5.4 Empirical Evidence

5.4.1 Data

Country	m	p	y	r	Date
RSA	NBR	CPI	IP	Banker's Acceptance	1986m01 - 2012m01
USA	NBR	CPI	IP	Federal Funds	1959m01 - 2013m04
CAN	ER	CPI	IP	Overnight	1975m01 - 2013m01
NOR	TL	CPI	IP	NIBOR	1973m01 - 2011m03

Table 5.1: **South Africa**: Data from the South Afican Reserve Bank; **USA**: Data from the Federal Reserve Bank of St. Louis; **Canada**: Data from Bank of Canada and Statistics Canada (CANSIM Tables); **Norway**: Data from Norges Bank and Statistics Norway; NBR = Non-borrowed Reserves (Total Reserves - Borrowed Reserves); ER = Excess Reserves; TL = Total Liquidity; CPI = Consumer Price Index; GDP = Gross Domestic Product; IP = Industrial Production Index

The data used are monthly observations and are summarised in Table 5.1. In all countries the measure of the price level is the consumer price index (CPI). The level of real income, a proxy for business cycle activity, is measured in all countries by either industrial or manufacturing production (IP). All variables are logged, except for the various interest rates. First-order differences were taken with respect to the logged values of the price level (CPI) and several of the non-stationary liquidity measures (TL, NBR, ER)[37].

5.4.1.1 Liquidity Measures

Several liquidity measures were used in the analysis. These variables were selected based on data availability. They were tested for the presence of a unit root through an Augmented Dickey-Fuller (ADF) test. However, in the case of the VAR specification, the liquidity variables were often left in level terms, even when non-stationary, as it is believed that the transformation of variables is not always necessary when integrated of order one. The theory is that in large samples, OLS is still consistent regardless of whether the VAR contains integrated components (Fung and Gupta, 1997). Variables that needed to be seasonally adjusted were smoothed using the X-12 ARIMA package in Eviews. Figure 5.7 presents the selection of liquidity variables.

Several calculations were necessary to obtain the relevant liquidity measures. In the case of the USA, all measures were readily available and were extracted directly from the Federal Reserve Database. The non-borrowed reserves series was discontinued, which limits the availability of data. Information pertaining to reserves for South Africa was gathered from the SARB's online database. Non-borrowed reserves (NBR) for South Africa were calculated as total reserves with the SARB minus the total liquidity provided by the SARB. Due to data availability, NBR was calculated only for the period 1986m01 to 2012m02. In the case of Canada, excess reserves were calculated as reserves in excess of the statutory minimum reserves required to be held by chartered banks. Excess and total reserves are equal after 1994m07, since the reserve requirement was phased out in July 1994. The data was gathered from the CANSIM tables, available from Statistics Canada. For Norway, NBR was not calculated; total liquidity (which is domestic sight deposits) was used instead. Data was gathered from the Norges Bank's website. The sample period for Norway ends in the third quarter of 2011, as this marks the start of the quota regime.

[37]The growth rate (first difference) of the liquidity measures was not always used, but was used in the cases where the inclusion of the variable in level terms resulted in an unstable VAR.

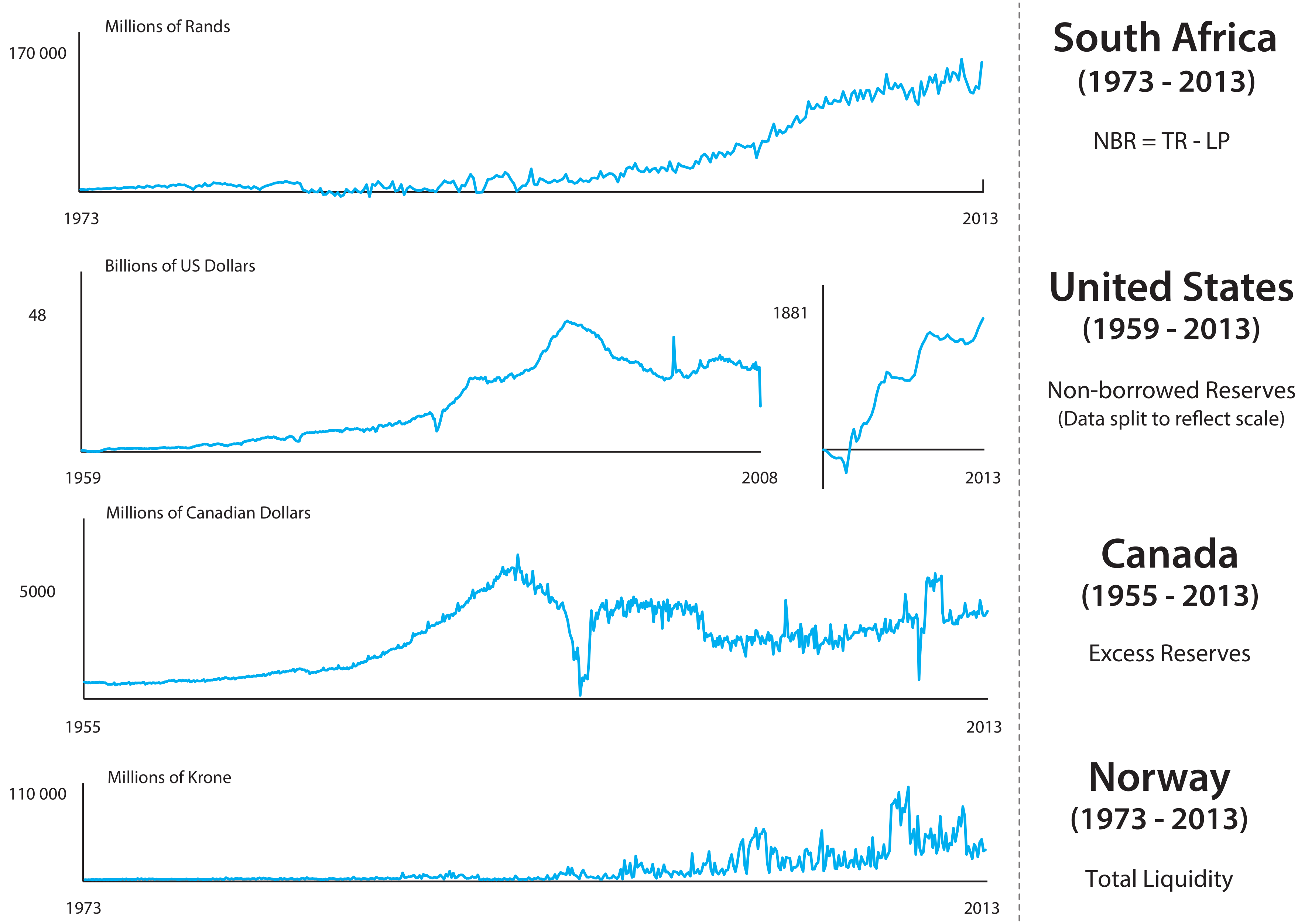


Figure 5.7: Raw data on different liquidity measures used

5.4.1.2 Interest Rates

Different money market rates were used in the analysis. In general, the shortest market rate was used. However, since the data is presented at a monthly frequency, the nuances of daily shifts in interest rates were lost. In the case of the USA, the effective federal funds rate was used. For South Africa, the interest rate with the most observations is the Bank rate. The problem I encountered with using the Bank rate was that it is determined by the SARB for the most part, and not endogenously in the market. Other available interest rates are the 90-Day Banker's Acceptance rate (BAR), the 30 Day Treasury Bill rate (TBR) and the South African Benchmark Overnight rate (SABOR). Ideally, one would like to use SABOR, as it is the shortest market rate. However, data for SABOR was available only from September 2001, which greatly reduced my sample size. Therefore, I decided to use the Banker's Acceptance rate in my analysis. Figure 5.8 illustrates how these rates relate to each other. The Money Market Funds or Overnight Rate is used in Canada, and in Norway the Norwegian Interbank Offered Rate (NIBOR)[38] is used.

5.4.2 Rolling Regression

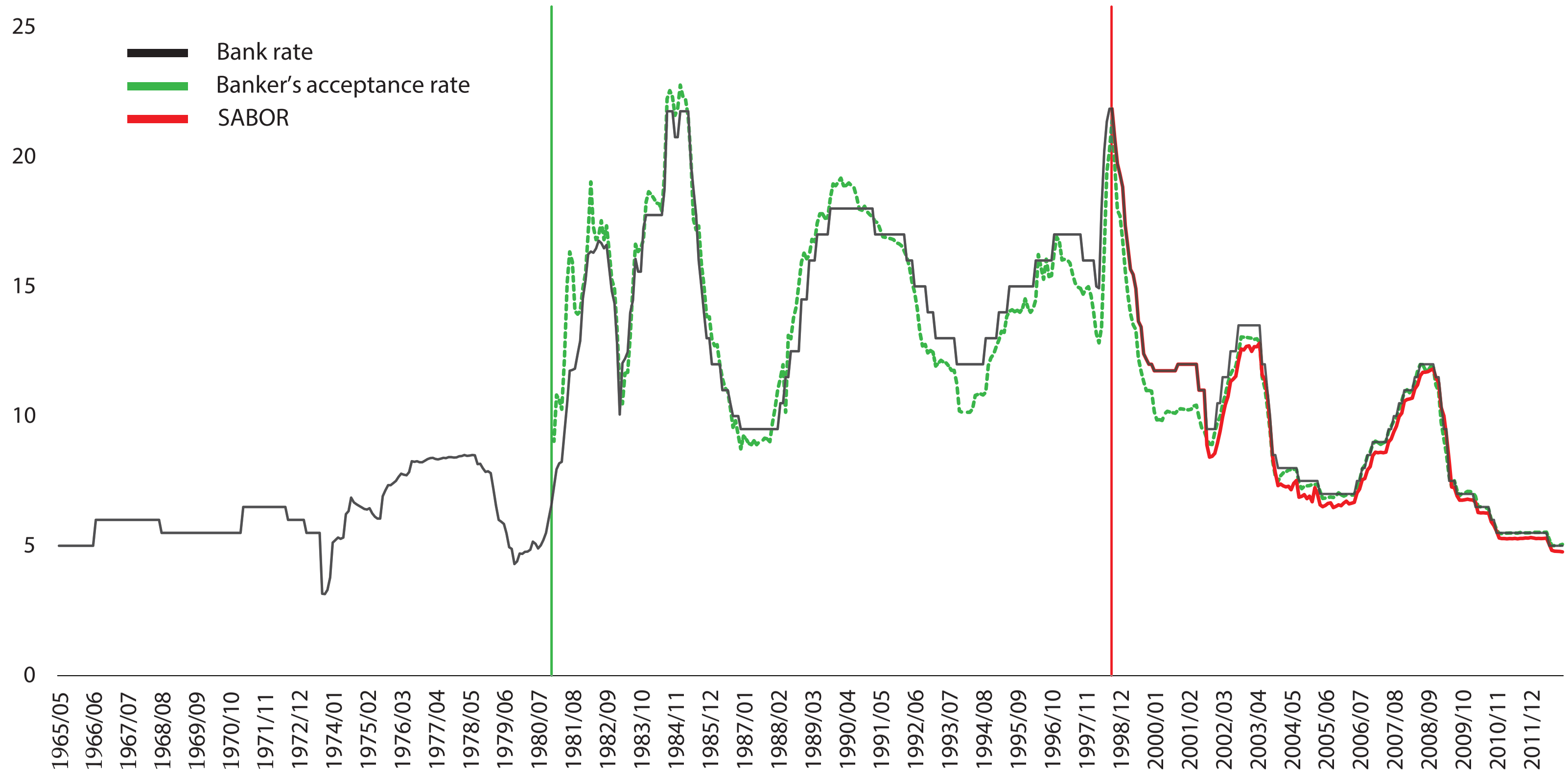
The regression equation is a dynamic version of the static equation used in Chapter 5.2 to explain the liquidity effect. The empirical specification for this dynamic regression model tries to link interest rates to liquidity, output growth and inflation.

$$r_t = \alpha + \beta_i r_{t-i} + \delta_i m_{t-i} + \eta_i g_{t-i} + \theta_i p_{t-i} + \phi_i x_{t-i} + \varepsilon_t, \quad \varepsilon_t \sim (0, \sigma_\varepsilon^2) \tag{5.3}$$

where, r_t is the interest rate, m_t represents liquidity, g_t is real output growth, p_t is inflation, x_t is the foreign exchange rate and ε_t is the error term. The lag length for each country was determined primarily by a general to specific approach of adding lags to the model up to the point where the introduction of additional lags delivered statistically insignificant results. The information criterion was also used to determine whether deepening the lags would contribute to improved homoscedasticity of the errors[39]. The lag length for the different specifications varied between two and four lags. One of the shortcomings of the specification is that it does not consider country-specific historic events, such as banking crises (Norway), major political events (South Africa), and so forth.

A rolling (or moving window) regression was performed for all four countries. A rolling analysis of a time series is often used to determine model stability over time (i.e. whether a parameter

[38]The shortest form of interest rate (i.e. Tomorrow/Next) was used, which is the equivalent of an overnight rate.
[39]The results from these tests are not provided.



Source: South African Reserve Bank

Figure 5.8: South African short-term interest rates

is constant over time) (Zivot and Wang, 2006). In my case, a parameter estimate of liquidity, δ, was computed over a moving window, where the size of the sliding window was fixed at fifty months and incremented by one month. Several regressions were performed using this technique, each providing a parameter estimate at a different time window. By using this method, one can see the spatial variations in the sample. Only a specific sample of observations was taken into account in each window. Data outside this window have no influence and were not taken into account. Observations within this window were weighted equally (Zivot and Wang, 2006). This time-varying parameter model provides insight into the changing nature of the relationship between interest rates and liquidity. More advanced state-space models, such as the TVP-VAR model in Chapter 5.4.4, were used to provide a more accurate description of the true nature of δ. The function of the rolling regression was to confirm the time-varying nature of the parameters of the model.

5.4.2.1 Results

In this section the results of the rolling regressions for all four countries, with country-specific liquidity measures, are depicted and discussed. Figure 5.9 shows the rolling regressions for all four countries, with previously defined liquidity variables of interest[40]. The results for each country are discussed in turn.

5.4.2.1.1 South Africa The rolling regression with respect to non-borrowed reserves took place over a small sample period, from 1986 to 2012. The results are not definitive, with parameter estimates on both sides of the horizontal axis. The confidence interval indicates that there is most likely no effect of non-borrowed reserves on the interest rate in this sample. Several other, broader liquidity measures, like high-powered money (MB) and the money supply (M1 and M2), were also tested, and are shown in Appendix A. However, the tests revealed relatively little new information, as a similar trend is recorded for these variables. In other words, analyses undertaken with a range of liquidity measures, from narrow to broad monetary aggregates, illustrates no concrete evidence for a stable or persistent relationship with the Banker's Acceptance rate.

5.4.2.1.2 USA The relationship between NBR, in the second panel of Figure 5.9, and the federal funds rate is consistently negative until we reach the moving window samples ending

[40] Dashed lines indicate 95% confidence intervals.

in 1992[41]. There are point estimates along the series where the relationship turns positive, but these observations are scattered. The segment between 1992 and 2008 shows a stable parameter value centred on zero, indicating little to no relationship between the federal funds rate and non-borrowed reserves. A similar trend is seen when other liquidity variables are used. Exact inference pertaining to the interdependence of interest rates and liquidity will not be hazarded. However, it would be appropriate to say that the relationship has changed with time and that the response of the federal funds rate to movements in liquidity has been dampened. In 2008 the Fed transitioned to a floor regime, paying interest on reserves equal to the target funds rate.

5.4.2.1.3 Canada The third panel in Figure 5.9 shows the results from a rolling regression on the Canadian data. The liquidity measure used in this instance is excess reserves. The motivation for using this liquidity measure is attributed to the paper on the liquidity effect in Canada by Fung and Gupta (1997). They determine that excess cash reserves, as a liquidity variable, is the appropriate measure to use for Canada and delivers a significant liquidity effect. Non-borrowed reserves are believed to be inappropriate in the Canadian institutional setting. According to Dingle et al. (1972), "in the short run the central bank seeks to influence the asset holdings of chartered banks and interest rates in the money market by adjusting the supply of excess cash reserves in relation to the continually changing level desired by the banks". This sentiment is reinforced by White and Poloz (1980), who believe that the "Bank of Canada influences changes in the short-term interest rates by supplying quantities of *excess cash reserves*". The literature, therefore, suggests that "cash management by the banks focusses on excess reserves" (Clinton, 1991).

The graph illustrates that capturing a liquidity effect is plausible for regression window samples ending before 1995. However, after these observations the relationship seems to wither. This result speaks to the transition to a corridor system. One can postulate that after this transition the Bank of Canada appears to have successfully insulated the market for bank reserves from their open market operations, and thereby have dulled the accompanying liquidity effect. In addition, broader monetary aggregates do not show signs of a significant and stable relationship with the overnight rate, as shown in Appendix A.

5.4.2.1.4 Norway As previously stated, NBR was not calculated for Norway. A proxy for this variable, referred to as total liquidity, was used. Total liquidity was calculated as the sight

[41] The inference of a negative relationship is tentative as the upper bound of the confidence interval indicates the possibility of a slightly positive relationship.

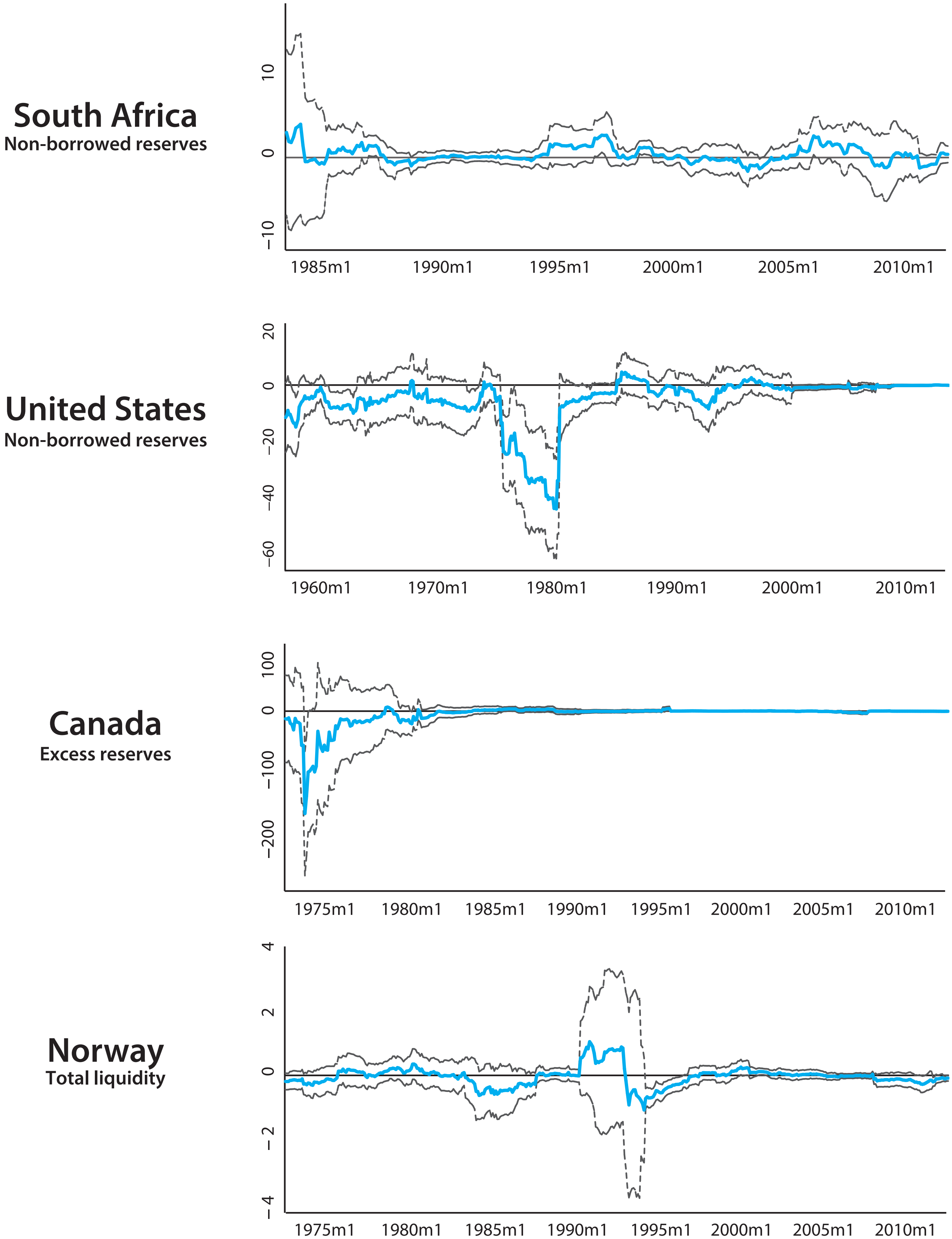


Figure 5.9: Rolling regression results for four countries

deposits made at the Norges Bank. An analysis of the relationship between total liquidity and the short-term interest rate reveals that an sporadic liquidity effect is plausible. The positive values recorded in the late 1980s and early 1990s is in part attributable to the Norwegian banking crisis that peaked during 1991 and 1992. A systemic failure of the banking system resulted in a frantic pursuit of liquidity during this period. The transition to a floor regime in 2001 shows up clearly in the graph. It is possible to state that in this selected sample, after 2001, there is little to no effect on the interest rate from fluctuations in the level of liquidity holdings. Looking at the movement of the parameter estimates for high-powered money, in Appendix A, one observes a resemblance to the results obtained for total liquidity.

5.4.3 Structural Vector Autoregression

Vector autoregressive (VAR) models have been the workhorse of empirical macroeconomics since the early 1980's (Kilian, 2011)[42]. In his iconic *Econometrica* paper[43], Sims (1980) first suggested the usage of VAR models in favour of the large-scale simultaneous equation models of the time. These large macroeconometric models were remnants from the Cowles Commission and often involved hundreds of equations, where identification was achieved through the exclusion of variables without economic, or statistical, prejudice (Bjørnland, 2000). Sims was especially critical of the "incredible identifying restrictions" imposed by econometricians in these large structural models, as these restrictions had no theoretical basis (Sims, 1980). In addition, he suggested to shift the focus from structural to reduced-form models, where endogenous variables are modelled jointly. An extensive literature has developed around the idea of reduced-form VAR models, as discussed in Watson (1994) and Lütkepohl (2011).

Early attempts at VAR modelling were considered atheoretical, as outlined by Cooley and LeRoy (1985). Developing a structural model requires believable restrictions on certain variable coefficients, to generate mutually uncorrelated structural shocks. It was only in the work of Sims (1986), Bernanke (1986), Blanchard and Watson (1986) and Blanchard (1989) that a more structural approach to VAR modelling started to develop. As explained by Kilian (2011), a structural approach involves "identifying assumptions that must be motivated based on institutional knowledge, economic theory, or other extraneous constraints on the model responses". Initially, restrictions were made in terms of short-run relationships, but the work of

[42] There is a detailed discussion on the impact of VAR models on empirical macroeconomics in the work of Canova (1999)

[43] This paper is one of his contributions to "empirical research on cause and effect in the macroeconomy" that eventually led to him being awarded the Nobel Memorial Prize in Economic Sciences in 2011. He shared the prize with Thomas Sargent.

Blanchard and Quah (1989) helped extend this to include long-run dynamics. The literature on identification is ever expanding, with a gamut of restrictions possible, ranging from short-run, long-run, sign or even heteroscedasticity restrictions. In the next section the methodology for the structural vector autoregression (SVAR) is briefly described, which is followed by a discussion on the identification strategy implemented.

5.4.3.1 Methodology

The structural model of the economy is represented by the following simultaneous equation system[44],

$$A\mathbf{y}_t = F_1\mathbf{y}_{t-1} + \ldots + F_s\mathbf{y}_{t-s} + u_t \qquad u_t \sim N(0, \Sigma\Sigma) \tag{5.4}$$

where $t = s+1, \ldots, n$. In this specification $\mathbf{y}_t$ is a $k \times 1$ vector of variables that summarise the state of the economic system (i.e. observed variables), while u_t is a $k \times 1$ vector of the orthogonal (iid) structural shocks, whereby,

$$\Sigma = \begin{pmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & \sigma_k \end{pmatrix}$$

$F_1, \ldots, F_s$ is a $k \times k$ matrix of coefficients, and the matrix A is a square $(k \times k)$ matrix of structural parameters that indicates the contemporaneous relationships in the model. In this paper, the vector $\mathbf{y_t}$ contains current observations on four variables. The variables in the system are $[r, m, y, p]$, where r is a short-term interest rate, m is the liquidity measure, y is the growth in real output and p is inflation.

We are unable to estimate the equation because the system is not observable. Instead we transform the equation into the following estimable reduced form:

$$\mathbf{y}_t = B_1\mathbf{y}_{t-1} + \ldots + B_s\mathbf{y}_{t-s} + A^{-1}\Sigma\epsilon_t, \qquad \epsilon_t \sim N(0, I_k) \tag{5.5}$$

where $B_i = A^{-1}F_i$ for $i = 1, \ldots, s$. Equation 5.5 is the vector autoregression (VAR) representation of the structural model. The explicit variance-covariance decomposition, as presented by $A^{-1}\Sigma\epsilon_t$, will prove useful in the discussion of time-varying parameter VARs in the next section (Primiceri, 2005).

[44] As presented in (Nakajima, 2011).

5.4.3.2 Identification Strategy

According to the structural VAR approach, a proper identification strategy requires imposing restrictions on the structural parameters found in the A matrix. Restrictions imposed in this matrix should reflect the contemporaneous feedback between the elements of the matrix. The simultaneous relations are identified recursively, with a lower triangular structure of the form:

$$A = \begin{pmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{pmatrix} \begin{pmatrix} y \\ p \\ m \\ r \end{pmatrix}$$

5.4.3.2.1 Restriction. *The primary restriction imposed is that the short-run policy rate reacts contemporaneously to output, prices and reserves.*

Identification in the liquidity effect literature originates from the research on the monetary transmission mechanism, illustrating how monetary policy is thought to be implemented and transmitted. A substantial literature has developed around the impact of monetary policy shocks on real activity. In fact, the monetary transmission channel must be one of the most vigorously studied mechanisms in empirical macroeconomics. The emphasis on understanding how the use of monetary policy instruments transmit to the broader economy is crucial to policymakers and research economists alike. An extensive survey on the impact of monetary policy in the US is conducted by Christiano et al. (1999), with similar work done for the Euro area by Peersman and Smets (2001), and low-income countries by Mishra and Montiel (2013).

The identification scheme used in this chapter is similar to that of Christiano and Eichenbaum (1992). The restriction can be blocked into two parts. First, the effect that output, prices and reserves have on the policy rate. In terms of the first block, the explanation provided in the literature is that the central bank cannot respond immediately to changes in real activity (Arias et al., 2015). In this setup, the central bank takes information on the current level of output and prices into account when making decisions as to its policy stance. This informational assumption was first suggested by Bernanke and Blinder (1992). However, this idea has been contested by the fact that central banks do not have monthly data available on output and prices (Christiano et al., 1999). Another way to view this, is that output and prices (endogenous macroeconomic variables) react to changes in the policy rate, with a lag.

Second, the response of the interest rate to the liquidity measure. In this ordering the central bank will, for example, adjust the level of liquidity with changes in the current effective interest rate, which means that a shock to the liquidity measure "reflect exogenous shocks to monetary policy" (Christiano et al., 1999). Another feasible ordering would have been $(y, p, r, m)'$, such as that of Christiano et al. (2005). However, results remained qualitatively similar, despite changes in these short-run restrictions[45]. Decisions about the level of liquidity will therefore be made taking into consideration the contemporaneous changes in the interest rate. In addition, the level of liquidity is contemporaneously influenced by the price level and real economic output.

5.4.3.3 Results

This section discusses the impulse response functions from my SVAR. The shock was applied to selected liquidity measures. Only narrow measures of money were used in the analysis, as these measures are believed to carry the most information on the behaviour of relevant market participants. The first step in estimating the VAR was to determine the appropriate lag length. In this regard, the Schwarz Information Criterion (SIC) and Akaike Information Criterion (AIC) were used for each model. The results from the tests are not reported. AIC often suggests lags in excess of 12 for the models that span the entire sample, but the SIC suggests a more modest lag depth of between 10 and 12. The related literature suggests 12 lags, which appears to be consistent with the findings of the SIC. In the case where different subsamples were used the suitable lag length was found to be between 4 and 6.

	Monetary policy regime sample periods				
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
RSA		1965 - 1980	1980 - 1989	**1990 - 1998**	**1998 - 2012**
USA	**1959 - 1970**	**1970 - 1979**	**1979 - 1987**	**1987 - 2006**	**2006 - 2013**
CAN	1963 - 1970	**1971 - 1982**	**1983 - 1991**	**1992 - 2000**	**2000 - 2012**
NOR		**1973 - 1985**	**1986 - 1992**	**1993 - 2000**	**2001 - 2011**

Table 5.2: Subsamples identified from country-specific literature

The different subsamples identified from the literature for each country are presented in Table 5.2. The actual subsamples used are in bold; these are in line with the specified dates but are subject to data availability. The IRFs only demonstrate the effect of an innovation on money to the relevant short-term interest rate. The dashed lines represent the 95% confidence interval around the point estimates of the IRFs. One generally considers the result to be significant if both the upper and lower confidence bands appear on the same side of the horizontal (zero)

[45] Several plausible alternative orderings were tried with no reversal of sign or significance encountered.

line (Fung and Gupta, 1997). The transmission to the broader economy is not important for our analysis.

5.4.3.3.1 South Africa Figure 5.10 represents the impulse response functions (IRFs) from the VAR estimation over different sample periods. The liquidity variable enters the VAR equation in levels, and the VAR satisfies the stability condition, whereby all eigenvalues lie within the unit root circle. The first panel represents the entire sample. In this sample a delayed liquidity effect is captured. However, the second panel indicates the presence of a liquidity puzzle, whereby a negative relationship between money and the interest rate is not readily observable. The second panel corresponds to the period before the adoption of inflation targeting (i.e. 1998), while the third panel is the post-IT sample. The response shown in the third panel is similar to the first, with the post-IT sample potentially the biggest driver of the IRF of the whole sample. In terms of sensitivity analysis, several VAR specifications were tested, using different interest rates and liquidity variables. Obtaining a significant liquidity effect with other liquidity measures was rare and normally occurred with a lag. There is little evidence that this relationship has been stable and persistent across monetary policy regimes.

5.4.3.3.2 USA The results obtained from the VAR estimation for the USA agree with the findings in the literature. Figure 5.11 reveals that the relationship of the federal funds rate and non-borrowed reserves remains negative and eventually disappears once a hybrid / floor system is adopted. The results are compelling and indicate that in the USA there is some evidence of a decoupling of the balance sheet. This result is not surprising as most of Bernanke's term as Fed chairperson has involved an unprecedented expansion of the balance sheet, while nominal interest rates were pushed close to the zero lower bound.

5.4.3.3.3 Canada When excess reserves are used as the measure of money, in Figure 5.12, a liquidity puzzle is observed for Canada. The relationship between interest rates and excess reserves seems to appear as zero for all samples considered. The final sample period represents the adoption of an inflation targeting regime in 1999. Evidence of the decoupling principle seems especially strong in Canada, with the movement in excess reserves after 1999 eliciting almost no response in the overnight interest rate.

5.4.3.3.4 Norway Figure 5.13 reflects the IRFs from an innovation in total liquidity holdings. The pre-IT samples indicate no significant result from the perturbation in liquidity. The post-IT

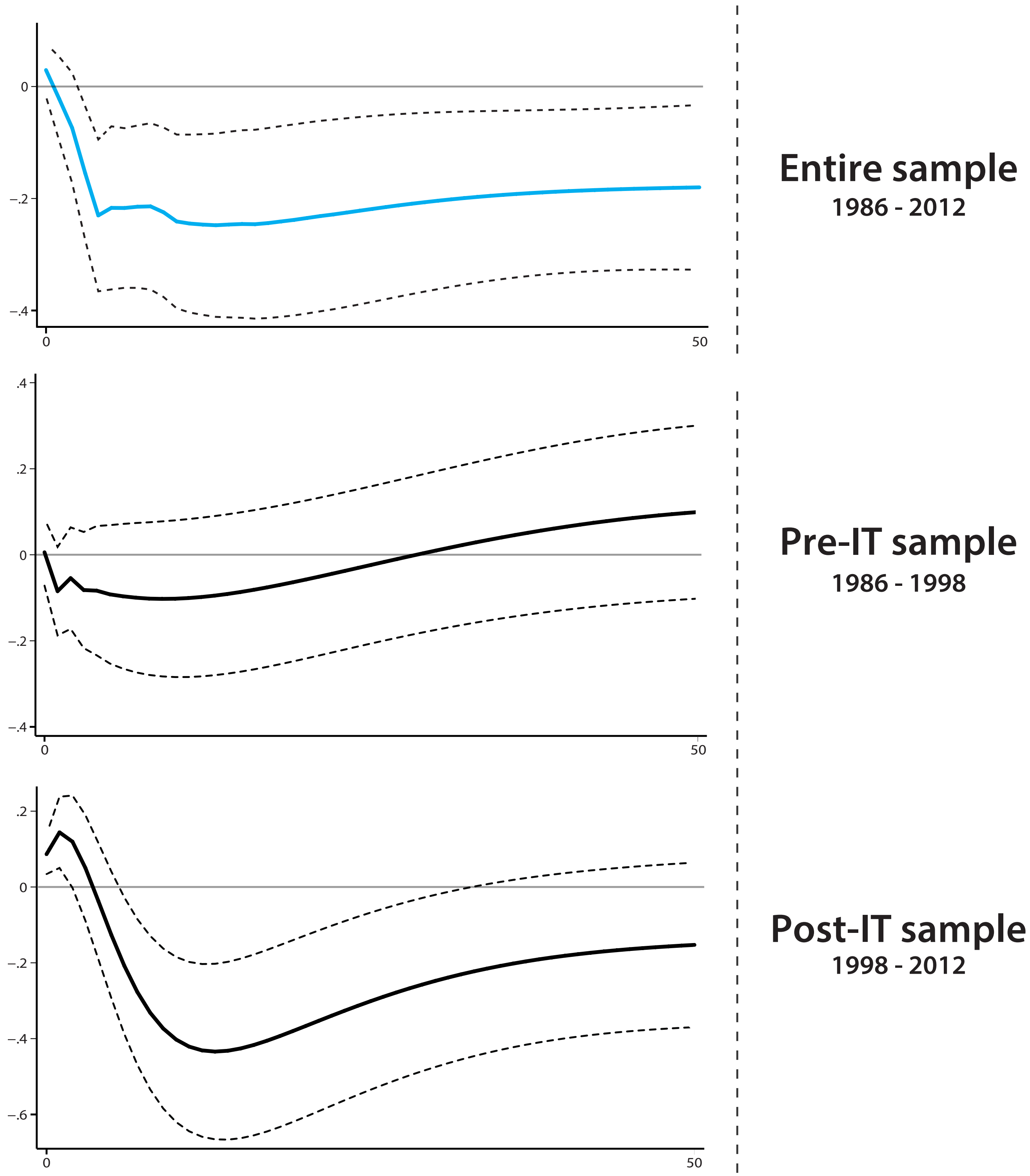


Figure 5.10: Impulse response functions for South Africa

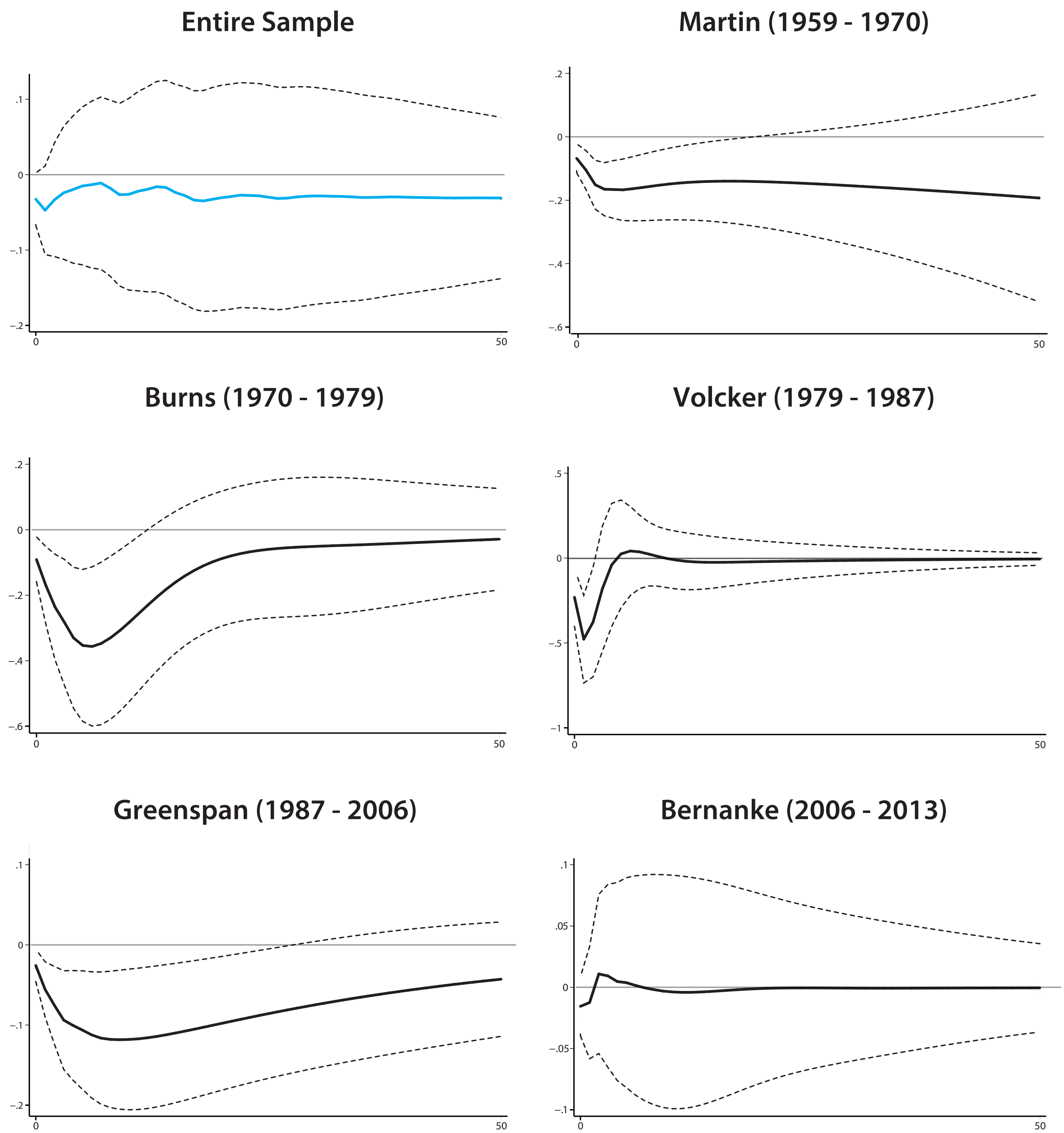


Figure 5.11: Impulse response functions for USA

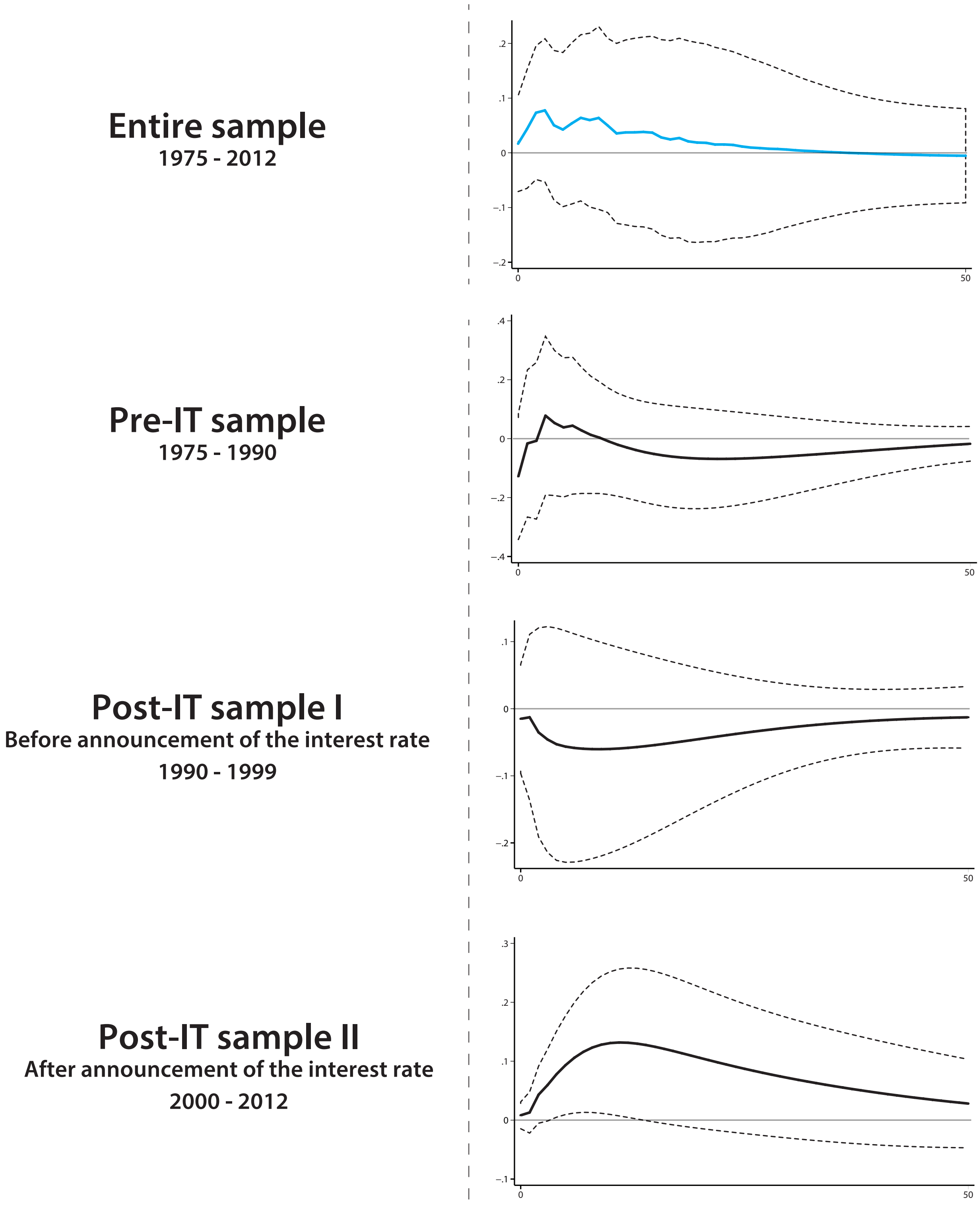


Figure 5.12: Impulse response functions for Canada

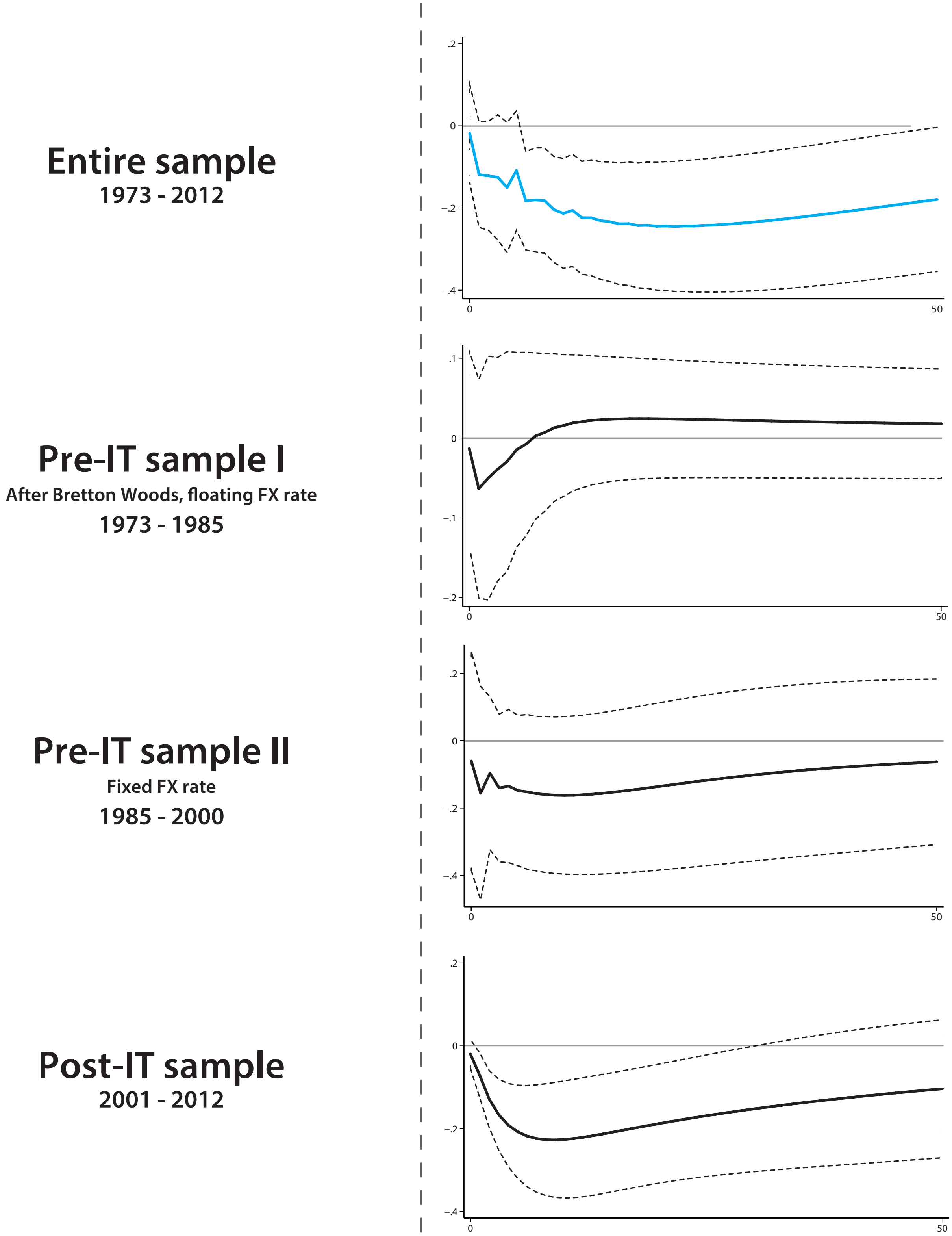


Figure 5.13: Impulse response functions for Norway

samples suggest the possibility of a liquidity effect. This is an interesting result in that one would expect the Norwegian money market rates to be completely immune to movements in the level of bank reserves, since the Norges bank maintains a high level of liquidity in the market (in excess of demand), as indicated by line m_{s_2} in Figure 5.4. Owing to the arbitrary nature of selecting sample spaces in this exercise, it might be more useful to look at a methodology that combines the time-varying nature of the parameters together with elements of a structural modelling approach.

5.4.4 Time-Varying Parameter Vector Autoregression

VARs have been highly influential in macroeconomic research during the last three decades. In particular, these models have proven valuable in the process of identifying comovements among multiple economic variables (Doh and Connolly, 2012). Estimating impulse response functions have given researchers a way to determine the effect of imposing structural shocks on a system of variables. There are, however, two general concerns with the usage of VARs. First, the VAR approach assumes time-invariant coefficients and variances, which turns out to be a quite strong and perhaps too restrictive assumption (Doh and Connolly, 2012; Koop and Korobilis, 2010; Charleroy, 2013). In recent years it has been posited that the data generating process of economic variables has “drifting coefficients and shocks of stochastic volatility” (Nakajima, 2011). Pursuant to this notion, the hypothesis of this paper points to the potential time-varying impact of changes in monetary policy implementation. In the context of the SVAR used, regime shifts were identified based on the analysis of country-specific historical readings. A TVP-VAR model could potentially reduce the subjective nature of subsample selection, by combining the strengths of both the rolling regression and the traditional VAR model.

Second, even for VARs of moderate size, like the model utilised in Chapter 5.4.3.1, the number of parameters become quite large in relation to the observations, which translates to wider confidence regions (i.e. less precise estimates) for the impulse response functions (Eisenstat et al., 2013). This problem is exacerbated in the case of TVP-VAR models, which have high dimensionality due to the introduction of time variation in coefficients and/or volatility. Bayesian methods have been proposed to address concerns of “tractability and over-parameterisation in small samples” (Doh and Connolly, 2012). To this end, this paper employs a multivariate Bayesian time-varying parameter vector autoregression (TVP-VAR) model.

5.4.4.1 Methodology

The introduction of time variation in either the coefficients or volatility started in the late 1990s (Doh and Connolly, 2012). One of the first papers to incorporate time-varying coefficients into a VAR model, was that of Cogley and Sargent (2001), with the objective of defining the contours of the US inflation and unemployment dynamics over the post-war period. Their research was criticised by Sims (2001) and Stock (2001) for making the assumption of constant variance, while the data clearly indicates the presence of stochastic volatility. It was argued that the "variance of exogenous shocks may have changed over time; which motivates the inclusion of multivariate stochastic volatility to VAR models" (Koop and Korobilis, 2010). In response to these claims of model misspecification, Cogley and Sargent (2005) proceeded to include volatility in their time-varying coefficient model. This framework provided the platform for the hugely influential paper by Primiceri (2005).

The biggest contribution of Primiceri's (2005) paper was the fact that all parameters are allowed to vary over time, even the simultaneous relations of the structural shock. Several macroeconomic issues have been evaluated under this framework, as it captures the "time-varying nature of the underlying structure in the economy in a flexible and robust manner" (Nakajima, 2011). The major drawback to this method is that estimation is difficult, with the likelihood function becoming intractable (i.e. almost impossible to solve analytically). In response to this problem, Markov Chain Monte Carlo (MCMC) methods, in the context of Bayesian inference, have been suggested.

In order to comprehend the structure of the TVP-VAR it is easiest to start with the SVAR framework, as presented in Chapter 5.4.3.1. Following the work of Primiceri (2005) and Nakajima (2011), one can rewrite (5.5) as,

$$\mathbf{y}_t = X_t\boldsymbol{\beta} + A^{-1}\Sigma\epsilon_t, \tag{5.6}$$

where the rows of the B_is have been stacked to form $\boldsymbol{\beta}$ and $X_t = I_k \otimes (\mathbf{y}'_{t-1}, \ldots, \mathbf{y}'_{t-s})$. The coefficients and volatility in this SVAR are time-invariant, which means that there is no need to elevate this equation to a state-space dimension. All state variables are observed and the distinction between measurement and the state transition equation is superfluous. In order to extend this model to the TVP-VAR framework, I allowed the various parameters to change over time. Accordingly, the specification became a state-space representation of the VAR with time-varying coefficients and stochastic volatility:

$$\mathbf{y}_t = X_t\boldsymbol{\beta}_t + A^{-1}{}_t\Sigma_t\epsilon_t, \tag{5.7}$$

where the coefficients $\boldsymbol{\beta}_t$ and parameters A_t and Σ_t all become time-varying[46]. The variables and sample period used in the application of the TVP-VAR model are identical to those used in Chapter 5.4.3.1. Four lags were used in this VAR. There are several plausible ways to model the process of the time-varying parameters. Let $\mathbf{a}_t = (a_{21}, a_{31}, a_{32}, \ldots, a_{k,k-1})'$ be a stacked vector of lower triangular elements in the A_t matrix and $\mathbf{h}_t = (h_{1t}, \ldots, h_{kt})'$ with $h_{jt} = \log \sigma^2_{jt}$. Adopting the methodology of Primiceri (2005), the dynamics of the parameters in (5.7) are specified as follows,

$$\boldsymbol{\beta}_{t+1} = \boldsymbol{\beta}_t + u_{\beta_t} \tag{5.8}$$

$$\mathbf{a}_{t+1} = \mathbf{a}_t + u_{a_t} \tag{5.9}$$

$$\mathbf{h}_{t+1} = \mathbf{h}_t + u_{h_t} \tag{5.10}$$

The elements of $\boldsymbol{\beta}_{t+1}$, the free elements of matrix A_t, and the standard deviations (σ_t), are assumed to evolve as random walks. A popular alternative to the random walk process is to select one of the more general autoregressive processes. However, the assumption of a random walk process enables the model to take permanent shifts into account, as opposed to the gradual nature of shifts associated with autoregressive processes. In addition, there are fewer parameters to be estimated under the random walk assumption. The distributional assumptions with regard to the parameters in (5.7) are illustrated in the following matrix:

$$\begin{pmatrix} \epsilon_t \\ u_{\beta_t} \\ u_{a_t} \\ u_{h_t} \end{pmatrix} \sim N \left(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_a & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix} \right)$$

for $t = s+1, \ldots, n$, where $\boldsymbol{\beta}_{s+1} \sim N(\mu_{\beta_0}, \sigma_{\beta_0})$, $\mathbf{a}_{s+1} \sim N(\mu_{a_0}, \sigma_{a_0})$ and $\mathbf{h}_{s+1} \sim N(\mu_{h_0}, \sigma_{h_0})$. In this chapter I followed the convention of assuming that the variance-covariance structure for the innovations of the time-varying parameters (Σ_a, Σ_h) are diagonal matrices.

The TVP-VAR model relies on the implementation of Bayesian inference through MCMC methods, which means that prior selection will come into play. For the purpose of this study, an uninformative prior was assumed for the initial state: $\mu_{\beta_0} = \mu_{a_0} = \mu_{h_0} = 0$ and $\Sigma_{\beta_0} = \Sigma_{a_0} = \Sigma_{h_0} = 10 \times I$. This indicates that no *a priori* information was available to the researcher[47]. A popular alternative is the training sample prior, used by Primiceri (2005), where parameters are set according to OLS estimates taken from a small presample of the data. The following priors were selected

[46]Equation 5.5 is known as the measurement equation.

[47]For a detailed discussion on prior selection in TVP-VAR models, refer to the monograph of Koop and Korobilis (2010).

for the i-th diagonals of the covariance matrices:

$$(\Sigma_\beta)_i^{-2} \sim IW(25, 0.01I), \quad (\Sigma_a)_i^{-2} \sim \Gamma(4, 0.02), \quad (\Sigma_h)_i^{-2} \sim \Gamma(4, 0.02) \tag{5.11}$$

where IW and Γ are the inverse Wishart and Gamma distributions, respectively. An in-depth discussion on the estimation methodology is omitted [48]. Gibbs sampling, a Bayesian estimation algorithm, was used to obtain the joint posterior distribution of parameters. This MCMC algorithm iteratively draws parameters and unobserved states from lower dimensional conditional posteriors (drawing one parameter at a time while keeping other parameters constant). Computation of the posterior estimates was achieved through a draw of 10 000 samples, after the first 1000 burn-in draws were disposed of[49].

5.4.4.2 Results

The IRFs for the TVP-VAR are interpreted in a similar fashion to the rolling regression estimates. The three IRF lines in, for example, Figure 5.14, depict the first, second and fourth period impulse responses to a one standard deviation shock in non-borrowed reserves at different points in time. In other words, each point in time has three corresponding impulse responses. The reason for the selection of the first, second and fourth period ahead IRFs is that I was trying to capture the short-run effect of reserves on interest rates.

5.4.4.2.1 South Africa In contrast to the results shown for the rolling regression parameter estimates in Chapter 5.4.2 and somewhat similar to IRFs in Chapter 5.4.3.1, the IRFs for the TVP-VAR (at one, two and four periods ahead) indicate that there is a negative relationship between non-borrowed reserves and the banker's acceptance rate that deepens at each point in time with subsequent impulse responses. This relationship is stable throughout the sample and parameter volatility abates even further after adopting the inflation targeting regime in 1998. This relationship indicates a strong liquidity effect for the South African reserve regime. This result is in line with the traditional model of monetary policy implementation. It appears that the South African Reserve Bank does not insulate its interest rate from movements in reserves, which means that the decoupling or separation of monetary policy instruments is not plausible.

[48] Interested parties are referred to the work of Primiceri (2005) or Nakajima (2011).

[49] Computational results are achieved in MATLAB R2014a using the TVP-VAR code provided by Jouchi Nakajima at `https://sites.google.com/site/jnakajimaweb/tvpvar`.

5.4.4.2.2 United States The narrative elicited from the SVAR for the United States in Chapter 5.4.3.1 was one of a waning liquidity effect over time. The results obtained from the TVP-VAR, from Figure 5.15, preserves this narrative and confirms the intuition that monetary policy implementation has undergone a significant metamorphosis. In particular, it is believed that a transition has been facilitated by the changing of the guard at the Federal Reserve. Looking at Figure 5.15, which delineates the different eras of the Federal Reserve chairpersons since the Second World War, one observes a clear deterioration of the liquidity effect corresponding to the changeover of incumbents. The most distinct change in the liquidity effect occurs with the induction of Volcker as chairman; with a clear upward trajectory originating in the late 1970's in all three IRFs. This corresponds to the literature on the liquidity effect, with researchers finding it particularly difficult to identify this effect as time progresses.

5.4.4.2.3 Canada The Bank of Canada appears to be quite adept at insulating its interest rate from movements in excess reserves. This sentiment rings true for the entire sample, but is most palpable after the adoption of the inflation targeting regime. The post inflation targeting sample reflects a lower volatility of the IRFs, as well as movement on both sides of the horizontal axis. This pattern is similar to the one observed in the rolling regression from Chapter 5.4.2. It is therefore plausible that there is a decoupling of balance sheet movements from interest rate policy in Canada.

5.4.4.2.4 Norway The final case to consider is that of Norway. One would expect that with the floor regime enacted by the Norges Bank since 1992, there would be a distinct separation of the movements in liquidity and overnight interest. This is not exactly the case, and perhaps requires a more detailed investigation as to why. Consider the TVP-VAR IRFs from Figure 5.17, with particular interest paid to the post-1990 period. The precipitous dip in the period from 1990 to 1995 could be attributed, in part, to the European Monetary system crisis of the early 1990s. During this period commercial banks were stockpiling liquidity in the expectation of liquidity drying up in the interbank market. In addition, the Norges Bank reduced the interest rate to bolster economic growth.

The combination of these events has produced a liquidity effect, which is potentially spurious considering that the overnight interest rate movement was not necessarily driven by the demand for reserves, but rather was a policy response to the economic environment. It is entirely possible that some deviation in the overnight rate was caused by the liquidity hoarding, but the magnitude of the effect would be difficult (if not impossible) to identify. The only thing that is certain in this case is that the magnitude of the effect is exaggerated in Figure 5.17. After this period the relationship rapidly moves toward zero, becomes positive, and then turns negative again. Identifying a clear narrative here is difficult.

5.5 Chapter Conclusion

The hypothesis of the paper is that no clear and stable link exists between liquidity and interest rates, so that various levels of reserves can exist for a given interest rate. One can gather from the VAR results that the relationship between money market interest rates and the various reserve concepts used changes significantly with the sample used. This result is corroborated by the rolling regression and TVP-VAR results for the USA, Canada and Norway.

The most patent proof of decoupling was observed in the USA and Canada. One would expect Norway to show signs of decoupling because of their floor system; however, there is evidence to suggest a small liquidity effect exists. The result is surprising, but the negative relationship recorded could be due to several factors, in particular, it could reflect a combination of the expansionary stance of the Norges Bank and the liquidity-seeking behaviour of banks during a credit crunch. In the case of our reserve regime, South Africa, the results seem to indicate that a liquidly effect is plausible. It would be wrong to claim that the decoupling principle was in full force. This means that the South African market for reserves is not insulated fully from movements in the short-term interest rate and vice versa.

A tentative conclusion is that the decoupling principle exists for countries that do not employ a reserve regime. The implication for monetary policy is that central banks might be able to use their balance sheets independently from their interest rate instrument, providing an additional dimension to monetary policy conduct. This result is significant in the wake of the events of the financial crisis of 2007. Central banks could potentially use their balance sheets to combat financial instability while retaining their key policy rate as a tool with which to combat inflation.

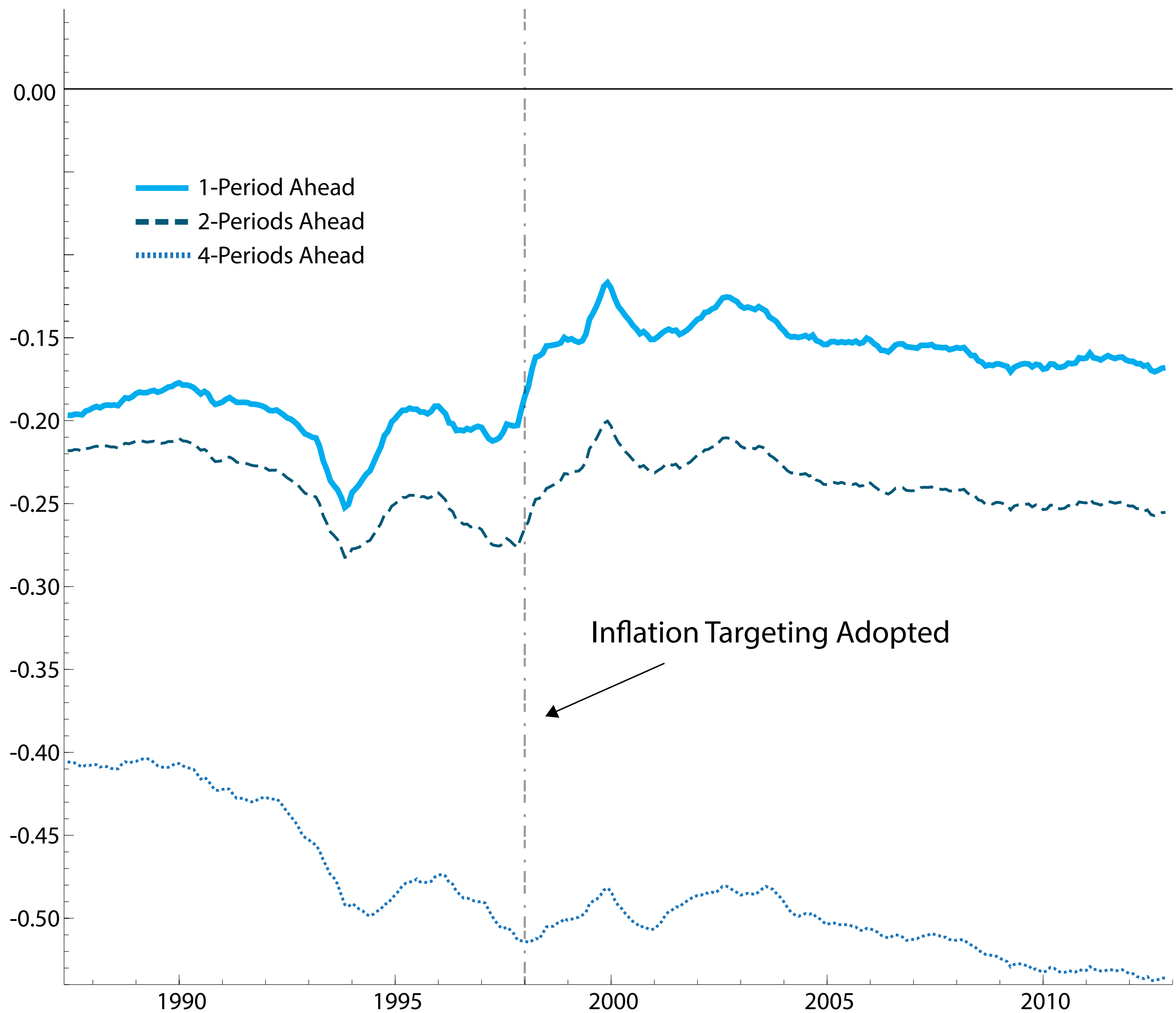


Figure 5.14: Impulse response functions from TVP-VAR for South Africa

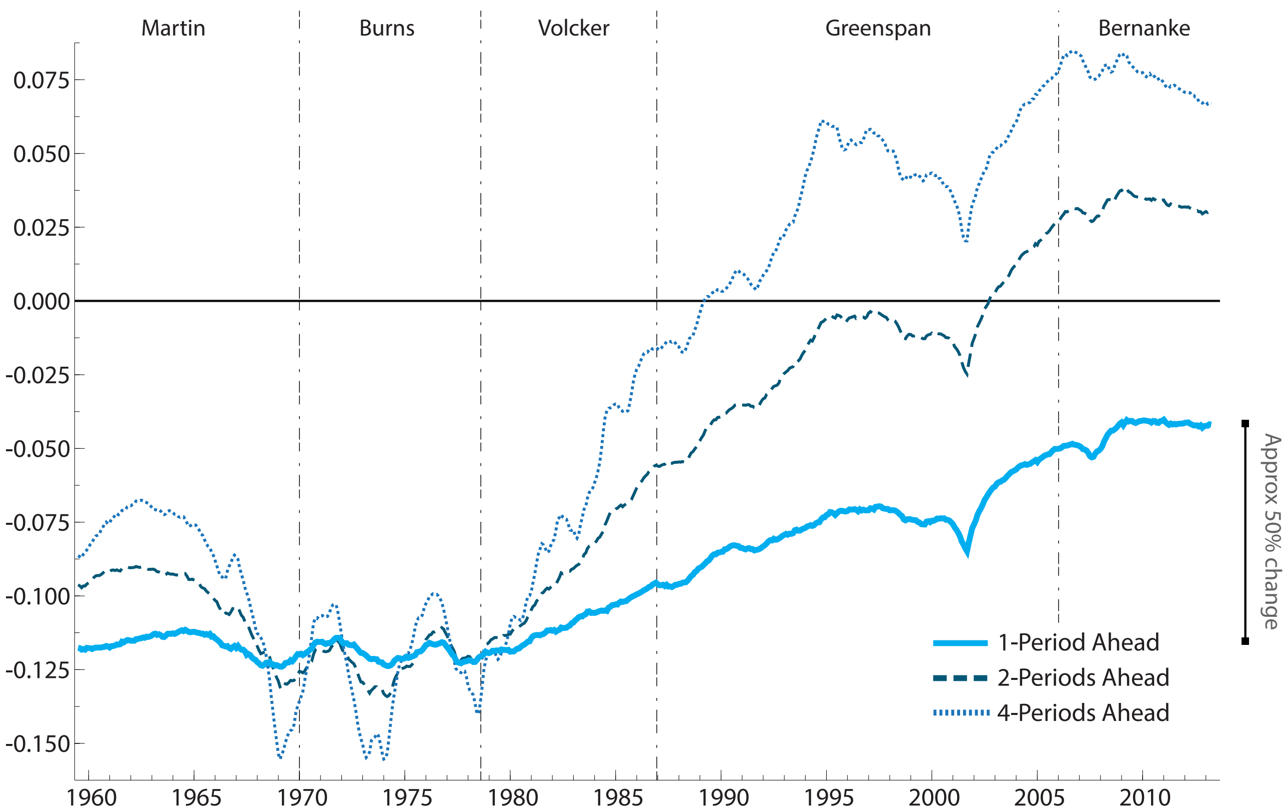


Figure 5.15: Impulse response functions from TVP-VAR for USA

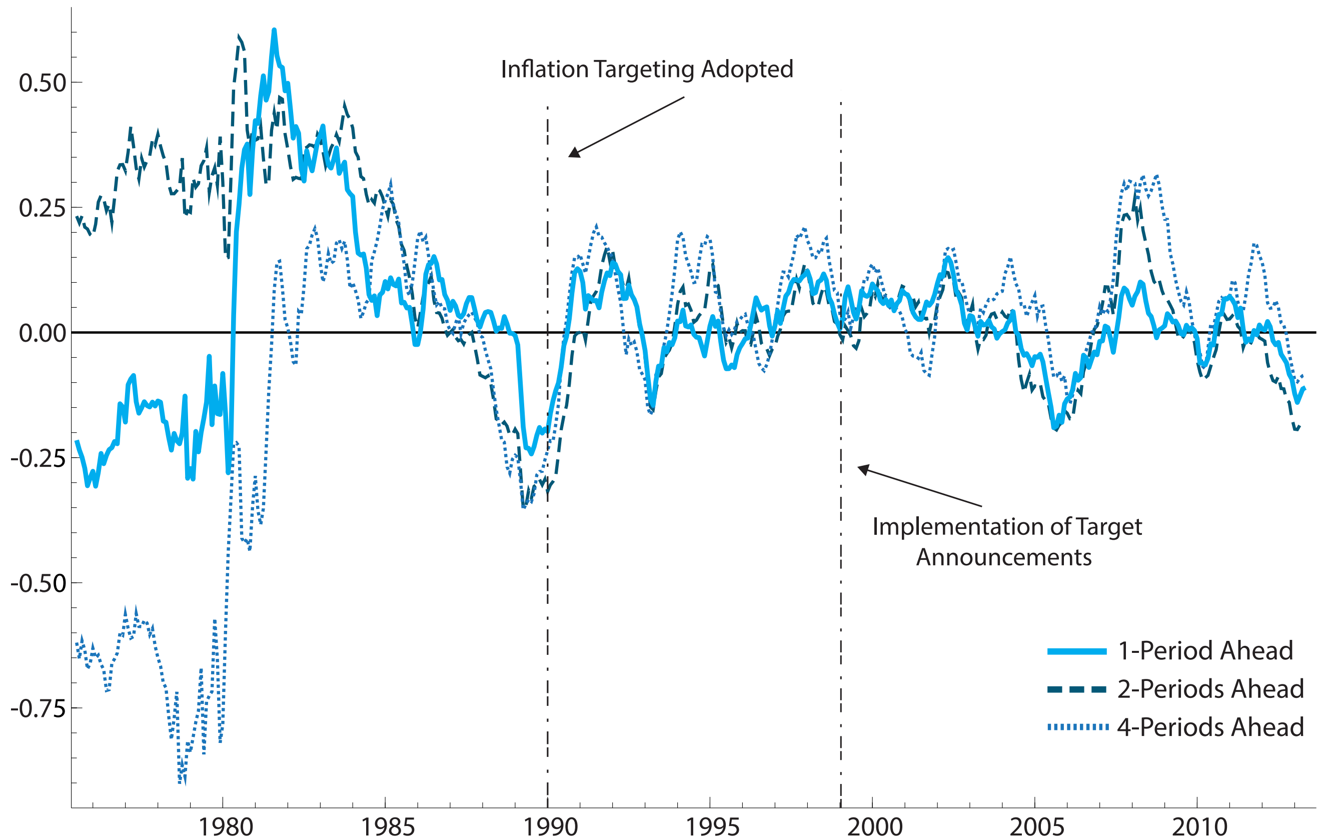


Figure 5.16: Impulse response functions from TVP-VAR for Canada

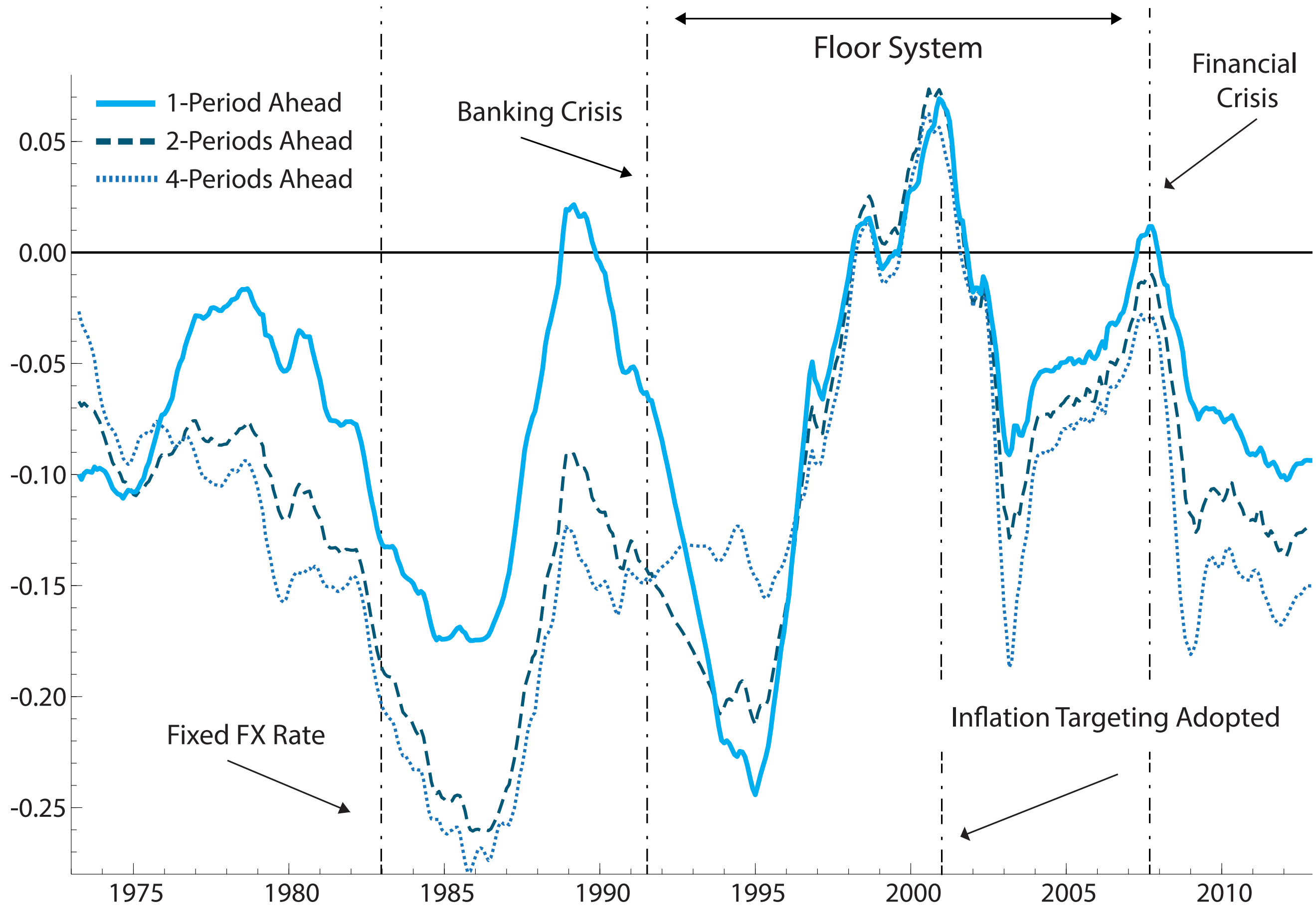


Figure 5.17: Impulse response functions from TVP-VAR for Norway

Chapter 6

Model

In this chapter, the basis of the DSGE model used for the analysis in the next two chapters is formulated. In addition to a discussion on the general setup of the model, the chapter includes a discussion on the financial stability implications of changes to the size of the central bank's balance sheet. Expansion of the central bank's balance sheet is often referred to as quantitative easing, but within the more specific typology of Borio and Disyatat (2010), this increase of central bank liabilities is called bank reserves policy[1]. An extension of the model to include changes in the composition of the assets of the central bank's balance sheet is deferred to the next chapter.

6.1 Introduction

The policy arsenal of central banks has undergone a noticeable expansion in recent years. Policymakers are no longer limited to the one monetary policy instrument, a short-term interest rate, which was central to the New Neoclassical synthesis (Woodford, 2003). Balance sheets of monetary authorities are playing an increasingly important role in policy formulation, as recently emphasised by Bernanke (2011). Policies that increase the size and composition of central bank balance sheets are now used in conjunction with interest rate policy to achieve, simultaneously, price- and financial stability[2].

[1] Cúrdia and Woodford (2010) classify this as reserve-supply policy.

[2] Macroprudential policy measures, as later discussed, are also being used to varying degrees by central banks, existing on occasion as part of the monetary policy space and at other times separated by independence from monetary authorities.

Central banks have traditionally, since the 1970s, considered the balance sheet only in its capacity to steer the overnight rate towards the policy target. The objective of this paper is to determine in what capacity central bank lending can be used to support financial stability. My hypothesis is most similar to that of Goodhart et al. (2011), who consider the potential role of the central bank's balance sheet in the pursuit of financial stability, but I differ on a few specifics.

First, my model is set in a dynamic general equilibrium setting, which - unlike a comparative static setting - allows the researcher to consider the dynamics of the economy. The model presented here is similar to the approach adopted in de Walque et al. (2010). However, I embedded the essential properties of their real business cycle (RBC) model into a New-Keynesian setting with price and wage rigidities, which allows for a richer understanding of the implications of monetary policy.

Second, I endeavoured to provide a more realistic presentation of central bank lending. In Goodhart et al. (2011), the monetary base is mapped one-to-one onto the interest rate, which is not an accurate representation of modern central bank practice. Two important contributions to the literature that also look at the impact of monetary injections on financial stability are de Walque et al. (2010) and Dib (2010a). However, in both of these papers, the monetary authority is structured with direct money injections from the central bank to the commercial (merchant/lending) bank. My paper differs in that it includes collateralised repurchase agreements, as first modelled in Reynard and Schabert (2009) and more recently in Schabert (2015) and Hörmann and Schabert (2015).

The chapter is structured as follows. First, I provide an overview of the related literature, ranging from issues pertaining to financial frictions in DSGE models to methods for employing central bank lending in mainstream models. Second, the model is presented, with the integration of the mechanism proposed by Schabert (2015) in the banking and public sector. The model is kept as simple as possible, abstracting from financial frictions in the demand side of the credit market. Third, a discussion follows on the results of the impulse response functions following (i) a balance sheet expansion and (ii) an increase in the policy rate (monetary tightening). Finally, the last section concludes.

6.2 Literature Review

The two decades preceding the Great Recession were marked by an unprecedented consensus on the "intellectual and institutional framework for monetary policy" (Bernanke, 2011). At the heart of the consensus is the dynamic general equilibrium framework, which was pioneered by Leeper and Sims (1994) and Schorfheide (2000). It was then further propelled into the mainstream by the seminal contributions of, among others, Woodford (2003), Smets and Wouters (2003, 2007) and Christiano et al. (2005). This macroeconometric modelling paradigm has been implemented universally by central banks, who were able to utilise the models successfully to understand the consequences of policy actions better, and thereby achieve macroeconomic stability. However, these models were not equipped to forestall financial market failure.

Economics, as a discipline, has developed with the use of theoretical frameworks that often ignore knotty real-world frictions in order to remain tractable and computationally feasible (de Walque et al., 2010). Theorists make assumptions that reduce complex real-world interactions into digestible mathematical equations. Some of these assumptions have been questioned in the wake of the international financial crisis. A particular concern is the idea that financial markets are perfect and complete, with the implication that financial shocks are irrelevant to real economic outcomes (Roger and Vlcek, 2012). There was a commonly held belief that finance, in the first approximation, was irrelevant to business cycle movements (Woodford, 2003). However, owing to recent events, it has been acknowledged that the financial crisis originated from a collapse of financial intermediation, which has cemented the idea that credit market frictions have real implications (Ahn and Tsomocos, 2013). The shortcomings of macroeconomic models revealed during the crisis have led many, such as Kirman (2010), Caballero (2010), Stiglitz (2011), Krugman (2011), DeLong (2011) and Kay (2012), to question the underlying assumptions of DSGE models. The next section discusses several approaches to introducing endogenous financial frictions into the existing New-Keynesian framework.

6.2.1 Financial Frictions in DSGE Models

Prudent monetary policy, as defined in pre-crisis policy models, is primarily understood with respect to price stability. Financial stability is often considered as a by-product of inflation targeting[3], with financial sectors curiously absent from the majority of mainstream models (Borio, 2014). However, it is now recognised that the "achievement of price stability [. . .] does not guarantee financial stability" (Goodhart, 2011). The dearth of financial markets in core models is contrasted by a rich vein of research in the periphery that accentuates the role of financial market conditions in propagating cyclical fluctuations. Fisher (1933) and Keynes (1936) were among the earliest to develop an alternative narrative that explained how impaired

[3]This issue is discussed in more detail in Chapter 3.

credit markets[4] could substantially contribute to a decline in the real economy[5]. More recently, in the post-war period, these points have been brought to the fore by the contributions of Minsky (1957, 1982) and Kindleberger (2000). Their argument is directly at odds with the assumption of perfectly competitive financial markets, as used by Modigliani and Miller (1958) in their capital structure irrelevance proposition[6].

6.2.1.1 Demand-Side Frictions

In perfectly competitive financial markets there are no frictions that limit access to credit, which allows no insight into scenarios where agents are credit constrained. Financial frictions have been introduced into DSGE models to address this limitation. Pioneering contributions to the literature, to include information asymmetries and non-convex transaction costs, were put forward by Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). Both of these veins of research proposed alterations to the consensus approach, introducing frictions in the demand side of the credit market, where banks act exclusively as intermediaries between households and firms. Financial market conditions in these models serve to frame a more complete narrative of the forces that propagate economic growth.

6.2.1.1.1 External Finance Premium Bernanke and Gertler (1989) were the first to consolidate successfully the financial accelerator mechanism and general equilibrium framework. The inclusion of a financial accelerator is significant as it allows endogenous credit market developments to act both as a source of business cycle fluctuations and as an amplification device. Bernanke and Gertler (1989) postulate that, in the light of tightened financial market conditions, temporary credit shocks could have a strong and persistent effect on the business cycle. To sufficiently constrain credit markets, they integrate the costly state verification framework proposed by Townsend (1979) into a general equilibrium environment.

Costly state verification entails the existence of information asymmetries that obscure the borrower-lender relationship. In the model developed by Bernanke and Gertler (1989), a newly proposed agent, namely the entrepreneur, plays a central role. One of the noteworthy functions of this entrepreneur is its ability to produce capital from consumption goods. In addition, entrepreneurs invest out of their own wealth, as well as taking loans from households. The

[4]Examples of impaired credit conditions include, “sharp increases in insolvencies and bankruptcies, rising real debt burdens, collapsing credit prices, and bank failures” (Bernanke et al., 1999).

[5]Theories were developed owing to the events surrounding the Great Depression.

[6]This assumption asserts that the capital structure of banks is largely irrelevant and indeterminate for lending decisions, and thereby, real economic outcomes.

entrepreneur's net worth is subject to an idiosyncratic shock, where the outcome of the shock is directly observed by the entrepreneur but not the originator of the loan. Lenders would ideally want to know whether entrepreneurs will be able to repay their debt. However, lenders are forced to pay a monitoring cost if they wish to gain information as to the solvency of the entrepreneur. Therefore, borrowing is limited, because monitoring a loan applicant is costly (Brzoza-Brzezina et al., 2011). Efficiency in the process of matching potential borrowers and lenders is reduced (Bernanke et al., 1999).

In this framework, borrowers face a risk premium that decreases with their net worth (Roger and Vlcek, 2012). Standard debt contracts include a premium on the interest rate to cover the cost of default in case of negative wealth shocks (Christiano et al., 2010). An endogenous wedge between the lending and risk free rates is created and is called the external finance premium (Brzoza-Brzezina et al., 2011). In other words, the price of loans is directly affected in this economy. A decrease in price negatively affects the net worth of the entrepreneur and increases the financial friction. The result is lower levels of investment in the next period, coupled with a lower net worth. This feedback mechanism results in strong persistence as the result of tight financial market conditions.

This model setup was further improved by Carlstrom and Fuerst (1997), who incorporated the dynamics into a New-Keynesian DSGE model. Bernanke et al. (1999) added nonlinear capital adjustment costs, to become the workhorse financial accelerator model that is used in many central banks around the world[7]. Important contributions that built on this structure were made by Christiano et al. (2003, 2008) and De Fiore and Uhlig (2005). More recently, Christiano et al. (2014) contributed to the existing paradigm by introducing "idiosyncratic uncertainty in the allocation of capital". Entrepreneurs face uncertainty in the process of converting capital into effective capital, where the magnitude of this uncertainty is modelled as 'risk'.

6.2.1.1.2 Collateral Constraint The financial accelerator proposed by Kiyotaki and Moore (1997) operates in terms of a different friction than the external finance premium. In this model, the agents differ regarding their time preference. As dictated by their preference, agents are identified as either a lender or borrower. Intermediation exists between these two specific groups. Borrowers differ in this market and are required, by the financial intermediary, to provide collateral for loans. Whereas the friction in Bernanke and Gertler (1989) is based in asymmetric information and affects the price of loans, this friction functions on the basis of incomplete contracts and directly impacts on the specific quantity of loans (Kiyotaki and Moore, 1997).

[7]Nonlinear capital adjustment costs added another amplification effect to the model.

Owing to criticism by Kocherlakota (2000) regarding the ability of credit constraint frameworks to generate an empirically valid amplification of shocks, several signficant attempts were made to develop a more realistic setting. Cooley et al. (2004) stand out as one of the early attempts at providing a more quantitatively accurate representation. This was achieved by not focusing exclusively on collateralised debt as the primary form of financing for the firm, but rather by including state-contingent financial contracts. Iacoviello (2005) combined elements of the financial accelerator model developed by Bernanke et al. (1999) and the collateral constraint, as in Kiyotaki and Moore (1997). The original contribution of this model is that firms need to provide real estate as collateral, which he motivates both on practical and substantive grounds.

Financial frictions were initially introduced almost exclusively on the demand side of credit markets, with an explicit focus on the balance sheets of non-financial borrowers (Meh and Moran, 2010). Unfortunately, these models neglect the role of financial intermediaries, treating them as a veil (Gertler and Karadi, 2011). Recent events surrounding the financial crisis highlighted the importance of financial shocks originating in the banking sector as a source of business cycle fluctuations (Dib, 2010a). This has resulted in a concerted effort to develop models that explore disruptions in the supply of credit in financial markets (Falagiarda and Saia, 2013). In a liquidity crisis, financial intermediaries become credit constrained and this friction reveals how shocks in the financial economy could have implications for the real economy (de Walque et al., 2010).

6.2.1.2 Supply-Side Frictions

The international financial crisis has highlighted the central role of financial shocks in driving macroeconomic indicators in the real economy (Quadrini, 2011). Researchers are now tasked with the advancement of models that better incorporate frictions on the supply side of credit markets, specifically fostering models with persuasive, well-founded, banking sectors. Investigation has revealed several components that are believed to be crucial in capturing the essence of a sophisticated banking sector. Some of the particular characteristics that need to be incorporated are related to bank capital, interest rate spreads, interbank markets and the possibility of default. I now briefly touch on some of these issues[8].

6.2.1.2.1 Banking Sectors and Bank Capital Several authors have endeavoured to construct realistic banking sectors. The first wave of models had the specific goal of approximating

[8]These themes do not provide a comprehensive account of all the important issues related to developing a functioning banking sector. Some papers will also belong to more than one specific theme.

the bank capital channel. Previously, it was thought that, in line with the assumptions found in Modigliani and Miller (1958), the structure of bank capital was unimportant in lending decisions. However, empirical evidence suggests that the capital position of a bank directly affects bank lending and thereby real economic activity (Roger and Vlcek, 2012). There has been a large influx of these types of models, with many central banks adopting them as the new workhorse. The reason for this is that policymakers wish to incorporate the recent changes to Basel III regulatory requirements. Generally, these models still follow either the collateral constraint or financial accelerator framework[9], with the addition of a bank capital/equity channel.

Early incarnations of this type of model that try to develop the bank capital channel are those of Markovic (2006), Van den Heuvel (2008) and Angeloni and Faia (2009). The work of Markovic (2006)[10] is particularly influential. The most important contribution in his paper, which builds on the financial accelerator framework, is the introduction of a banking sector where banks face adjustment costs in capital accumulation. Asymmetric information between a bank and its shareholders is the source of the adjustment cost, as shareholders need to incur search costs before investing, creating an environment where the continued procurement of bank capital is considered costly (Markovic, 2006).

6.2.1.2.2 Interest Rate Spreads While the focus on bank capital is crucial, one has to consider that the financial crisis was characterised by widening credit spreads and disruptions in equity markets. Adrian and Shin (2011) point out that financial shocks were transmitted to the real sector, primarily through these channels. Remarkably, in the case of a perfectly competitive banking sector, only one interest rate is considered significant, namely the policy rate (Gerali et al., 2010). The importance of including a time-varying interest rate spread is highlighted in the work of Cúrdia and Woodford (2009, 2010). They include an ad hoc friction in financial intermediation that gives rise to a spread between the loan and policy rate. Increases in the credit spreads are indicative of constrained credit markets, referred to as 'tighter' financial conditions by Cúrdia and Woodford (2009). This credit friction challenges the unrealistic assumption that a single interest rate governs the behaviour of all agents.

Gerali et al. (2010) also indicate a role for the rate at which different interest rates adjust. Their model is built on the back of contributions by Bernanke et al. (1999), Smets and Wouters (2003) and Iacoviello (2005). In this model, financial intermediaries are permitted to set the interest rate charged for deposits collected from households. In this imperfectly competitive

[9] Sometimes even a hybrid of the two.
[10] A model developed at the Bank of England.

banking sector, one observes a wedge between loan rates and the interbank (policy) rate set by the central bank. These authors find that including sticky bank rates produces a financial decelerator (attenuator) effect[11].

In the work of Gertler and Karadi (2011), households are randomly assigned roles as workers or bankers. Bankers provide credit to firms, but constraints are imposed as to the resources they can obtain from deposits and the interbank market. Binding constraints induce a spread between deposit and loan rates. Christiano et al. (2014) present a similar framework, with a spread generated by the possibility of firm failure.

Empirically, one observes time-varying credit spreads, with notable increases in spreads during times of financial turmoil. Cúrdia and Woodford (2010) hypothesise that spreads need to be taken into account by the monetary authority when making policy decisions, specifically through adjustment of the Taylor Rule to incorporate these spreads. Modifying the Taylor Rule in this fashion affords central bankers the opportunity to respond better to shocks originating in the financial sector. Charles Goodhart, in his commentary on the work of Cúrdia and Woodford (2009), welcomes the introduction of the modelled disruption in financial intermediation but provides a scathing critique on the absence of default risk.

6.2.1.2.3 Interbank Markets and Default The failure of interbank markets is increasingly viewed as central to the damage caused by the financial crisis. In order to model this risk, researchers have to develop an active banking sector where banks are allowed to interact and possibly default. Relatively few papers have incorporated banking sectors and default (Roger and Vlcek, 2012). Perhaps the first to include an explicit banking sector is that of Gerali et al. (2010). Their model includes a constraint on bank balance sheets, which affects bank capital, profit and thereby the supply of loans in the economy. Unfortunately, there is no interaction among wholesale banks in this model.

Gertler and Kiyotaki (2010) take another approach to the interbank market. Financial institutions in this setup are exposed to liquidity shocks that distinguish them from one another. These idiosyncratic shocks can potentially disrupt the intermediation process and thereby real economic activity. The biggest shortcoming of this model is that financial institutions resemble a homogenous intermediary in aggregate. In other words, the banking sector does not consist of heterogenous agents, and therefore, can not truly represent an interbank market. However, the work of Gertler et al. (2016) builds on their earlier model, introducing a wholesale banking sector, alongside the retail banking sector. The purpose of this work was to include components

[11] In addition to the financial accelerator and bank capital channel identified in their model.

of the failure of the shadow banking system during the recent crisis by allowing for runs on the wholesale banks. Several papers, such as Robatto (2014), Gertler and Kiyotaki (2015) and Ferrante (2015), have started to develop the possibility of bank runs in dynamic models.

A relatively new stream of research, which was built on the model developed by Goodhart et al. (2006)[12], provides advances in the development of interbank markets and default. One of the most important contributions of their body of work has been the inclusion of a heterogenous and endogenous banking sector. They abstract from the representative agent approach in modelling the banking system. This allows for the interaction of banks on the interbank market and thereby the possibility of modelling the reactions of commercial banks to certain shocks. Failure of banks, or endogenous default as developed by Shubik and Wilson (1977) and Dubey et al. (2005), is one of the primary features of this model. Failure is a function of the risk preference of banks in this system, with the riskiest banks assigned the highest probability of default. These failures are not isolated events in this model and have system-wide implications for the survival of other banks.

Several authors have adopted this framework to explore various macroeconomic issues. Some of the important articles in this tradition are those of Goodhart et al. (2009), de Walque et al. (2010), Dib (2010a,b), Hilberg and Hollmayr (2011), Martinez and Tsomocos (2011), Carrera and Vega (2012) and Ahn and Tsomocos (2013). My model most closely resembles the work of de Walque et al. (2010).

6.2.1.2.4 Macroprudential Policy In this chapter, financial stability is defined in terms of endogenous default, but several other definitions exist[13]. After the crisis, a large body of literature developed around the idea of financial instability and how to combat it. The avenue explored most frequently to target financial stability is that of macroprudential regulation. Approaches that capture the interaction of balance sheet policies and financial stability are more limited.

Galati and Moessner (2013) provide an excellent discussion on macroprudential policies, while the articles by Friedrich et al. (2015) and Collard et al. (2015) discuss the introduction of these policy measures into DSGE models[14]. Of particular interest in this thesis is an article by Woodford (2016) that looks at both the role of quantitative easing and macroprudential policy

[12]This article is the culmination of years of research and several other articles are linked in the model's construction (see, for example, Aspachs et al. (2006a); Tsomocos and Zicchino (2005); Aspachs et al. (2006b); Goodhart and Tsomocos (2006)).

[13]In fact, there is little consensus in the literature on the exact definition of financial stability, see the article by Borio and Drehmann (2009) for a discussion.

[14]While the literature is interesting in its own right, a full literature review is not attempted here.

in combating financial instability. He found that among the three policy instruments[15] available to the central bank, quantitative easing generates the lowest risk for financial instability for a given increase in aggregate demand (Woodford, 2016). In fact, quantitative easing can be used in conjunction with macroprudential policy to almost entirely negate the build-up of financial imbalances.

6.2.2 Central Bank Lending as Prudential Policy Tool

This section explores the effect of a change in the size of the balance sheet on financial stability[16], through central bank lending. Goodhart et al. (2011) ask a similar question by incorporating the monetary base into their financial fragility framework and analysing its potential for use as a prudential policy tool[17]. It differs from the model presented in this paper in a few significant ways, as depicted in the next section. Their paper can be seen as an intellectual successor to William Poole's (1970) solution of the instrument problem, in that they explore the effectiveness of both the monetary base and interest rates as tools of monetary policy, in a setting where the liquidity effect functions perfectly.

Several papers have considered the optimal instrument choice in achieving price stability. The work of Poole (1970) signified a watershed in the discussion on the instrument problem, with the interest rate winning out as the most effective in achieving price stability. Poole (1970) argued that the policy rate encompasses all the desired characteristics, especially in its tightness to inflation[18]. Sargent and Wallace (1975) add forward-looking features in their model and find, in contrast to Poole (1970), that money growth policies have an advantage over interest rate policies. This result has been contested by several authors, namely, McCallum (1981), Woodford (2003) and, more recently Atkeson et al. (2007) and Woodford (2008). However, I am not interested in the instrument problem as it pertains to price stability.

In fact, the question posed here is much simpler. The objective is to design a model that formalizes the idea from the post-crisis discourse that balance sheets matter[19] for financial stability (du Plessis, 2012). Monetary policy research in the last few years has been focused on the central bank's balance sheet, because the short-term interest rate as a conventional tool

[15] Short-term policy rate, macroprudential policy and quantitative easing.

[16] There are several definitions of financial stability in the literature. I follow the approach of Goodhart et al. (2006) in this paper.

[17] The paper by Grauwe and Gros (2009) poses a question is in the same vein. They endeavoured to determine whether there is a trade-off between price and financial stability in the use of monetary policy tools.

[18] An instrument "is tighter than another if it is more closely linked to the feature it is meant to influence" (Atkeson et al., 2007).

[19] This includes the balance sheet of the central bank, as well as those of financial institutions.

of monetary policy is limited in its scope to address financial stability. The policy rate is often regarded as a blunt tool against the build-up of financial imbalances accompanying movements in asset prices and credit aggregates (Bernanke, 2011)[20]. In addition, as stated in the Tinbergen principle, "if the number of policy targets surpasses the number of instruments, then some targets may not be met" (Tinbergen, 1952).

Ultimately, policymakers should not overburden policy tools with too many targets, as it impedes the proper functioning of that instrument. Following this logic, several developed country central banks have already used balance sheet operations - by altering the size and composition of their balance sheets - to address dysfunctional markets (Bernanke, 2011). The primary contribution of this model is in the addition of a more realistic representation of central bank lending.

6.2.2.1 Central Bank Lending in DSGE Models

Several papers have been developed with the goal of capturing a more realistic discount window lending function of the central bank in DSGE models. An early contribution is that Gertler and Kiyotaki (2010), who looked to develop a model of discount window lending in a DSGE model. In this setup, as previously mentioned, financial intermediaries are credit constrained and have access to the central bank's lending facilities. However, these commercial banks do not offer collateral in return for central bank liquidity. In a similar fashion, the work of Bocola (2015) builds on the framework of Gertler and Kiyotaki (2010) to determine the effect of LTROs. However, borrowing is still not collateralised in this model.

The model of van der Kwaak (2015) is based on the work of Gertler and Karadi (2011) but restructures the way in which commercial banks are financed. Commercial banks receive financing through "net worth, deposits and [central bank] liquidity" (van der Kwaak, 2015). His model deviates from Gertler and Karadi (2011) in that obtaining central bank liquidity requires government bonds as collateral, with private sector assets not being eligible. While there are several similarities between the model from this chapter and and that of van der Kwaak (2015), his structure does not include a dimension for the heterogeneous interbank sector and endogenous default.

In order to model central bank lending accurately, I looked to the early work of Reynard and Schabert (2009), and more recently Schabert (2015) and Hörmann and Schabert (2015). Their framework, as was discussed in the section on financial intermediaries, uses a haircut

[20] It is generally believed that monetary policy is not effective in 'leaning' against an upswing in the credit cycle and should rather assume an accommodative position to 'clean' after the bubble has burst (White, 2009).

mechanism to facilitate collateralised lending. This approach is also tied to a broader literature that uses haircuts as tools for monetary policy. Some of the relevant readings in this regard are Adrian and Shin (2009), Ashcraft et al. (2011), Cúrdia and Woodford (2011) and Hilberg and Hollmayr (2011). The model presented in the next section aims to deliver insight into how agents (primarily financial intermediaries and firms) respond to changes in the size of a central bank's balance sheet.

6.3 The Model

This section provides an account of the dynamic stochastic general equilibrium (DSGE) model, which draws from the work of Smets and Wouters (2003, 2007), de Walque et al. (2010), Schabert (2015) and Hörmann and Schabert (2015). The model consists of six sectors. Both the household and firm sectors are closely related to the canonical New-Keynesian DSGE formulation of Smets and Wouters (2003, 2007)[21]. One significant difference is that the firm is allowed to default on its loans, as in de Walque et al. (2010). In addition, financial intermediation is included in the banking sector, which consists of two heterogenous banks, both with the option to default on loans (but not on deposits).

The deposit bank receives deposits from households and provides loans to the interbank market, while the merchant bank borrows from the interbank market and issues loans to firms. Merchant banks are also able to hold bonds issued by the government. These bonds serve as collateral in open market operations. The banking sector is similar to that of de Walque et al. (2010) but adds a form of collateralised central bank lending in the vein of Schabert (2015) and Hörmann and Schabert (2015). The government can potentially purchase goods, raise lump-sum taxes and issue bonds. I extend this model in the following chapter to include both short- and long-term bonds, with the long-term bonds modelled as perpetuities, as in Chen et al. (2012a). The central bank sets the main refinancing rate according to a Taylor-type rule, supplies reserves in exchange for eligible collateral and decides through the haircut mechanism on the size (and potentially composition) of its balance sheet.

6.3.1 Households

The household sector in this model closely follows that of Smets and Wouters (2003), which consists of a continuum of infinitely-lived households, indexed by $j \in [0, 1]$. Households

[21] In other words, the model combines advancements in real business cycle (RBC) methodology with sticky prices and wages gathered from the New Keynesian framework.

maximise a lifetime utility function given by

$$\max_{\{C_{j,t},N_{j,t},D_{j,t}\}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^h)^s \left[U^h_{j,t+s}\right] \tag{6.1}$$

where β^h is a discount factor and the utility function is separable in consumption and labour.

$$U^h_{j,t} = \frac{1}{1-\sigma_c}(C_{j,t} - hC_{j,t-1})^{1-\sigma_c} - \frac{1}{1+\sigma_n}(N_{j,t})^{1+\sigma_n} \tag{6.2}$$

Utility depends positively on the consumption of j goods, $C_{j,t}$ (relative to an external habit variable $H_t = h \cdot C_{j,t-1}$) and negatively on the labour supply $N_{j,t}$. The coefficient of relative risk aversion is σ_c, which is also known as the inverse of the intertemporal elasticity of substitution. The Frisch elasticity of labour supply is σ_l. Households maximise utility subject to the flow budget constraint,

$$T_t + \frac{D_{j,t}}{R^d_t} + C_{j,t} = w_{j,t}N_{j,t} + A_{j,t} + \frac{D_{j,t-1}}{\pi_t} + T^r_t. \tag{6.3}$$

The household invests in deposits, $D_{j,t}$ at the risk-free rate of R^d_t and supplies labour at the real wage rate, $w_{j,t}$. The government taxes households in the form of T_t, and the central bank provides seignorage revenue, T^r_t[22]. It is also assumed, as in Smets and Wouters (2003), that state-contingent securities, $A_{j,t}$, insure against idiosyncratic shocks, leaving households “homogenous with respect to consumption and asset holdings” in equilibrium (Christiano et al., 2005).

At this point, it is worth mentioning that several components of the standard DSGE framework are excluded. First, there is no explicit role for money in this model, which is ostensibly the biggest shortcoming in this model. However, the focus of this thesis is not on the cash holdings of households. Extensions of this model will include a cash-in-advance constraint as the preferred method of delivery[23]. Second, investment opportunities are limited to deposits, but could potentially include several other securities and investment vehicles. Third, households are not subject to preference shocks, which are considered part and parcel of the modern modelling approach in the DSGE literature (Smets and Wouters, 2003, 2007). These additions could potentially be added to the framework, but they are not the focus of the analysis and, therefore, are excluded initially.

[22]The public sector is not consolidated in this model

[23]The paper by Schabert (2015) includes a CIA constraint in favour of the popular MIU method. The exclusion of money in this model is briefly discussed in Appendix B.3.

6.3.1.1 Consumption and Savings

The objective function (6.1) is maximised taking into consideration the flow budget constraint (6.3), which yields the following first-order conditions for consumption and deposit holdings.

$$(\partial C_t) \qquad (C_t - hC_{t-1})^{-\sigma_c} = \lambda_t^h \tag{6.4}$$

$$(\partial D_t) \qquad \beta^h \mathbb{E}_t \left[\left(\frac{\lambda_{t+1}^h}{\pi_{t+1}} \right) \right] = \frac{\lambda_t^h}{R_t^d} \tag{6.5}$$

Combining these equations, with $(C_{t+1} - hC_t)^{-\sigma_c} = \lambda_{t+1}^h$, gives the Euler equation as,

$$\beta^h \mathbb{E}_t \left[\frac{(C_{t+1} - hC_t)^{-\sigma_c}}{\pi_{t+1}} \right] = \frac{(C_t - hC_{t-1})^{-\sigma_c}}{R_t^d} \tag{6.6}$$

The Euler equation encapsulates the intertemporal consumption and saving decisions of the household. In the next two sections I identify the labour supply and wage-setting behaviour of the household, as presented in Fernández-Villaverde and Rubio-Ramírez (2006).

6.3.1.2 Labour Supply

Households supply homogenous labour to an intermediate labour union. Each household j has monopolistic power over the supply of its labour services (which means it can set its own price in the labour market). The labour union differentiates these labour services (Smets and Wouters, 2003; Brzoza-Brzezina et al., 2011). Aggregate labour demand N_t is given by the Dixit-Stiglitz aggregator function,

$$N_t = \left(\int_0^1 (N_{j,t})^{\frac{\eta-1}{\eta}} dj \right)^{\frac{\eta-1}{\eta}} \tag{6.7}$$

Labour packers buy the differentiated labour from the unions, and package and resell the services to intermediate goods producers. The maximisation problem for the labour packers, who try to maximise the production function, given by (6.7), is

$$\max_{N_{j,t}} \left(w_t N_t - \int_0^1 w_{j,t} N_{j,t} dj \right) \tag{6.8}$$

where w_t^h represents the households' differentiated labour wages and w_t, the aggregate wage.

The first-order condition for the maximisation problem is

$$w_t \frac{\eta}{\eta-1}\left(\int_0^1 \left(N_{j,t}\right)^{\frac{\eta-1}{\eta}} d^j\right)^{\frac{-1}{\eta-1}} \frac{\eta-1}{\eta}\left(N_{j,t}\right)^{\frac{-1}{\eta}} - w_{j,t} = 0 \tag{6.9}$$

and the associated labour demand function is

$$N_{j,t} = \left(\frac{w_{j,t}}{w_t}\right)^{-\eta} N_t \qquad \forall j \tag{6.10}$$

where the aggregate wage in the economy is represented by

$$w_t = \left(\int_0^1 \left(w_{j,t}\right)^{1-\eta} dj\right)^{\frac{1}{1-\eta}} \tag{6.11}$$

6.3.1.3 Wage Setting

In this economy, the households set their wages according to Calvo's setting. In this scheme, households can optimally adjust their wages after receiving a random signal with probability $(1-\theta_w)$. A household j that receives this signal will be able to set a new nominal wage to maximise its utility subject to the demand for labour services. Households that do not receive the signal can only partially index their wages to past values of inflation according to the following rule:

$$w_{j,t+1} = \left(\pi_t\right)^{\tau_w} w_{j,t} \tag{6.12}$$

where τ_w is the degree of wage indexation. This implies that if the household cannot change the wage for k periods, with $\tau_w = 0$, then the normalised wage after k periods is $\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} w_{j,t}$. The maximisation problem relies not only on the optimisation of (6.1) with respect to the budget constraint in (6.3), but also on the labour demand function presented in (6.10) and the wage indexation formula in (6.12). This relevant part of the maximisation is given by

$$\max_{w_{j,t}} \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[-\frac{1}{1+\sigma_n}\left(N_{j,t}\right)^{1+\sigma_n} + \lambda_{j,t+s}^h \prod_{s=1}^{k} \frac{\left(\pi_{t+s-1}\right)^{\tau_w}}{\pi_{t+s}} w_{j,t} N_{j,t+k}\right] \tag{6.13}$$

subject to

$$N_{j,t+k} = \left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \frac{w_{j,t}}{w_{t+k}} \right)^{-\eta} N_{t+k} \quad \forall j \tag{6.14}$$

All households set the same wage because, as stated in Fernández-Villaverde and Rubio-Ramírez (2006), "complete markets allow them to hedge the risk of the timing of wage change"; this means we drop the j[24]. The first-order condition for this problem is

$$\begin{aligned} &\frac{\eta-1}{\eta} w_t^* \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\lambda_{t+s}^h \left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \right)^{1-\eta} \left(\frac{w_t^*}{w_{t+k}} \right)^{-\eta} N_{t+k} \right] \\ &= \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \frac{w_t^*}{w_{t+k}} \right)^{-\eta(1+\sigma_n)} (N_{t+k})^{1+\sigma_n} \right] \end{aligned} \tag{6.15}$$

From this we can define

$$f_t^1 = \frac{\eta-1}{\eta} w_t^* \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\lambda_{t+s}^h \left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \right)^{1-\eta} \left(\frac{w_t^*}{w_{t+k}} \right)^{-\eta} N_{t+k} \right] \tag{6.16}$$

$$f_t^2 = \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \frac{w_t^*}{w_{t+k}} \right)^{-\eta(1+\sigma_n)} (N_{t+k})^{1+\sigma_n} \right] \tag{6.17}$$

The equality $f_t^1 = f_t^2$ returns the first order condition. It is possible to express f_t^1 and f_t^2 recursively as

$$f_t^1 = \frac{\eta-1}{\eta} (w_t^*)^{1-\eta} \lambda_t^h (w_t)^{\eta} N_t + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{1-\eta} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta-1} f_{t+1}^1 \tag{6.18}$$

$$f_t^2 = \left(\frac{w_t}{w_t^*} \right)^{\eta(1+\sigma_n)} (N_t)^{(1+\sigma_n)} + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{-\eta(1+\sigma_n)} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta(1+\sigma_n)} f_{t+1}^2 \tag{6.19}$$

Since $f_t^1 = f_t^2$, we can set $f_t = f_t^1 = f_t^2$, which gives us

$$f_t = \frac{\eta-1}{\eta} (w_t^*)^{1-\eta} \lambda_t (w_t)^{\eta} N_t + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{1-\eta} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta-1} f_{t+1} \tag{6.20}$$

$$f_t = \left(\frac{w_t}{w_t^*} \right)^{\eta(1+\sigma_n)} (N_t)^{(1+\sigma_n)} + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{-\eta(1+\sigma_n)} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta(1+\sigma_n)} f_{t+1} \tag{6.21}$$

[24] w_t^* is the common reset price

Finally, given equation (6.11), the optimal wage-setting problem delivers the following real wage index law of motion

$$w_t^{1-\eta} = \theta_w \left(\frac{(\pi_{t-1})^{\tau w}}{\pi_t} \right)^{1-\eta} (w_{t-1})^{1-\eta} + (1-\theta_w)({w_t}^*)^{1-\eta} \tag{6.22}$$

Having defined the first-order conditions that govern the behaviour of the household, I move on to a model of the firm in the next section.

6.3.2 Firms

Firms in this paper resemble those in the standard New-Keynesian literature, which translates to a single final good and continuum of intermediate goods being produced. In this setting, the final goods sector is perfectly competitive, while one encounters monopolistic competition in the markets for intermediate goods. Intermediate goods are indexed by i, where i is distributed over the unit interval. These firms produce differentiated goods and sell them to aggregators – who combine them into the final good. In other words, final goods producers package the intermediate goods and sell them to households for consumption.

6.3.2.1 Final-Good Sector

Final goods producers are the aggregators in this economy. They produce a homogenous good Y_t by combining intermediate goods $y_{i,t}$ through a Dixit-Stiglitz technology. The associated production function is,

$$Y_t = \left(\int_0^1 (y_{i,t})^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \tag{6.23}$$

where $y_{i,t}$ is the quantity of the intermediate good used in production, ϵ is the elasticity of substitution (time-varying markup in the goods market). Final goods producers maximise their profits subject to the production function in (6.23), taking as given all intermediate goods prices and the final goods price. The maximisation problem of the final goods producer is

$$\max_{y_{i,t}} \left(p_t Y_t - \int_0^1 p_{i,t} y_{i,t} di \right) \tag{6.24}$$

The associated input-demand function (same procedure used when calculating the wages) from this problem is

$$y_{i,t} = \left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t \tag{6.25}$$

and the final goods price is,

$$p_t = \left(\int_0^1 (p_{i,t})^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}} \tag{6.26}$$

6.3.2.2 Intermediate Goods Producers

In this section, there is a continuum of monopolistically competitive intermediate goods producers of unit mass. Firms set their prices, $p_{i,t}$, according to the Rotemberg pricing assumption to maximise profit, π^f[25]. In addition to setting their prices they choose the a level of employment, $N_{i,t}$, and the amount they wish to borrow from merchant banks, $L^b_{i,t}$. These firms also default on their loan repayment, with probability $1-\psi_t$. In the case of default, firms experience both disutility and pecuniary costs. Combining these elements, one finds that the firm maximises profit in the following manner:

$$\max_{\{p_{i,t}, N_{i,t}, L^b_{i,t}, \psi_t, y_{i,t}, K_{i,t}, \pi^f_t\}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^f)^s \left[(\pi^f_{t+s}) - d_\psi(1-\psi_{t+s})\right] \tag{6.27}$$

where B^f is the firm's discount factor, and d_ψ is the disutility parameter associated with default. Each good is produced (supplied) using the following Cobb-Douglas production technology:

$$y_{i,t} = K^{\alpha}_{i,t} N^{1-\alpha}_{i,t} \tag{6.28}$$

where $K_{i,t}$ is the capital rented by the firm and $N_{i,t}$ the number of workers employed (i.e. labour input rented). Capital accumulation for this firm is characterised by

$$K_{i,t} = (1-\varphi)K_{i,t-1} + \frac{L^b_{i,t}}{R^c_t}\left[1 - \Gamma\left(\frac{L^b_{i,t}}{L^b_{i,t-1}}\right)\right] \tag{6.29}$$

[25] The Rotemberg pricing mechanism is used because interest rates are predetermined, which means that marginal cost is unique to the firm. I did not want price setting to interfere with the default decision which meant that the symmetry of Rotemberg wourld be most appropriate, see de Walque and Pierrard (2010) for a discussion. Rotemberg and Calvo present with the same reduced-form New Keynesian Phillips Curve, representing similar dynamics for inflation and output. In other words, up to the first order, the dynamics of these two mechanisms are the same (Blanchard and Galí, 2007).

where φ is the rate at which capital depreciates and Γ is a convex investment adjustment cost[26]. In this equation firms replenish their capital stock by borrowing $L^b_{i,t}$ at a price of $\frac{1}{R^c_t}$. Finally the profit function is given by,

$$\pi^f_t = \left(\frac{p_{i,t}}{p_t}\right) y_{i,t} - w_t N_{i,t} - \psi_t \frac{L^b_{i,t-1}}{\pi_t} - \frac{\omega_\psi}{2}\left((1-\psi_{t-1})L^b_{i,t-2}\right)^2$$
$$-\frac{\varrho}{2}\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p} p_{i,t-1}} - 1\right)^2 Y_t \tag{6.30}$$

where ω_ψ is the pecuniary cost of default parameter, ϱ is a quadratic price adjustment cost and $\bar{\pi}$ is the steady-state value of inflation. The FOCs with respect to capital and labour for this problem are

$$(\partial N_{i,t}) \qquad w_t = (1-\alpha) K^{\alpha}_{i,t} {L_{i,t}}^{-\alpha} \tag{6.31}$$
$$(\partial K_{i,t}) \qquad \lambda^f_{i,t} - \beta^f \mathbb{E}_t[(1-\varphi)\lambda^f_{i,t+1}] = \alpha K^{\alpha-1}_{i,t} L^{1-\alpha}_{i,t} \tag{6.32}$$

which means that the constant returns-to-scale Cobb-Douglas production function delivers the following marginal cost function:

$$mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t}{\alpha}\right)^{\alpha}$$
$$= \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{\lambda^f_t - \beta^f \mathbb{E}_t[(1-\varphi)\lambda^f_{t+1}]}{\alpha}\right)^{\alpha} \tag{6.33}$$

The investment equation derived from the first-order conditions for this maximisation problem is

$$(\partial L^b_{i,t}) \qquad \frac{\lambda^f_{i,t}}{R^c_t}\left(1 - \Gamma\left(\frac{L^b_{i,t}}{L^b_{i,t-1}}\right) - \Gamma'\left(\frac{L^b_{i,t}}{L^b_{i,t-1}}\right)\frac{L^b_{i,t}}{L^b_{i,t-1}}\right)$$
$$= \beta^f \mathbb{E}_t\left[\frac{\psi_{t+1}}{\pi_{t+1}} - \frac{\lambda^f_{i,t+1}}{R^c_{t+1}}\left(\Gamma'\left[\frac{L^b_{i,t+1}}{L^b_{i,t}}\right]\left(\frac{L^b_{i,t+1}}{L^b_{i,t}}\right)^2\right)\right] + (\beta^f)^2 \mathbb{E}_t\left[\omega_\psi (1-\psi_{t+1})^2 L^b_{i,t}\right] \tag{6.34}$$

[26]This convex investment adjustment cost function $\Gamma(\cdot)$ is equal to zero at steady state. In addition, the first derivative $\Gamma'(\cdot)$ also equals zero at steady state. The explicit functional form is $\Gamma\left(\frac{L^b_{i,t}}{L^b_{i,t-1}}\right) = \frac{\theta}{2}\left(\frac{L^b_{i,t}}{L^b_{i,t-1}} - 1\right)^2$.

The default decision is reflected by

$$(\partial \psi_t) \qquad \frac{L^b_{i,t-1}}{\pi_t} = d_\psi + \beta^f \omega_\psi \left[(1-\psi_t)(L^b_{i,t-1})^2\right] \tag{6.35}$$

6.3.2.2.1 Price setting I used the Rotemberg pricing assumption, so that all intermediate firms set the same prices and produce the same quantities (de Walque et al., 2010). The price was set by taking into account the marginal cost, price adjustment cost and the market demand function. The relevant part of the maximisation problem is as follows:

$$\max_{\{p_{i,t}\}} = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^f)^s \left[\left(\frac{p_{i,t}}{p_t}\right) y_{i,t} - (mc_t) y_{i,t} - \frac{\varrho}{2}\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p} p_{i,t-1}} - 1\right)^2 Y_t \right] \tag{6.36}$$

subject to the demand for intermediate goods,

$$y_{i,t} = \left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t$$

Inserting the value for $y_{i,t}$ gives the following problem:

$$\max_{\{p_{i,t}\}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^f)^s \left[\left(\frac{p_{i,t}}{p_t}\right)\left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t - (mc_t)\left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t - \frac{\varrho}{2}\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p} p_{i,t-1}} - 1\right)^2 Y_t \right]$$

The first-order condition with respect to $p_{i,t}$ is,

$$\begin{aligned}(\partial p_{i,t}) \qquad & (1-\epsilon)(p_{i,t})^{-\epsilon}(p_t)^{\epsilon-1} Y_t + (\epsilon) mc_t (p_{i,t})^{-\epsilon-1}(p_t)^{\epsilon} Y_t \\ & - \varrho Y_t \left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p} p_{i,t-1}} - 1\right)\left(\frac{1}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p} p_{i,t-1}}\right) \\ & + \varrho \beta^f \mathbb{E}_t Y_{t+1}\left(\frac{p_{i,t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p} p_{i,t}} - 1\right)\left(\frac{p_{i,t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}(p_{i,t})^2}\right)\end{aligned}$$

Aggregate over all retailer prices, i.e. $p_t = \int_0^1 (p_{i,t}) di$, gives us the following price Phillips curve:

$$\begin{aligned} & \left(\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}} - 1\right)\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}} \\ & = \beta^f \mathbb{E}_t \left[\left(\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}} - 1\right)\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}\frac{y_{t+1}}{y_t}\right] + \left[\frac{1-\epsilon(1+mc_t)}{\varrho}\right] \end{aligned} \tag{6.37}$$

6.3.3 Banking Sector

The banking sector consists of two specialised banks. Deposit banks receive deposits from households at the deposit rate and lend money to the interbank market at the interbank rate. The merchant bank is the link to the firm; it borrows from the interbank market and supplies loans to the firms. Both of these banks may face defaults on their loans.

6.3.3.1 Deposit Banks

Deposit banks lend L_t^l to the interbank market at the interbank rate R_t^l. It is possible, with probability $(1-\delta_t)$, that the bank is not reimbursed for its loan. These banks also receive deposits $D_t^l = \int D_{j,t} dj$ from households, which they must pay at a deposit rate of R_t^d. There is no possibility for deposit banks to default on the loans of households. The maximisation programme for the bank is

$$\max_{\{D_t^l, L_t^l\}} = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^l)^s \left[\frac{(\pi_{t+s}^l + 1)^{1-\sigma_l}}{1-\sigma_l} \right] \tag{6.38}$$

subject to the constraint

$$\pi_t^l = \frac{D_t^l}{R_t^d} - \frac{D_{t-1}^l}{\pi_t} + \delta_t \frac{L_{t-1}^l}{\pi_t} - \frac{L_t^l}{R_t^l} \tag{6.39}$$

The formulation of the bank in this model abstracts from real security holdings[27], a supervisory authority and own funds, when compared with the setup in de Walque et al. (2010). The balanced budget condition here is $D_t^l = L_t^l$. The most important contribution to the paper lies with the merchant banks. The first-order conditions for this maximisation problem are,

$$(\partial D_t^l) \qquad \frac{1}{R_t^d} \dot{U}_t^l = \beta^l \mathbb{E}_t \left[\frac{1}{\pi_{t+1}} \dot{U}_{t+1}^l \right] - \Xi_t \tag{6.40}$$

$$(\partial L_t^l) \qquad \frac{1}{R_t^l} \dot{U}_t^l = \beta^l \mathbb{E}_t \left[\frac{\delta_{t+1}}{\pi_{t+1}} \dot{U}_{t+1}^l \right] + \Xi_t \tag{6.41}$$

where $\dot{U}_t^l = (\pi_t^l + 1)^{-\sigma_l}$ and Ξ_t is the multiplier on the balanced budget condition. These first-order conditions are the Euler equations for deposits from households and loans to the interbank market, respectively (de Walque et al., 2010). Combining them gives the following

[27] Future versions of this model will include an array of security options

equation:

$$\frac{1}{R_t^d}\dot{U}_t^l = \beta^l \mathbb{E}_t\left[\frac{1}{\pi_{t+1}}\dot{U}_{t+1}^l\right] + \beta^l \mathbb{E}_t\left[\frac{\delta_{t+1}}{\pi_{t+1}}\dot{U}_{t+1}^l\right] - \frac{1}{R_t^l}\dot{U}_t^l$$

$$\dot{U}_t^l\left(\frac{1}{R_t^d} + \frac{1}{R_t^l}\right) = \beta^l \mathbb{E}_t\left[\left(\frac{1+\delta_{t+1}}{\pi_{t+1}}\right)\dot{U}_{t+1}^l\right] \tag{6.42}$$

6.3.3.2 Merchant Banks

Merchant banks complete the financial intermediation narrative for the banking sector. These banks, referred to by Goodhart et al. (2006) as retail banks, borrow money from the interbank market L_t^l at the interbank rate R_t^l, receive government debt B_t (which is issued at the price $1/R_t^b$ and delivers a payoff of one in $t+1$) and receive reserves from the central bank M_t at the nominal policy rate R_t^m. Merchant banks may choose not to repay their debt, with a probability of $(1-\delta_t)$. Default takes on a very specific character in this model. Banks that default are not excluded from the interbank market. They experience disutility (d_δ) and non-pecuniary costs as a result of this decision. These banks are also the originators of loans for the firms. They provide loans L_t^b at the credit rate of R_t^c. Firms may also choose not to repay their debt, with probability $(1-\alpha_t)$.

The reserves received, M_t, are from outright purchases of securities by the central bank (i.e. permanent open market operations). The monetary authority can perform this operation to change the size of its balance sheet (Akhtar, 1997). It is also possible to include temporary repurchase agreements, as presented in Schabert (2015). These repurchase agreements entail overnight transactions in the reserve market so that the overnight rate is kept in line with the policy rate. This type of fine-tuning is not included in this model.

6.3.3.2.1 Collateralised Lending It is worthwhile taking some time to explain the mechanism underlying outright purchases. The collateralised lending in this model of Schabert (2015) uses "Treasury bills as collateral for central bank money", with the price of these liabilities being the policy rate R_t^m. Reserves can be gained, at this policy rate (or repo rate) by exchanging treasuries, ΔB_t^c, in the following way[28]:

$$M_t = \kappa \cdot \Delta\frac{B_t^c}{R_t^m} \quad \text{where} \quad \Delta B_t^c \leq B_{t-1} \tag{6.43}$$

[28] I followed the nomenclature of Schabert (2015) and Bredemeir et al. (2015) in this regard.

The second part of this equation relays the fact that the merchant bank is limited to the amount of treasuries exchanged for reserves by the stock of treasuries carried over from the previous period. Following Schabert (2015), I then combined these equations and introduced the collateralised lending constraint on the merchant bank, in the form of

$$M_t \leq \kappa \cdot \frac{B_{t-1}}{R_t^m \pi_t} \tag{6.44}$$

where $M_t = M_t^p - \frac{M_{t-1}^p}{\pi_t}$. The role of this constraint is embodied in the ability of the merchant bank to "acquire money, M_t, in exchange for the discounted value of treasury bills carried over from the previous period" as elucidated by Bredemeir et al. (2015). Alternatively, this equation could be interpreted as a central bank money supply constraint. In this equation, κ_t represents a monetary policy instrument in addition to the policy rate. This instrument allows the central bank to control the supply of reserves as a fraction of the discounted market value of government bonds held by the private sector

6.3.3.2.2 Defining κ Before continuing, it is important to conceptualise the meaning of κ, as it is central to the dynamics of this model. This parameter[29] represents different values for the loan-to-value (LTV) ratio, ranging from $0 < \kappa \leq 1$. It is often referred to as the haircut parameter, where a haircut is represented by $(1 - \kappa)$. Finally, it could also be called the collateral requirement. In this thesis it will be referred to either as the haircut parameter/variable or as the collateral requirement. This is done in order to avoid confusion with the LTV ratios of macroprudential policy from the Basel Accords.

The lower values of κ represent a higher required amount of bonds to acquire reserves. As an example, if the value of the parameter is 0.9, then it represents a 10% haircut[30]. To further illustrate this point, consider a treasury security with a value of $100 where the haircut on this relatively safe security is 10%. This security would then be accepted as collateral for a loan up to the value of $90, while a riskier security with a higher haircut is only eligible for a relatively smaller loan (Hilberg and Hollmayr, 2011). Increases in the parameter represent an increase in the size of the central bank balance sheet, as the collateral can be used to obtain greater amounts of liquidity.

[29]Important is important to note that I initially defined κ as a parameter, where the model of Schabert (2015) considers it only as a variable. Defining it as a parameter allows the setting of specific scenarios relevant to the central question of the chapter. I did utilise it in its capacity as a variable, following an AR(1) process, in some scenarios. This is discussed in more detail in the results section.

[30]The naming convention can be somewhat counter-intuitive. I ideally would have wanted to refer to κ as the LTV instead of the haircut (the two are complements).

6.3.3.2.3 Budget Constraint Finally, merchant banks are subject to the constraint that liabilities equal assets, i.e. liquidity borrowed from the interbank market should equal the expected payoffs from assets. This means that in this model there is a balanced budget constraint, as in Cúrdia and Woodford (2011) and Christoffel and Schabert (2014), which is the following:

$$L_t^l = M_t^p + B_t + L_t^b \tag{6.45}$$

The balance sheet constraint means that merchant banks need to pay for the interbank liquidity that they obtain through money holdings, bonds or the extension of loans. Another potentially useful constraint to generate demand for money is a cash-in-advance style minimum reserve requirement, such as $\Theta L_{t-1}^l \leq M_t^p$. This was originally included in the model, but its inclusion did not alter the results significantly. A further discussion on this reserve requirement is included in Appendix B.3.

The banks aim to maximise the present value of profits subject to (6.44), (6.45) and the profit equation (6.47). The maximisation is also subject to a disutility cost in d_δ,

$$\max_{\{M_t, M_t^P, B_t, L_t^l, L_t^b, \delta t\}} = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^b)^s \left[\left(\frac{(\pi_{t+s}^b + 1)^{1-\sigma_b}}{1-\sigma_b} \right) - d_\delta (1 - \delta_{t+s}) \right] \tag{6.46}$$

The real profits of the merchant bank π_t^b is then given by

$$\begin{aligned} \pi_t^b = & \frac{L_t^l}{R_t^l} - \delta_t \frac{L_{t-1}^l}{\pi_t} + \psi_t \frac{L_{t-1}^b}{\pi_t} - \frac{L_t^b}{R_t^c} + \frac{B_{t-1}}{\pi_t} - \frac{B_t}{R_t^b} \\ & - M_t^p + \frac{M_{t-1}^p}{\pi_t} - \frac{\omega_\delta}{2} \left[(1 - \delta_{t-1}) L_{t-2}^l \right]^2 - M_t (R_t^m - 1) \end{aligned} \tag{6.47}$$

where ω_b represents a pecuniary cost from defaulting. The first-order conditions for this maximisation problem are,

$$
\begin{aligned}
(\partial M_t^P) \qquad & \dot{U}_t^b = \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b}{\pi_{t+1}} \right) - \Upsilon_t \\
(\partial M_t) \qquad & \dot{U}_t^b = R_t^m (\dot{U}_t^b + \eta_t) \\
(\partial B_t) \qquad & \dot{U}_t^b \frac{1}{R_t^b} = \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b + \kappa \cdot \eta_{t+1}}{\pi_{t+1}} \right) - \Upsilon_t \\
(\partial L_t^l) \qquad & \dot{U}_t^b \frac{1}{R_t^l} = \beta^b \mathbb{E}_t \left[\left(\frac{\delta_{t+1}}{\pi_{t+1}} \right) \dot{U}_{t+1}^b \right] + (\beta^b)^2 \mathbb{E}_{t+1} \left[\left(\omega_\delta (1 - \delta_{t+1})^2 L_t^l \right) \dot{U}_{t+2}^b \right] + \Upsilon_t \\
(\partial L_t^b) \qquad & \dot{U}_t^b \frac{1}{R_t^c} = \beta^b \mathbb{E}_t \left[\frac{\psi_{t+1}}{\pi_{t+1}} \dot{U}_{t+1}^b \right] - \Upsilon_t \\
(\partial \delta_t) \qquad & \dot{U}_t^b \frac{L_{t-1}^l}{\pi_t} = d_\delta + \omega_\delta \beta^b \mathbb{E}_t \left[\left((1 - \delta_t)(L_{t-1}^l)^2 \right) \dot{U}_{t+1}^b \right]
\end{aligned}
$$

where $\dot{U}_t^b = (\pi_t^b + 1)^{-\sigma_b}$, η_t is the multiplier associated with the collateralised lending constraint and Υ_t is the multiplier on the balanced budget constraint. For the latter, it can be defined as $\Upsilon_t = \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b}{\pi_{t+1}} \right) - \dot{U}_t^b$. Substituting this into the above equations to eliminate it gives the following set of equations,

$$\dot{U}_t^b = R_t^m (\dot{U}_t^b + \eta_t) \tag{6.48}$$

$$\frac{1}{R_t^b} = 1 + (\dot{U}_t^b)^{-1} \beta^b \mathbb{E}_t \left(\frac{\kappa \cdot \eta_{t+1}}{\pi_{t+1}} \right) \tag{6.49}$$

$$\frac{1}{R_t^l} = 1 - (\dot{U}_t^b)^{-1} \beta^b \mathbb{E}_t \left[\left(\frac{\delta_{t+1} + 1}{\pi_{t+1}} \right) \dot{U}_{t+1}^b \right] + (\dot{U}_t^b)^{-1} (\beta^b)^2 \mathbb{E}_{t+1} \left[\left(\omega_\delta (1 - \delta_{t+1})^2 L_t^l \right) \dot{U}_{t+2}^b \right] \tag{6.50}$$

$$\frac{1}{R_t^c} = 1 + (\dot{U}_t^b)^{-1} \beta^b \mathbb{E}_t \left[\left(\frac{\psi_{t+1} - 1}{\pi_{t+1}} \right) \dot{U}_{t+1}^b \right] \tag{6.51}$$

$$\dot{U}_t^b \frac{L_{t-1}^l}{\pi_t} = d_\delta + \omega_\delta \beta^b \mathbb{E}_t \left[\left((1 - \delta_t)(L_{t-1}^l)^2 \right) \dot{U}_{t+1}^b \right] \tag{6.52}$$

The following complimentary slackness condition holds:

$$\eta_t \left[\kappa \frac{B_{t-1}}{\pi_t} - R_t^m M_t \right] = 0, \quad \eta_t \geq 0, \quad \left(\kappa \frac{B_{t-1}}{\pi_t} - R_t^m M_t \right) \geq 0$$

6.3.4 Public Sector

6.3.4.1 Government

The government in this economy buys goods, has access to lump-sum transfers T_t and issues debt (in the form of bonds). Bonds are held by either the merchant banks B_t or the central bank B_t^c. The total stock of newly issued bonds by the government is $B_t^g = B_t + B_t^c$. Following Reynard and Schabert (2009) and Schabert (2015) the growth of the bond supply is constant, equal to Ω and exogenously determined. It is given by

$$B_t^g = \Omega B_{t-1}^g \tag{6.53}$$

where $\Omega > 1$. As shown with the calibration, the growth of these short-term securities is close to that of inflation. Only short-term risk-free bonds, similar to treasury bills, are considered in this chapter, with bonds of longer maturity introduced in the next chapter. The budget constraint for the treasury is

$$G_t + \frac{B_t^g}{R_t^b} = \frac{B_{t-1}^g}{\pi_t} + T_t \tag{6.54}$$

6.3.4.2 Central Bank

The monetary authority is able to supply reserves outright through open market purchases, where newly issued reserves is reflected by, $M_t = M_t^p - \frac{M_{t-1}^p}{\pi_t}$. The central bank collects government bonds in return for newly issued reserves. In addition, interest accrues at the main refinancing rate R_t^m, which translates into a return of $M_t{\cdot}R_t^m$ at period t.

The budget constraint for the central bank, following Schabert (2015) is,

$$T_t^r - M_t R_t^m = \frac{B_{t-1}^c}{\pi_t} - \frac{B_t^c}{R_t^b} \tag{6.55}$$

Following Reynard and Schabert (2009) and Bredemeir et al. (2015), seignorage revenues are presented as

$$T_t^r = B_t^c \left(1 - \frac{1}{R_t^b}\right) + (R_t^m - 1)M_t \tag{6.56}$$

The public sector is not consolidated, and the central bank transfers go directly to households. When I substituted the central bank transfers, as in the central bank budget constraint, bond holdings evolved according to

$$B_t^c - \frac{B_{t-1}^c}{\pi_t} = M_t^p - \frac{M_{t-1}^p}{\pi_t} \tag{6.57}$$

Following Schabert (2015), I restricted the initial values, $B_{-1}^c = M_{-1}^p$, which leads to a central bank balance sheet condition, with $B_t^c = M_t^p$. In addition, the central bank sets the policy rate according to a feedback rule, which takes into account how the central bank adjusts the p olicy rate response to changes in its own lags, inflation, a measure for the real output-gap, and contemporary output growth:

$$R_t^m = (R_{t-1}^m)^{\rho_r}(R^m)^{1-\rho_r}\left(\frac{\pi_t}{\pi}\right)^{\rho_\pi(1-\rho_r)}\left(\frac{y_t}{y}\right)^{\rho_y(1-\rho_r)}\left(\frac{y_t}{y_{t-1}}\right)^{\rho_d y(1-\rho_r)} \tag{6.58}$$

To summarise, in this model the central bank has two instruments. As delineated by Hörmann and Schabert (2013), these instruments are presented as the following:

1. *Conventional instrument*: The policy rate, R_t^m.

2. *Quantitative easing (size of balance sheet)*: Increase reserves available against eligible assets (short-term bonds) in open market operations by increasing κ.

Quantitative easing in this setting consists only of changes in the size of the balance sheet, although the next chapter includes a dimension for the composition. Selecting a value for κ determines the size, with larger values resulting in a greater selection of bonds available as collateral.

6.3.5 Market Clearing/Aggregation

The final goods market is in equilibrium. Firms and banks directly consume their profits (not owned by households). The aggregate resource constraint is

$$\begin{aligned} Y_t = {} & C_t + G_t + \pi_t^f + \pi_t^b + \pi_t^l + K_t - (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[\Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \\ & + \frac{\omega_\delta}{2}\left[(1-\delta_{t-1})L_{t-2}^l\right]^2 + \frac{\omega_\psi}{2}\left[(1-\psi_{t-1})L_{t-2}^b\right]^2 \\ & + \frac{\varrho}{2}\left(\frac{p_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{t-1}} - 1\right)^2 Y_t \end{aligned} \tag{6.59}$$

The aggregate production function is

$$Y_t = K_t^{\alpha} N_{i,t}^{1-\alpha} \tag{6.60}$$

The aggregated law of motion for capital is

$$K_t = (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[1 - \Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \tag{6.61}$$

6.4 Equilibrium Conditions

In this section a partial equilibrium analysis is conducted, with specific reference to monetary transmission and endogenous default in the model. Evaluating the equations analytically provides intuition as to the results expected from the model. First, a discussion on the monetary transmission mechanism is provided. There is a vast amount of literature on the transmission of conventional interest rate policy to real activity. Figure 2.3 from Chapter 2 gives an idea of the agreed upon channels for the transmission of a change in the policy rate, with a brief discussion on these channels provided below. Second, I provide a look at the conditions that need to be met for the collateral constraint on merchant banks to be binding. Third, I provide an analysis on the relationship between default, interest rates and loan activity in the economy.

6.4.1 Interest Rates

This section highlights the relationship between the policy rate and selected market interest rates. In order to properly frame the discussion, some simplifying assumptions are stipulated. I assume that the non-pecuniary default cost is equal to zero, $\omega_\delta = 0$, repayment rates are constant, $\overline{\delta}$ and $\overline{\psi}$, and the momentary utility for banks is linear. This means that in $\sigma_b = 1$ and $\sigma_l = 1$, which effectively translates to $(\pi_t^b + 1)^{-\sigma_b} \approx 1$ in steady state.

6.4.1.1 Interest Rate Spreads

First, I consider the relationship between the deposit rate, R^d, and the interbank loan rate, R^l. Intuitively, the presupposition is that the deposit rate should be lower than the interbank loan rate, since the depository institutions would traditionally finance their lending primarily through deposits, making a profit from the difference between rates. To explore this relationship, I unified the first order conditions of the deposit bank. In equilibrium $R^d = R^l \cdot \overline{\delta}$, which means that $R^d < R^l$ since $0 < \overline{\delta} < 1$. In other words, the level of the interbank loan rate is intrinsically linked to the possibility of default, by reflecting a risk premium derived from default. Therefore, in this model, the deposit banks charge a higher rate on interbank loans because they take on a small default risk in issuing these loans. In the case that $\delta = 1$, the transmission from R^d to R^l would be direct, in that $R^d = R^l$.

Furthermore, one can think about this relationship as one between savers, borrowers and intermediaries. In this case, the saver is represented by the household, while the merchant bank takes on the role of the borrower. Intermediaries, represented by the deposit bank, generate a spread between the "interest received by savers and that paid by borrowers" (Cúrdia and Woodford, 2010). Early attempts to fashion such an interest rate spread between borrowers and savers include Sudo et al. (2008), Hülsewig et al. (2009), Cúrdia and Woodford (2010) and Gerali et al. (2010). A more recent attempt that delivers a qualitatively similar mechanism is found in Gertler and Karadi (2011).

Second, I analysed the link between the credit and interbank loan rates by looking at the first-order conditions of the merchant bank. We see that $R^c \cdot \overline{\psi} = R^l \cdot \overline{\delta}$, with the intuition being that a higher repayment rate is associated with a lower interest rate. As calibrated in this model $\overline{\delta} > \overline{\psi}$, which, in turn, means that firms are believed to repay less frequently, which means that the risk premium is relatively higher for credit extended to firms. In other words, merchant banks institute a premium on the financing they receive from the interbank market, making firm loans costlier.

Interestingly, this relation also shows that defaults on firm loans can indirectly impact on deposit banks, through their effect on merchant banks, as also illustrated in Christiano et al. (2014). Another way to think about this, in the context of a disruption to financial intermediation, is that a disturbance in the interbank market will indirectly affect the borrowing conditions for firms, as described in Gertler and Karadi (2013).

Third, the bond rate is related to the interbank loan rate through the following equation, as derived in the first-order conditions of the merchant bank:

$$R^l \cdot \overline{\delta} = R^b(1 + \eta\kappa)$$

In the case where the haircut parameter is positive, $\kappa > 0$, then $R^b < R^l$, which aligns with our intuition, seeing that the interbank loan rate is linked to a risky asset and short-term government bonds (treasuries) are considered completely safe. In addition, the spread between the bond rate and the loan rate is also positive, owing to default risk and the potential for the bonds to be used as liquidity.

Finally, consider the case of how the policy rate is transmitted to the interbank loan rate. Combining the first-order condition on newly issued reserves, money holdings, interbank and firm loans gives the following relation to the interbank rate: $R^m(\eta+1) = R^l \cdot \overline{\delta} \cdot (\overline{\delta}+1)^{-1}$. In this setting, with $R^m < R^l$, the central bank directly impacts the interbank loan rate through setting the policy rate. In the literature there are several articles, such as those of Goodfriend (2007b), De Fiore and Tristani (2011) and Cúrdia and Woodford (2015), that emphasise the spread between the loan and policy rates in particular.

6.4.1.2 Monetary Transmission Path

Having completed the transmission path, the relationship between rates reads as $R^m < R^b < R^d < R^l < R^c$. We can use this to determine the transmission from the policy rate to the broader range of interest rates in the economy. For example, lowering the policy rate lowers the cost of credit and potentially increases the supply of loanable funds in the economy. This behaviour is in line with a narrow credit, or bank lending, channel (Bernanke et al., 1999; Cova and Ferrero, 2015). To gain a better understanding of this transmission path, it is useful to look at some of the more popular channels identified in the literature.

6.4.1.2.1 Transmission Channels Some of the different channels through which a change in the policy rate is thought to affect market rates and loan supply, and thereby the rest of the economy, are presented here[31]. This discussion is useful in that some of the channels are referenced in the results section of the chapter. The channels, as identified in Mishkin (2001), Kuttner and Mosser (2002) and Ireland (2006) are as follows: (i) interest rate channel, (ii) equity price channel, (iii) balance sheet / broad credit channel, (iv) bank lending / narrow credit channel, and (v) exchange rate channel. Some have also argued for the inclusion of the risk channel[32] of monetary policy, as first discussed in Rajan (2005). I provide a brief discussion on the first four channels.

First, the interest rate channel is the traditional mechanism for the transmission of the policy rate to aggregate demand, as emphasised in conventional Keynesian IS-LM models (Mishkin, 2001)[33]. In this channel an increase in the policy rate would mean an increase in the real

[31] The effects are summarised in Figure 2.3 from the discussion of transmission channels in Chapter 2

[32] This was briefly discussed in the third chapter. A substantial literature has developed around this topic, with the article by Smets (2014) providing an interesting take on the role of monetary policy in contributing to financial stability.

[33] See the article by (Taylor, 1995) for a good discussion on the empirical validity of the interest rate channel.

interest rate, which translates into an increase in the cost of investment/durable goods. Firms and households invest less as a result, which adversely affects aggregate demand.

Second, the equity price channel contains two separate channels, one which originates from contributions made by Tobin (1969) in his q-theory of investment and the other from the life-cycle hypothesis as presented in Ando and Modigliani (1963). First, consider an increase in money supply, which generally means that households will have more money to spend in stock markets, in turn generating demand for equity and raising its price. In Tobin's q theory, an increase in the price of equity will result in increased investment spending (Mishkin, 2001). Second, the wealth channel as discussed in Ando and Modigliani (1963), specifically looks at changes in household behaviour as a result of asset price movements (Kuttner and Mosser, 2002). Increasing interest rates can have the effect of reducing the value of durable assets (such as bonds with a longer maturity), which decreases the wealth of individuals. A reduction in wealth naturally leads to lower levels of consumption, which means that aggregate demand is impacted.

Third, the broad credit/balance sheet channel was developed by Bernanke and Gertler (1989) and discusses the role that the balance sheet position of key financial institutions play in the transmission of monetary policy. In particular, interest rate movements often bring about changes to the balance sheet, cash flow and net worth of banks and firms (Mishkin, 2001). An increase in the interest rate could, for example, negatively impact cash flow and net worth, which would lead to less collateral being available for loans in the economy. Financial frictions play a key role in this channel, as discussed earlier in this chapter.

Finally, the narrow credit/bank lending channel was first developed by Roosa (1951) and was reformulated by Blinder and Stiglitz (1983) and Bernanke and Blinder (1988). In this channel, an increase in the policy rate is met with an equal decrease in bank reserves, which means that demand deposits will decrease. As a result of the fact that banks are reliant on deposits to generate loans, this also causes loans to decrease. Bank financing is an important part of credit in the economy. With a reduced supply of credit, households and firms will reduce spending, which means lower aggregate demand (Ireland, 2006).

The final two channels are often referred to as the credit channel and are seen more in the light of an amplification device on existing transmission channels, as argued by Bernanke and Gertler (1995). In addition, clear empirical support for certain channels, such as the bank lending channel, have been difficult to come by, with conflicting evidence in the literature.

6.4.2 Collateral Constraint

Importantly, for the collateral constraint to be binding, the policy rate should be lower than that of interbank liquidity. The central bank needs to supply money at a lower price than banks are willing to pay in the interbank market. The merchant bank must be incentivised to hold reserves (i.e. there is some liquidity premium on the holding of reserves). When we compare these rates we see that this is the case, with

$$\eta = \left[\frac{R^l \left(\frac{\bar{\delta}}{1+\bar{\delta}} \right)}{R^m} \right] - 1 \tag{6.62}$$

This condition implies that the constraint is binding if the central bank sets the policy rate below the interbank rate. If $\eta = 0$ and the collateral constraint is not binding, changes to the policy rate will not impact the equilibrium allocation of reserves (Hörmann and Schabert, 2015). In this setting merchant banks will use as many eligible assets as possible to get money at the policy rate, up until the interest rate spread (resulting from the liquidity premia) is eliminated, where $R^l \left(\frac{\bar{\delta}}{1+\bar{\delta}} \right) = R^m$.

6.4.3 Endogenous Default

As before, several simplifying assumptions are made, similar to those established in de Walque and Pierrard (2010), to shed light on the role of endogenous default. I assumed that there is no discounting $\beta = 1$, no inflation $\pi_t = 1$ and utility functions are linear (by setting $\sigma_b = \sigma_l = 1$).

First, we look at the supply side of the credit market. The supply of interbank liquidity, which is provided by the deposit bank, is governed by the following equation,

$$\frac{1}{R^l} = \delta$$

This expression captures the negative relationship between R^l and δ. In other words, a higher repayment rate will result in a lower interest rate on interbank loans . Similarly, with respect to loans to firms,

$$\frac{1}{R^c} = \psi$$

This equation shows the negative relationship between the repayment and credit rates. Second, we explore the demand side of the credit market. Combining the merchant bank's first-order conditions for interbank loans and the repayment rate, we find the following steady-state relationship:

$$\frac{1}{R^l} = 1 - \frac{d_\delta(1-\delta)}{L^l}$$

This indicates a negative relationship between the quantity of interbank loans and the interbank rate, while a positive relationship is observed with respect to the default rate, $(1-\delta)$, and interbank rate. Similarly for firms, I combined the first-order condition with respect to firm loans and default,

$$\frac{1}{R^c} = 1 - \frac{d_\psi(1-\psi)}{L^b}$$

This has similar implications for the firm. For example, an increase in the credit rate will lead to a lower quantity of loans to firms. de Walque et al. (2010) refer to this as "negatively sloped credit demand". In addition, an increase in the default rate, $(1-\psi)$, is associated with a lower quantity of loans, indicating that increases in liquidity to the firms will generally lead to lower default.

6.5 Calibration

Calibration of the household, firm and government largely follows the work of Smets and Wouters (2003, 2007), while monetary policy and the banking sector is calibrated to reflect the values in line with de Walque and Pierrard (2010). Model parameters are partitioned into sets or groups, similar to those of Christiano et al. (2014). In this tradition, the first group contains parameters that are set *a priori*. Within this set, calibrated parameters are summarised in Table C.1, while imposed steady states and steady-state ratios are presented in Table C.2. The second set consists of implied steady state values, such as those on search costs and default disutility, which are provided in the appendices. The discussion in this section highlights the motivation for the first set of parameters.

6.5.1 Real Sector

The calibration of the real sector arises predominantly from widely accepted parameter estimates found in the New-Keynesian literature. As seen in Table C.1, habit formation $h = 0.57$, the coefficient of relative risk aversion $\sigma^c = 1.35$ and inverse Frisch elasticity of labour supply

$\sigma^n = 2.4$ are similar to those found in Smets and Wouters (2003). The elasticity of substitution with respect to labour η and goods ϵ varieties are both set to 3. In terms of price/wage setting, the wage indexation and Calvo parameters are set to $\tau^w = 0.62$ and $\theta^w = 0.2$, respectively. Output is normalised to 1. Employment/labour hours is normalised to 0.33. The production function takes on a Cobb-Douglas form, with $\alpha = 0.3$, implying that steady-state labour share of total output is 70%. The depreciation rate φ is calibrated to 0.03, with annual depreciation on capital equal to 12%. The consumption steady-state ratio is assumed to be 0.42, while the firm profit steady state ratio is 0.1[34]. Calibration implies that the capital to output ratio is $K/Y \approx 8$ and the loan to output ratio is $L^b/Y \approx 0.2$, which is similar to those of Smets and Wouters (2003) and de Walque et al. (2010). The government spending and taxation ratio to total output is 0.185 and 0.187, respectively. There are three parameters associated with adjustment costs in this model; these are defined in terms of price $\varrho = 120$, wage $\gamma_p = 0.47$ and investment $\theta = 6.77$.

6.5.2 Banking Sector

Calibration in this section largely follows the work of de Walque and Pierrard (2010). Several interest rates are quoted in this paper. The quarterly real deposit rate is 0.66%, and the quarterly real policy rate is 0.55%. The discount factor is calculated as $\beta = \pi_{ss}/R^d_{ss}$, which I fixed to be the discount factor for all agents in the model[35]. Following data from Castrén et al. (2010), the quarterly probability of default for banks is 0.5%, whereas the firm default rate in steady state is 2.5%. Deposit and merchant bank profits are quite small related to total output, namely $\pi^b/Y = \pi^l/Y = 0.0001$. I also imposed a ratio of interbank loans to firms loans in steady state as in de Walque and Pierrard (2010), with $L^l/L^b = 0.8$ [36].

6.6 Model Dynamics

In this section, I looked at the impact on financial stability originating from shocks to (i) the haircut mechanism, κ_t, and (ii) the nominal short-term policy rate with selected levels for κ. First, I looked at the financial market impact of implementing a balance sheet expansion,

[34]The consumption ratio is normally larger, refer to Smets and Wouters (2003), but in our case firm and bank profits are not distributed to the household

[35]Relaxing this assumption allows different discount rates for the households, firms and banks.

[36]Changes to these ratios do not significantly impact results, but they do influence some of the implied parameter values. Ratios were chosen close to the ones cited in de Walque et al. (2010) but are not exactly the same, in order to retain a positive value for the endogenous disutility and search cost parameters.

through an increase in the value of κ_t. This first scenario is similar to the analysis of de Walque et al. (2010), Dib (2010a), Hilberg and Hollmayr (2011) and Goodhart et al. (2011), who employ expansionary monetary policy through an increase in the monetary base. The model differs, primarily, in the way that the balance sheet expansion is implemented. In this model, the collateralised lending mechanism provides an endogenous provision of liquidity, as in Schabert (2015), rather than a pure injection.

Second, I conducted an experiment that simulates a scenario, similar to the exit strategy recently performed by the Fed, whereby the nominal short-run policy rate is increased, with varying degrees of change to the size of the central bank balance sheet, reflected by different κ values. The similarity of this scenario to that of an exit strategy lies in the fact that the Fed was able to increase the federal funds rate without significantly impacting the size of the balance sheet. In this model, values of κ can be set so that reserves move independently from the policy rate, in order to achieve a similar result. In this scenario the point of departure does not have to be from the ZLB. I implemented this Contractionary interest rate policy by the applying a shock to the Taylor rule (6.58).

It is worth mentioning that model estimation was not attempted. The contribution of the paper is in its theoretical construction, with calibration being sufficient for the purpose of exposition. Clear data adherence in the model is a topic for future research. The analysis starts with the expansion of the central bank balance sheet.

6.6.1 Balance Sheet Expansion

One can think about this expansion as an increase in the availability of reserves. In other words, it represents a 'pure' form of QE, such as that stipulated in Bernanke and Reinhart (2004), Reis (2009), Woodford (2012) and Christensen and Krogstrup (2016). First, I describe the real sector impact from the balance sheet expansion. Second, I look at the effect on the financial sector, which is of the greatest importance for this discussion, as I want to determine the impact on financial stability from balance sheet expansion. The results from this section should be quite similar to those of a decrease in the policy rate, as the level of reserves and policy rate are inextricably linked through the collateralised borrowing mechanism.

6.6.1.1 Clarification: Variable (κ_t) vs Parameter (κ)

Clarification on one possible point of confusion is required before I continue with a discussion on the model dynamics. In this section I consider an exogenous shock process for the collateral requirement, κ_t, which follows an autoregressive process. With the balance sheet expansion, the law of motion for this process is $\kappa_t = \rho_\kappa(\kappa_{t-1}) + \xi_t^\kappa$, where ξ_t^κ is an exogenous i.i.d shock. However, in the next section, I consider a fully adjustable haircut parameter κ, in the form of a scalar. For the scenarios presented in the next section, where a contractionary interest rate policy is considered, I believe it to be more instructive to simply set parameter values that remain constant over time[37], which allows our analysis effectively to be comparable to the study of Goodhart et al. (2011), where the value of κ is implicitly set to one. In terms of an approximation to reality, haircuts are not generally time-varying as they are officially fixed by central banks (Falagiarda and Saia, 2013). This means that fixing κ to certain value over time is considered a better representation of actual implementation.

6.6.1.2 Real Sector

Illustrating the effect of a shock to κ_t entails setting the starting value of κ_t to below one[38]. In my experiment the value is fixed at 0.5 initially, which implies that agents are liquidity constrained, with only a fraction of securities available as collateral[39]. With the policy adjustment, the value for κ_t increases so that the LTV ratio is close to, but not exceeding, 100%. An increase in κ_t means that more bonds are becoming liquid (Hörmann and Schabert, 2015). The expansion of the central bank balance sheet (often referred to as QE) is reflected in a positive innovation to κ_t, which affects the pertinent real variables, showing the expected sign and trajectory. Real consumption, expenditure and employment all increased with the expected hump shape, a characteristic of the Smets and Wouters (2003, 2007) framework. Real sector results from the next section, with contractionary monetary policy through an increase in the policy rate, almost identically mirror the results from this increase in κ_t.

6.6.1.3 Financial Sector

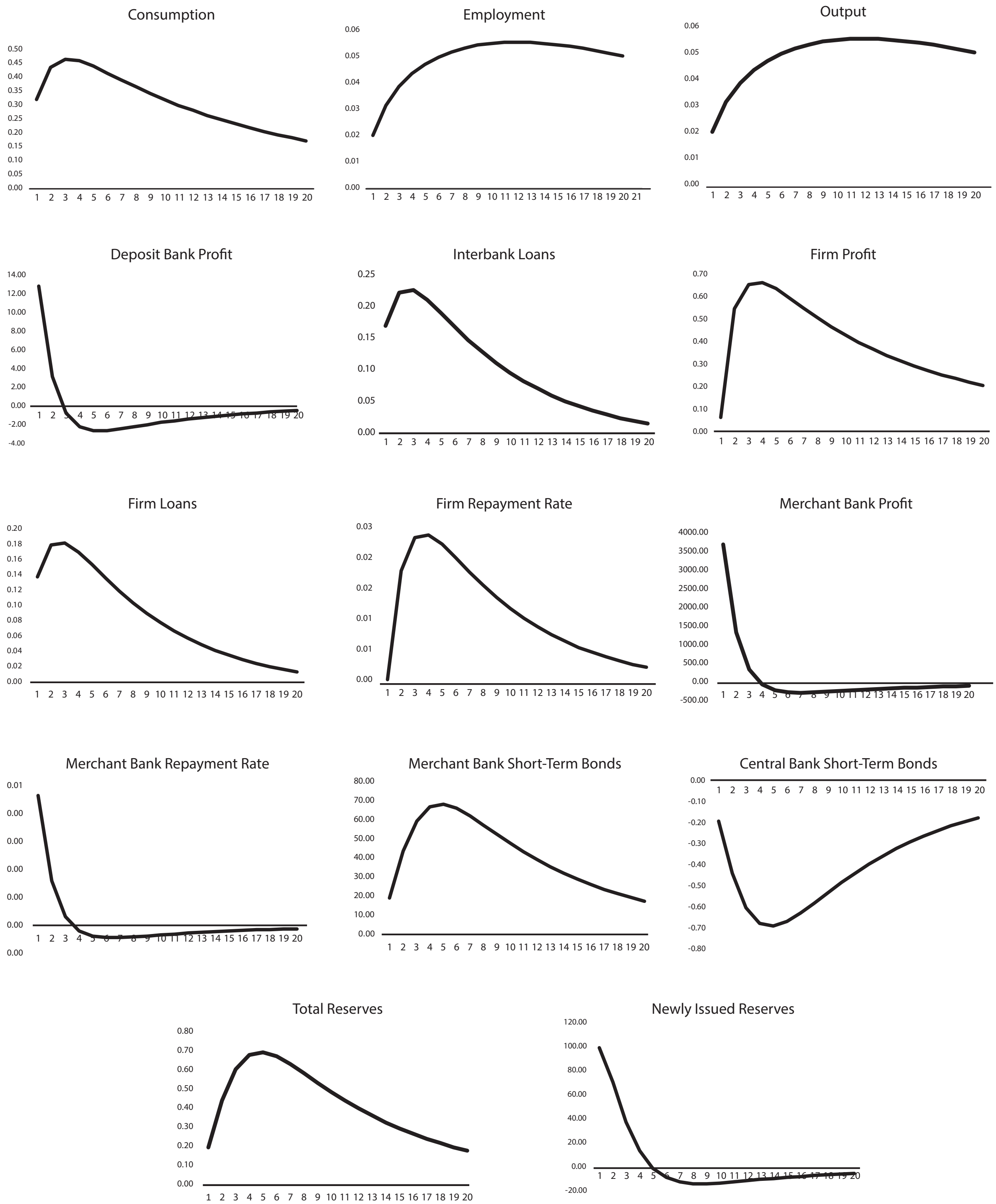
While real sector results are important to determine whether the model provides an accurate description of the broader macroeconomy, I am primarily interested in the banking sector behaviour. The central hypothesis of this chapter pivots on the response of financial institutions

[37]Technically this is similar to setting the autoregressive parameter on the haircut process to one, which also delivers a constant value over time.

[38]With a value of $\kappa = 1$ representing complete relaxation of the constraint on the amount of collateral eligible for the purpose of transformation to a more liquid asset. Seeing as a positive innovation is applied to κ, with $0 < \kappa \leq 1$, the initial value needs to be below one, otherwise the constraint is violated.

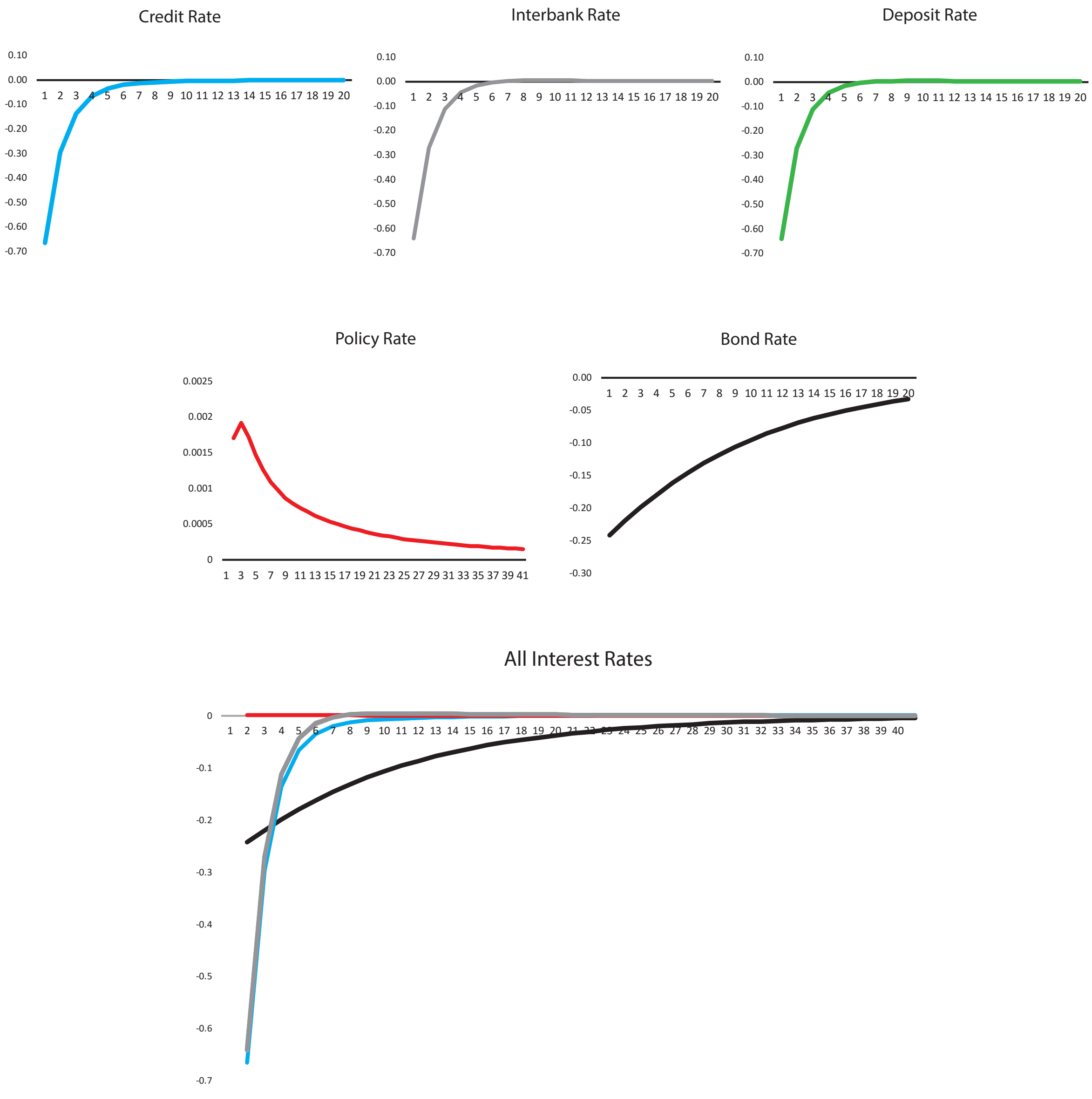
[39]This starting value is in fact close to the haircut imposed on some private sector investors in the recent financial crisis.

Figure 6.1: Balance sheet expansion: Real and financial sector



Note: Y-axis values represent percentage deviation movement from steady state, resulting from 100% shock to collateral requirement

Figure 6.2: Balance sheet expansion: Interest rates



Note: Y-axis values represent percentage point deviation from steady state from 100% shock to collateral requirement to variation in the collateralised borrowing constraint. Therefore, I focus the greatest part of the discussion on the relevant actions of the agents involved in financial intermediation, specifically looking at the behaviour of the firm, deposit bank, merchant bank and central bank.

6.6.1.3.1 Deposit Bank First, the reduction in the price of interbank funds (i.e. the interbank rate), as a result of the increase in liquidity, translates to increased interbank activity. This finding is shared in the work of Dib (2010b), which points to a possible increase in interbank borrowing following a negative shock to the haircut. My results are further corroborated by the findings of Hilberg and Hollmayr (2011). In their study lowering the haircut results in a decrease in the interbank market rate as well as an increase in interbank lending activity[40]. Balance sheet expansion and lower interbank rates mean that fewer merchant banks are likely to default on interbank loans. This result agrees with that of Goodhart et al. (2011), who state that the expectation of a higher level of credit in the economy causes the probability of default to decline. The profitability of the deposit bank increases because the marginal benefit from extending loans exceeds the cost.

6.6.1.3.2 Firm Second, the expansionary balance sheet policy increases the firm's profit, due to reduced capital costs and an increase in cheap liquidity available from merchant banks[41]. The increase in liquidity originating from the shock to the collateral requirement causes a decrease across a wide range of interest rates in the economy, with the credit rate exhibiting a sharp contraction. With borrowing conditions improved, one observes an increase in loans extended to firms. Easier credit market conditions manifests in an increase in the repayment rate on loans (i.e. the default rate decreases); effectively improving financial stability with respect to the firm. Improved balance sheet health is one of the primary goals of liquidity extension on the part of the central bank (Bernanke, 2012). In the wake of the financial crisis several central banks established liquidity facilities and enacted quantitative easing programs in order to generate firm borrowing. Results presented here provide confirmation that liquidity injections should be, in principle, able to accomplish this.

6.6.1.3.3 Merchant Bank Third, reserves held on the balance sheet of the central bank increases as a result of the shock. Merchant banks increase their demand for reserves, as short-term bonds can now easily be traded for liquidity. In fact, they increase their stock of

[40]Banks are structured in a slightly different way in their model, with the deposit bank the one with direct access to the central bank's reserves

[41]In this model the merchant bank is the firm's only source of funding for investment

short-term bonds - which serve as collateral for reserves - to finance their spending, which drives down the price on these bonds. This result is supported by the work of Kandrac and Schlusche (2015), who show that "lending growth accelerates in response to increases in reserves". It is even argued as far back as Friedman and Schwartz (1963) that the creation of reserves leads banks to hold more than the sufficient level, which would then translate into an increase in investments and loans extended in the economy. This result is also consistent with the empirical evidence, as the recent study by Boeckx et al. (2016) shows that balance sheet expansion on the part of the ECB significantly increased bank lending. In addition, the credit supply to firms is increasing due to a positive spread between the credit and interbank rates. The central bank's role as an intermediary is clearly felt in this economy, with borrowing conditions improving in all markets when the collateral requirement is relaxed.

6.6.1.3.4 Central Bank Finally, the increase in the reserves held on the balance sheet of the central bank is met with an increase in the policy rate. While this movement might seem counterintuitive, the increase in the policy rate is also observed in the work of Niestroj et al. (2013). It is believed that this is the result of the way in which the feedback mechanism from the Taylor rule is structured. The increase in output resulting from the increase in the size of the balance sheet means that the policy rate increases to counter the movement. However, the net effect of the balance sheet expansion is positive in this case, with movement in the short-run nominal policy rate not being able to counter the effect of the expansion, as seen by the fact that all other interest rates in the economy are declining (in contrast to the policy rate). In the next section, I look at the impact on the economy from implementing a contractionary interest rate policy.

6.6.2 Contractionary Interest Rate Policy

In this section, I consider the response of the economy when the short-term nominal policy rate has been increased, known as contractionary monetary policy. I introduced multiple scenarios with a choice over different values for an exogenously controlled haircut parameter[42]. Four values for the haircut at different intervals, 1, 0.7, 0.3 and 0.05 were chosen for the analysis. These values represent a 100%, 70%, 30% and 5% LTV ratio, respectively. The value of $\kappa = 1$ was chosen to reflect the situation in which there is no collateralised lending restriction: all short-term bonds are eligible. This formed my baseline specification.

[42]As opposed to the shock form the previous section.

For the second value, the literature provides an LTV ratio of $\kappa = 0.7$ as a realistic representation from data for the Euro area on mortgages offered as collateral, such as quoted in Gerali et al. (2010). Although mortgage securities are not directly relatable to short-term bonds, one can think of this as realistic to some asset classes with lower eligibility as collateral. The true value for short-term bonds would be closer to $\kappa = 0.9$, but this would not allow the exaggeration of the effect required, as it is too close to the baseline model where $\kappa = 1$. Finally, a value of $\kappa = 0.3$ was chosen to reflect a deepened but not entirely unrealistic haircut[43], representing a scenario of low interest rate sensitivity[44]. Finally, the value of $\kappa = 0.05$ is an effective decoupling of the interest rate and reserves.

6.6.2.1 Real Sector

The first few panels show the traditional hump-shaped responses to a monetary policy tightening, as in Smets and Wouters (2003, 2007). The results are similar for all iterations of κ. In all the stated scenarios a drop in output, inflation, employment and investment is observed, as expected in the case of a policy rate increase. All these variables fall and then gradually converge to their steady states.

In this scenario, it appears that with lower the value of κ, the more the effect of the interest rate increase is dampened. For example, the realised impulse response values for consumption in Figure 6.3 are progressively higher with successive reductions in the haircut parameter. Intuitively, this is the result of a relatively more accommodative central bank balance sheet position, which is captured by the relatively lower values of κ.

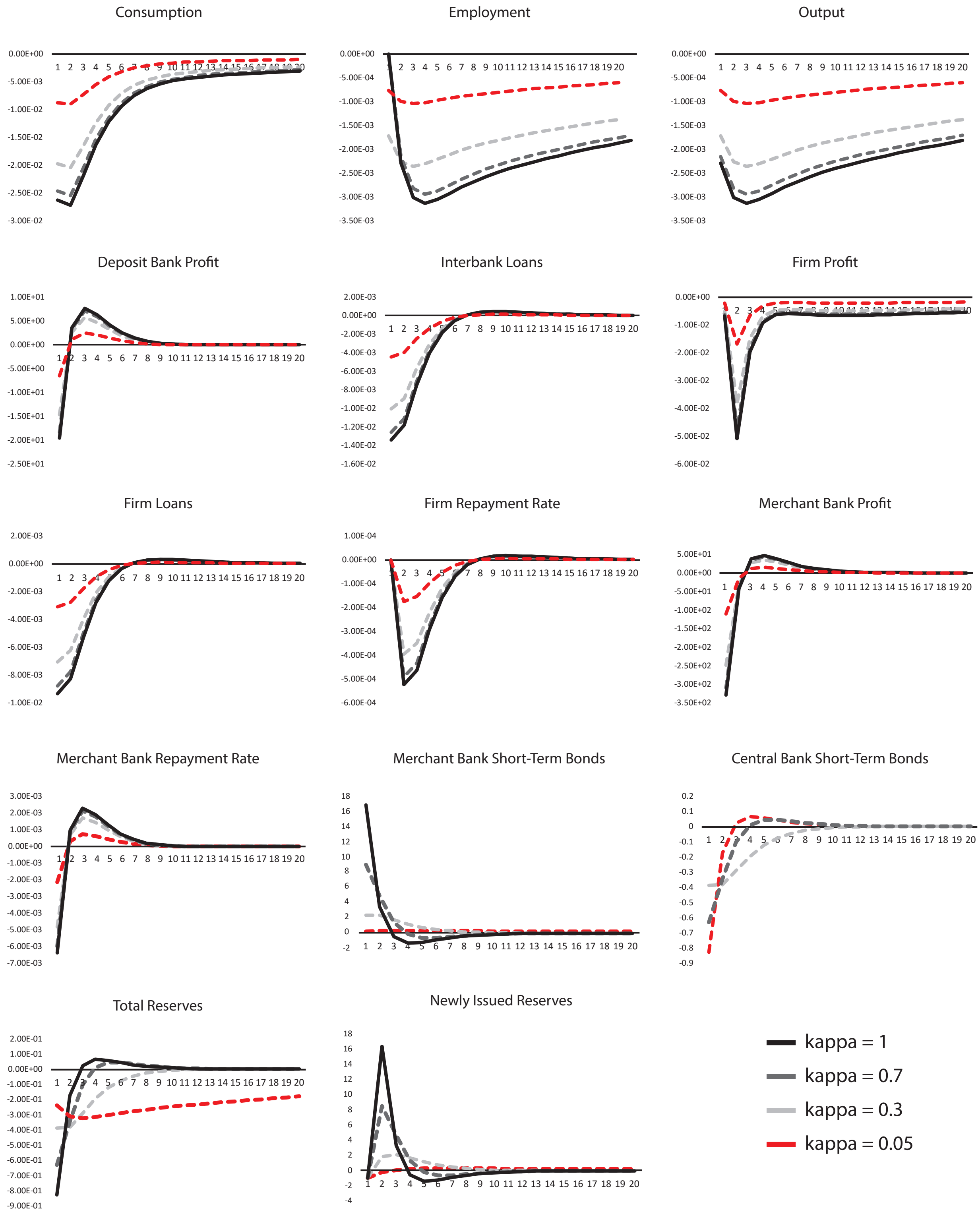
6.6.2.2 Financial Sector

Real sector results from my model largely corroborate the empirical findings from comparable dynamic general equilibrium models. With the discussion on real sector effects exhausted in other studies, it affords me the opportunity to shift the focus of the analysis to the financial sector. The discussion follows a simple template. First, the impulse responses associated with each financial institution are evaluated on the basis of the benchmark case, with no constraint on central bank lending (i.e. $\kappa = 1$). Second, the baseline is compared with the scenarios in

[43] In fact, the ECB under their liquidity provision programs extended loans to some financial institutions where the haircut was close to 30%; normally on bottom tier asset classes (Gerali et al., 2010)

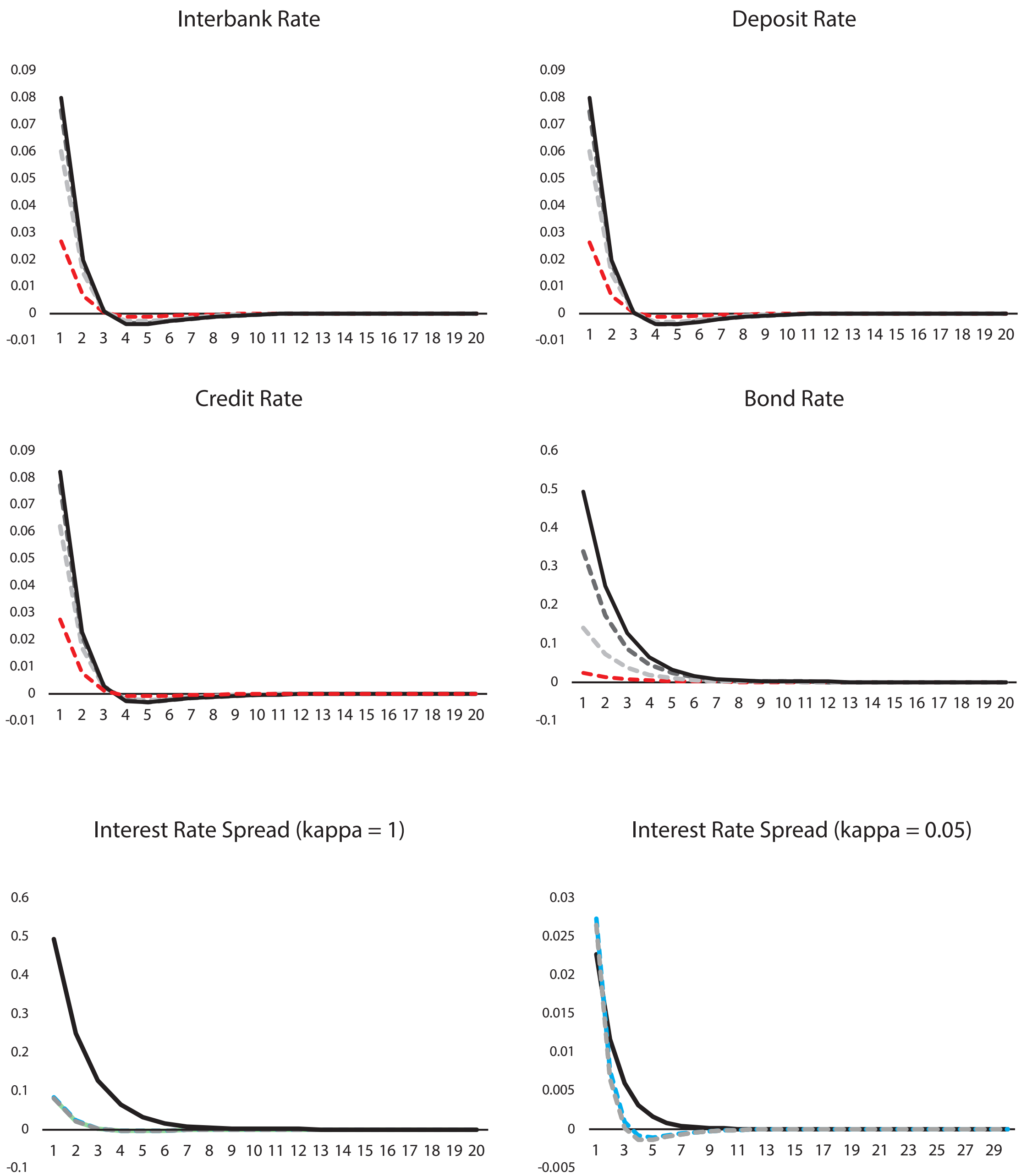
[44] A true decoupling would require a value of $\kappa = 0$, however, setting the value for κ too low causes indeterminacy in the model. The value of 0.05 was chosen because lower levels deliver similar results.

Figure 6.3: Contractionary interest rate policy: Real and financial sector



Note: Y-axis values represent percentage deviation from steady state, resulting from 1 percentage point shock to the policy rate.

Figure 6.4: Contractionary interest rate policy: Interest rates



Note: Y-axis values represent percentage point deviation from steady state, resulting from 1 percentage point shock to the policy rate.

which the haircut constraint is imposed (i.e. $\kappa = 0.7$, $\kappa = 0.3$ and $\kappa = 0.05$). Another way to frame this second scenario is to consider the usage of interest rate policy while balance sheet policy is bounded, in the same vein as Harrison (2012).

6.6.2.3 Clarification: Decoupling Principle

In order to understand the results better, one important clarification is necessary, as there are potentially conflicting effects occurring. Usually in open market operations conducted to affect a negative impact on the short-term interest rate, the central bank would drain reserves from the economy by selling short-term securities to (merchant) commercial banks. In the model presented the initial decrease in the interest rate, with $\kappa = 1$, is met with a relatively large decrease in the amount of reserves. This is expected, as the value of κ, along one dimension, represents a sensitivity of reserves to the movement in the interest rate. Lower values of κ result in lower initial decreases of reserves held by merchant banks (i.e. a higher relative level of reserves), indicating a lower responsiveness of reserves to changes in the interest rate. This relates to the discussion on the decoupling principle in the previous chapter.

However, on the other hand, merchant banks in the scenario where $\kappa = 1$ have accumulated more short-term bonds to trade for reserves (as they yield higher returns with an increase in the policy rate) and also have the means to convert these bonds to reserves, over the longer-run. By this I mean that all their short-term bonds can be offered as collateral in obtaining liquidity: there is no collateral restriction. In comparison, while the initial reduction in reserves is relatively low for lower values of κ, the exchange of short-term bonds for reserves operates more slowly with lower values of κ. Therefore, in the case where $\kappa = 1$, for example, the initial reduction in reserves is sharp due to the interest rate increase. However, in this instance the merchant bank has greater means to obtain (now higher yielding) reserves in exchange for short-term bonds, allowing a potentially quicker recovery.

6.6.2.3.1 Deposit Bank ($\kappa = 1$) First, in the case of the deposit bank - which provides liquidity in the interbank market - an increase in the policy rate gets partially transmitted through to the interbank interest rate, creating a positive spread between the policy and interbank rate. As indicated in the partial equilibrium analysis, this spread is generated primarily by the size of the merchant bank default parameter, δ.

Given the higher price on interbank market investment, the demand for interbank loans decreases (Goodhart et al., 2011). Deposit bank profits are negatively affected by the contractionary policy at first, but then steadily increase over the next few quarters to surpass its steady-state value. Profits increase, with interbank loans starting to accumulate and the interbank rate returning to its pre-shock levels. While this result might seem counter-intuitive, there is evidence to support it in the literature[45]. Giri (2014) states that the policy rate increase appears to benefit the net creditor/surplus bank in the economy. In fact, Goodhart et al. (2011) refer to the deposit bank as the net lender in their paper. The intuition is that net creditors are eventually able to take advantage of the fact that interbank lending now occurs at a higher price.

6.6.2.3.2 Deposit Bank ($\kappa = 0.7$; $\kappa = 0.3$; $\kappa = 0.05$) Reducing the value of κ induces a relative increase in central bank reserves in the short-run, as the result of reduced interest rate sensitivity of reserves. To be clear, this initial expansion of the central bank balance sheet is a relative one, as it is in comparison to the case where reserves are more reactive to movements in the interest rate, namely $\kappa = 1$. The most striking impact from this relative increase in reserves is the relatively higher level of loans extended on the interbank market, which is most readily observed with $\kappa = 0.05$. Interestingly, it appears that the price of interbank lending is a function of the amount of loans, with the pass-through of the policy rate on the interbank rate being relatively stronger in the increased liquidity environment.

Deposit bank profit decreases less sharply to the contractionary interest rate shock with lower values of κ, dampening the negative effect of the policy stance. However, profit recovery is faster with higher values of κ, leaving the deposit bank with a marginally higher level of profit in the longer-run. This appears to be linked to the movement of the interbank rate, showing the interest rate sensitivity of profits.

6.6.2.3.3 Firm ($\kappa = 1$) Second, I look to the response of the firm. As expected, firm loans decrease due to the increase in the loan rate imposed by the monetary policy shock. Firm profits decrease, which confirms my intuition. In addition, firm repayment decreases, which translates into an increase in the probability of firm default. There appears to be a positive correlation between loans to the firm and the repayment rate, as highlighted by the partial equilibrium analysis. In other words, the lower the number of loans extended to firms, the higher the probability of default. This could indicate that in times when firms are credit constrained it becomes more difficult to repay their debt. The number of loans to firms decreases with the increase in the real credit rate and decline in the value of firms' capital.

[45] In the bank lending channel, it is possible for a supply-driven bank to be profitable with an increase in the interest rate (Kuttner and Mosser, 2002).

6.6.2.3.4 Firm ($\kappa = 0.7$; $\kappa = 0.3$; $\kappa = 0.05$) When the central bank broadens its role as intermediary, through a decrease in κ, there is a relative decrease in the credit rate. Also, the quantity of firm loans continues to increase in line with the initial expansion in the central bank's balance sheet. The increase in firm loans contains elements of both demand and supply. On the one hand, firm demand could be heightened because of easier borrowing conditions. However, an increase in the liquidity available to the merchant bank is also a factor in the increased number of loans extended, indicating that the determination of loan quantity is not purely based on movements in the credit rate.

6.6.2.3.5 Merchant Bank ($\kappa = 1$) Third, I considered the case of the merchant bank. Before discussing the result, it is important, once again, to highlight the context for the scenario at hand. Looking at the collateralised lending equation (6.44), one observes that central bank intermediation directly affects the merchant bank in the model, as it receives reserves from the central bank in return for government bonds proportional to the haircut parameter. Another important interpretation of the equation, in the case where $\kappa = 1$, is that the relationship between the policy rate and newly issued reserves is one-to-one. In other words, interest rate sensitivity is defined by this parameter. In this case, with $\kappa = 1$, an increase in the policy rate should result in a commensurately negative response in reserves, i.e. as used in Goodhart et al. (2011). However, the results from Chapter 5 indicate that this sensitivity parameter might take on a range of values, depending on the monetary policy regime in question[46].

As expected, merchant banks experience a negative effect on their profit from the contractionary policy, due to the increased cost in external financing. The number of bonds in the merchant bank portfolio increases initially, for several plausible reasons. First, open market operations by the central bank place short-term securities with the merchant bank in return for reserves. It is difficult to see from the figure, but newly issued reserves are decreasing initially. This decrease is overshadowed by the accompanying increase in demand for reserves, with merchant banks aggressively pursuing liquidity as a result of the contractionary policy imposed.

Second, an increase in short-term bonds - as they are convertible to reserves in future - reflects the substitution away from the relatively more expensive interbank market as source of liquidity. This finding is corroborated by Giri (2014), who finds that these banks move away from the interbank market toward the purchases of government bonds in the case of monetary tightening. After the initial increase, the merchant bank short-term bond supply decreases rapidly, as it

[46]The results from Chapter 5 also reveal that there is rarely occasion to believe that the value for κ would strictly be equal to one. The only instance where this is truly possible is in a reserve regime, but even in this regime it is likely that the sensitivity is lower than one. In other words, the elasticity of demand for reserves might be lower on the money demand curve.

is exchanged for reserves. This then, leads to sharp, but temporary, increase in total reserves. With the increase in the policy rate, the merchant banks want to deposit more reserves at the central bank, a result that is shared by Hilberg and Hollmayr (2011). Finally, the increasing cost of borrowing, as a result of the monetary policy shock, increases default rates for the merchant bank.

6.6.2.3.6 Merchant Bank ($\kappa = 0.7$; $\kappa = 0.3$; $\kappa = 0.05$) Decreasing the value of κ decreases the level of bonds held by the merchant bank, relative to the benchmark (i.e. $\kappa = 1$). Importantly, this increased collateral requirement reduces the amount of reserves that can be acquired by the merchant bank (Niestroj et al., 2013). In other words, after a few periods, the tightening of the collateral constraint (with lower values of κ) results in a relatively lower level of reserves being available to the merchant bank.

Lowering the value of κ results in an increase in the repayment rate on interbank loans. In addition, an increase in the repayment rate from loans issued to firms is observed. Merchant banks are affected by lower borrowing costs and, therefore, lend more to their customers, i.e. the firms (Goodhart et al., 2011). With lower values of κ, the liquidity position of the merchant bank improves to the extent that it can better service firm loan demand. Both firm and merchant bank profitability increase as a result of the liquidity improvement. In summary, banks anticipate that the increase in liquidity/credit would mean an overall higher level of credit extension. The probability of default for both banks and firms will decrease, because of the liquidity position and the increase in profitability associated with this constraint (Goodhart et al., 2011).

6.6.2.3.7 Central Bank Finally, the central bank increases the policy rate, which results in an initial decrease in both total and newly issued reserves[47]. This negative relationship indicates that the decoupling is not complete, with lower levels of κ generating a greater decoupling of the quantity and price of reserves. In other words, for lower values of κ, we see that the reserve sensitivity to interest rate changes declines, with a subdued effect on the reserves for $\kappa = 0.3$. Selecting a parameter value at the lower end of the spectrum produces an interest rate increase with little impact on the number of reserves.

6.6.2.3.8 Interest Rates The spread between interest rates changes significantly with different values of κ. Decreasing the value of the haircut parameter narrows the spread between the

[47] Once again the initial decline in total reserves is difficult to see on the graph.

bond rate and other market rates. This decreased spread could be indicative of improvement in the market conditions. As discussed in Cúrdia and Woodford (2010), one would expect tighter financial conditions to be met with an increase in interest rate spreads. In addition, higher values of κ represent an increased ability for the policy rate to affect market rates. The pass-through of the policy rate increase is experienced most intensely in the movement of the bond rate.

6.6.2.3.9 Exit Strategy In order to generate an exit from the ZLB, the value of κ would have to be as close to zero as possible. The current model would, however, have to be extended along several dimensions to capture the full effects of such a strategy. The work from this section points to the possibility that there would be a short-run gain from severing ties with the balance sheet in the case of an interest rate increase. This is because reserves do not decrease with a rise in the policy rate under decoupling. In the longer-run, in this model, money supply might be higher with a decoupling, even if banks are constrained by their inability to exchange bonds for reserves. The decoupling effect dominates in this model, with improved financial stability and real economic performance associated with lower values of κ. However, this analysis does not capture the full complexity of the strategy, which is why it is deferred to future research.

This result does, however, raise an important question. In the case where central banks increase the interest rate, with the balance sheet completely decoupled (such as a floor regime) it would mean that banks hold a higher than normal level of reserves. This might act to partially counteract some of the influence of the interest rate increase. Policymakers need to weigh the cost and benefits of implementing these policies in the light of this result.

6.7 Chapter Conclusion

In developing the model for this chapter, I attempted to address some of the shortcomings of modern DSGE models. Several attractive features are combined into one model, with the purpose of looking at changes in the size of the balance sheet of the central bank. Some of the important amendments to the traditional New-Keynesian DSGE model are endogenous default, an interbank market with heterogeneous banks, interest rate spreads and a role for balance sheet policies. In particular, the addition of the collateralised borrowing mechanism from Schabert (2015) provides an elegant way to present endogenous changes in the size of the balance sheet of the central bank.

Central banks, in the model, have the ability to inject liquidity into the financial system through open market operations. Injections are specifically directed at the merchant bank, as dictated by the collateralised borrowing constraint. Merchant banks, are similar, in reality, to commercial banks with direct access to central bank reserves. As depicted by an increase in the value of κ_t, a balance sheet expansion results in improved borrowing conditions for these banks, which, in turn, improves interbank market activity and reduces firm and interbank loan default. The finding from this chapter illustrates that expanding the balance sheet of the central bank can have system-wide implications, especially with respect to the agents responsible for credit extension to the broader economy.

In addition, central banks have full control over the haircut mechanism, κ, which affords them the ability to alter the size of the balance sheet autonomously. It is plausible that in some scenarios this will allow them to implement interest rate policy in conjunction with balance sheet policy, amplifying, or perhaps detracting from, the effect of interest rate policy. As illustrated in the last part of the chapter, the central bank can increase the interest rate and decide on varying degrees of balance sheet size, dependent on the value of κ. Smaller values of κ, for example, will impose stricter lending conditions and reduce the availability of credit in the system. In the next chapter, I determine what effect changes in the composition of the balance sheet might have on financial stability and economic activity.

Chapter 7

Model with Long-term Bonds

This chapter extends the model presented in Chapter 6 to include long-term securities, allowing the central bank to affect the economy through changes in the composition of its balance sheet. Balance sheet policy of this type usually attempts to influence the price of a specific asset class. However, there are other avenues through which asset purchases in my model might impact the macroeconomy, specifically in the financial sector. Changes to the baseline model primarily affect three sections of the model, namely the merchant bank, central bank and government.

7.1 Literature Review

The literature on large-scale asset purchases (LSAPs) identifies several important channels for the transmission of nonstandard policies[1]. One of the primary channels identified in the literature is the portfolio balance channel. As mentioned in the second chapter, asset purchases are often ineffective in New Keynesian DSGE models, as expertly demonstrated in Eggerston and Woodford (2003). Wallace's irrelevance result posits that reserves and government bonds are perfect substitutes, which means that the portfolio balance effects are not observed in the event of strategic asset purchases. Changes to the central bank balance sheet, in terms of size and composition, effectively have no role to play in affecting real variables. As shown by Cúrdia and Woodford (2011), this result holds even in models with demand-side credit frictions where agents believe assets to be perfect substitutes. However, the recent strand of empirical evidence on LSAPs highlights the fact that portfolio balance effects do exist[2] and contribute substantially

[1]There is a discussion on this literature in Chapter 2.5.1.
[2]Chapter 4.1 provides a discussion on the empirical evidence on large-scale asset purchases.

to changes in long-term rates[3]. Keeping this in mind, it could be fruitful to look at models of asset purchases that have some degree of imperfect asset substitutability.

7.1.1 LSAPs in DSGE

7.1.1.1 'Flattening the Yield Curve'

After the initial shock of the financial crisis, with the policy rate of most advanced economies nearing the ZLB, central banks considered several alternative tools to stimulate economic activity and address dysfunctional financial markets. As a recourse, most central banks initiated asset purchase programs in order to affect longer-term interest rates. Lowering longer-term rates is thought to assist the traditional monetary policy mechanism by reducing private sector borrowing rates (Bernanke and Reinhart, 2004). Broad channels of operation in achieving this goal, as identified in the literature, are the expectations (or signalling) and portfolio balance channels (Woodford, 2012). The model developed in this chapter exploits the transmission mechanism under portfolio rebalancing. In order to generate the impact from LSAPs in a DSGE model, one requires some assumptions on the substitutability of assets. Models that incorporate this channel have to justify why investors value securities used in asset purchases beyond their risk-adjusted payoff (Chodorow-Reich, 2014).

7.1.1.1.1 Preferred Habitat One of the earliest DSGE models to capture imperfect asset substitution is the model by Andres et al. (2004). In this model the agents have heterogeneous preferences with regard to long-term government bonds, which generate the portfolio balance effects. Models in this tradition are often referred to as 'preferred habitat' models. In this model, the central bank has the power to influence a specific segment of the yield curve through its manipulation of the relative asset supply. Vayanos and Vila (2009) build on the work of Andres et al. (2004) to develop a general equilibrium preferred habitat model with segmented markets. Apart from these two papers, very few dynamic general equilibrium models incorporating central bank asset purchases existed before the crisis. However, the implementation of balance sheet policies during the financial crisis resulted in a surge in the DSGE literature on the impact of large-scale asset purchases.

Chen et al. (2012a) estimate the impact of long-term security purchases in a DSGE model with segmented asset markets. Their preferred habitat approach, in the vein of Vayanos and Vila

[3] It should be noted that, although there is a fair number of studies that register the portfolio balance effects, there are some who contest its existence - see the discussion in Chapter 4.1

(2009), allows monetary policy to still be effective at the ZLB, with purchases of long-term securities resulting in local supply effects. Transaction costs added to the supply of long-term securities allow LSAPs to operate while the short-term policy rates is fixed at the ZLB, in that it would be able to flatten the yield curve through the reduction of a risk premium (Chen et al., 2012a). Asset purchases in a preferred habitat framework are also proposed in the work of Harrison (2012), and Falagiarda and Saia (2013) to study the impact of unconventional policies, with some minor adjustments to each model to answer specific policy questions.

7.1.1.1.2 Constrained Borrowing Another line of research attempts to look specifically at LSAPs as a form of central bank intermediation, with the work of Gertler and Karadi (2011) among the first to incorporate asset purchases as a monetary policy tool into a DSGE framework. In the process of intermediation, a financial market agent acquires an asset by issuing the relevant counterparty some form of short-term debt (Gertler and Karadi, 2013). In QE1, for example, the central bank acted as an intermediary by providing short-term government debt (borrowed from the Treasury) in return for illiquid assets to failing financial institutions. LSAPs in this type of model matter only when there is a disruption in the process of financial intermediation. Without constraints on borrowing, any premium arising from activity in the asset market will be eliminated through arbitrage. In this setup, LSAPs will be effective only if private intermediaries face borrowing constraints.

Continuing in this vein is the work of Del Negro et al. (2013), who employ the credit market frictions of Kiyotaki and Moore (2012) in a DSGE model. In their model, firms are allowed to invest only a certain proportion of their illiquid assets, known as a resaleability constraint, whereas government bonds are free from any such restrictions. Government bonds are, therefore, more liquid and the constraint generates a liquidity premium on the unaffected asset. Gertler and Karadi (2013) argue that this type of model is not only applicable to credit policy, but also to the purchase of long-term bonds (i.e. quasi-debt management). The argument is that, without any limits to arbitrage, there should be no premium to exploit on either short- or long-term government bonds. With constraints on private intermediaries and financial market frictions that increase the term premium, long-term rates may be reduced by targeted purchases by the central bank (Gertler and Karadi, 2013). Finally, the model of Cahn et al. (2014) builds on the models of Smets and Wouters (2007), Gertler and Kiyotaki (2010), and Gertler and Karadi (2011) to allow for securities of longer maturity in order to assess the impact of the VLTROs as implemented by the ECB.

7.1.1.2 Targeted Asset Purchases

During times of financial distress, the rationale behind credit easing lies in its ability to affect long-term interest rates. However, another consideration is the scenario where economic activity picks up again after the crisis. One would expect banks to exit the current deleveraging phase and for asset prices to rejoin their upward trajectory. The danger lies in asset prices that grow to exceed their fundamental value, thereby creating an asset price bubble. White (2009) suggests "pre-emptive tightening" of monetary policy to rein in credit cycles and resist credit bubbles. However, it is generally believed that monetary policy is not effective in "leaning" against an upswing in the credit cycle and should rather assume an accommodative position to "clean" up after the bubble has burst. This result is considered part of the Jackson Hole Consensus, whereby it is considered important to focus the attention of monetary policy on low and stable inflation. As argued by Bernanke and Gertler (2000), attempts to influence asset price movements (i.e. 'leaning against the wind') detracts from the pursuit of the inflation objective. In addition, in a recent article Ajello et al. (2015) find that the benefit from increasing the interest rate to counter the build-up of financial imbalances to be negligible.

This type of reaction also distorts the price stability mandate, assigning a dual mandate to interest rate policy. Tinbergen (1952) comments that policymakers should have "one instrument for one goal", while Mundell (1962) states that "policies should be paired with objectives on which they have the most influence". However, mopping up after a bubble has burst is risky in that policymakers cannot be certain that they will be able to clean up in the aftermath, as is evident by the macroeconomic challenges currently faced. In that case it would be sensible to assign balance sheet measures the role of depressing asset values once a bubble is identified[4]. Balance sheet measures have the added advantage that they could target a specific asset of interest, whereas interest rates would affect all asset values[5]. In my model the central bank could plausibly attempt targeted asset purchases of risky securities (longer-term bonds) in an attempt to improve the health of financial institution balance sheets. The next section presents the extension to the model in the previous chapter to include long-term bond purchases.

7.2 The Model

The model presented here gives the central bank the ability to influence the supply of long-term government bonds. In particular, it combines elements of the papers by Chen et al. (2012a),

[4]Identification of asset bubbles is another complicated matter and will not be addressed in this dissertation
[5]Naturally, purchases of a specific asset class would also impact on other interest rates

Niestroj et al. (2013), Hörmann and Schabert (2015), and Schabert (2015). In this section the amendments to the model in Chapter 6 are presented, with only the affected sectors shown. Of particular importance are the changes to the merchant bank sector, which gains a new investment vehicle (namely long-term securities). Imperfect asset substitutability is enforced by the collateralised borrowing mechanism. The irrelevance result is overcome through the introduction of multiple assets that are viable as collateral for reserves (Niestroj et al., 2013). A liquidity premium is generated through the interest rate spread on eligible versus non-eligible assets. This embedded premium can be manipulated by the central bank through its setting of the relevant haircut parameter (Schabert, 2015). Government and central bank sectors are also implicated by the introduction of these bonds.

7.2.1 Merchant Bank

The following section describes the behaviour of merchant banks, with the important introduction of long-term securities in both the budget and collateral constraints. I have chosen to adopt the approach of Woodford (1998, 2001) in modelling the stock of long-term bonds. This method is widely accepted and is also used in the work of Andres et al. (2004), Chen et al. (2012a), Harrison (2012), van der Kwaak (2015), and Chin et al. (2015).

7.2.1.1 Long-term Bonds

In this setting government bonds are modelled as perpetuities[6] that cost p_t^L at time t and pay an exponentially decaying coupon Φ^s at time $t+s+1$, where $0 < \Phi \leq 1$. Introducing long-term bonds into the profit function (6.47) from Chapter 6 results in the following addition:

$$\pi_t^b = \ldots + \sum_{s=1}^{\infty} \Phi^{s-1} B_{t-s}^L - p_t^L B_t^L \ \ldots \tag{7.1}$$

In order to simplify this equation, one can take advantage of the fact that the period t price of a long-term bond issued s periods ago, p_{t-s}^L, in period $t-s$, is a function of the coupon and current price of the bond, as pointed out by Woodford (2001) and Chen et al. (2012a). In other words

$$p_{t-s}^L = \Phi^s p_t^L \tag{7.2}$$

[6]As explained in Woodford (2001), this perpetuity generates a constant, infinite, stream of interest payments. A practical example of this is the British consol. An interesting paper by Cochrane (2015) suggests using perpetuities in dealing with US Federal debt.

Using this equation, the profit equation (7.1) can be rewritten in a "recursive formulation", as in Chen et al. (2012a). In other words, the equation is used to transform $\sum_{s=1}^{\infty} \Phi^{s-1} B_{t-s}^L$ into a function of B_t^L. This simplification allows long-term bonds to be expressed as one-period bonds that pay their nominal return after one period, similar to the way in which short-term bonds are represented.

A long-term bond issued $s-1$ periods ago is equal to Φ^{s-1} new bonds. At time $t-1$, with no arbitrage, using (7.2) delivers the following:

$$
\begin{aligned}
p_{t-1}^L B_{t-1}^L &= \sum_{s=1}^{\infty} p_{t-s}^L B_{t-s}^L \qquad \text{substitute } p_{t-s}^L \text{ with } p_{t-1}^L \Phi^{s-1} \\
p_{t-1}^L B_{t-1}^L &= \sum_{s=1}^{\infty} p_{t-1}^L \Phi^{s-1} B_{t-s}^L \qquad \text{divide by } p_{t-1}^L \\
B_{t-1}^L &= \sum_{s=1}^{\infty} \Phi^{s-1} B_{t-s}^L
\end{aligned}
$$

In addition, as given in Chen et al. (2012a), the gross yield to maturity (long-term interest rate) on the long-term bond is,

$$
R_t^L = \frac{1}{p_t^L} + \Phi^s \tag{7.3}
$$

Perpetuity redeems all old bonds in each period, where the bond pays the following:

$$
1 + \Phi p_{t+1}^L = p_{t+1}^L \left(\frac{1}{p_{t+1}^L} + \Phi^s \right) = p_{t+1}^L R_{t+1}^L \tag{7.4}
$$

At time t we have that B_{t-1}^L is worth $B_{t-1}^L(1+\Phi p_t^L)$. Substituting it with p_t^L we get, at time t, that B_{t-1}^L is worth $B_{t-1}^L(1+[\Phi/(R_t^L-\Phi)]) = p_t^L R_t^L B_{t-1}^L$.

This alters the real profits of the merchant bank in the following way, giving the final form

$$
\begin{aligned}
\pi_t^b = {} & \frac{L_t^l}{R_t^l} - \delta_t \frac{L_{t-1}^l}{\pi_t} + \psi_t \frac{L_{t-1}^b}{\pi_t} - \frac{L_t^b}{R_t^c} + \frac{B_{t-1}^S}{\pi_t} - \frac{B_t^S}{R_t^b} + \frac{p_t^L R_t^L B_{t-1}^L}{\pi_t} - p_t^L B_t^L \\
& - M_t^p + \frac{M_{t-1}^p}{\pi_t} - \frac{\omega_\delta}{2}\left[(1-\delta_{t-1})L_{t-2}^l\right]^2 - M_t(R_t^m - 1)
\end{aligned} \tag{7.5}
$$

In addition to the change on the budget constraint, the introduction of long-term bonds impacts the open market operation mechanism, adding another dimension to policy action. Now we are not concerned only with changing the size of the balance sheet; we wish to change the composition as well. This means that our collateral constraint changes to become

$$M_t \leq \kappa^s \cdot \frac{B^S_{t-1}}{R^m_t \pi_t} + \kappa^l \cdot \frac{p^L_t R^L_t B^L_{t-1}}{R^m_t \pi_t} \tag{7.6}$$

An increase in both κ^s and κ^l will result in a change in the size and composition of the balance sheet of the bank. However, if there is a change in κ^l, with a corresponding sterilising change in κ^s, then the size will remain the same but the composition will change (Hörmann and Schabert, 2015). The central bank, in this regard, has full control over its balance sheet, providing intermediation services to merchant banks (Niestroj et al., 2013). Effective demand for securities of differing maturities is determined by the exogenous combination of κ values.

The balanced budget condition also changes to incorporate the newly introduced security. It now looks similar to that of Niestroj et al. (2013). This equation is given by

$$L^l_t = M^p_t + L^b_t + B^S_t + \mathbb{E}_t \left(p^L_{t+1} R^L_{t+1} B^L_t \right) \tag{7.7}$$

The first-order conditions for the merchant bank remain the same, with the exception of an additional derivative with respect to long-term bonds. The new FOC is

$$(\partial B^L_t) \qquad \dot{U}^b_t p^L_t = \beta^b \mathbb{E}_t \left(\frac{\dot{U}^b_{t+1} + \kappa^l \cdot \eta_{t+1} p^L_{t+1} R^L_{t+1}}{\pi_{t+1}} \right) - \Upsilon_t \mathbb{E}_t \left(p^L_{t+1} R^L_{t+1} \right) \tag{7.8}$$

The complimentary slackness condition for the merchant bank now becomes

$$\begin{aligned} &\eta_t \left[\kappa^s \cdot \frac{B^S_{t-1}}{\pi_t} + \kappa^l \cdot \frac{p^L_t R^L_t B^L_{t-1}}{\pi_t} - R^m_t M_t \right] = 0 \\ &\eta_t \geq 0, \quad \left(\kappa^s \cdot \frac{B^S_{t-1}}{\pi_t} + \kappa^l \cdot \frac{p^L_t R^L_t B^L_{t-1}}{\pi_t} - R^m_t M_t \right) \geq 0 \end{aligned}$$

7.2.2 Public Sector

7.2.2.1 Government

In general, the public sector consists of a treasury (government) and a central bank. The government performs the same functions discussed in the previous chapter. The exception introduced in this chapter is that of its issuance of long-term bonds. Short-term bonds still grow at a constant rate, where $\Gamma \geq 1$. Long-term bonds, however, are modelled as perpetuities (as alluded to in the section on the merchant bank). The growth of long-term bonds follows an autoregressive process, as in Chen et al. (2012a),

$$p_t^L B_t^L = \left(\frac{p_{t-1}^L B_{t-1}^L}{\pi_t}\right)^{\rho_b} e^{\xi_t^L} \tag{7.9}$$

where $\rho_b \in (0,1)$ and $\xi_{L,t}$ is an i.i.d. exogenous shock. Similar to Chapter 6.3.4.1, B_t^{TS} is the total stock of short-term bonds, which is held either in the banking sector B_t^S or by the central bank, B_t^{CS}. The equation that represents this relation is $B_t^{TS} = B_t^S + B_t^{CS}$. In a similar vein, we will have that the total supply of long-term bonds is $B_t^{TL} = B_t^L + B_t^{CL}$. Introducing long-term bonds changes the budget constraint to read

$$G_t + \frac{B_{t-1}^{TS}}{\pi_t} + \frac{p_t^L R_t^L B_{t-1}^{TL}}{\pi_t} = \frac{B_t^{TS}}{R_t^b} + p_t^L B_t^{TL} + T_t \tag{7.10}$$

The left-hand side of the equation represents spending in real terms, while the right represents treasury income. The first term on the left-hand side represents real government spending, while the other components are the real cost of servicing bonds that are maturing in the current period. On the right-hand side, we have the market value of the total amount of short- and long-term bonds issued in the current period, in addition to tax collected (Chen et al., 2012a).

7.2.2.2 Central Bank

The monetary authority is able to supply money outright through open market purchases (M_t^p). The central bank collects government bonds in return for newly issued money. In addition, interest accrues at the main refinancing rate, R_t^m, which translates into a return of $M_t \cdot R_t^m$ at period t. Newly issued money is reflected by, $M_t = M_t^p - \frac{M_{t-1}^p}{\pi_t}$, for which the central bank receives government bonds.

The interest earnings of the central bank, as in Schabert (2015), is

$$T_t^r = B_t^{CS}\left(1 - \frac{1}{R_t^b}\right) + \frac{p_t^L R_t^L B_{t-1}^{CL}}{\pi_t} - p_{t-1}^L B_{t-1}^{CL} + M_t(R_t^m - 1) \tag{7.11}$$

The central bank reinvests the wealth exclusively in government bonds, which means the budget constraint adjusted for long-term bonds now becomes

$$T_t^r - \frac{B_{t-1}^{CS}}{\pi_t} + \frac{B_t^{CS}}{R_t^b} = \frac{p_t^L R_t^L B_{t-1}^{CL}}{\pi_t} - p_t^L B_t^{CL} + \left(M_t^p - \frac{M_{t-1}^p}{\pi_t}\right) R_t^m \tag{7.12}$$

Bond holdings evolve according to

$$B_t^{CS} - \frac{B_{t-1}^{CS}}{\pi_t} + p_t^L B_t^{CL} - \frac{p_{t-1}^L B_{t-1}^{CL}}{\pi_t} = M_t^p - \frac{M_{t-1}^p}{\pi_t} \tag{7.13}$$

Restricting the initial values leads to the central bank balance sheet condition

$$B_t^{CS} + p_t^L B_t^{CL} = M_t^p \tag{7.14}$$

In this setting the central bank now controls three instruments. As stated in Chapter 6.3.4.1, the first two tools are the policy rate and quantitative easing (increasing the size of the balance sheet). In this chapter, with the introduction of long-term bonds, it has been shown that the central bank is able to change the composition of its balance sheet by adjusting the fraction of short-term bonds relative to long-term bonds eligible for reserves. In other words the central bank can now change both κ^s and κ^l.

For the purpose of this model, $0 < \kappa^s \leq 1$ and $0 < \kappa^l \leq 1$. The sum of these can be greater than one, $0 < (\kappa^s + \kappa^l) \leq 2$. Importantly, for the purpose of affecting a change *only in the composition of balance sheet* it must be the case that the sum of κ^s and κ^l remain the same. This is best explained through an example. Consider a case where $\kappa^s = 0.5$ and $\kappa^l = 0.5$. If a change in the composition alone was to be generated, I would have to match the decrease in one value of κ, with an increase in the other. This *sterilising* change can be the following, $\kappa^s = 0.2$ and $\kappa^l = 0.8$. In this new setting, long-term bonds are more eligible as collateral, which makes them relatively more attractive. In addition, it changes the relative bond-holdings of the central bank, which will now accept more long-term debt. This does not, however, change the size of the balance sheet, as the allotment of bonds for liquidity is still the same.

The model from the previous chapter is nested in this model. By allowing $\kappa^l = 0$, it removes the credit easing component from the model, and once again the model is left with only two tools of operation. In summary, this brings about three instruments, interest rate policy, quantitative easing and credit easing. The rest of the chapter investigates the implications of changing the composition of the assets held on the central bank's balance sheet.

To summarise, in this model the central bank has three instruments, namely the following:

1. *Conventional instrument*: The policy rate, R_t^m.

2. *Quantitative easing (size of balance sheet)*: Increase reserves against eligible assets (short-term or long-term bonds) in open market operations by increasing κ^s or κ^l.

3. *Credit easing (composition of balance sheet)*: Changes in the composition of the balance sheet, without affecting size, implemented by a change in κ^l, and met with a sterilising change in κ^s.

Finally, it is also important to point out that the central bank can decide to use these policies in combination, potentially increasing the size and composition of the balance sheet. In the next section, I conduct a partial equilibrium analysis, similar to that of the previous chapter.

7.3 Equilibrium Conditions

In this section I provide an analytical evaluation of the monetary transmission mechanism. In order to evaluate properly the equilibrium conditions some hermeneutic simplifications are stipulated. Equilibrium conditions for endogenous default are quite similar to those of Chapter 6.4.1. Changes in long-term bond rates affect default through their relationship with credit and interbank rates. This relationship is discussed in the following section.

7.3.1 Monetary Transmission

As discussed in the previous chapter, interest rate spreads are at the heart of the transmission mechanism in models that include several markets and differing asset classes. These spreads are indicative of the health of the financial system at large, as experienced during the recent crisis[7]. In order to evaluate the conditions effectively, I reduced complexity by adopting the same assumptions as in Chapter 6.4.1. I also added the assumption that inflation is zero, $\pi = 1$.

In our current setting, the only new addition to the pool of interest rates is that of the long-term bond rate. The new monetary transmission path relies on the relationship between the short- and long-term bond rates, which is presented as

$$\frac{1 - \kappa^s \eta R^b}{R^b} = \frac{1 - \kappa^l \eta R^L}{R^L - \Phi}$$

This relationship indicates the importance of Φ in creating a wedge between the short- and long-term rates. If $\Phi = 0$, then the long-term bonds have the same maturity as their short-term counterparts. The larger the value of Φ, the greater the interest rate spread (i.e. a higher long-term rate is achieved). Extending the maturity increases the overall riskiness and, thereby, the yield of the underlying asset.

[7]See the article by Cúrdia and Woodford (2011) for a discussion on the importance of interest rate spreads. Also look at the brief discussion in Chapter 6.2.1.2.

7.4 Calibration

Changes in terms of calibration occur primarily in the banking and central bank sectors. This discussion highlights only the differences between the model in this chapter and that of the previous chapter, with a summary of the newly calibrated parameters and imposed steady-state values provided in Table C.1 and Table C.2 in Appendix C.

The long-term rate was imposed and set at $R^L_{ss} = 1.075$, which is close to the calibrated value presented in Niestroj et al. (2013) for the Euro area. This value maintains the hierarchy of interest rates, as discussed in the monetary transmission section. The average duration of the long-term bond was set at 5.5 years[8], which means that the coupon rate of the perpetuity can be calculated as $\Phi = (5.5 \cdot R^L_{ss} - R^L_{ss})/5.5$. Implied steady-state values are further discussed in Appendix C.

7.5 Model Dynamics

Following the structure of Chapter 6, I analyse the impact of several different shocks and associated scenarios. First, a shock is applied to κ^l_t, which represents the proportion of long-term bonds eligible as collateral in open market operations. This shock produces results similar to those of large-scale asset purchases, by inducing demand for a long-term bonds. I compare this result with (i) a shock to the long-term bond growth rate, and (ii) the balance sheet expansion result from Chapter 6. Second, I introduced contractionary monetary policy with different combinations of κ^s and κ^l, to affect changes to the composition of the balance sheet. I am particularly interested in the impact that varying these parameters could have on default rates, the extension of loans to firms, and interbank trading. In addition, long-term yields and several interest rate spreads were examined to determine whether the policy performed as expected.

7.5.1 Large-scale Asset Purchases

Large-scale asset purchases in this section of the model entail both an expansion of, and a change in the composition of assets of the balance sheet of the central bank. In other words, it will be a combination of quasi-debt management and reserve-supply policy from the typology

[8]This was modelled on the average duration of 7-year US Treasury bills, but the value could be changed, with a duration of 7.5 years as an alternative in the case of a 10 year Treasury (Chen et al., 2012a).

of Borio and Disyatat (2010), similar to actual LSAPs conducted during the crisis. The way I approached this was to apply a shock to κ_t^l, which represents the eligibility of long-term bonds as collateral, while keeping κ^s fixed. An increase in κ_t^l is intended to simulate the effect of increasing the quantity demanded of long-term bonds (relative to short-bonds) for the merchant bank. Modelling the LSAPs in this way aligns more with the LTROs implemented by the ECB. In this scenario assets are not directly purchased by the central bank, rather, there is a change made in the bonds that are eligible for collateral (Gertler and Karadi, 2013).

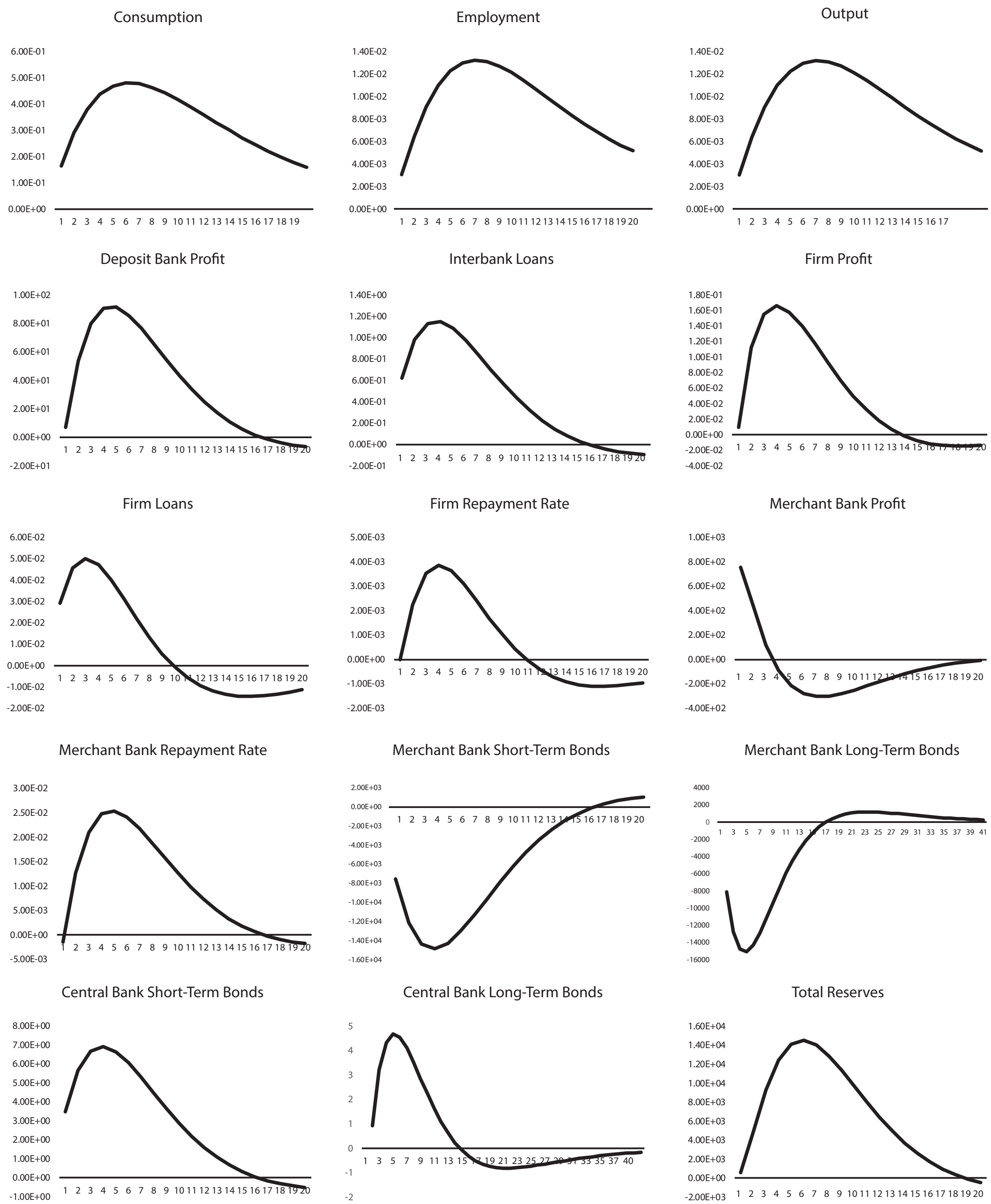
In order to do this, κ_t^l is presented as a time-varying variable following an autoregressive process. Specifically, the haircut on long-term bonds, as a variable, follows an AR(1) process, such that $\kappa_t^l = \rho_l \kappa_{t-1}^l + \xi_t^l$, with $\rho_l \in (0, 1)$ and $\xi_{l,t}$ an i.i.d. exogenous shock, while keeping the haircut on short-term bonds, κ^s, constant over time (i.e. takes on a scalar value). Both the haircut mechanisms on short- and long-term bonds will have the same initial value, with a shock then imposed on the long-term bond haircut value. This expansionary shock should simulate the general function of LSAP policies.

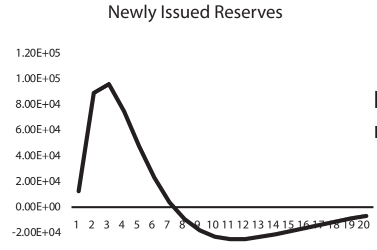
7.5.1.1 Financial Sector

The real sector effects of LSAPs are not discussed but are presented in Figure 7.1. However, the results in terms of real activity are consistent with those found in Chen et al. (2012a), Harrison (2012), and Falagiarda and Saia (2013). To be clear, the goal is not to replicate the events of the financial crisis, nor the unconventional policies that tried to remedy failing economies. The approach is purely theoretical, considering several plausible scenarios that might materialise from intervention in long-term bond markets by the central bank. The initial values for the collateral requirement, before applying the shock, are $\kappa^s = 0.5$ and $\kappa_t^l = 0.5$. A shock to κ_t^l in the magnitude of approximately 0.5 was imposed, while κ^s was fixed. The shock implies both an increase in the size of the balance sheet of the central bank, in addition to a greater allotment of long-term bonds available as eligible collateral.

7.5.1.1.1 Deposit Bank First, deposit banks experience an increase in profitability as a result of increased deposits from households and a greater volume of loans extended. This expansionary shock increases the repayment rate for merchant banks, indicating that LSAPs have the potential to increase interbank activity. However, a decrease in interbank rates mean that, although the deposit bank is extending more credit, the price of that credit has declined. Profit made in the first few quarters is supported by the increase in deposits made by households, as the LSAP program increases their relative wealth, which affords them the opportunity to deposit money at the bank.

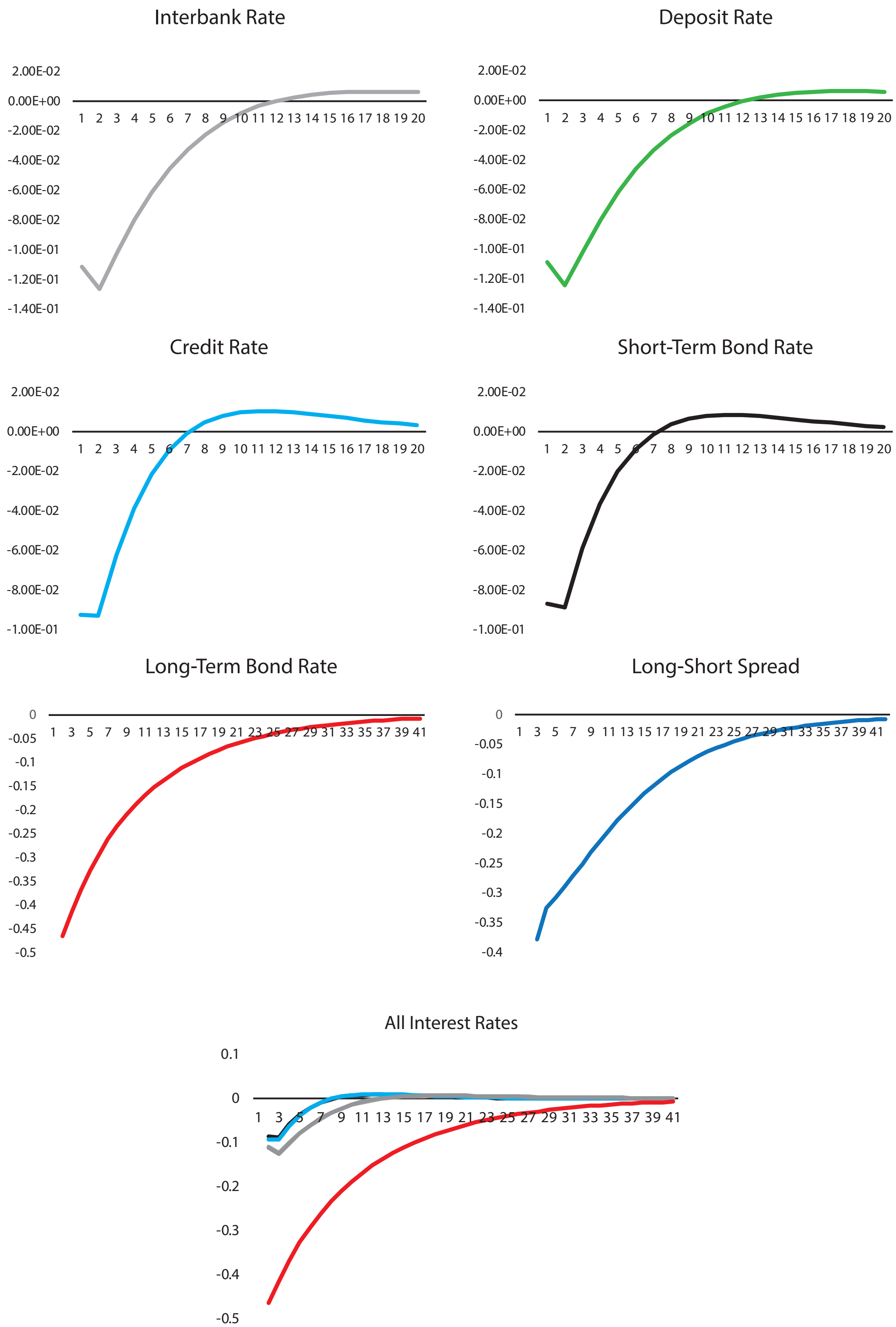
Figure 7.1: Large-scale asset purchases: Real and financial sector





Note: Y-axis values represent percentage deviation from steady state, resulting from 100% shock to long-term collateral requirement.

Figure 7.2: Large-scale asset purchases: Interest rates



Note: Y-axis values represent percentage point deviation from steady state, resulting from 100% shock to long-term collateral requirement.

7.5.1.1.2 Firm Second, borrowing conditions are easier for firms under a large-scale asset purchase program, as the amount of acquirable reserves are increasing, with merchant banks now allowed to offer up more of their previously illiquid debt as collateral (Niestroj et al., 2013). This is reflected in the significant decrease of the credit rate. In addition to an increase in loans to firms, there is a decrease in the probability of default on these loans.

7.5.1.1.3 Merchant Bank Third, the merchant bank gains the most from the increase in κ^l, with profitability improving significantly in the wake of the shock. Imposing the shock significantly alters the behaviour of these banks, causing them to sell the majority of their holdings of long-term bonds - as can be seen by the decrease in long-term bonds on their balance sheets - in return for reserves. One could argue that this enacts a portfolio balance effect, with merchant banks moving their asset holdings away from long-term bonds. This effect spreads to several asset markets, moving beyond local supply effects (Dai et al., 2013). Newly issued, and total reserves, are increasing, which reflects the exchange of long-term bonds for reserves.

A significant portion of these long-term bonds are sold and then used to extend credit to firms. This process entails converting long-term bonds to reserves, which can be seen in the increase in total liabilities at the central bank. A portion of merchant bank reserves are then used to fuel an extension of loans. In addition, the merchant bank decides to trade a large portion of its short-term bonds in the same manner as its long-term securities. The central bank has achieved its goal, with more activity in the interbank markets as well as relaxation of the borrowing conditions for firms. In addition, the long-term rate has been depressed, which further improves borrowing conditions.

7.5.1.1.4 Central Bank Finally, the composition of the central bank balance sheet has certainly been affected through the application of this shock. It now holds more liabilities, primarily against long-term bonds. Gertler and Karadi (2013) refer to this as central bank intermediation, in that the central bank has "financed its asset purchases with variable interest-bearing liabilities". The benefit of central bank intermediation in this setting is that it is effectively limitless, as the central bank liabilities are essentially government debt. Having purchased these long-term securities off the balance sheet of the merchant bank, it now holds a significant portion of the long-term debt from the private sector, as also found in the work of Falagiarda and Saia (2013). In addition, the central bank has accepted some short-term debt in return for reserves.

7.5.1.1.5 Interest Rates The long-term interest rate has been reduced at the hand of the LSAP program, which is one of the intended goals of implementing the policy initiative (Falagiarda and Saia, 2013). All other interest rates, except the policy rate[9], experience a negative shock as a result of the portfolio balance effect generated from the expansionary policy (Dai et al., 2013). Unsurprisingly, the long-term rate is depressed the most of all the affected interest rates, as it is most closely tied to the increased purchase of long-term securities. This translates into a flattening of the yield curve and signifies a decrease in the term premium associated with the long-term rate, similar to the result of Harrison (2012) and Falagiarda and Saia (2013).

7.5.2 Comparisons with LSAPs

7.5.2.1 Large-scale Asset Purchases vs Increase in Long-term Bonds

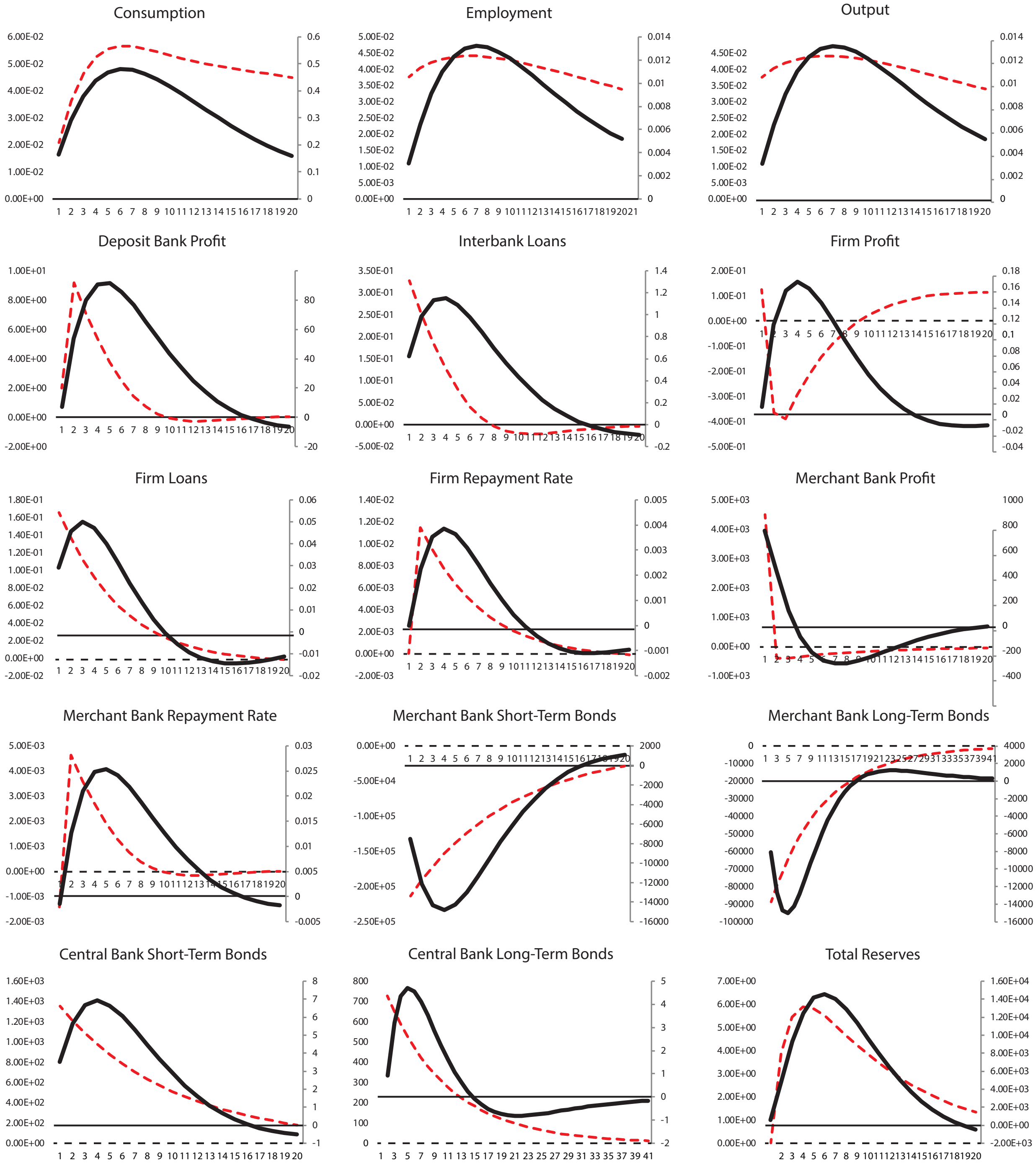
An alternative way to think about large-scale asset purchases, is simply to increase the overall stock of long-term bonds in the economy. In order to generate a meaningful impact from the asset purchases, some agents need to have a preference for long-term bonds in order to establish imperfect asset substitutability. In this case, central banks can influence the relative supply of assets, reducing long-term security scarcity. I expect private sector agents to balance their portfolios toward the scarce asset, buying short-term bonds in order to obtain more of the scarce resource. However, this will depend on the preferences of agents in our model. To that end, the ad hoc 'preference' structure for the merchant bank will be one where short- and long-term bonds serve equally well as collateral. In reality, I did not explicitly model preferences. However, I approximated them by altering the ability of merchant banks[10] to convert bonds of differing maturities into reserves. This result is compared with the LSAP scenario of the previous section.

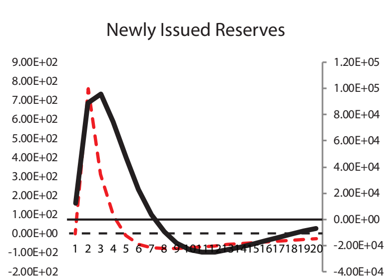
7.5.2.1.1 Shock to growth of B_t^{TL} with $\kappa^s = 0.5$ and $\kappa^l = 0.5$ In this scenario the merchant bank can transform both short- and long-term bonds into reserves with the same relative ease. In comparison with the results from the previous section, it is clear that in both cases the direction of the movement in the selected values is almost identical. Only a few differences were recorded. First, in the case of the long-term bond growth shock, the merchant banks have a sharper initial increase in the demand for liquidity. This is the result of the direct injection of reserves. Second, the overall movement of variables in the case of the haircut shock is sustained across a longer period. In particular, the long-term bond shock generates a sharp, brief, impact

[9] I believe this is the result of the increase in output, with the feedback mechanism from the Taylor Rule causing the policy rate to increase.

[10] Could be perceived as our preferred habitat investor.

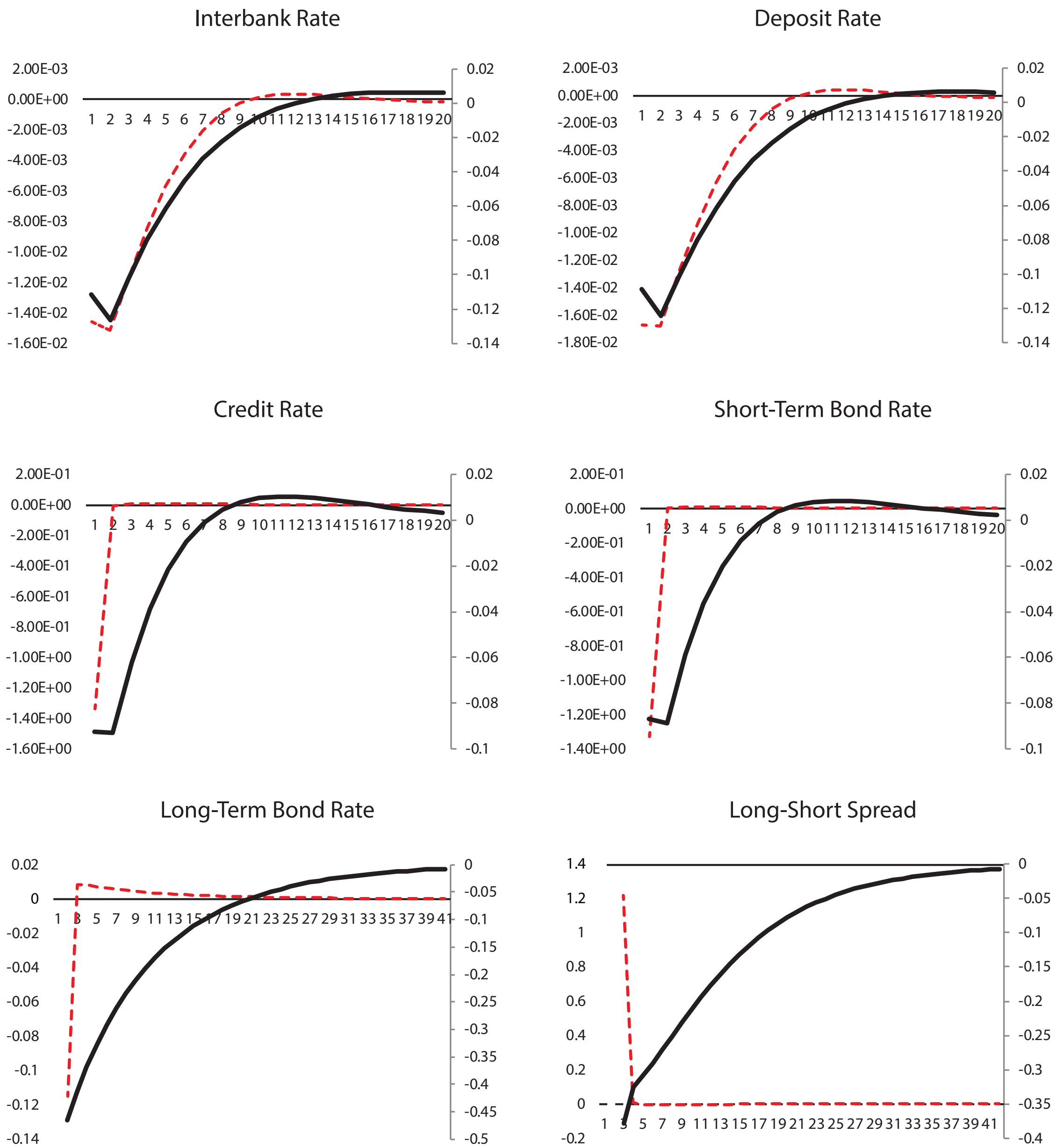
Figure 7.3: LSAPs vs. Increase in long-term bond growth: Real and financial sector





Note: Y-axis values represent percentage deviation from steady state.
The black line (right axis) is from a 100% shock to long-term collateral requirement, while the red dotted line (left axis) is from a shock to the long-term bond growth rate.

Figure 7.4: LSAPs vs. Increase in long-term bond growth: Interest rates



Note: Y-axis values represent percentage point deviation from steady state.
The black line (right axis) is from a 100% shock to long-term collateral requirement,
while the red dotted line (left axis) is from a shock to the long-term bond growth rate.

on interest rates, while LSAPs produces a smoother transition. This can be attributed to the autoregressive nature of the haircut process, with a high level of persistence imposed.

Third, firm profit decreases in the case of a long-term bond shock, while the opposite is true in the alternative scenario. This could be a result of more loans extended by merchant banks under the LSAP scenario. Finally, the long-short interest rate spread in the case of LSAPs is negative, while the spread is positive in the alternative. In addition, a greater spread variability between market rates is generated by the shock to the collateral requirement on long-term bonds.

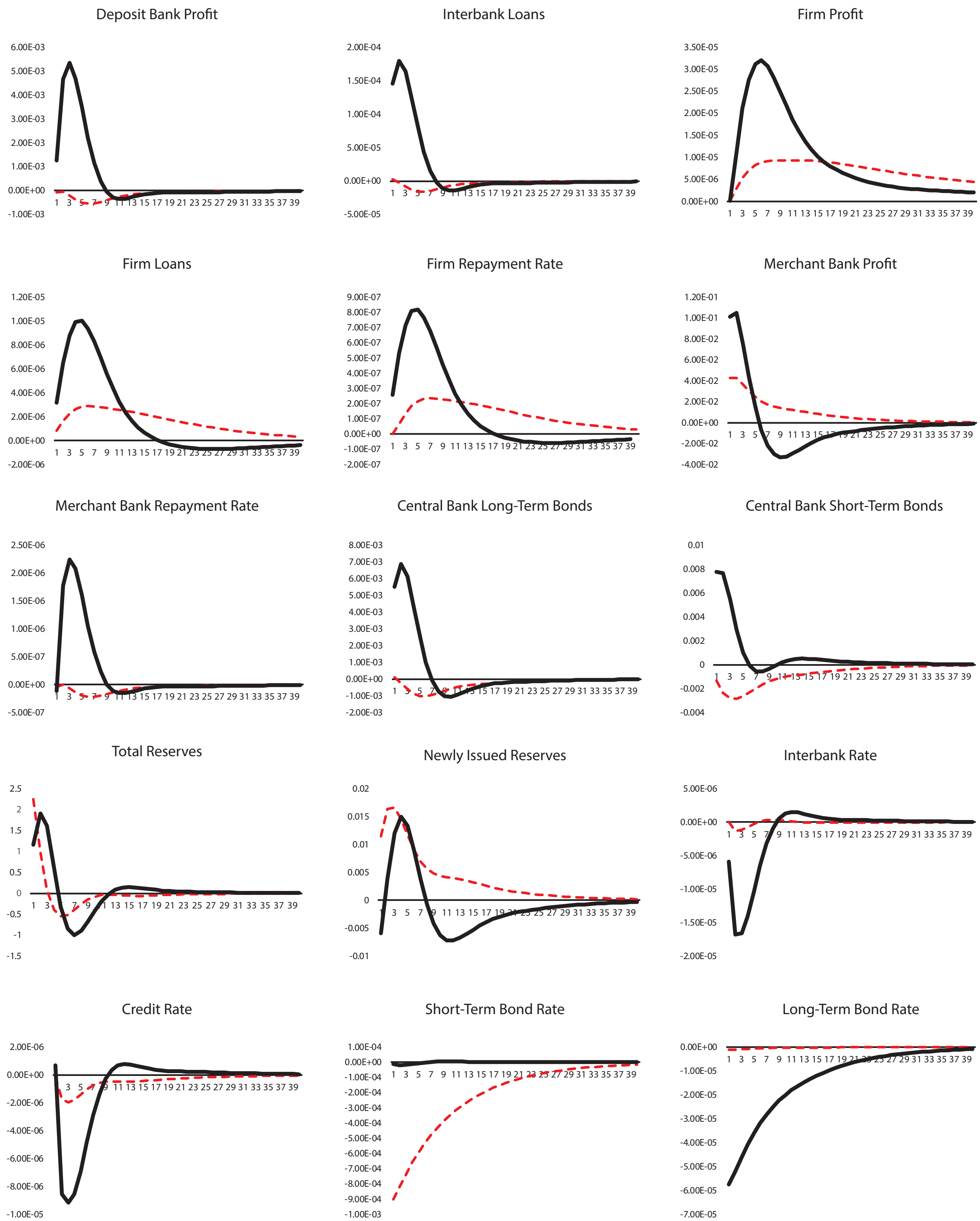
While there are some minor differences, the overall results are highly similar. Importantly, this indicates that the mechanism presented in this model can generate effects similar to those already established in the literature (i.e. the long-term bond growth innovation). It carries the benefit of allowing collateralised lending to occur naturally within the confines of the model, as opposed to a forced exogenous injection of liquidity. Merchant banks are left with more options with respect to balance sheet actions performed by the central bank.

7.5.2.2 Reserve vs Quasi-debt Management Policies

Using the complete framework affords the ability to draw a comparison between the reserve-supply ('pure' QE) model from Chapter 6 and the quasi-debt management model in this chapter. In order to conduct this comparison, the following initial values for, and shocks to κ^s and κ^l are used. First, $\kappa^s_t = 0.5$, as in Chapter 6, but κ^l is now fixed to equal 0.01. The value of κ^l is allowed to be close - but not equal - to zero, as this leads to indeterminacy in the model. In this setup there are virtually no long-term bonds held on the balance sheet of the central bank, which is similar to the model of Chapter 6. In this first scenario, a shock is imposed on κ^s_t, equal to that of Chapter 6, which generates $\kappa^s + \kappa^l \approx 1$. In essence this is a balance sheet expansion with short-term bonds offered exclusively as eligible collateral. Christensen and Krogstrup (2016) argue that this type of 'pure' QE delivers a reserve-induced portfolio balance effect.

In the comparative scenario, an initial value of $\kappa^s = 0.5$ was fixed. However, in this instance a shock was imposed on κ^l_t, which has an initial value of $\kappa^l = 0.01$. The shock imposed raises the value of κ^l close to 0.5, which means that the combined post shock value is $\kappa^s + \kappa^l \approx 1$. With this shock the central bank is implementing a change in the composition of its balance sheet, which initially contained only short-term bonds, to now incorporate long-term bonds. From this comparison one could potentially distinguish the reserve and supply-induced portfolio

Figure 7.5: Reserve vs Quasi-debt management policies



Note: Y-axis values represent percentage (point) deviation from steady state. The black solid line is from a 100% shock to long-term collateral requirement, while the red dotted line is 100% shock to short-term collateral requirement.

balance effects from each another, as defined in Christensen and Krogstrup (2016)[11]. Only the important differences observed from these shocks are discussed and depicted in Figure 7.5.

To reiterate, the different scenarios allow the identification of two types of balance sheet policies: one results in only short-term assets held on the balance sheet of the central bank, while the other comprises a mix of short- and long-term securities. From Figure 7.5, one can see that the most observable differences across these scenarios are primarily related to the relative movement of interest rates in the economy. With the introduction of long-term securities on the balance sheet of the central bank, the long-term rate reacts more sharply, exhibiting stronger downward movement. As discussed in Chapter 4, this idea is supported in the literature, as it was one of the primary goals of implementing LSAPs. In other words, the yield curve is sufficiently flattened by the introduction of long-term bonds. This reduction in the long-term rate gets transmitted to other market rates, with the interbank, credit and deposit rates all significantly lower in the second scenario, with long-term bonds.

Another important result is that greater interbank and firm lending is generated in the long-term asset purchase scenario. This translates into better merchant bank and firm repayment rates, which means greater financial stability. Deposit bank and firm profit is also increased, while merchant bank profit is similar across these scenarios. Finally, while the level of reserves in the economy increases, the balance sheet of the central bank in the quasi-debt management scenario contains a greater selection of short and long-term bonds.

From these results it can be concluded that LSAPs might have the added benefit of being able to relax market conditions through their impact on interest rates. This is corroborated by the work of Cahn et al. (2014), who find "that lengthening the maturity of LTROs helps relax the bankers incentive constraint above and beyond the direct effect of short-term liquidity injections". Liquidity provided with the acquisition of short-term bonds is still invaluable, however, and its impact should not be overlooked. The question as to the relative contribution of increasing reserves versus purchasing illiquid assets is an interesting one, which could be a topic for future research, as pointed out by Kandrac and Schlusche (2015) and Christensen and Krogstrup (2016).

7.5.3 Contractionary Interest Rate Policy

In this section I follow on from the discussion in the previous chapter, looking now at changing the composition of the balance sheet[12]. Changes in the composition of central bank assets is

[11]These channels are discussed in Chapter 2, under the discussion of the portfolio balance channel. I do not attempt to assign a weight to any of the channels in this thesis.

[12]Looking at a contractionary monetary policy shock gives us grounds for comparison with the previous chapter.

represented in two scenarios, with the selection of different values for the haircut parameters under the control of the central bank. First, the baseline scenario is presented, with a 10% haircut on long-term bonds and an accompanying 90% haircut on short-term bonds. This setup is closest to the model from the previous section where $\kappa^s = 1$ and $\kappa^l = 0$, which is why I look to it as a point of departure. Another way to frame this scenario is to think in terms of the preference of the central bank. In this scenario the central bank welcomes the fact that the merchant bank considers short-term securities a convenient way to access reserves, providing the central bank with more short-term bonds in return for its unique form of liability.

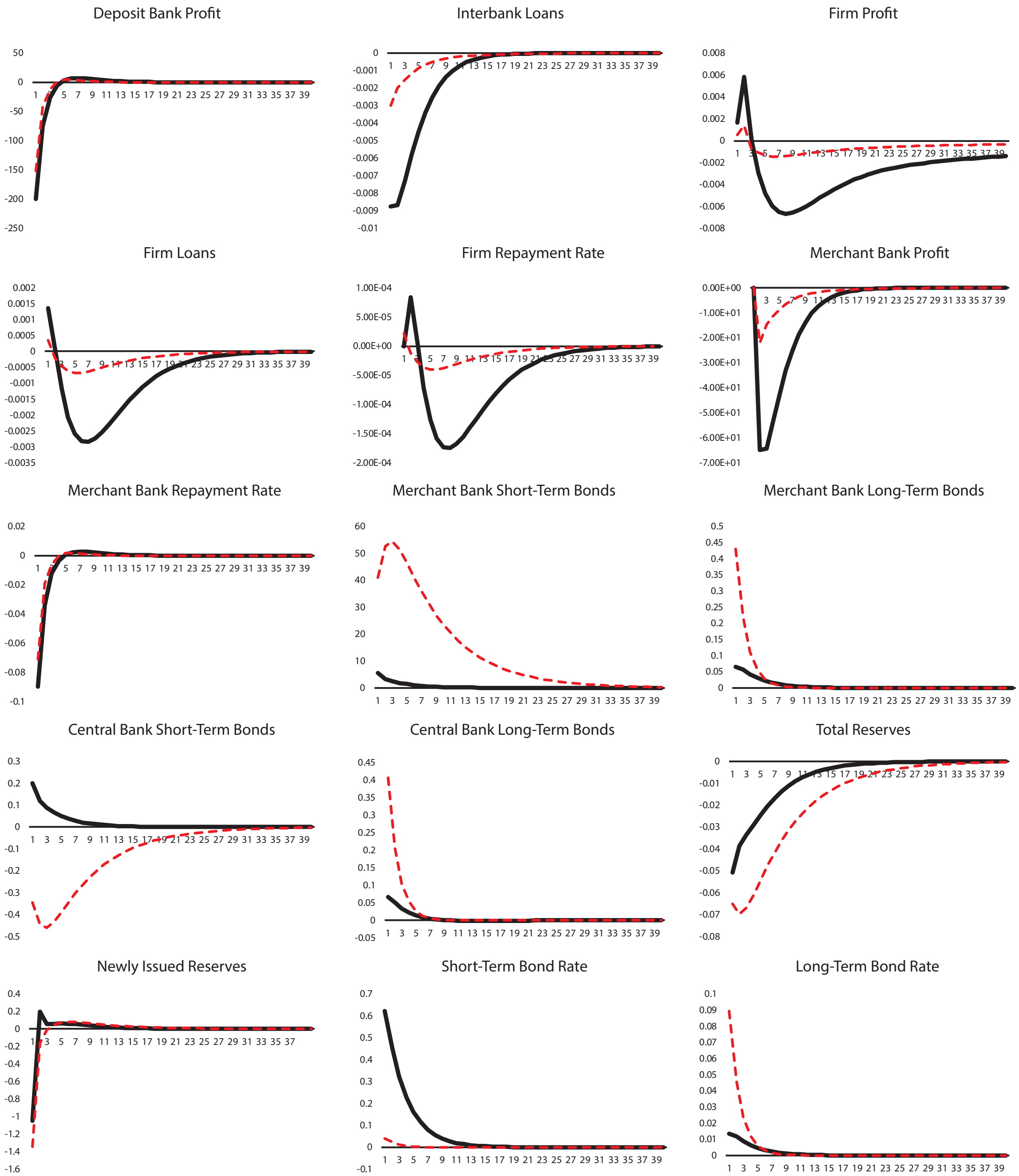
Second, I developed a scenario which entails a 10% haircut on short-term bonds in relation to a sterilising 90% haircut on long-term bonds. This action changes the overall risk profile of the merchant and central banks (and, by extension, the government). In this scenario the merchant bank finds it easier to part with longer-term securities, which reduces the riskiness associated with the assets on the merchant bank's balance sheet. Conceptually, these assets are modelled to resemble long-term government debt, as well as MBS or agency debt, in that they are more risky than short-term bonds. One can think of this scenario as being similar to LSAPs, with the central bank indicating a preference for riskier longer-term securities (making them easier to convert to liquidity). This is regarded as an endogenous form of LSAPs, because one expects firms to sell more of their longer-term bonds under this scenario, with the central bank being able to steer the quantity of long-term bonds through its usage of the relevant parameters in the collateralised lending mechanism.

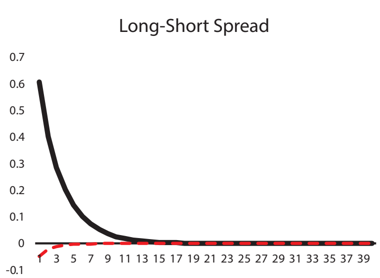
7.5.3.1 Baseline: $\kappa^s = 0.9$ and $\kappa^l = 0.1$

The first scenario places a greater emphasis on the central bank's issue of short-term bonds to commercial banks. I consider this to be the baseline case, as it most closely resembles the functioning of central bank intermediation as depicted in Chapter 6. Collateralised open market operations are usually conducted on the basis of a trade between short-term government bonds and central bank liabilities (reserves). In addition to normal open market operations, the merchant bank is allowed access to central bank liabilities by offering up a fraction of its illiquid long-term bonds. Under the current constraint imposed, it is more convenient to obtain reserves by offering short-term bonds as collateral. It is also necessary to state that long-term bonds are higher yielding (higher interest rate) than reserves and short-term bonds. The reason for this being that there is a term premium associated with holding this asset, making it inherently more risky.

I identify the firm, deposit bank and merchant bank activities as being of particular importance in this analysis. Therefore, they are each discussed in turn, providing a template for discussion

Figure 7.6: Contractionary interest rate policy





Note: Y-axis values represent percentage (point) deviation from steady state, resulting from a one percentage point shock to the policy rate. The black solid line represents the baseline scenario, while the red dotted line represents the scenario with long-term bond preferences.

that I will utilise for the different scenarios. Refer to the IRFs from Figure 7.6 for the ensuing exposition.

First, the credit rate decreases initially in response to the increase in the policy rate. This result is counter-intuitive, as we would expect a positive pass-through. However, it is short-lived and represents the only sign reversal among the different market rates[13]. After the first period decline, the credit rate becomes positive, which is more in line with expectations. As a result of the behaviour of the credit rate, firm profits initially increase, but then fall below the pre-shock value in response to the monetary policy shock. The eventual decline in profitability is similar to the result from the setup without long-term bonds, where $\kappa^l = 0$ and $\kappa^s = 1$. Loans extended to the firm increase in the first quarter after the shock, but then decrease by a substantial amount, which is in line with the behaviour of the credit rate. The repayment rate on loans exhibits an initial increase, but then we have a steep decrease in repayment as the firms respond to the rise in the credit rate.

Second, the policy shock has a significant negative impact on interbank loans. In addition to the policy rate impact, the decrease in interbank loans can be explained by the increase in demand for short- and long-term bonds on the part of the merchant bank, indicating a substitution away from interbank loans to relatively abundant and easily convertible government securities. The pass-through of the policy rate is greater to the short- than the long-term rate. This is in line with expectations, considering the structure of the collateralised borrowing mechanism, with the haircut allowing a greater transfer of the shock to the short-term rate. Repayments on interbank loans declines following the shock, as a result of the increased cost of borrowing. Deposit bank profit suffers at the hand of the policy shock and takes several quarters to return to normal. Furthermore, merchant bank profit decreases sharply following the shock, and remains low for a few quarters.

Finally, central bank liabilities decrease initially given the increase in the policy rate. Merchant banks buy relatively cheap short- and long-term debt, which increases the quantity of both assets on their portfolio, while decreasing the amount reserves held. This highlights the action of commercial banks given an increased availability of investment vehicles. Ultimately, the central bank holds a greater absolute amount of short- and long-term bonds on its balance sheet in this scenario.

Interest rates on assets eligible for collateral carry the greatest weight of the pass-through from the shock. The short-term bond rate does not fully absorb the movement in the policy rate[14],

[13] The fact that the deviation is so brief leads me to believe that it is an artefact in the model, rather than an explicit feature.

[14] In this scenario the magnitude of the increase in the short-term bond rate is just above 60% of the movement in the policy rate.

but is more reactive than the long-term bond rate. There is a liquidity premium placed on short-term bonds in this case. Both of these rates are above the deposit, credit and interbank loan rates, which reflects the spread on bonds offered as collateral versus those that are not.

7.5.3.2 LSAPs: $\kappa^s = 0.1$ and $\kappa^l = 0.9$

This scenario is similar to the preferred habitat approach, in that investors 'prefer' to invest in longer-term assets. In this scenario merchant banks face a limited supply of money in return for their short-term bonds, relative to long-term bonds. This means that short-term bonds are limited in their capacity to be converted to central bank liabilities. Converting long-term bonds to money (an illiquid to liquid asset) is facilitated by a lower haircut on long-term bonds. This is quite similar to the LSAP programs implemented by the US in the first few rounds of so-called quantitative easing. I compare the results to those of the first (baseline) scenario.

First, firms behave similarly in the different scenarios posed, with the most obvious difference being in the repayment rate of the firm. Under increased long-term bond purchases, the repayment rate decreases more gradually and remains persistently below the pre-shock value. In addition, the credit rate also moves less severely in this instance, with the initial drop being more moderate. Second, interbank loans once again decrease, but by a smaller magnitude. This means that merchant banks are increasing their exposure to the interbank market in this scenario. One interpretation would be that these merchant banks are finding it more lucrative to access wholesale funding than to exchange their long-term bonds for reserves. It might also be that long-term bonds are yielding such a high return that it is not worth trading them in. In addition, the deposit bank makes slightly smaller losses in this scenario.

Third, the lower interbank rate translates into an associated decrease in merchant bank default. Although the impact from the change is small in terms of the merchant bank default, it is important. It indicates that inducing sales of long-term bonds to the central bank has resulted in a slight decrease in the default rate. This does not mean that merchant banks got rid of all their long-term securities, but a large portion ended up on the balance sheet of the central bank. In addition, the total level of short-term bonds held by the central bank decreases, with merchant banks looking to purchase short-term bonds, but being constrained by the haircut imposed.

Ultimately, in this setup the central bank balance sheet contains more long-term securities and fewer short-term bonds. The overall level of liabilities decreases as merchant banks appear to favour securities over reserves. The increased long-run interest rate sensitivity dictates that the increase in the policy rate will have a greater effect on the long-term rate than in the previous scenario.

7.6 Chapter Conclusion

In this chapter I have included long-term bonds available for collateral in open market operations. The introduction of these bonds in a non-trivial way affords the central bank the opportunity to change the composition of the assets held on its balance sheet, with a significant impact on the financial markets and the real sector. In particular, the introduction of long-term government bonds draws a comparison to quasi-debt management operations, such as those conducted by the Fed by means of the Maturity Extension Program (MEP). It is clear from the scenarios presented here that adding long-term bond purchases further assists, beyond that of reserve-supply policy, in providing liquidity and securing financial stability. The primary mechanism through which the introduction of long-term bonds is realised is in lowering the long-term rate, which results in easier borrowing conditions for the broader economy.

In comparison with the previous chapter, which entailed only the purchase of short-term assets, the economic conditions were relaxed even further under long-term bond purchases, with the effect most clearly represented in a reduction of the price of the asset targeted. With large-scale asset purchases being potentially more beneficial to financial stability than ‘pure’ QE, they might be used in a complementary fashion with interest rate and macroprudential policy to combat the build-up of financial imbalances in specific sectors, such as the mortgage market. This does, however, increase the financial market footprint of the central bank, which should be considered before conducting such a policy. Financial market exposure notwithstanding, targeted purchases could present a sharper instrument than the short-term policy rate.

Chapter 8

Conclusion

> *Lord Cobbold, former Governor of the Bank of England, is reputed once to have said "A Central Bank is a bank, not a study group". What I take this to mean is that the essence of Central Banking lies in its power to create liquidity, by manipulating its own balance sheet. The question is often asked whether a Central Bank that sets interest rates should also manage financial stability. This question is put the wrong way around. The question should be whether a Central Bank that manages both liquidity and financial stability should also be given the task of setting interest rates.*
>
> — Charles Goodhart (2011)

Central banks were designed with the unique ability to generate liquidity, in the form of bank reserves, providing them with a monopoly over the issuance of their liabilities (Tucker, 2014). As originally envisaged, the principal role for the central bank is the provision of liquidity to key financial institutions in times of crisis, the so-called lender-of-last-resort function as first described by Thornton (1802) and Bagehot (1873). Framed in this way, achieving financial stability through control of the central bank balance sheet is at the heart of *monetary* policy.

The nominal short-run policy rate has only recently become the conventional tool for monetary policy, with William Poole's (1970) success in solving the instrument problem shifting the focus of monetary policy toward the management of the policy rate. In the process, the modern central bank started to more closely resemble a 'study group', with countless hours of research devoted to determine the optimal path of the policy rate. However, the international financial crisis has served as a reminder to central bankers that the primary function of any central bank is the management of its balance sheet.

Since 2007 there has been a significant transformation in the way monetary policy is implemented and perceived, with an increased awareness of central bank balance sheets. While the adoption of balance sheet policies have been staggering in terms of magnitude and rapidity, the change in operational frameworks have been more subtle. New monetary policy tools found under corridor, floor and hybrid regimes have been introduced without attracting significant public attention.

The goal of this thesis, and its importance to the literature, was threefold. First, to bring clarity to the notion of balance sheet policies and their implementation. Some important questions were, for example, what is meant by quantitative easing or large-scale asset purchases? What are liquidity facilities and how do they differ from other balance sheet policies? What are the channels of transmission of the different balance sheet policies? How were these policies implemented by different countries?

Providing clarity to the public and policymakers alike, as to what balance sheet policies are, will help define their role in the future. While balance sheet policies have been used in the past, the crisis exposed a potentially new role for these policy instruments. It is still uncertain to what extent, and in which conditions, they need to be applied.

Second, to determine the changing nature of monetary policy implementation, through an empirical investigation on the relationship between central bank liabilities and the short-term nominal policy rate. New monetary policy regimes have emerged that will completely alter the way in which the operational procedures of central banks will have to be presented. Integrating new tools, such as interest on excess reserves and reverse repurchase agreements, into public consciousness is vital if policy objectives are to be achieved. Misunderstanding of policy actions in newly adopted regimes might make policy changes ineffective, with markets not knowing how to respond appropriately to the signals of central banks.

Third, to incorporate balance sheet policies into a DSGE model, in order to determine the impact of changes in the size and composition of central bank balance sheets on financial stability. Several papers have considered the broader macroeconomic implications of central bank intermediation. However, it is important to know in what capacity the central bank can use its balance sheets to foster financial stability, whether it be in providing short-term funding or combating the buildup of financial imbalances.

The rest of this chapter is devoted to a discussion on the results from the relevant chapters, as well as their contribution to the literature. In addition, shortcomings of each chapter are presented individually. Afterward, I point to some of the practical implications of this thesis. Finally, I conduct a discussion on the possible future dimensions for research.

8.1 Chapter Discussion

8.1.1 Chapter 2, 3, 4

In order to promote a coherent structure, I will bundle the discussion of these chapters together in the form of one collective literature review. Brief summaries of each chapter that contributed to the literature review are provided. This is followed by a discussion on the contribution and shortcomings of the literature review as a whole.

Chapter 2 starts by providing a historical perspective on the idea of balance sheet policies, with the origin reaching back to the experience of Japan in the early part of 2001. Japan implemented their quantitative easing program, with an expansion of the balance sheet, in order to strengthen their zero interest rate policy commitment. While not immediately regarded as successful, future iterations of this policy strategy helped the Japanese economy escape their two-decade slump. Unfortunately, their progress was short-lived, as in 2007-08 the financial crisis caused a global recession.

Chapter 2 also provided a typology of balance sheet policies, distinguishing between operations along the dimensions of size and composition. In addition to this broad division, a more narrow classification, as presented in Borio and Disyatat (2010), yielded a sharper, more refined, understanding of the mechanisms used to affect market activity. Transmission of these policies was discussed by considering theoretical arguments as to how balance sheet policies will impact financial markets and the broader macroeconomy.

In Chapter 3, the discussion started with the financial crisis, its triggers, amplification mechanisms and potential impact on the global economy. While this introduction to the proximate causes of the crisis, and the implications for monetary policy, is useful as context to the policy response, it was not meant as a comprehensive review. The primary interest was in providing a chronicle of the different balance sheet policies used by central banks across the globe. Different strategies were implemented by central banks, reflecting shortcomings and exposures to risk in their economies.

While the Fed, for example, immediately implemented an expansion of their balance sheet after the collapse of Lehman Brothers in 2008, the ECB only recently, in January 2015, underwent its first round of unsterilised asset purchases. This does not mean that the ECB did not attempt liquidity injections, in fact they implemented a LTRO programme that injected more than $1.3 trillion into the Euro area (Carpinelli and Crosignani, 2015). This chapter helped to frame the response of the identified central banks in terms of developments in their respective economies.

Chapter 4 evaluated whether policies implemented by central banks were successful in achieving their stated goals by conducting a survey on the empirical evidence. In this chapter, as suggested by the evidence, programmes initiated by central banks were largely effective. As can be seen from the counterfactuals without intervention, there was a clear possibility of systemic failure, both in the US and abroad. In other words, without the stimulating impact of balance sheet policies, it is plausible that another Great Depression would have resulted.

With central bank balance sheets inflated by attempts to improve the health of financial markets and bolster real activity, questions arose as to the possible consequences of using balance sheet policies. Some of the most frequently highlighted topics are that of international spillover effects, plausible exit strategies and issues of central bank independence.

8.1.1.1 Contribution

Although the literature review contained no original empirical work, I still consider it an important contribution. Due to the relative novelty of the way central bank balance sheets have been used in the crisis, there is considerable confusion as to the definitions and transmission mechanisms of balance sheet policies. The goal of this chapter was to provide clarity, or remove the 'mystique' as stated by Reis (2013), with respect to the central bank balance sheet, as concepts are often confused in both academic research and the media. Policymakers might also want to take note of the instruments available to them, as clearly delineated in this part of the thesis. It also set the scene for the empirical work and modelling done in the rest of thesis, by making the gap in the literature more apparent and thereby illustrating the importance of the research question of the thesis.

A particularly important discussion is found in Chapter 4, where the idea of exit strategies are mentioned. The Federal Reserve, for example, has initiated their 'liftoff', with an increase in the short-term policy rate in December 2015. However, even before this, they were testing the tools to accompany this rate hike, implementing short-term reverse repurchase agreements to firm the interest rate floor, from as early as 2013. However, this strategy is still relatively new and untested. It will, by all accounts, be a cause for debate in the years to come. In this thesis I provided a foundation for such a discussion, by going into detail on the mechanism proposed.

8.1.1.2 Shortcomings

As stated before, while this chapter provided a theoretical foundation to the thesis, it contains no relevant empirical work. In this sense, a contribution that could have been made is to include revised estimates of the impact of balance sheet policies found in some of the more influential studies.

One of the biggest shortcomings of the literature review is that financial (in)stability was not explicitly defined. This was purposefully done. In fact, earlier iterations of the thesis started with a lengthy discussion on the issues pertaining to financial stability, with the initial idea to develop a financial stability index. However, it soon became apparent that this would be a particularly nettlesome endeavour, as there is little consensus in the literature on the definition of financial stability and the metrics used to measure it.

While the concept of financial cycles and stability have been a topic of discussion for several decades, there is still no agreed upon way to think about it. The work of Borio and Drehmann (2009), in this regard, is a useful point of departure on how to identify financial cycles. In addition, they provide a detailed discussion on the different approaches used to model financial stability.

After a period of deliberation it was decided that the best approach would be to settle on a specific way to model financial stability. Ultimately, it felt that a protracted discussion on theories and measurement of financial stability detracted from the central focus of the thesis, which is about the possible uses for balance sheet policies. Financial stability was not entirely neglected however, as the literature review in Chapter 6 discusses, at length, the inclusion of financial market imperfections into DSGE models.

Another topic that was omitted from the discussion is that of macroprudential regulation. After the financial crisis, a large literature started to develop on this topic, with an excellent early survey provided by Galati and Moessner (2013). Macroprudential policy is relevant because it represents a vital tool in preventing the buildup of financial imbalances, avoiding concerns of systemic risk. In fact, if used correctly it could be a perfect complement to balance sheet policies, as indicated by Woodford (2016). However, it was not directly relevant to the discussion of balance sheet policies and therefore only mentioned on occasion.

8.1.2 Chapter 5

Recent developments in the way that central banks conduct monetary policy motivated the empirical work in this chapter. The first part of this chapter attempted to highlight the different monetary policy regimes and operational frameworks currently implemented. Regimes have shifted from the traditional reserve regime, where the policy rate is largely determined through the interaction of money supply and demand (as in the textbook IS-LM model), to more modern interpretations, where liquidity management is less evident and policy rate announcement dominates as primary lever, such as the corridor, floor or hybrid regimes.

In order to quantify the evolution of the changes in monetary policy implementation several empirical methods were used. In particular, I was interested to uncover the relationship between reserves and the policy rate, where the theorised negative relationship is known as the liquidity effect. First, a rolling regression was conducted to determine if the relationship between reserves and the policy rate was stable over time. Second, a SVAR was constructed, to provide theoretical backing to my estimation. The SVAR was then divided into subsamples, which were identified according to potential shifts in monetary policy regimes in different countries. Finally, a TVP-VAR was estimated for each country. This approach combined the best elements from the SVAR and rolling regression strategies. The goal being to trace the relationship of the policy rate and reserves over time.

The results largely followed theoretical predictions on the operation of monetary policy, with the reserve regime indicating the only significant liquidity effect. In the case of the US, for example, the fading liquidity effect over time was clearly observed, something that was captured in the literature on the topic. The implication is that under certain regimes it might be possible to expand the balance sheet of the central bank, without impacting a shift in the policy rate. Independent movement of the policy rate from the balance sheet of the central bank is known as the decoupling, or separation, principle.

8.1.2.1 Contribution

The discussion on the operational frameworks contributes to an understanding of different monetary policy regimes. Indicating that the traditional mechanism needs to be adapted to better reflect the way that several advanced economies implement monetary policy. Since the late 1990s monetary policy has, in several advanced economies, shifted to an announcement of the policy rate, and integration of several standing facilities, which should change the way in which monetary policy is taught.

Due to the relative novelty of the empirical model used, this was, to my knowledge, the first occasion that the liquidity effect problem has been approached with a TVP-VAR. It appears to be an appropriate method to answer the question at hand, resolving some of the concerns from other modelling approaches. This study updates earlier work on the liquidity effect in some countries, while, in the case of South Africa, it was the first of its kind.

8.1.2.2 Shortcomings

The biggest shortcoming of this chapter is the fact that the liquidity effect is modelled in terms of monthly data. Higher frequency data, such as daily or intradaily data, would better reflect the liquidity management operations of these central banks to keep the interest rate around the policy target. More sophisticated modelling of reserve management is also a part of these high frequency studies, which is neglected in this paper.

However, it is important to model lower frequency representations of the liquidity effect as well. Several modern DSGE models with developed central bank lending have an explicit role for the liquidity effect, with monetary models often incorporating a shock to money supply that affects a change in the policy rate, as discussed in Christiano et al. (1999). As many of these models are calibrated on monthly and quarterly data, it is necessary to provide a measure of the relationship between reserves issued and the movement of the interest rate. The one-to-one representation of the movement of reserves to interest rates, as in Goodhart et al. (2011), is not an accurate reflection of the relationship across all regimes. Monetary expansion is not always the dual of the interest rate.

8.1.3 Chapter 6

The first part of the chapter introduced the role of financial frictions in DSGE models. Starting with the seminal contributions of both Bernanke et al. (1999) and Kiyotaki and Moore (1997). Models that generate frictions in the demand side of the credit market were considered the workhorse of modern macroeconomics before the financial crisis. However, since 2007-08 a large literature has developed that looks at the supply of credit and how it can be disrupted. Some crucial elements in this vein are the development of a banking sector with an interbank market, spreads between relevant interest rates and incorporating some measure of financial (in)stability. In our case this meant the introduction of endogenous default as originally developed by Goodhart et al. (2006) and later extended by de Walque et al. (2010).

The model developed in this chapter combines several attractive features from other models in the literature. It builds on the RBC model of de Walque et al. (2010) in particular, extending it to a New-Keynesian DSGE setting. In addition, the model incorporated a role for collateralised central bank lending, as found in the work of Schabert (2015) and Hörmann and Schabert (2015). The mechanism from Schabert (2015) was then adapted so that the liquidity effect result from Chapter 5 could be included.

According to the result from the first scenario of the model, increases in the size of the balance sheet of the central bank allow greater lending and reduce the probability of default for both commercial (merchant) banks and firms. Balance sheet policies in this sense can be used to inject liquidity into the economy and improve functioning of financial markets. In addition, the second scenario shows that balance sheet policies can potentially be used in conjunction with interest rate policy. I looked at the case where the central bank increased the policy rate, which was then met with a small contraction of the balance sheet. This meant that even though lending conditions were tightened by the interest rate increase, liquidity withdrawn was not as drastic. This scenario could be seen as similar to the exit strategy recently implemented by the Fed.

8.1.3.1 Contribution

The biggest contribution of this chapter was the inclusion of collateralised central bank lending into a model with an active banking sector and endogenous default. Several models in the literature follow similar strategies, but few have a realistic dimension for the relationship between the commercial and central bank. In addition, only a limited amount of studies consider the role of balance sheet policy in promoting financial stability. Most of the literature is only concerned with the impact on real activity, while the role for balance sheet policies should extend beyond this.

In addition, the usage of the haircut parameter, κ, in this model, could be managed in such a way as to reflect the new operational frameworks currently implemented by central banks. In particular, one could construct a scenario that resembles the current exit strategy of the Federal Reserve. In this instance, the value for κ is set quite close to zero, to reflect a situation whereby there is an increase in the policy rate, with a limited impact on the size of the balance sheet. Setting the value for κ close to zero represents a simple way to model the decoupling principle.

8.1.3.2 Shortcomings

Naturally one of the big shortcomings of this purely calibrated approach is that I have neglected estimation. For an extension to the current work one could use Bayesian priors and estimation techniques to more closely tailor the model to a specific economy. In addition, another apparent shortcoming is not including demand side frictions, such as the financial accelerator from Bernanke et al. (1999). Several demand side frictions were initially included in the model, but caused interpretation of results to be unclear.

Additionally, incorporating a mechanism for the decoupling of the interest rate from reserves is a relatively new idea, fraught with dangers not yet uncovered. Policy tools could be working against each other in this scenario to potentially weaken the effect of traditional interest rate policy. However, in as far as monetary policy operates along a signalling channel, the central bank might be able to center inflation expectations on a certain target while performing balance sheet operations.

If balance sheet operations are not seen to deter from achieving the inflation target, it could be a potential tool for the provision of liquidity or, if need be, to prevent the buildup of financial imbalances. It would perhaps also be useful to do a historical decomposition to determine the contribution of balance sheet policies relative to interest rate policy in the economy, in terms of financial market impact.

Another perceived shortcoming is that I did not consider the case at the zero lower bound. This is intentional. In this model I wanted to consider scenarios outside of a crisis situation. I believe it to be clear that these policies could be used in times of financial distress. However, this model provided a look into the behaviour of the central bank and financial intermediaries in normal times, with new operational frameworks in place.

8.1.4 Chapter 7

Having considered the role that an increase in the size of the central bank balance sheet can play, the natural extension was to include the change in the composition. In this model I followed the approach of Woodford (1998, 2001) to introduce long-term bonds into the model of Chapter 6. Having long-term bonds affords the opportunity to look at large-scale asset purchases, such as those performed by the Fed. These quasi-debt management operations were primarily meant to decrease long-term rates and improve borrowing conditions across the economy. LSAPs were modelled in the first scenario, entailing both an expansion and maturity transformation of the central bank balance sheet. While these policies were normally implemented when the policy rate had reached the zero lower bound, it was a sufficient but not necessary condition for their usage. This LSAP scenario was then compared to the an increase in long-term bond growth, as well as the results from Chapter 6.

In the second scenario, changes were implemented to the composition of the assets on the balance sheet of the central bank, together with an increase in the policy rate. This shows what impact changes in the composition of the balance sheet can have when monetary policy functions as normal.

The findings of the chapter was in line with intuition on the topic. First, the quasi-debt management operations delivered a decrease in the long-term rates, and brought about greater borrowing in the economy. Merchant banks gained the most from these operations, with increased profitability and loans extended to firms. Results were similar to that of the increase in long-term bond growth. However, in comparison to the result of Chapter 6, the effects were more pronounced. Second, it was found that large-scale asset purchases could potentially be used alongside interest rate policy. This gives central banks the ability to target specific asset prices and lean against the wind of financial imbalances. In this sense, long-term bond purchases can be used in conjunction with both macroprudential and interest rate policy to affect financial stability.

8.1.4.1 Contribution

There is a dearth of literature on the financial stability implications of changes in composition of the central banks balance sheet. Most papers fall in two categories. First, they consider the impact of reserve-supply policy on financial stability and the broader economy, normally modelled as pure liquidity injections. Second, models that consider the implications of LSAPs on real activity. The contribution then, was adding a non-trivial role for changes in the composition of the central bank balance sheet, to measure the impact on financial institutions. In addition, the way that the model is structured allows for a comparison between short-term liquidity injections and maturity transformations.

8.1.4.2 Shortcomings

A shortcoming of this model is that it is limited to the broad dimensions of balance sheet policies, namely changes in the size and composition of the central bank balance sheet. Therefore, the result was quite general, not specifically tailored to a particular event or market. For example, the model only has space for the purchases of short- and long-term bonds, while a more complete model would include purchases of risky illiquid assets such as agency debt and mortgage-backed securities.

8.2 Practical Implications

Although the practical implications of the research in this thesis is generally limited to the second section, which covers my empirical work, there is also some practical use to be gained from the literature review. I believe the review to be a comprehensive account of balance sheet policies, making it useful for researchers or policymakers to use as a reference or starting point if they wish to compare a range of policy options. The experience of other central banks might dictate which policies and monetary policy regimes they could adopt. In addition, it could be used by media representatives to frame a more detailed discussion on issues pertaining to balance sheet policies.

The work of Chapter 5 will be important to both researchers and future teachers of monetary policy. As argued by Ihrig and Meade (2015), changes in monetary policy implementation will need to be included in future iterations of textbooks at both undergraduate and postgraduate level. If changes are not made to curricula, confusion with respect to monetary policy implementation will be the order of the day, as students struggle to match real world application to theoretical constructs. The current textbook model of monetary policy implementation is undoubtedly incorrect and will take some time to adjust.

The results from Chapter 6 and 7 can be viewed collectively, and can guide the behaviour of policymakers when it comes to implementing balance sheet policies in normal times, under newly formed monetary policy regimes. The benefits to financial markets are stressed in these chapters, which gives another perspective, and is not limited to the discussion of the effect on the real sector. Even though many countries will not implement these balance sheet policies, it might start a discussion on their usage within the current policy space.

8.3 Future Research

In this section I briefly discuss some avenues for future research. There is a specific focus on the later chapters of the thesis, as this is where empirical contributions were made. Improvements are suggested both in terms of alternative methodological and theoretical approaches.

8.3.1 Chapter 5

The literature on the liquidity effect is already quite saturated, with little left to contribute in terms of theoretical developments. However, in terms of methodology there are several newly developed econometric techniques that could contribute to the further development of a liquidity effect narrative. First, Factor-Augmented VAR (FAVAR) models have been gaining popularity in recent years. These models combine elements of factor analysis, Bayesian estimation and SVAR modelling, which affords the opportunity to incorporate information from large datasets. One of the earliest models in this tradition is that of Bernanke et al. (2005), which attempts to address the price puzzle in the monetary transmission mechanism. Second, the Markov-Switching SVAR can be used to incorporate nonlinearities, such as structural breaks, into the model. This could, for example, help to explain some of the irregularities experienced in the analysis on the Norwegian case study (Krolzig, 2000).

8.3.2 Chapter 6, 7

The usage of DSGE models has become pervasive in the last decade. Due to the rapidly growing contributions of models in the field, there is enormous room for growth, both in terms of the theoretical and, especially, methodological contributions of this thesis. I will not, however, cover the breadth of the potential methodological features that could be implemented in this model. In its calibrated form, the model is in the initial phase of development and can be expanded upon with several sophisticated techniques.

In terms of theory, several avenues for future research can emanate from these chapters. Most importantly, I believe, is adding a mechanism that represents macroprudential policy. A large literature has developed on the role of macroprudential regulation in its capacity to prevent systemic instability. In particular, the paper by Smets (2014) has stirred a discussion on the role of monetary versus macroprudential policy in leaning against the wind of the buildup of financial imbalances. In this vein, a natural extension of the thesis would be to compare and contrast the contributions of macroprudential and balance sheet policies in achieving financial stability. Some work in this regard has already been attempted, with the contribution of Woodford (2016), for example, offering some insight. He considered the role of quantitative easing, macroprudential policy and conventional interest rate policy as complementary policy dimensions in promoting financial stability.

The topic of the risk-taking channel of monetary policy also ties into this discussion. The idea that monetary policy can contribute to a search-for-yield was discussed before the financial crisis by Rajan (2005). In the wake of the crisis, the work of Borio and Zhu (2012) and Smets (2014) emphasise that the risk-taking channel of monetary policy should be implemented into the new monetary framework. It is, however, not only the monetary policy stance that can lead to a search for yield. Excessive lending on the part of the central bank can also generate risk-taking behaviour, as illustrated in the models of Collard et al. (2015) and Kandrac and Schlusche (2015). My model could benefit from the inclusion of excessive risk-taking on the part of financial market participants. Incorporating this behaviour could dampen, or eliminate, the positive impact on financial stability that the model currently enjoys.

This thesis is one of the first to discuss implementation of a decoupling principle in a DSGE framework. In terms of DSGE models, the only paper, to my knowledge, that incorporates this idea is that of Cahn et al. (2014). They consider the effect, of what they call, the separation principle, specifically looking at the ECB and LTROs. In their model this allows for the ECB to conduct balance sheet policies without affecting the policy rate. It is clear to me that more papers of this nature will come to light once the discussion on issues such as interest on reserves become part of the mainstream research agenda. There are already papers that look to model the mechanisms underlying interest on reserves, such as Kashyap and Stein (2012) and Ireland (2012).

Tying in with the idea of interest on reserves, is the concept of exit strategies. Seeing as the Fed recently implemented an increase in the federal funds rate, it might be useful to fully develop the implications for central bank balance sheets. Some notable contributions in the literature are Hilberg and Hollmayr (2011), Del Negro et al. (2013), Angeloni et al. (2014) and Palley (2015). Another avenue to consider is the international spillover effects from implementing these balance sheet policies. In this sense, one could develop a small open economy model to observe the financial stability impact from international spillovers, such as Alpanda and Kabaca (2015) and Chen et al. (2015).

8.4 Concluding Remarks

The central question of this thesis is uncomplicated. What is the role of balance sheet policies in achieving financial stability? The actions of central banks across the globe speak to the ability of central bank balance sheets to affect dysfunctional financial markets. The consensus is that, in times of distress, central banks should use their balance sheets to avoid economic collapse. However, it remains to be seen whether the usage of balance sheet policies will become the new status quo. I have attempted to show that, even in normal times, balance sheet policies could provide another plausible policy dimension in achieving financial stability, performing the role they were designed to play since their inception. In this sense, the central bank can reclaim its position as a bank, and not a study group.

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Appendix A

Chapter 5

A.1 Rolling Regression Figures

Presented on the next page, are some of the extra rolling regression results from Chapter 5. These results are from the usage of alternative liquidity measures.

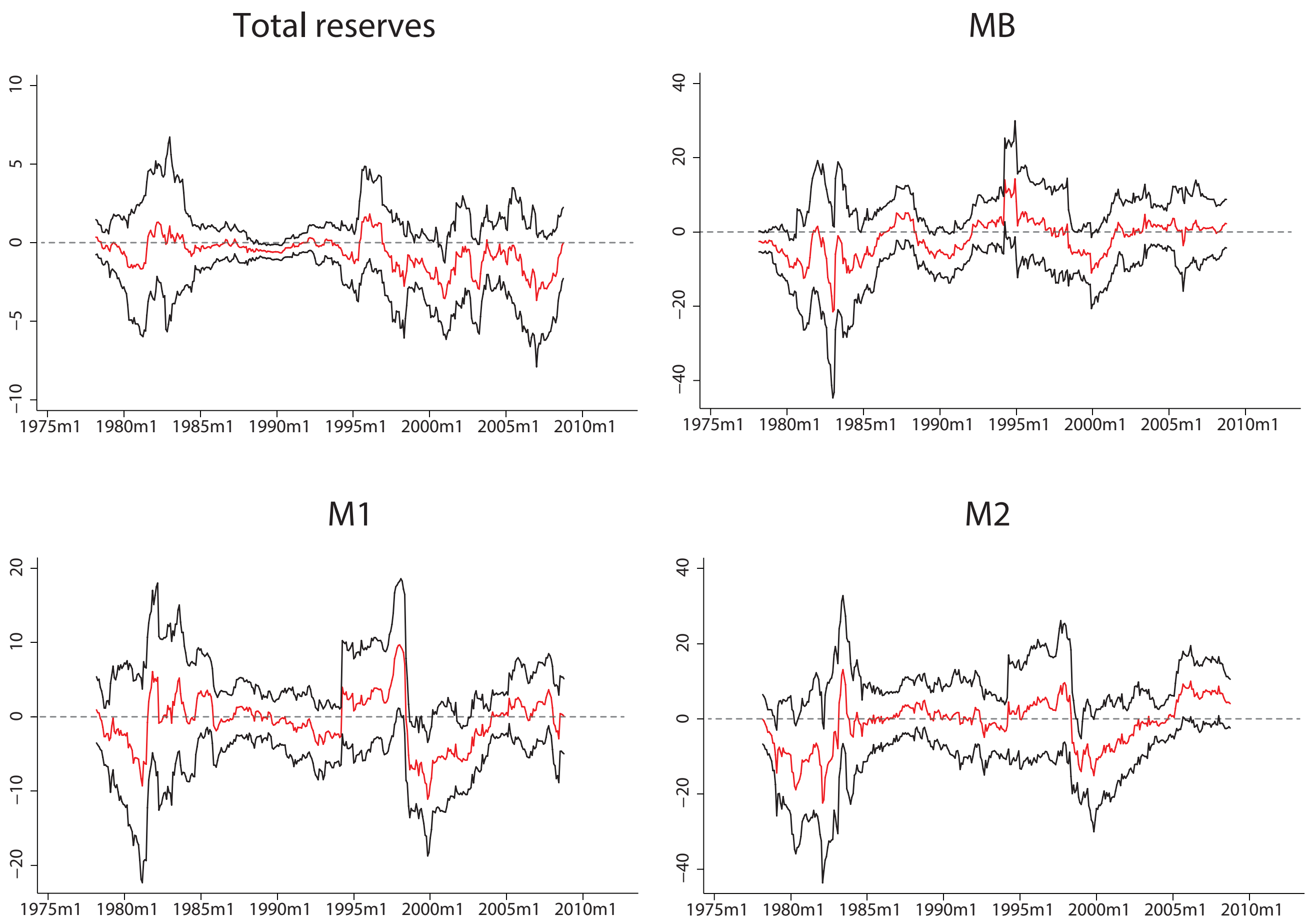

Figure A.1: Rolling regression results for SA with alternative liquidity measures

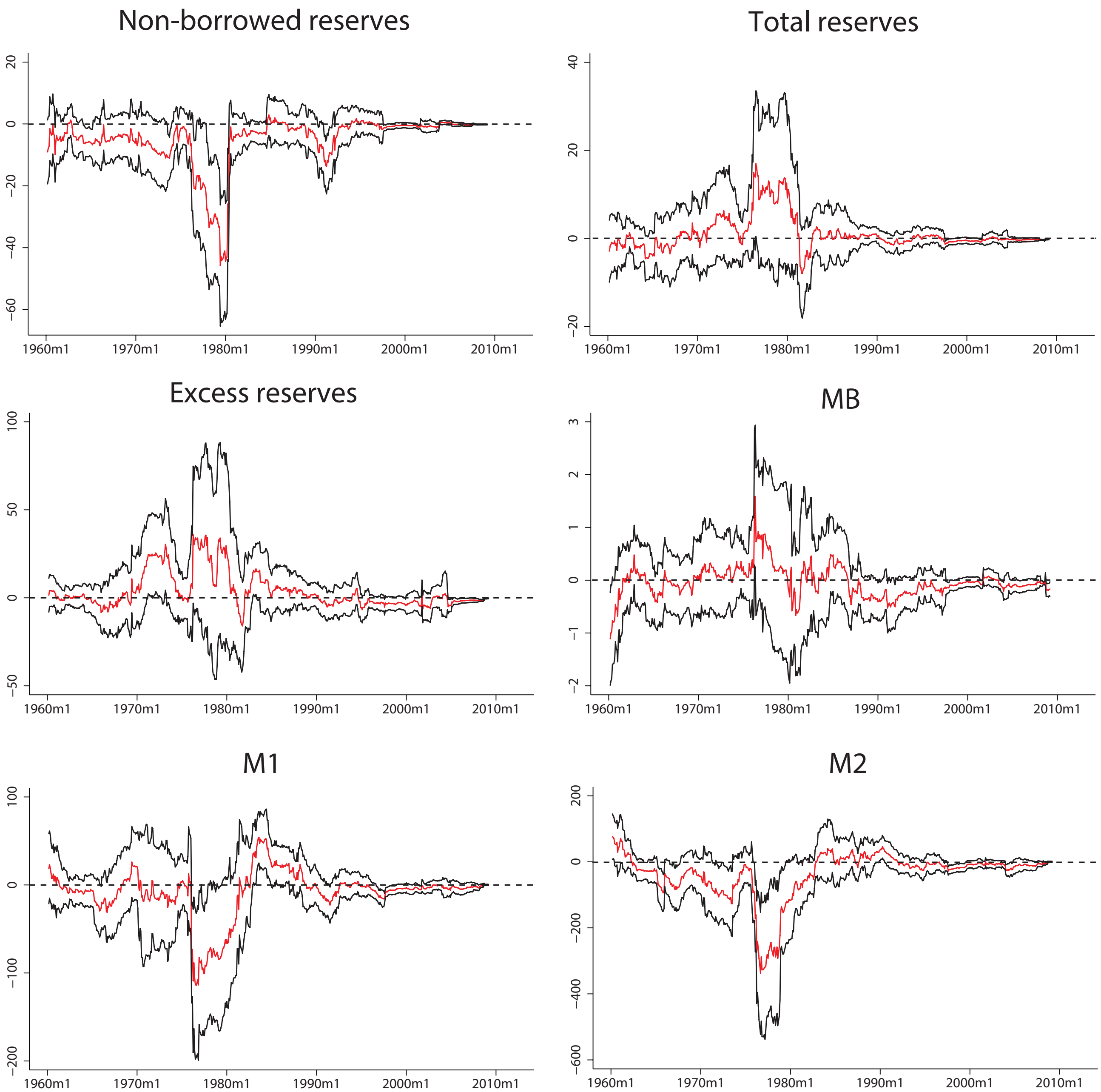

Figure A.2: Rolling regression results for the USA with alternative liquidity measures

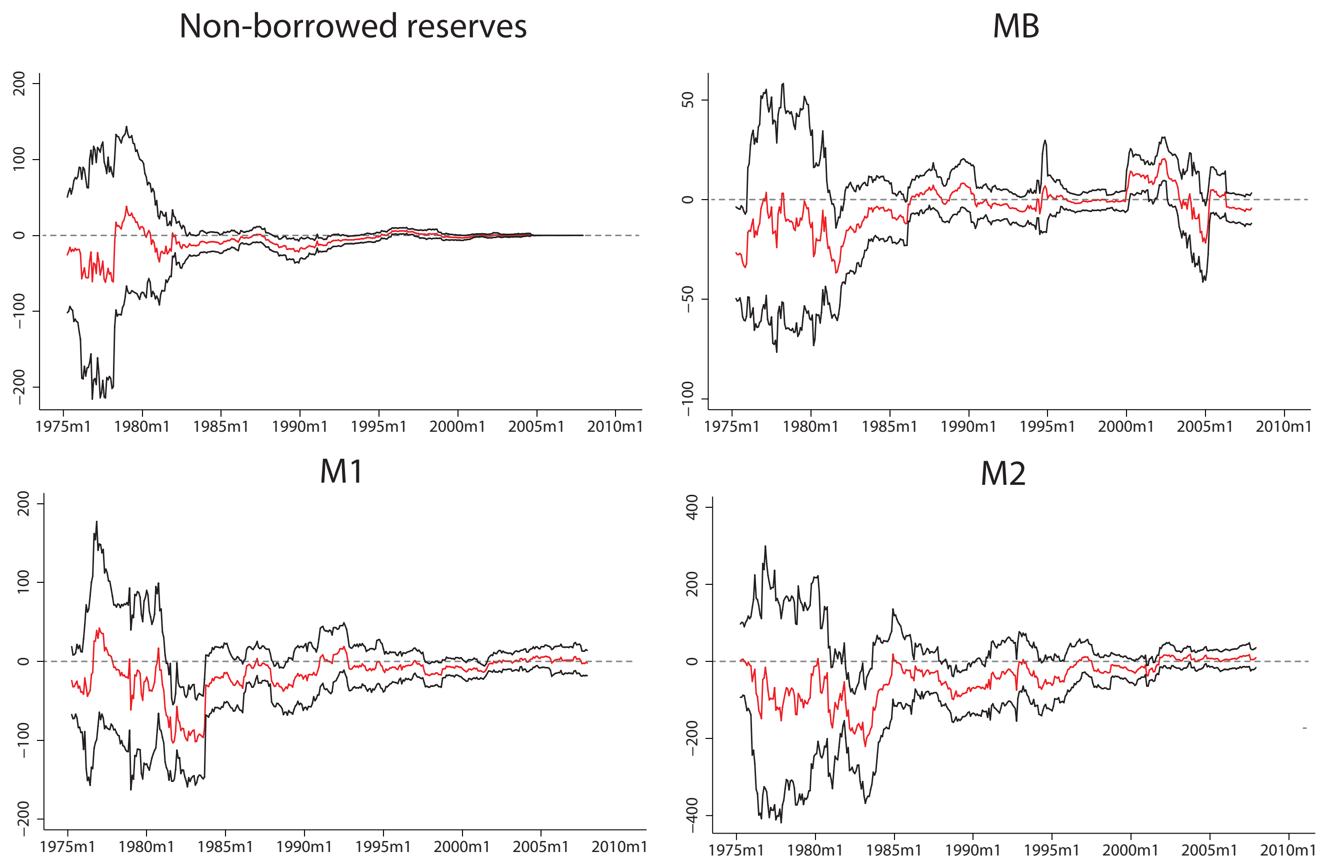

Figure A.3: Rolling regression results for Canada with alternative liquidity measures

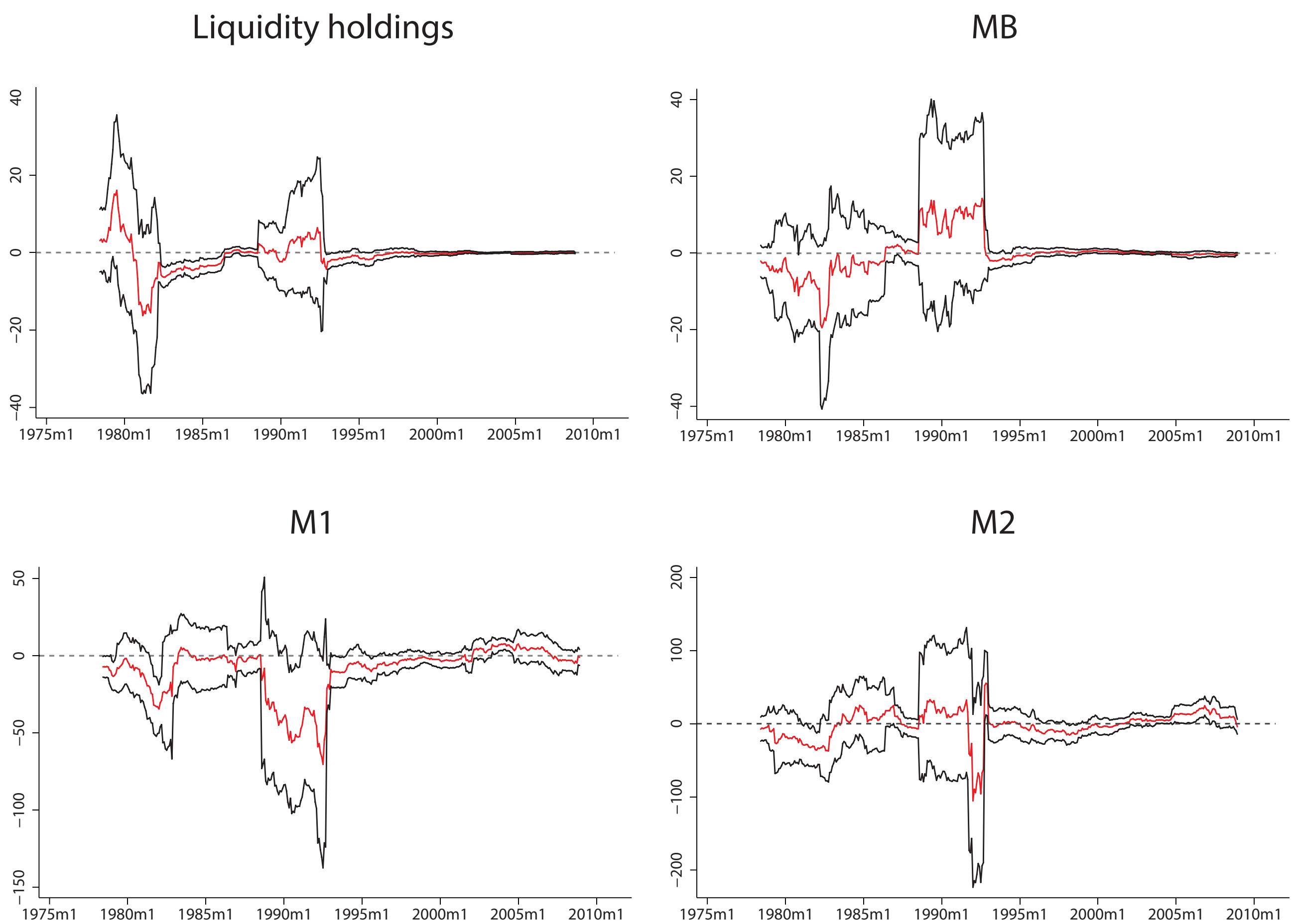

Figure A.4: Rolling regression results for Norway with alternative liquidity measures

Appendix B

Chapter 6

B.1 Log-Linearised Model

B.1.1 Example

In order to illustrate the approach followed to linearise the model in this thesis, an example is provided with respect to marginal utility of consumption. This is the FOC for the household w.r.t consumption,

$$(C_t - hC_{t-1})^{-\sigma_c} - h\beta \mathbb{E}_t (C_{t+1} - hC_t)^{-\sigma_c} = \lambda_t^h$$

The first step is to define $\Omega_t = (C_t - hC_{t-1})$, which gives us,

$$(\Omega_t)^{-\sigma_c} - h\beta \mathbb{E}_t (\Omega_{t+1})^{-\sigma_c} = \lambda_t^h$$

Using Uhlig's method, log-linearisation gives,

$$\begin{aligned}(\Omega_{ss})^{-\sigma_c}(1+\hat{\Omega}_t)^{-\sigma_c} - (\Omega_{ss})^{-\sigma_c} h\beta \mathbb{E}_t (1+\hat{\Omega}_{t+1})^{-\sigma_c} &= \lambda_{ss}^h (1+\hat{\lambda}_t^h) \\ (\Omega_{ss})^{-\sigma_c}(1-\sigma_c \cdot \hat{\Omega}_t) - (\Omega_{ss})^{-\sigma_c} h\beta \mathbb{E}_t (1-\sigma_c \cdot \hat{\Omega}_{t+1})^{-\sigma_c} &= \lambda_{ss}^h (1+\hat{\lambda}_t^h)\end{aligned}$$

Using the fact that in steady state $(\Omega_{ss})^{-\sigma_c}(1-h\beta) = \lambda_{ss}^h$, we have that,

$$\begin{aligned}\sigma_c \Omega_{ss}^{-\sigma_c} h\beta \mathbb{E}_t(\hat{\Omega}_{t+1}) - \sigma_c \Omega_{ss}^{-\sigma_c} \hat{\Omega}_t &= \lambda^h \hat{\lambda}_t^h \\ \sigma_c \left[h\beta \mathbb{E}_t(\hat{\Omega}_{t+1}) - \hat{\Omega}_t \right] &= (1-h\beta)\hat{\lambda}_t^h\end{aligned}$$

Next we can log-linearise, $\Omega_t = (C_t - hC_{t-1})$.

$$\Omega_{ss}(1+\hat{\Omega}_t) = C_{ss}(1+\hat{C}_t) - h{\cdot}C_{ss}(1+\hat{C}_{t-1})$$

Using the steady state $\Omega_{ss} = C_{ss} - hC_{ss}$ we can reduce the equation to,

$$\begin{aligned}\Omega_{ss}\hat{\Omega}_t &= C_{ss}\hat{C}_t - h{\cdot}C_{ss}\hat{C}_{t-1}\\ \therefore \quad \hat{\Omega}_t &= \frac{C_{ss}}{\Omega_{ss}}\left[\hat{C}_{t-1} - h{\cdot}\hat{C}_t\right]\end{aligned}$$

Substitute this variable to get,

$$\sigma_c\left[h\beta\mathbb{E}_t\left(\frac{C_{ss}}{\Omega_{ss}}\left[\hat{C}_{t+1} - h{\cdot}\hat{C}_t\right]\right) - \left(\frac{C_{ss}}{\Omega_{ss}}\left[\hat{C}_t - h{\cdot}\hat{C}_{t-1}\right]\right)\right] = (1-h\beta)\hat{\lambda}^h_t$$

$$\sigma_c\left[h\beta\mathbb{E}_t\left(\frac{C_{ss}}{C_{ss}-hC_{ss}}\left[\hat{C}_{t+1} - h{\cdot}\hat{C}_t\right]\right) - \left(\frac{C_{ss}}{C_{ss}-hC_{ss}}\left[\hat{C}_t - h{\cdot}\hat{C}_{t-1}\right]\right)\right] = (1-h\beta)\hat{\lambda}^h_t$$

We can use some algebra to simplify this equation,

$$\begin{aligned}\sigma_c\left[h\beta\mathbb{E}_t\left(\frac{1}{1-h}\left[\hat{C}_{t+1} - h{\cdot}\hat{C}_t\right]\right) - \left(\frac{1}{1-h}\left[\hat{C}_t - h{\cdot}\hat{C}_{t-1}\right]\right)\right] &= (1-h\beta)\hat{\lambda}^h_t\\ \left(\frac{h\beta\sigma_c}{1-h}\right)\mathbb{E}_t(\hat{C}_{t+1}) - \left[\frac{(1+h^2\beta)\sigma_c}{1-h}\right]\hat{C}_t + \left(\frac{h\sigma_c}{1-h}\right)\hat{C}_{t-1} &= (1-h\beta)\hat{\lambda}^h_t\end{aligned}$$

The work below shows the complete linearised version of the model for Chapter 6.

B.1.2 Household

B.1.2.1 Euler Equation

The Euler equation is,

$$h\beta^h\mathbb{E}_t\left[\frac{(C_{t+1}-hC_t)^{-\sigma_c}}{\pi_{t+1}}\right] = \frac{(C_t - hC_{t-1})^{-\sigma_c}}{R^d_t}$$

Log-linearisation delivers,

$$\begin{aligned}&\frac{h}{R^d_{ss}(C_{ss}-hC_{ss})^{\sigma_c}}\left[\frac{\sigma_c}{(1-h)}(\hat{C}_t - \hat{C}_{t-1}) + \hat{R}^d_t\right]\\ &= \frac{h\beta^h}{\pi_{ss}(C_{ss}-hC_{ss})^{\sigma_c}}\left[\frac{\sigma_c}{(1-h)}(\hat{C}_{t+1} - \hat{C}_t) + \hat{\pi}_{t+1}\right]\end{aligned} \tag{B.1}$$

B.1.2.2 Wage Setting

The next equation to consider is the law of motion of f_t. The first part of this equation is given by,

$$f_t = \frac{\eta-1}{\eta}(w_t^*)^{1-\eta}\lambda_t^h(w_t)^\eta N_t + \beta^h\theta_w\mathbb{E}_t\left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}}\right)^{1-\eta}\left(\frac{w_{t+1}^*}{w_t^*}\right)^{\eta-1} f_{t+1}$$

Linearising the equation starts as follows,

$$\begin{aligned} f_{ss}\exp^{\hat{f}_t} &= \frac{\eta-1}{\eta}(w_{ss}^*)^{1-\eta}\lambda_{ss}^h(w_{ss})^\eta N_{ss}\ \exp^{(1-\eta)\hat{w}_t^*+\hat{\lambda}_t^h+\eta\hat{w}_t+\hat{N}_t} \\ &+\beta\theta_w\pi_{ss}^{(\tau_w-1)(\eta-1)}f_{ss}\mathbb{E}_t\exp^{\hat{f}_{t+1}-(1-\eta)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}_{t+1}^*-\hat{w}_t^*]} \end{aligned}$$

With simplification we get,

$$\begin{aligned} f_{ss}\hat{f}_t &= \frac{\eta-1}{\eta}(w_{ss}^*)^{1-\eta}\lambda_{ss}^h(w_{ss})^\eta N_{ss}\left((1-\eta)\hat{w}_t^*+\hat{\lambda}_t^h+\eta\hat{w}_t+\hat{N}_t\right) \\ &+\beta\theta_w\pi_{ss}^{(\tau_w-1)(\eta-1)}f_{ss}\mathbb{E}_t\left[\hat{f}_{t+1}-(1-\eta)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}_{t+1}^*-\hat{w}_t^*]\right] \end{aligned}$$

In steady state we have that, $f_{ss}-\beta\theta_w f_{ss}\pi_{ss}^{(\tau_w-1)(1-\eta)} = \frac{\eta-1}{\eta}(w_{ss})^{1-\eta}\lambda_{ss}^h w_{ss}^\eta N_{ss}$, which we can use to simplify the equation above. The final linearised equation is then,

$$\begin{aligned} \hat{f}_t &= \left(1-\beta\theta_w\pi_{ss}^{(\tau_w-1)(1-\eta)}\right)\left((1-\eta)\hat{w}_t^*+\hat{\lambda}_t^h+\eta\hat{w}_t+\hat{N}_t\right) \\ &+\beta\theta_w\pi_{ss}^{(\tau_w-1)(\eta-1)}\mathbb{E}_t\left[\hat{f}_{t+1}-(1-\eta)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}_{t+1}^*-\hat{w}_t^*]\right] \end{aligned} \tag{B.2}$$

The second part of the law of motion for f_t is,

$$f_t = \left(\frac{w_t}{w_t^*}\right)^{\eta(1+\sigma_n)}(N_t)^{(1+\sigma_n)} + \beta\theta_w\mathbb{E}_t\left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}}\right)^{-\eta(1+\sigma_n)}\left(\frac{w_{t+1}^*}{w_t^*}\right)^{\eta(1+\sigma_n)} f_{t+1}$$

We start by linearising the equation in the following way,

$$\begin{aligned} f_{ss}\exp^{\hat{f}_t} &= \left(\frac{w_{ss}}{w_{ss}^*}\right)^{\eta(1-\sigma_m)}(N_{ss})^{1+\sigma_n}\ \exp^{\eta(1+\sigma_n)[\hat{w}_t-\hat{w}_t^*]+(1+\sigma_n)\hat{N}_t} \\ &+\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}f_{ss}\mathbb{E}_t\exp^{\hat{f}_{t+1}+\eta(1+\sigma_n)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}_{t+1}^*-\hat{w}_t^*]} \end{aligned}$$

From this it can be shown that,

$$
\begin{aligned}
f_{ss}\hat{f}_t = &\left(\frac{w_{ss}}{w^*_{ss}}\right)^{\eta(1-\sigma_m)} (N_{ss})^{1+\sigma_n} \left(\eta(1+\sigma_n)[\hat{w}_t - \hat{w}^*_t] + (1+\sigma_n)\hat{N}_t\right) \\
&+\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)} f_{ss}\mathbb{E}_t\left(\hat{f}_{t+1} + \eta(1+\sigma_n)[\hat{\pi}_{t+1} - \tau_w\hat{\pi}_t + \hat{w}^*_{t+1} - \hat{w}^*_t]\right)
\end{aligned}
$$

In steady state we have that, $f_{ss} - \beta\theta_w f_{ss}(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)} = \left(\frac{w_{ss}}{w^*_{ss}}\right)^{\eta(1-\sigma_m)} (N_{ss})^{1+\sigma_n}$, which we can use to simplify the equation above. The final linearised equation is then,

$$
\begin{aligned}
\hat{f}_t = &\left(1 - \beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}\right) \left(\eta(1+\sigma_n)[\hat{w}_t - \hat{w}^*_t] + (1+\sigma_n)\hat{N}_t\right) \\
&+\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}\mathbb{E}_t\left(\hat{f}_{t+1} + \eta(1+\sigma_n)[\hat{\pi}_{t+1} - \tau_w\hat{\pi}_t + \hat{w}^*_{t+1} - \hat{w}^*_t]\right) \qquad \text{(B.3)}
\end{aligned}
$$

B.1.2.3 Real Wage Index

In addition to the law of motion for f_t we have the real wage index, given by,

$$
1 = \theta_w\left(\frac{(\pi_{t-1})^{\tau w}}{\pi_t}\right)^{1-\eta}\left(\frac{w_{t-1}}{w_t}\right)^{1-\eta} + (1-\theta_w)(\pi^{w^*}_t)^{1-\eta}
$$

This equation can be written as,

$$
1 = \theta_w\pi_{ss}^{(\tau_w-1)(1-\eta)} \exp^{-(1-\eta)(\hat{\pi}_t - \tau_w\hat{\pi}_{t-1} + \hat{\pi}^w_t)} + (1-\theta_w)(\pi^{w^*}_{ss})^{1-\eta} \exp^{(1-\eta)\hat{\pi}^{w^*}_t}
$$

Which can then be log-linearised, to give,

$$
\theta_w\pi_{ss}^{(\tau_w-1)(1-\eta)}\left(\hat{\pi}_t - \tau_w\hat{\pi}_{t-1} + \hat{\pi}^w_t\right) = (1-\theta_w)(\pi^{w^*}_{ss})^{1-\eta}\,\hat{\pi}^{w^*}_t
$$

This provides us the final linearised equation,

$$
\frac{\theta_w\pi_{ss}^{(\tau_w-1)(1-\eta)}}{(1-\theta_w)(\pi^{w^*}_{ss})^{1-\eta}}\left(\hat{\pi}_t - \tau_w\hat{\pi}_{t-1} + \hat{\pi}^w_t\right) = \hat{w}^*_t - \hat{w}_t \qquad \text{(B.4)}
$$

B.1.3 Firm

B.1.3.1 Labour

The first order condition with respect to labour is,

$$w_t = (1-\alpha)K_t^{\alpha} N_t{}^{-\alpha}$$

This can be log-linearised to give,

$$\hat{w}_t = \alpha\hat{K}_t - \alpha\hat{N}_t \tag{B.5}$$

B.1.3.2 Capital

The first order condition with respect to capital is,

$$\lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f] = \alpha K_t^{\alpha-1} N_t^{1-\alpha}$$

This can be log-linearised to give,

$$\lambda_{ss}^f \hat{\lambda}_t^f - \beta^f \lambda_{ss}^f \mathbb{E}_t[(1-\varphi)\hat{\lambda}_{t+1}^f] = \alpha K_{ss}^{\alpha-1} N_{ss}^{1-\alpha}\left[(\alpha-1)\hat{K}_t + (1-\alpha)\hat{N}_t\right] \tag{B.6}$$

B.1.3.3 Marginal Cost

The real marginal cost function is,

$$mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{\lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f]}{\alpha}\right)^{\alpha}$$

where we can redefine $r_t = \lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f]$, which gives us,

$$mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t}{\alpha}\right)^{\alpha}$$

Log-linearising this equation gives,

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \alpha\hat{r}_t$$

The log-linearisation of r_t leaves us with,

$$\hat{r}_t = \frac{\hat{\lambda}_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\hat{\lambda}_{t+1}^f]}{1-\beta^f(1-\varphi)}$$

This gives us the final linearisation of the marginal cost function as,

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \frac{1}{1-\beta^f(1-\varphi)}\left[\hat{\lambda}_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\hat{\lambda}_{t+1}^f]\right] \tag{B.7}$$

B.1.3.4 Loans from merchant bank

The first order condition with respect to loans from the merchant bank is,

$$\begin{aligned}
&\frac{\lambda_t^f}{R_t^c}\left(1-\Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)-\Gamma'\left(\frac{L_t^b}{L_{t-1}^b}\right)\frac{L_t^b}{L_{t-1}^b}\right)\\
&=\beta^f\mathbb{E}_t\left[\frac{\psi_{t+1}}{\pi_{t+1}}-\frac{\lambda_{t+1}^f}{R_{t+1}^c}\left(\Gamma'\left[\frac{L_{t+1}^b}{L_t^b}\right]\left(\frac{L_{t+1}^b}{L_t^b}\right)^2\right)\right]+(\beta^f)^2\mathbb{E}_t\left[\omega_\psi(1-\psi_{t+1})^2L_t^b\right]
\end{aligned}$$

Log-linearisation leads to the following equation,

$$\begin{aligned}
&\frac{\lambda_{ss}^f}{R_{ss}^c}\left(\hat{\lambda}_t^f-\hat{R}_t^c\right)-\theta\frac{\lambda_{ss}^f}{R_{ss}^c}\left(\hat{L}_t^b-\hat{L}_{t-1}^b\right)+\theta\beta^f\frac{\lambda_{ss}^f}{R_{ss}^c}\mathbb{E}_t\left(\hat{L}_{t+1}^b-\hat{L}_t^b\right)\\
&=\beta^f\frac{\psi_{ss}}{\pi_{ss}}\mathbb{E}_t\left[(\hat{\psi}_{t+1}-\hat{\pi}_{t+1})\right]+(\beta^f)^2\frac{\omega_\psi}{2}(1-\psi_{ss})^2L_{ss}^b\left[-2\left(\frac{\psi_{ss}}{1-\psi_{ss}}\right)\hat{\psi}_{t+1}+\hat{L}_t^b\right]
\end{aligned} \tag{B.8}$$

B.1.3.5 Default

The first order condition with respect to default is,

$$\frac{L_{t-1}^b}{\pi_t} = d_\psi + \beta^f\omega_\psi\left[(1-\psi_t)(L_{t-1}^b)^2\right]$$

This equation can be written in log-linear form as,

$$\frac{L_{ss}^b}{\pi_{ss}}(1+\hat{L}_{t-1}^b-\hat{\pi}_t) = d_\psi + \beta^f\frac{\omega_\psi}{2}(1-\psi_{ss})(L_{ss}^b)^2\left[1-\left(\frac{\psi_{ss}}{1-\psi_{ss}}\right)\hat{\psi}_t+2\hat{L}_{t-1}^b\right]$$

B.1.3.6 Price Setting

Price setting is done in the vein of Rotemberg, given by the following equation,

$$\left(\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}}-1\right)\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}}$$
$$=\beta^f\mathbb{E}_t\left[\left(\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}-1\right)\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}\frac{y_{t+1}}{y_t}\right]+\left[\frac{1-\epsilon(1+mc_t)}{\varrho}\right]$$

Log-linearisation delivers,

$$\left(\frac{(1+\hat{\pi}_t)}{(1+\gamma_p(\hat{\pi}_{t-1}))}-1\right)\frac{(1+\hat{\pi}_t)}{(1+\gamma_p(\hat{\pi}_{t-1}))}$$
$$=\beta^f\mathbb{E}_t\left[\left(\frac{(1+\hat{\pi}_{t+1})}{(1+\gamma_p(\hat{\pi}_t))}-1\right)\frac{(1+\hat{\pi}_{t+1})}{(1+\gamma_p(\hat{\pi}_t))}\frac{1+\hat{y}_{t+1}}{1+\hat{y}_t}\right]+\frac{1-\epsilon}{\varrho}-\frac{\epsilon[mc_{ss}(1+\hat{mc}_t)]}{\varrho}$$

Further simplification yields,

$$[\hat{\pi}_t-\gamma_p(\hat{\pi}_{t-1})]=\beta^f\mathbb{E}_t\left[\hat{\pi}_{t+1}-\gamma_p(\hat{\pi}_t)\right]+\left(\frac{1-\epsilon}{\varrho}\right)\hat{mc}_t \tag{B.9}$$

B.1.4 Deposit Bank

B.1.4.1 Deposits

The first FOC for the deposit bank with respect to deposits is,

$$\frac{1}{R_t^d}(\pi_t^l+1)^{-\sigma_l}=\beta^l\mathbb{E}_t\left[\frac{1}{\pi_{t+1}}(\pi_{t+1}^l+1)^{-\sigma_l}\right]-\Xi_t$$

Log-linearisation delivers,

$$\frac{1}{R_{ss}^d}\left[\hat{R}_t^d+\left(\frac{\pi_{ss}^l}{1+\pi_{ss}^l}\right)\sigma_l\hat{\pi}_t^l\right]$$
$$=\beta^l\frac{1}{\pi_{ss}}\left[\left(\frac{\pi_{ss}^l}{1+\pi_{ss}^l}\right)\sigma_l\hat{\pi}_{t+1}^l+\hat{\pi}_{t+1}\right]-\Xi_{ss}\hat{\Xi}_t \tag{B.10}$$

B.1.4.2 Interbank Loans

The first FOC for the deposit bank with respect to interbank loans is,

$$\frac{1}{R_t^l}(\pi_t^l+1)^{-\sigma_l} = \beta^l \mathbb{E}_t\left[\frac{\delta_{t+1}}{\pi_{t+1}}(\pi_{t+1}^l+1)^{-\sigma_l}\right] + \Xi_t$$

Log-linearisation of this equation delivers,

$$\left(\frac{1}{R_{ss}^l}\right)\left[\hat{R}_t^l + \left(\frac{\pi_{ss}^l}{1+\pi_{ss}^l}\right)\sigma_l\hat{\pi}_t^l\right] \\ = \beta^l\left(\frac{\delta_{ss}}{\pi_{ss}}\right)\left[\hat{\pi}_{t+1} - \hat{\delta}_{t+1} + \left(\frac{\pi_{ss}^l}{1+\pi_{ss}^l}\right)\sigma_l\hat{\pi}_{t+1}^l\right] + \Xi_{ss}\hat{\Xi}_t \tag{B.11}$$

B.1.5 Merchant Bank

B.1.5.1 Money Holdings

The first order condition with respect to money holdings,

$$\dot{U}_t^b = \beta^b\mathbb{E}_t\left(\frac{\dot{U}_{t+1}^b}{\pi_{t+1}}\right) - \Upsilon_t$$

The final log-linearised equation is,

$$\frac{\pi_{ss}^b\sigma_b}{(\pi_{ss}^b+1)}\hat{\pi}_t^b = \beta^b\left[\frac{\pi_{ss}^b\sigma_b}{(\pi_{ss}^b+1)}\hat{\pi}_{t+1}^b + \hat{\pi}_{t+1}\right] - \Upsilon_{ss}\hat{\Upsilon}_t$$

B.1.5.2 Newly Issued Reserves

The first order condition with respect to newly issued reserves is,

$$\dot{U}_t^b = R_t^m(\dot{U}_t^b + \eta_t)$$

This gives the following log-linearised equation,

$$R_{ss}^m\eta_{ss}\left(\hat{R}_t^m + \hat{\eta}_t\right) \\ = -\left((\pi_{ss}^b+1)^{-\sigma_b}R_{ss}^m\right)\left[\hat{R}_t^m + \frac{\pi_{ss}^b\sigma_b}{(\pi_{ss}^b+1)}\hat{\pi}_t^b\right] + (\pi_{ss}^b+1)^{-\sigma_b}\frac{\pi_{ss}^b\sigma_b}{(\pi_{ss}^b+1)}\hat{\pi}_t^b - \Upsilon_{ss}\hat{\Upsilon}_t \tag{B.12}$$

B.1.5.3 Interbank Loans

The first order condition with respect to interbank loans,

$$\dot{U}^b_t \frac{1}{R^l_t} = \beta^b \mathbb{E}_t \left[\left(\frac{\delta_{t+1}}{\pi_{t+1}} \right) \dot{U}^b_{t+1} \right] + (\beta^b)^2 \mathbb{E}_{t+1} \left[\omega_\delta (1-\delta_{t+1})^2 L^l_t \dot{U}^b_{t+2} \right] + \Upsilon_t$$

The final log-linearised equation is,

$$\begin{aligned} &- \left(\frac{1}{R^l_{ss}} \right) \left[\hat{R}^l_t + \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_t \right] \\ &= \frac{\beta^b \delta_{ss}}{\pi_{ss}} \left[\hat{\delta_{t+1}} - \hat{\pi}_{t+1} - \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_{t+1} \right] \\ &+ (\beta^b)^2 \left(\frac{\omega_b}{2} \right) L^l_{ss} (1-\delta_{ss})^2 \left[-2 \left(\frac{\delta_{ss}}{1-\delta_{ss}} \right) \hat{\delta}_{t+1} + \hat{L}^l_t - \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_{t+2} \right] + \Upsilon_{ss} \hat{\Upsilon}_t \end{aligned} \tag{B.13}$$

B.1.5.4 Loans to Firms

The first order condition with respect to loans to firms,

$$\dot{U}^b_t \frac{1}{R^c_t} = \beta^b \mathbb{E}_t \left[\frac{\psi_{t+1}}{\pi_{t+1}} \dot{U}^b_{t+1} \right] - \Upsilon_t$$

The final log-linearised equation is,

$$- \left(\frac{1}{R^c_{ss}} \right) \left[\hat{R}^c_t + \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_t \right] = \beta^b \left(\frac{\psi_{ss}}{\pi_{ss}} \right) \left[\hat{\psi}_{t+1} - \hat{\pi}_{t+1} - \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_{t+1} \right] - \Upsilon_{ss} \hat{\Upsilon}_t \tag{B.14}$$

B.1.5.5 Short Term Bonds

The first order condition with respect to bonds is,

$$\dot{U}^b_t \frac{1}{R^b_t} = \beta^b \mathbb{E}_t \left(\frac{\dot{U}^b_{t+1} + \kappa \cdot \eta_{t+1}}{\pi_{t+1}} \right) - \Upsilon_t$$

The final log-linearisation is,

$$\begin{aligned} &- \frac{1}{R^b_{ss}} (\pi^b_{ss}+1)^{-\sigma_b} \left[\hat{R}^b_t + \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_t \right] \\ &= \beta^b (\pi^b_{ss}+1)^{-\sigma_b} \frac{1}{\pi_{ss}} \left[-\hat{\pi}_{t+1} - \frac{\pi^b_{ss}\sigma_b}{(\pi^b_{ss}+1)} \hat{\pi}^b_{t+1} \right] + \beta^b \frac{\kappa \eta_{ss}}{\pi_{ss}} \left[-\hat{\pi}_{t+1} + \hat{\kappa}_{t+1} + \hat{\eta}_{t+1} \right] - \Upsilon_{ss} \hat{\Upsilon}_t \end{aligned} \tag{B.15}$$

B.1.5.6 Default

The first order condition with respect to default is

$$\dot{U}_t^b \frac{L_{t-1}^l}{\pi_t} = d_\delta + \omega_b \beta^b \mathbb{E}_t \left[\left((1-\delta_t)(L_{t-1}^l)^2 \right) \dot{U}_{t+1}^b \right]$$

The final log-linearisation is,

$$\begin{aligned} &\frac{L_{ss}^l}{\pi_{ss}(\pi_{ss}^b+1)^{\sigma_b}} \left(\hat{L}_{t-1}^l - \frac{\pi_{ss}^b \sigma_b}{(\pi_{ss}^b+1)} \hat{\pi}_t^b - \hat{\pi}_t \right) - d_\delta \\ &= \beta^b \left(\frac{\omega_\delta}{2} \right) (1-\delta_{ss})(L_{ss}^l)^2 (\pi_{ss}^b+1)^{-\sigma_b} \mathbb{E}_t \left[\left(\frac{\delta_{ss}}{1-\delta_{ss}} \right) \hat{\delta}_t + 2\hat{L}_{t-1}^l - \frac{\pi_{ss}^b \sigma_b}{(\pi_{ss}^b+1)} \hat{\pi}_{t+1}^b \right] \end{aligned} \tag{B.16}$$

B.1.6 Central Bank

B.1.6.1 Budget Constraint

The budget constraint of the central bank is,

$$T_t^r - M_t R_t^m = \frac{B_{t-1}^c}{\pi_t} - \frac{B_t^c}{R_t^b}$$

Log-linearisation gives,

$$T_{ss}^r \hat{T}_t^r - R_{ss}^m M_{ss} \left(\hat{R}_t^m + \hat{M}_t \right) = \frac{B_{ss}^c}{\pi_{ss}} \left(\hat{B}_{t-1}^c - \hat{\pi}_t \right) - \frac{B_{ss}^c}{R_{ss}^b} \left(\hat{B}_t^c - \hat{R}_t^b \right) \tag{B.17}$$

B.1.6.2 Eligible Assets

Collateralised lending equation is,

$$M_t = \kappa_t \cdot \frac{B_{t-1}}{R_t^m \pi_t}$$

Log-linearisation gives,

$$M_{ss} \hat{M}_t = \kappa_{ss} \frac{B_{ss}}{R_{ss}^m \pi_{ss}} \left(\hat{\kappa}_t + \hat{B}_{t-1} - \hat{\pi}_t - \hat{R}_t^m \right) \tag{B.18}$$

B.1.6.3 Feedback Rule

Central bank sets the policy rate according to this feedback ,

$$R_t^m = (R_{t-1}^m)^{\rho_r}(R_{ss}^m)^{1-\rho_r}\left(\frac{\pi_t}{\pi_{ss}}\right)^{\rho_\pi(1-\rho_r)}\left(\frac{Y_t}{Y_{ss}}\right)^{\rho_Y(1-\rho_r)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\rho_d Y(1-\rho_r)} e^{\xi_{R,t}}$$

Log-linearisation gives,

$$\hat{R}_t^m = \rho_r(\hat{R}_{t-1}^m) + (1-\rho_r)\left[\rho_\pi\hat{\pi}_t + \rho_Y\hat{Y}_t + \rho_{dY}(\hat{Y}_t - \hat{Y}_{t-1})\right] + \xi_{R,t} \tag{B.19}$$

B.1.7 Government

B.1.7.1 Government Budget Constraint

The government budget constraint is,

$$G_t + \frac{B_t^g}{R_t^b} = \frac{B_{t-1}^g}{\pi_t} + T_t$$

Log-linearisation gives,

$$G_{ss}\hat{G}_t + \frac{B_{ss}^g}{R_{ss}^b}\left(\hat{B}_t^g - \hat{R}_t^b\right) = \frac{B_{ss}^g}{\pi_{ss}}\left(\hat{B}_{t-1}^g - \hat{\pi}_t\right) + T_{ss}\hat{T}_t \tag{B.20}$$

B.1.7.2 Growth Rate of Bonds

The growth rate of bonds is,

$$B_t^g = \Omega B_{t-1}^g$$

Log-linearisation gives,

$$\hat{B}_t^g = \Omega\left(\hat{B}_{t-1}^g - \hat{\pi}_t\right) \tag{B.21}$$

B.1.8 Market Clearing

B.1.8.1 Market Clearing

The market clearing condition is,

$$\begin{aligned} Y_t = {} & C_t + G_t + \pi_t^f + \pi_t^b + \pi_t^l + K_t - (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[\Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \\ & + \frac{\omega_\delta}{2}\left[(1-\delta_{t-1})L_{t-2}^l\right]^2 + \frac{\omega_\psi}{2}\left[(1-\psi_{t-1})L_{t-2}^b\right]^2 \\ & + \frac{\varrho}{2}\left(\frac{p_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{t-1}} - 1\right)^2 Y_t \end{aligned}$$

Log-linearisation gives,

$$\begin{aligned} Y_{ss}\hat{Y}_t = {} & C_{ss}\hat{C}_t + G_{ss}\hat{G}_t + \pi_{ss}^f\hat{\pi}_t^f + \pi_{ss}^b\hat{\pi}_t^b + \pi_{ss}^l\hat{\pi}_t^l + K_{ss}\hat{K}_t - (1-\varphi)K_{ss}\hat{K}_{t-1} \\ & + (\omega_\delta)(1-\delta_{ss})^2(L_{ss}^l)^2\left[-2\left(\frac{\delta_{ss}}{1-\delta_{ss}}\right)\hat{\delta}_{t-1} + 2\hat{L}_{t-2}^l\right] \\ & + (\omega_\psi)(1-\psi_{ss})^2(L_{ss}^b)^2\left[-2\left(\frac{\psi_{ss}}{1-\psi_{ss}}\right)\hat{\psi}_{t-1} + 2\hat{L}_{t-2}^b\right] \end{aligned} \tag{B.22}$$

B.1.8.2 Production Function

The aggregate production function is,

$$Y_t = K_t^\alpha N_t^{1-\alpha}$$

Log-linearisation gives,

$$\hat{Y}_t = \alpha\hat{K}_t + (1-\alpha)\hat{N}_t \tag{B.23}$$

B.1.8.3 Capital

The aggregated law of motion for capital is,

$$K_t = (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[1 - \Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right]$$

Log-linearisation gives,

$$\hat{K}_t = (1-\varphi)\hat{K}_{t-1} + \frac{L^b_{ss}}{R^c_{ss}K_{ss}}(\hat{L}^b_t - \hat{R}^c_t) \tag{B.24}$$

B.1.9 Extra Equations

B.1.9.1 Household Budget Constraint

Household budget constraint is,

$$\frac{D^l_t}{R^d_t} + C_t - T_t = w_t N_t + \frac{D^l_{t-1}}{\pi_t} - T^r_t$$

Log-linearisation gives us,

$$\begin{aligned}&\frac{D^l_{ss}}{R^d_{ss}}\left(\hat{D}^l_t - \hat{R}^d_t\right) + C_{ss}(\hat{C}_t) - T_{ss}(\hat{T}_t)\\&= w_{ss}N_{ss}\left(\hat{w}_t + \hat{N}_t\right) + \frac{D^l_{ss}}{\pi_{ss}}\left(\hat{D}^l_{t-1} - \hat{\pi}_t\right) - T^r_{ss}(\hat{T}^r_t)\end{aligned} \tag{B.25}$$

B.1.9.2 Indexing Rule

The indexing rule is,

$$w_{j,t+1} = (\pi_t)^{\tau_w} w_{j,t}$$

Log-linearisation gives us,

$$\hat{w}_{t+1} - \hat{w}_t = (\pi_{ss})^{\tau_w}(\tau_w \hat{\pi}_t) \tag{B.26}$$

B.1.9.3 Balancing equations

There are several budget balancing equations, The log-linearised equations are,

$$\hat{D}^l_t = \hat{L}^l_t \tag{B.27}$$

$$L^l_{ss}\hat{L}^l_t = M^p_{ss}\hat{M}^p_t + B_{ss}\hat{B}_t + L^b_{ss}\hat{L}^b_t \tag{B.28}$$

$$\hat{M}^p_t = \hat{B}^c_t \tag{B.29}$$

$$B^g_{ss}\hat{B}^g_t = B^c_{ss}\hat{B}^c_t + B_{ss}\hat{B}_t \tag{B.30}$$

B.1.9.4 Shocks

Besides the shock on the feedback rule, the shock I impose on κ_t is similar to that of Hilberg and Hollmayr (2011). The equation for κ is defined as $\kappa_t = \rho_\kappa \kappa_{t-1}\xi_{\kappa,t}$, where is $\xi_{\kappa,t}$ is the innovation. Log-linearisation gives,

$$\hat{\kappa}_t = \rho_\kappa \hat{\kappa}_{t-1} + \xi_{\kappa,t} \tag{B.31}$$

Another plausible way to impose a shock on liquidity, as in Niestroj et al. (2013), is to simply add it in this equation, as follows,

$$M_t \leq \kappa_t \cdot \frac{B_{t-1}}{R^m_t \pi_t} + \xi_{M,t} \tag{B.32}$$

This method was also attempted, but the haircut method was favored, as it framed the question more accurately.

B.2 Calibration and Steady States

In the following section there is a brief discussion on the implied steady state values for this model. The value of the β parameter is set by imposing a value for the deposit rate, $R^d = 1.006$, and inflation, $\pi = 1.0051$, in steady state. From the household's first order conditions one gets, $\beta = \pi_{ss}/R^d_{ss}$. The discount factor is structured to be the same for all sectors, as in de Walque et al. (2010). Discussion on the interest rate transmission in provided in the chapter. The value of the multiplier on the household budget constraint, with habit formation set at $h = 0.57$ and coefficient of relative risk aversion at $\sigma^c = 1.35$, is,

$$\lambda^h_{ss} = h(C_{ss} - hC_{ss})^{-\sigma_c}$$

In the instance above the value for C_{ss} is found by imposing a steady state consumption to output ratio. The Calvo parameter on wages is calibrated to be $\tau_w = 0.62$ and the elasticity of substitution between labour varieties is $\eta = 0.2$, which means I can deliver the value for $\pi^{w^*}_{ss}$, which is,

$$\pi^{w^*}_{ss} = \frac{1 - \theta_w \pi_{ss}^{(1-\eta)(\tau_w - 1)}}{(1 - \theta_w)^{\frac{1}{1-\eta}}}$$

With this value established, the following value for f_{ss} can be found, given the inverse Frisch elasticity of labour supply, $\sigma_n = 2.4$, and the wage indexation parameter, $\tau^w = 0.62$. The equation is as follows,

$$f_{ss} = \frac{(\pi^{w^*}_{ss})^{-\eta(1+\sigma_n)}(N_{ss})^{(1+\sigma_n)}}{1 - \beta\theta_w(\pi_{ss})^{\eta(1-\tau_w)(1+\sigma_n)}}$$

With the value of f_{ss} determined and $N_{ss} = 0.33$, I have that,

$$w^*_{ss} = \frac{1 - \beta\theta_w f_{ss}(\pi_{ss})^{(1-\eta)(\tau_w - 1)}}{\frac{\eta-1}{\eta}\lambda^h_{ss}(\pi^{w^*}_{ss})^{\eta} N_{ss}}$$

The value for output is normalised to one, while the labour steady state value is $N_{ss} = 0.33$. With the capital share of output calibrated as, $\alpha = 0.3$, the implied steady state value of K_{ss} is,

$$K_{ss} = \left(\frac{Y_{ss}}{N_{ss}^{(1-\alpha)}}\right)^{\frac{1}{\alpha}}$$

Given this value of K_{ss} and the depreciation rate of, $\varphi = 0.03$, the steady state of loans extended to firms is defined as $L^b_{ss} = K_{ss}R^c_{ss}\varphi$. Next, the steady state wage is given by

$w_{ss} = (1-\alpha)(K_{ss}^{\alpha})(N_{ss}^{-\alpha})$. With these values I can determine the multiplier for the firm budget constraint as,

$$\lambda_{ss}^{f} = \frac{\alpha(K_{ss})^{\alpha-1}(N_{ss})^{1-\alpha}}{1-\beta(1-\varphi)}$$

The value of the marginal cost in steady state is given by $mc_{ss} = (\epsilon-1)/\epsilon$, where $\epsilon = 3$. Having normalised merchant bank profit in steady state to $\pi_{ss}^{b} = 0.0001$, the value of the multiplier on the collateralised lending constraint is,

$$\eta_{ss}^{m} = (\pi_{ss}^{b}+1)^{-\sigma_b}\left(\frac{1}{R_{ss}^{m}} - 1\right)$$

The multiplier on the balanced budget condition is written as,

$$\Upsilon_{ss} = (\pi_{ss}^{b}+1)^{-\sigma_b}\left(\frac{\beta^{b}}{\pi_{ss}} - 1\right)$$

The steady state for the bond rate is endogenously determined by,

$$R_{ss}^{b} = \frac{\pi_{ss}}{\beta^{b}} \cdot \left[\frac{(\pi_{ss}^{b}+1)^{-\sigma_b}}{(\pi_{ss}^{b}+1)^{-\sigma_b} + \kappa_{ss}\eta_{ss}^{m}}\right] - \frac{\Upsilon_{ss}}{(\pi_{ss}^{b}+1)^{-\sigma_b}}$$

The repayment rate of interbank loans is calibrated to be $\delta = 0.995$, which means the utility cost from merchant bank default is,

$$\omega_{\delta} = \frac{\left(\frac{1}{R_{ss}^{l}} - \frac{\beta\delta_{ss}}{\pi_{ss}}\right)}{\beta^{2}L_{ss}^{l}(1-\delta_{ss})^{2}}$$

The repayment rate of firm loans is set at $\psi = 0.975$, which combined with the revealed value of ω_{δ}, gives,

$$d_{\delta} = \frac{L_{ss}^{l}}{\pi_{ss}} - \frac{\left(\frac{\omega_{\delta}}{2}\right)\beta(1-\delta_{ss})(L_{ss}^{l})^{2}}{(\pi_{ss}^{b}+1)^{\sigma_b}}$$

In addition, with ω_{δ} determined, one can back out the value of ω_{ψ} from the market clearing condition, as follows,

$$\omega_{\psi} = \frac{(Y_{ss} - C_{ss} - G_{ss} - \pi_{ss}^{f} - \pi_{ss}^{l} - \pi_{ss}^{b} - \varphi K_{ss} - \omega_{\delta})}{(1-\psi_{ss}(L_{ss}^{b})^{2})\left[(1-\delta_{ss})(L_{ss}^{l})^{2}\right]^{-1}}$$

In the above equation the values for G_{ss}, π^f_{ss} and π^l_{ss} are determined from steady state ratios imposed, and similar to de Walque et al. (2010), $L^l_{ss} = 0.7L^b_{ss}$. Given ω_ψ, the equation for d_ψ is,

$$d_\psi = \frac{L^b_{ss}}{\pi_{ss}} - \beta\left(\frac{\omega_\psi}{2}\right)(1-\psi_{ss})L^b_{ss}$$

With T_{ss} given by the imposed steady state ratios, and $D^l_{ss} = L^L_{ss}$ from the deposit bank balanced budget constraint, remittances to households is given by,

$$T^r_{ss} = -\left(\frac{D^l_{ss}}{R^d_{ss}} + C_{ss} + T_{ss} - w_{ss}N_{ss} - \frac{D^l_{ss}}{\pi_{ss}}\right)$$

Total bond supply is reflected in the following equation,

$$B^T_{ss} = (T_{ss} - G_{ss})\left[\frac{1}{R^b_{ss}} - \frac{1}{\pi_{ss}}\right]^{-1}$$

This allows me to write, $B^c_{ss} = B^g_{ss} - B_{ss}$, which gives $M^p_{ss} = B^c_{ss}$ from the initial condition. Finally, the reserves steady state is $M_{ss} = \kappa B_{ss}(R^m_{ss}\pi_{ss})^{-1}$.

B.3 Reserve Requirement

One of the potential shortcomings mentioned in the thesis is that there is no explicit role for money. In this largely cashless economy it could be useful to introduce some cash-in-advance constraints on the household, deposit and merchant banks. These constraints were initially attempted, but introduced a much greater deal of complexity, somewhat detracting from the central message. Consider the merchant bank for a moment. A CIA constraint on this bank can be motivated as a minimum reserves requirement. Below is a representation of what such requirement might look like.

In particular, it would require the merchant bank to hold a certain fraction of its interbank loans in the form of liquidity, generating demand for M^p_t. Normally with this type of constraint the commercial banks is forced to hold a fraction of deposits, but the merchant bank does not have access to household deposits. The minimum reserve requirement takes the following form,

$$\Theta L^l_{t-1} \leq M^p_t$$

with Θ the fraction of interbank loans held. The first order conditions of the merchant bank will be altered in the following way,

$$\begin{aligned}
&\dot{U}_t^b = R_t^m(\dot{U}_t^b + \eta_t) \\
&\frac{1}{R_t^b} = 1 + (\dot{U}_t^b)^{-1}\left[\beta^b \mathbb{E}_t\left(\frac{\kappa \cdot \eta_{t+1}}{\pi_{t+1}}\right) + \zeta_t\right] \\
&\dot{U}_t^b\left(\frac{1}{R_t^l} + \frac{1}{R_t^c}\right) = \beta^b \mathbb{E}_t\left[\left(\frac{\delta_{t+1} + \Theta \cdot \zeta_{t+1} + \psi_{t+1}}{\pi_{t+1}}\right)\dot{U}_{t+1}^b\right] + \\
&(\beta^b)^2 \mathbb{E}_{t+1}\left[\left(\omega_\delta(1-\delta_{t+1})^2 L_t^l\right)\dot{U}_{t+2}^b\right] \\
&\dot{U}_t^b \frac{L_{t-1}^l}{\pi_t} = d_\delta + \omega_\delta \beta^b \mathbb{E}_t\left[\left((1-\delta_t)(L_{t-1}^l)^2\right)\dot{U}_{t+1}^b\right]
\end{aligned}$$

where ζ is the newly introduced multiplier on the reserve requirement. There are several differences visible when incorporating these changes. For example it can be already be seen with the partial equilibrium analysis that the relationship between deposit, credit, interbank lending and bond rates are different, becoming more complex to analyse in levels,

$$R_{ss}^d = R_{ss}^l \delta_{ss} = R_{ss}^c(\Theta\zeta_{ss} + \psi_{ss}) = R_{ss}^b \cdot \left((1 - R_{ss}^b - \zeta_{ss} \cdot R_{ss}^b) \cdot \kappa_{ss}\eta_{ss}\right)^{-1}$$

While it is worthwhile to introduce this constraint, the question has to be asked, does it alter the result in a significant way? In general, the results obtained are highly similar. Does it add to the understanding of the model? In this instance, it might provide additional motivation as to the merchant bank's demand for money, but on the other hand it makes the model more complex and difficult to navigate. For the sake of brevity, and clarity, it was excluded.

Appendix C

Chapter 7

C.1 Log-Linearised Model

The household, firms and deposit banks are the same as in the previous chapter. This section only represents the log-linearised equations that are introduced in this chapter. Namely those that are related to the introduction of long-term bonds.

C.1.1 Merchant Bank

C.1.1.1 Long-Term Bonds

The first order condition with respect to long-term bonds is,

$$(\partial B_t^L) \qquad \dot{U}_t^b p_t^L = \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b + \kappa^l \cdot \eta_{t+1} p_{t+1}^L R_{t+1}^L}{\pi_{t+1}} \right) - \Upsilon_t \mathbb{E}_t \left(p_{t+1}^L R_{t+1}^L \right)$$

Eliminating Υ_t, this equation can be rewritten as,

$$\begin{aligned} \dot{U}_t^b p_t^L = {} & \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b + \kappa^l \cdot \eta_{t+1} p_{t+1}^L R_{t+1}^L}{\pi_{t+1}} \right) \\ & - \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b p_{t+1}^L R_{t+1}^L}{\pi_{t+1}} \right) + \dot{U}_t^b \mathbb{E}_t \left(p_{t+1}^L R_{t+1}^L \right) \end{aligned}$$

Which can then be simplified to,

$$\dot{U}_t^b p_t^L = \frac{\beta^b}{\pi_{t+1}} \mathbb{E}_t \left(\dot{U}_{t+1}^b + \kappa^l \cdot \eta_{t+1} p_{t+1}^L R_{t+1}^L - \dot{U}_{t+1}^b p_{t+1}^L R_{t+1}^L \right) + \dot{U}_t^b \mathbb{E}_t \left(p_{t+1}^L R_{t+1}^L \right)$$

The final log-linearisation is,

$$\begin{aligned}
&\left(\frac{1}{R_{ss}^L - \Phi}\right) (\pi_{ss}^b + 1)^{-\sigma_b} \left[-\left(\frac{R_{ss}^L}{R_{ss}^L - \Phi}\right) \hat{R}_t^L - \frac{\pi_{ss}^b \sigma_b}{(\pi_{ss}^b + 1)} \hat{\pi}_t^b \right] \\
&= \frac{\beta^b}{\pi_{ss}(\pi_{ss}^b + 1)^{\sigma_b}} \left[-\hat{\pi}_{t+1} - \frac{\pi_{ss}^b \sigma_b}{(\pi_{ss}^b + 1)} \hat{\pi}_{t+1}^b \right] + \frac{\beta^b \kappa_{ss}^l \eta_{ss}^m R_{ss}^L}{(R_{ss}^L - \Phi)\pi_{ss}} \left[\hat{\kappa}_{t+1}^l - \hat{\pi}_{t+1} + \eta_{t+1}^{\hat{m}} - \left(\frac{\Phi}{R_{ss}^L - \Phi}\right) \hat{R}_t^L \right] \\
&- \frac{\beta^b R_{ss}^L}{(R_{ss}^L - \Phi)\pi_{ss}(\pi_{ss}^b + 1)^{\sigma_b}} \left[-\frac{\pi_{ss}^b \sigma_b}{(\pi_{ss}^b + 1)} \hat{\pi}_{t+1}^b - \hat{\pi}_{t+1} - \left(\frac{\Phi}{R_{ss}^L - \Phi}\right) \hat{R}_{t+1}^L \right] \\
&+ \frac{R_{ss}^L}{(R_{ss}^L - \Phi)(\pi_{ss}^b + 1)^{\sigma_b}} \left[-\frac{\pi_{ss}^b \sigma_b}{(\pi_{ss}^b + 1)} \hat{\pi}_{t+1}^b - \left(\frac{\Phi}{R_{ss}^L - \Phi}\right) \hat{R}_{t+1}^L \right] \qquad \text{(C.1)}
\end{aligned}$$

C.1.2 Government

C.1.2.1 Government Budget Constraint

The government budget constraint is,

$$G_t + \frac{B_{t-1}^{TS}}{\pi_t} + \frac{p_t^L R_t^L B_{t-1}^{TL}}{\pi_t} = \frac{B_t^{TS}}{R_t^b} + p_t^L B_t^{TL} + T_t$$

The final log-linearisation is,

$$\begin{aligned}
&G_{ss}\hat{G}_t + \frac{B_{ss}^{TS}}{\pi_{ss}}(\hat{B}_{t-1}^{TS} - \hat{\pi}_t) + \frac{B_{ss}^{TL} R_{ss}^L}{(R_{ss}^L - \Phi)\pi_{ss}} \left[\hat{B}_{t-1}^{TL} - \hat{\pi}_t - \left(\frac{\Phi}{R_{ss}^L - \Phi}\right) \hat{R}_t^L \right] \\
&= \frac{B_{ss}^{TS}}{R_{ss}^b}(\hat{B}_t^{TS} - \hat{R}_t^b) + T_{ss}\hat{T}_t + \frac{B_{ss}^{TL}}{(R_{ss}^L - \Phi)} \left[\hat{B}_t^{TL} - \left(\frac{R_{ss}^L}{R_{ss}^L - \Phi}\right) \hat{R}_t^L \right] \qquad \text{(C.2)}
\end{aligned}$$

C.1.2.2 Growth Rate of Long-Term Bonds

The equation for the growth of long-term bonds is,

$$p_t^L B_t^L = \left(\frac{p_{t-1}^L B_{t-1}^L}{\pi_t} \right)^{\rho_b} e^{\xi_t^L}$$

The final log-linearisation is,

$$\hat{B}_t^L = \left(\frac{R_{ss}^L}{R_{ss}^L - \Phi}\right)\hat{R}_t^L + \rho_b\left[\hat{B}_{t-1}^L - \left(\frac{R_{ss}^L}{R_{ss}^L - \Phi}\right)\hat{R}_{t-1}^L - \hat{\pi}_t\right] + \xi_t^L$$

C.1.3 Central Bank

C.1.3.1 Budget Constraint

The first order condition with respect to bonds is,

$$T_t^r - \frac{B_{t-1}^{CS}}{\pi_t} + \frac{B_t^{CS}}{R_t^b} = \frac{p_t^L R_t^L B_{t-1}^{CL}}{\pi_t} - p_t^L B_t^{CL} + \left(M_t^p - \frac{M_{t-1}^p}{\pi_t}\right) R_t^m$$

The final log-linearisation is,

$$\begin{aligned}
&T_{ss}^r \hat{T}_t^r - \frac{B_{ss}^{CS}}{\pi_{ss}}(\hat{B}_{t-1}^{CS} - \hat{\pi}_t) + \frac{B_{ss}^{CS}}{R_{ss}^b}(\hat{B}_t^{CS} - \hat{R}_t^b) + \frac{B_{ss}^{CL}}{(R_{ss}^L - \Phi)}\left[\hat{B}_t^{CL} - \left(\frac{R_{ss}^L}{R_{ss}^L - \Phi}\right)\hat{R}_t^L\right] \\
&= \frac{B_{ss}^{CL} R_{ss}^L}{(R_{ss}^L - \Phi)\pi_{ss}}\left[\hat{B}_{t-1}^{CL} - \hat{\pi}_t - \left(\frac{\Phi}{R_{ss}^L - \Phi}\right)\hat{R}_t^L\right] + M_{ss}^p R_{ss}^m\left(\hat{M}_t^p + \hat{R}_t^m\right) \\
&- M_{ss}^p R_{ss}^m (\pi_{ss})^{-1}(\hat{M}_{t-1}^p + \hat{R}_t^m - \hat{\pi}_t)
\end{aligned} \tag{C.3}$$

C.1.3.2 Eligible Assets

The first order condition with respect to bonds is,

$$M_t = \kappa_t^s \cdot \frac{B_{t-1}^S}{R_t^m \pi_t} + \kappa_t^l \cdot \frac{p_t^L R_t^L B_{t-1}^L}{R_t^m \pi_t}$$

The final log-linearisation is,

$$\begin{aligned}
M_{ss}\hat{M}_t &= \kappa_{ss}^s \frac{B_{ss}}{R_{ss}^m \pi_{ss}}\left(\hat{\kappa}_t^s + \hat{B}_{t-1} - \hat{\pi}_t - \hat{R}_t^m\right) \\
&+ \frac{\kappa_{ss}^l B_{ss}^L R_{ss}^L}{(R_{ss}^L - \Phi)\pi_{ss} R_{ss}^m}\left[\hat{\kappa}_t^l + \hat{B}_{t-1}^l - \left(\frac{\Phi}{R_{ss}^L - \Phi}\right)\hat{R}_t^L - \hat{\pi}_t - \hat{R}_t^m\right]
\end{aligned} \tag{C.4}$$

C.1.4 Extra Equations

C.1.4.1 Balanced Budget Constraints

There are three affected balanced budget conditions.

$$
\begin{aligned}
L^l_{ss}\hat{L}^l_t &= M^p_{ss}\hat{M}^p_t + L^b_{ss}\hat{L}^b_t + B^S_{ss}B^S_t + \frac{B^{CL}_{ss}R^L_{ss}}{(R^L_{ss}-\Phi)\pi_{ss}}\left[\hat{B}^{CL}_t - \hat{\pi}_{t+1} - \left(\frac{\Phi}{R^L_{ss}-\Phi}\right)\hat{R}^L_{t+1}\right] \\
M^p_{ss}\hat{M}^p_t &= B^{CS}_{ss}\hat{B}^{CS}_t + \frac{B^{CL}_{ss}}{(R^L_{ss}-\Phi)}\left[\hat{B}^{CL}_t - \left(\frac{R^L_{ss}}{R^L_{ss}-\Phi}\right)\hat{R}^L_t\right] \\
B^{TL}_{ss}\hat{B}^{TL}_t &= B^L_{ss}\hat{B}^L_t + B^{CL}_{ss}\hat{B}^{CL}_t
\end{aligned}
$$

C.2 Calibration and Steady States

Calibration for the household, firm and deposit bank remain the same. However, with respect to the merchant bank, central bank and government there are a few changes. The determination of the value of Φ requires setting the R^L_{ss}. I follow the work of Chen et al. (2012a) in this regard, which delivers,

$$\Phi = (5.5 \cdot R^L_{ss} - R^L_{ss})/5.5$$

The next change observed is with the merchant bank. With equations becoming unwieldy as this point, I had to break them into parts. Presented below are some of the selected substitutions made, arising from the the equations in the model. These equations are named, X_s, X_l, Z_s and Z_l. The values of X_s and X_l come from a combination of the collateralised borrowing constraint and the central bank budget constraint, while Z_s and Z_l come from the addition of the balanced budget condition for the merchant bank.

$$
\begin{aligned}
X_s &= \frac{\pi_{ss}\kappa^s_{ss}}{\pi_{ss}-1(R^m_{ss}\pi_{ss})} + 1 \\
X_l &= \frac{\pi_{ss}}{(\pi_{ss}-1)}\left(\frac{\kappa^l_{ss}R^L_{ss}}{(R^L_{ss}-\Phi)\pi_{ss}R^m_{ss}} + \frac{1}{(R^L_{ss}-\Phi)}\right) \\
Z_s &= \left(\frac{1}{\pi_{ss}} - \frac{1}{R^b_{ss}} - \frac{\kappa^s_{ss}}{(R^m_{ss}\pi_{ss})}\right) \\
Z_l &= \left(\frac{R^L_{ss}}{(R^L_{ss}-\Phi)\pi_{ss}} - \frac{1}{(R^L_{ss}-\Phi)} - \frac{\kappa^l_{ss}R^L_{ss}}{(R^L_{ss}-\Phi)\pi_{ss}R^m_{ss}}\right)
\end{aligned}
$$

With these components, I can now show how the rest of the implied values are achieved. First, the value for B^S_{ss} can be given by,

$$B^S_{ss} = \left[\frac{L^l_{ss}}{R^l_{ss}} - \frac{\delta_{ss}L^l_{ss}}{(\pi_{ss})} + \frac{\psi_{ss}L^b_{ss}}{\pi_{ss}} - \frac{L^b_{ss}}{R^c_{ss}} - \pi^b_{ss} - \frac{\omega_\delta}{2}\left((1-\delta_{ss})L^l_{ss}\right)^2\right] \cdot (Z_s X_l/X_s + Z_l)^{-1}$$

With the value for B^S_{ss} determined, I can now establish the value of B^L_{ss} with the following equation,

$$B^L_{ss} = \frac{L^l_{ss}}{X_l} - (X_s/X_l)B^S_{ss} - \frac{L^b_{ss}}{X_l}$$

Using the collateralised lending equation, I can determine the value for M_{ss}, as,

$$M_{ss} = \frac{\kappa^s_{ss}B^S_{ss}}{R^m_{ss}\pi_{ss}} + \frac{\kappa^l_{ss}B^l_{ss}R^L_{ss}}{(R^L_{ss} - \Phi)\pi_{ss}R^m_{ss}}$$

With the value of M_{ss} identified, the value for M^p_{ss} is given by,

$$M^p_{ss} = \frac{M_{ss}\pi_{ss}}{(\pi_{ss} - 1)}$$

Once again, to avoid messy equations, I define a component of the equation for B^{CL}_{ss} as Y_l,

$$Y_l = \frac{1}{(R^L_{ss} - \Phi)}\left(\frac{1}{\pi_{ss}} - \frac{1}{R^b_{ss}}\right) + \frac{R^L_{ss}}{\pi_{ss}(R^L_{ss} - \Phi)}$$

The equation for B^{CL}_{ss} can then be written as,

$$B^{CL}_{ss} = \frac{M_{ss}R^m_{ss}}{Y_l} - T^r_{ss}$$

With B^{CL}_{ss}, the equation used for B^{CS}_{ss} is,

$$B^{CS}_{ss} = M^p_{ss} - \frac{B^{CL}_{ss}}{(RL_s s - \Phi)}$$

Finally, the values for B^{CS}_{ss} and B^{CS}_{ss} are determined form the balanced budget conditions for short- an long-term bonds, which are given by,

$$B^{TL}_{ss} = B^L_{ss} + B^{CL}_{ss}$$
$$B^{TS}_{ss} = B^S_{ss} + B^{CS}_{ss}$$

This concludes the discussion on implied steady state values for Chapter 7.

Table C.1: Calibrated parameters

Parameter	Description	Value
h	Habit formation (consumption)	0.57
σ^c	Coefficient of relative risk aversion	1.35
σ^n	Inverse Frisch elasticity of labour supply	2.4
σ^l	Coefficient for deposit bank (NB)	1.35
σ^b	Coefficient for merchant bank (NB)	1.35
η	Elasticity of substitution between labor varieties	3
ϵ	Elasticity of substitution between goods varieties	3
τ^w	Wage indexation parameter	0.62
θ^w	Calvo parameter (wages)	0.2
α	Capital share of output	0.3
φ	Depreciation rate	0.03
θ	Firms' investment adjustment cost	6.77
ϱ	Price adjustment cost – Calvo parameter (prices)	120
γ_p	Another component of wage adjustment cost	0.47
Γ	Bond supply growth rate	1.055
ρ_r	Interest rate smoothing coefficient (Taylor Rule)	0.5
ρ_π	Feedback coefficient to inflation in monetary policy rule	1.68
ρ_y	Feedback coefficient to output growth deviation	0.01
ρ_{d^y}	Feedback coefficient to output growth deviation	0.16

Table C.2: Imposed steady states and ratios

Parameter	Description	Value
π	Inflation	1.051
R^d	Deposit rate	1.065
R^m	Policy rate (Central Bank)	1.06
R^L	Long-term bond rate	1.075
δ	Repayment rate (deposit bank)	0.995
ψ	Repayment rate (merchant bank)	0.975
N	Labour steady state	0.33
C/Y	Consumption spending to output ratio	0.42
π^f/Y	Firm profit to output ratio	0.1
π^l/Y	Deposit bank profit to output ratio	0.0001
π^b/Y	Merchant bank profit to output ratio	0.0001
G/Y	Government spending to output ratio	0.1854
T/Y	Taxation to output ratio	0.187
L^l/L^b	Interbank to firm loan ratio	0.65

C.3 Code

This section includes the code used for the final model with long-term bonds. It depicts the contractionary interest rate shock from Chapter 7.

```
//========================================================================
// FINAL MODEL (Contractionary Interest Rate Policy)
//========================================================================

//========================================================================
// ENDOGENOUS VARIABLES
//========================================================================

var c_hat               // consumption
    lambdah_hat         // Lagrange multiplier (household)
    Rd_hat              // nominal (interest) deposit rate
    PI_hat              // inflation
    f_hat               // variable for recursive formulation of wage setting
    w_hat               // real wage
    wstar_hat           // optimal real wage
    N_hat               // aggregate labour demand
    K_hat               // capital
    lambdaf_hat         // Lagrange multiplier (firm)
    mc_hat              // marginal cost
    Rc_hat              // credit rate (rate at which loans are provided)
    Lb_hat              // loans to firms
    psi_hat             // default rate on loan repayment for firms is (1-psi)
    Rl_hat              // interbank rate, rate at which loans are provided to merchant banks
    deltta_hat          // default rate on loan repayment for merchant banks is (1-delta)
    Ll_hat              // loans to merchant bank (interbank loans)
    Rm_hat              // refinancing rate (policy rate)
    t_hat               // tax
    y_hat               // aggregate output
    Dl_hat              // deposit holdings
    pil_hat             // deposit bank profit
    pif_hat             // firm profit
    pib_hat             // merchant bank profit
    tr_hat              // central bank transfers
    Rb_hat              // bond rate
    I_hat               // newly issued reserves
    Bs_hat              // merchant bank short-term bond holdings
    Bts_hat             // total short-term bond supply
    Bcs_hat             // central bank short-term bond holdings
    eeta_hat            // multiplier on collateral constraint
    g_hat               // government spending
    RL_hat              // yield to maturity
    Bcl_hat             // central bank long-term bond holdings
    Btl_hat             // total supply of long-term bonds
    Bl_hat              // merchant bank long-term bond holdings
    mp_hat;             // outright purchases of reserves
```

```
//==========================================================================
// EXOGENOUS VARIABLES
//==========================================================================

varexo em elb emp ekp;

//==========================================================================
// PARAMETERS
//==========================================================================

parameters  h           // consumption habit formation
//          betta_h     // discount factor (household)
//          betta_f     // discount factor (firm)
//          betta_l     // discount factor (deposit bank)
//          betta_b     // discount factor (merchant bank)
            sigmac      // coefficient of relative risk aversion (consumption)
            sigman      // inverse Frisch elasticity of labour supply
            eta         // elasticity of substitution between labor varieties
            epsilon     // elasticity of substitution between goods varieties
            tauw        // wage indexation parameter
            thetaw      // Calvo parameter wages (portion that can no change their wage)
            alppha      // capital share of output
//          dpsi        // disutility associated with default (firm)
            varphi      // depreciation rate
            theta       // investment adjustment cost (firm)
//          wpsi        // pecuniary cost of default (firm)
            varrho      // price adjustment cost (firm) (Calvo parameter for prices)
            gammap      // wage adjustment cost
//          ddelta      // disutility from default (merchant bank)
//          wdelta      // pecuniary cost from default (merchant bank)
            varpi       // bond supply growth rate
            kappal      // haircut (long-term bonds - composition)
            kappas      // haircut (short-term - size)
            rhoR        // interest smoothing coefficient Taylor rule
            rhoPI       // feedback coefficient to inflatioon monetary policy rule
            rhoy        // feedback coefficient to output growth deviation in monetary policy rule
            rhody       // similar to the previus one (think on this one a bit)
            vartheta    // fraction of repos, set exogenously by the central bank
            mu          // minimum reserve ratio
            Phii        // paramater to solve indeterminancy
            sigmal      // coefficient for deposit bank
            sigmab      // coefficient for merchant bank
            gaama       // bond growth rate
            chii        // paramater to solve indeterminancy
```

```
//==========================================================================
// STEADY STATES AND RATIOS (IMPOSED)
//==========================================================================

            PI_ss
            Rd_ss
            Rm_ss
            psi_ss
            deltta_ss
            N_ss
            y_ss
            gy_ss
            cy_ss
            pify_ss
            pily_ss
            piby_ss
            ty_ss
            rrho_ss
            RL_ss
            rhob

//==========================================================================
// SHOCKS
//==========================================================================

            std_m
            std_lb
            std_mp;

//==========================================================================
// CALIBRATED PARAMETER VALUES (IMPOSED)
//==========================================================================

h               = 0.57;               // DW DSGE. Alternative is 0.55 from CS or 0.97 from FV.
sigmac          = 1.35;               // DW DSGE
sigman          = 2.4;                // DW DSGE. Alternative is 2 from CS or 1.17 from FV.
sigmal          = 1.35;               // DW DSGE
sigmab          = 1.35;               // DW DSGE
eta             = 3;                  // CS. Alternative is 3 from DW DSGE or 10 from FV.
epsilon         = 3;                  // CS. Alternative is 3 from DW DSGE or 10 from FV.
tauw            = 0.62;               // FV. This is an estimated parameter, form the data.
thetaw          = 0.2;                // FV. Estimated parameter.
alppha          = 0.33;               // CS. This is the same as DW. However, FV estimated 0.22.
varphi          = 0.025;              // DW DSGE. FV has it as 0.025, CS as 0.03, SW as 0.025.
theta           = 6.77;               // DW DSGE.
varrho          = 260;                // DW DSGE. Alternative is 120 from Niestroj.
gammap          = 0.47;               // DW DSGE.
varpi           = 2;                  // Niestroj.
kappas          = 0.9;                // This is the haircut on short-term bonds
kappal          = 0.1;                // Haircut on long-term bonds
rhoR            = 0.7;                // CS. Parameter estimate. The prior chosen is 0.7.
rhoPI           = 1.68;               // CS. Parameter estimate. Prior chosen is 1.5.
rhoy            = 0.01;               // CS. Parameter estimate. Prior chosen is 0.01.
rhody           = 0.16;               // DW DSGE. Alternate in Smets and Wouters.
```

```
vartheta        = 0.1;                // CS. Fraction of money held outright.
mu              = 0.02;               // CS.
Phii            = 0;
gaama           = 1.055;
chii            = 0.001;
rhob            = 0.9;

//==========================================================================
// STEADY STATES (IMPOSED)
//==========================================================================
rrho_ss         = 1.025;
PI_ss           = 1.051;
Rd_ss           = 1.07;
Rm_ss           = 1.06;
RL_ss           = 1.075;
psi_ss          = 0.975;
deltta_ss       = 0.995;
N_ss            = 0.3;
y_ss            = 1;


//==========================================================================
// CALIBRATED RATIOS (IMPOSED)
//==========================================================================
gy_ss           = 0.1854;                 // This is the government spending to gdp ratio
cy_ss           = 0.45;                   // Consumption to gdp ratio
pify_ss         = 0.1;                    // Firm profit to gdp ratio
pily_ss         = 0.0001;                 // Deposit bank profit to gdp ratio
piby_ss         = 0.0001;                 // Merchant bank to gdp ratio
ty_ss           = 0.18;


//==========================================================================
// SHOCK PARAMETERS
//==========================================================================

std_m           = 1;
std_lb          = 10;
std_mp          = 10;

//==========================================================================

model(linear);

//==========================================================================
// STEADY STATES (IMPLIED)
//==========================================================================

// Steady states as functions of parameters and calibrated values


# Rc_ss         = Rd_ss/psi_ss;
# Rl_ss         = Rd_ss/deltta_ss;
# PSI           = (5.5*RL_ss - RL_ss)/5.5;
# mc_ss         = (epsilon - 1)/epsilon;
# betta_h       = PI_ss/(Rd_ss);
```

```
# betta_f       = betta_h;
# betta_l       = PI_ss/(Rl_ss*deltta_ss);
# betta_b       = PI_ss/(Rc_ss*psi_ss);
# PIstarw_ss    = ((1 - thetaw*(PI_ss)^((1 - eta)*(tauw - 1)))/((1 - thetaw))^(1/(1 - eta)));
# f_ss          = (((PIstarw_ss)^(-eta*(1 + sigman)))*(N_ss)^(1 + sigman))/
                  (1 - betta_h*thetaw*(PI_ss)^(eta*(1 - tauw)*(1 + sigman)));
# K_ss          = (y_ss/(N_ss^(1-alppha)))^(1/alppha);
# Lb_ss         = K_ss*Rc_ss*varphi;
# ky_ss         = K_ss/y_ss;
# g_ss          = gy_ss*y_ss;
# c_ss          = cy_ss*y_ss;
# pif_ss        = pify_ss*y_ss;
# pil_ss        = pily_ss*y_ss;
# pib_ss        = piby_ss*y_ss;
# eeta_ss       = ((pib_ss+1)^(-sigmab))*(1/(Rm_ss)-1);
# Rb_ss         = Rd_ss*((pib_ss+1)^(-sigmab)/(eeta_ss*kappas + ((pib_ss+1)^(-sigmab))));
# Dl_ss         = 0.7*Lb_ss;
# Ll_ss         = Dl_ss;
# w_ss          = (1-alppha)*(K_ss^(alppha))*(N_ss^(-alppha));
# t_ss          = ty_ss*y_ss;
# lambdaf_ss    = (alppha*((K_ss)^(alppha-1))*((N_ss)^(1-alppha)))/(1-(betta_f*(1-varphi)));
# lambdah_ss    = h*((c_ss-h*c_ss)^(-sigmac));
# wstar_ss      = (1 - betta_h*thetaw*(PI_ss^((1-eta)*(tauw-1)))*f_ss)/
                  ((eta-1/eta)*(lambdah_ss)*(PIstarw_ss^(-eta))*N_ss);
# wdelta        = ((1/Rl_ss) - ((betta_b*(deltta_ss))/PI_ss))/((betta_b^2)*Ll_ss*((1-deltta_ss)^2));
# wpsi          = ((y_ss - c_ss - g_ss - pif_ss - pib_ss - pil_ss - varphi*K_ss - (wdelta)*((1-deltta_ss)*Ll_ss)^2)/
                  (((1-psi_ss)*Lb_ss)^2));
# dpsi          = (Lb_ss/PI_ss) - (betta_f*((wpsi/2)*(1-psi_ss))*Lb_ss^2);
# ddelta        = (((Ll_ss/PI_ss) - (wdelta/2)*betta_b*(1-deltta_ss)*Ll_ss^2))/((pib_ss+1)^(sigmab));
# tr_ss         = -(Dl_ss/Rd_ss + c_ss + t_ss - w_ss*N_ss - Dl_ss/PI_ss);
# Xs            = (PI_ss/(PI_ss-1))*(kappas/(Rm_ss*PI_ss)) + 1;
# Xl            = (PI_ss/(PI_ss-1))*(kappal*RL_ss/((RL_ss - PSI)*PI_ss*Rm_ss)) + (1/(RL_ss - PSI));
# Zs            = (1/PI_ss - 1/Rb_ss - kappas/(Rm_ss*PI_ss));
# Zl            = (RL_ss/((RL_ss - PSI)*PI_ss) - 1/(RL_ss - PSI) - kappal*RL_ss/((RL_ss - PSI)*PI_ss*Rm_ss));
# Bs_ss         = (Ll_ss/Rl_ss - deltta_ss*Ll_ss/(PI_ss) + psi_ss*Lb_ss/PI_ss -
                  Lb_ss/Rc_ss - pib_ss - (wdelta/2)*((1-deltta_ss)*Ll_ss)^2)/((Zs*Xl)/Xs + Zl);
# Bl_ss         = (Ll_ss/Xl - (Xs/Xl)*Bs_ss - Lb_ss/Xl);
# I_ss          = ((kappas*Bs_ss)/(Rm_ss*PI_ss) + kappal*Bl_ss*RL_ss/((RL_ss - PSI)*PI_ss*Rm_ss));
# mp_ss         = (I_ss*PI_ss/(PI_ss-1));
# Yl            = ((1/(RL_ss - PSI))*((1/PI_ss) - (1/Rb_ss)) + RL_ss/((PI_ss)*(RL_ss - PSI)));
# Bcl_ss        = (I_ss*Rm_ss)/Yl - tr_ss;
# Bcs_ss        = mp_ss - (Bcl_ss/(RL_ss - PSI));
# Btl_ss        = Bl_ss + Bcl_ss;
# Bts_ss        = Bs_ss + Bcs_ss;
```

```
//======================================================================
// LOG LINEARISED MODEL
// =====================================================================

// The full model is represented here.

//======================================================================
// HOUSEHOLD
// =====================================================================

// 1. Euler Equation
(h/(Rd_ss*((c_ss - h*c_ss)^(sigmac))))*((sigmac/(1-h))*(c_hat - c_hat(-1)) + Rd_hat) + (chii)*Dl_hat =
        (h*betta_h/(PI_ss*((c_ss - h*c_ss)^(sigmac))))*((sigmac/(1-h))*(c_hat(+1) - c_hat) + PI_hat(+1));

// 2 + 3. Wage setting
f_hat = (1-betta_h*thetaw*(PI_ss)^((tauw-1)*(1-eta)))*((1-eta)*wstar_hat + lambdah_hat + eta*w_hat + N_hat) +
        betta_h*thetaw*(PI_ss)^((tauw-1)*(eta-1))*
        (f_hat(+1)-(1-eta)*(PI_hat(+1) - tauw*PI_hat + wstar_hat(+1) - wstar_hat));

f_hat = (1-betta_h*thetaw*(PI_ss)^(eta*(1-tauw)*(1+sigman)))*((eta*(1+sigman))*(w_hat - wstar_hat) + (1+sigman)*N_hat) +
        betta_h*thetaw*((PI_ss)^(eta*(1-tauw)*(1+sigman)))*
        (f_hat(+1) + eta*(1+sigman)*(PI_hat(+1) - tauw*PI_hat + wstar_hat(+1) - wstar_hat));

// 4. Real wage index
((thetaw*(PI_ss)^((tauw-1)*(1-eta)))/(1-thetaw)*((PIstarw_ss)^(1-eta)))*(PI_hat - tauw*PI_hat(-1) + w_hat - w_hat(-1))
      = wstar_hat - w_hat;

// =====================================================================
// FIRM
// =====================================================================

// 5. FOC Labour
w_hat(+1) = alppha*(K_hat(+1)) - alppha*(N_hat(+1));

// 6. FOC Capital
lambdaf_hat*lambdaf_ss - betta_f*(1-varphi)*lambdaf_ss*lambdaf_hat(+1) =
        alppha*(K_ss^(alppha-1))*(N_ss^(1-alppha))*((alppha-1)*K_hat + (1-alppha)*N_hat);

// 7. Marginal cost
mc_hat = (1-alppha)*w_hat + (1/(1-betta_f*(1-varphi)))*(lambdaf_hat - betta_f*(1-varphi)*lambdaf_hat(+1));

// 8. FOC Loans from merchant bank
(lambdaf_ss/Rc_ss)*(lambdaf_hat - Rc_hat) - ((theta*lambdaf_ss)/(Rc_ss))*(Lb_hat - Lb_hat(-1)) +
        ((betta_f*theta*lambdaf_ss)/(Rc_ss))*(Lb_hat(+1) - Lb_hat) =
        ((betta_f*psi_ss)/(PI_ss))*(psi_hat(+1) - PI_hat(+1)) +
        (betta_f^2)*(wpsi/2)*((1-psi_ss)^2)*Lb_ss*(-2*(psi_ss/(1-psi_ss))*psi_hat(+1) + Lb_hat);

// 9. FOC Default
(Lb_ss/PI_ss)*(1+ Lb_hat(-1) - PI_hat) = dpsi +
        betta_f*(wpsi/2)*(1-psi_ss)*(Lb_ss^2)*(1 - (psi_ss/(1-psi_ss))*psi_hat + 2*Lb_hat(-1));

// 10. Price setting
PI_hat = (betta_f/(1+betta_f*gammap))*PI_hat(+1) + (gammap/(1+betta_f*gammap))*PI_hat(-1) +
       (1/(1+betta_f*gammap))*((1-epsilon)/varrho)*mc_hat;
```

```
// ======================================================================
// DEPOSIT BANK
// ======================================================================

// 11. FOC Deposits
(1/Rd_ss)*(-Rd_hat - (pil_ss/(pil_ss+1))*sigmal*pil_hat) =
        betta_l*((1)/PI_ss)*(-(pil_ss/(pil_ss+1))*sigmal*pil_hat(+1) - PI_hat(+1))
        - (1/Rl_ss)*(Rl_hat + (pil_ss/(pil_ss+1))*sigmal*pil_hat)
        + ((betta_l*deltta_ss)/PI_ss)*(deltta_hat(+1) - PI_hat(+1) - (pil_ss/(pil_ss+1))*sigmal*pil_hat(+1));

// ======================================================================
// MERCHANT BANK
// ======================================================================

// 12. FOC Interbank loans
((1/Rl_ss))*((-1/(Rl_ss*((1/Rl_ss))))*Rl_hat - (pib_ss/(pib_ss+1))*sigmab*pib_hat) =
          ((betta_b*(deltta_ss))/PI_ss)*(((deltta_ss)/(deltta_ss))*deltta_hat(+1) - PI_hat(+1)
           - (pib_ss/(pib_ss+1))*sigmab*pib_hat(+1)) +
          ((betta_b)^2)*(wdelta/2)*((1-deltta_ss)^2)*Ll_ss*(-2*(deltta_ss/(1-deltta_ss))*deltta_hat(+1) + Ll_hat
          - (pib_ss/(pib_ss+1))*sigmab*pib_hat(+2))
          +(pib_ss/(pib_ss+1))*sigmab*pib_hat - ((pib_ss/(pib_ss+1)/PI_ss)*sigmab*pib_hat(+1) + PI_hat(+1));

// 13. FOC Loans to firms
(1/(Rc_ss))*(-Rc_hat - (pib_ss/(pib_ss+1))*sigmab*pib_hat) =
        betta_b*(psi_ss/(PI_ss))*(psi_hat(+1) - PI_hat(+1) - (pib_ss/(pib_ss+1))*sigmab*pib_hat(+1))
        +(pib_ss/(pib_ss+1))*sigmab*pib_hat - ((pib_ss/(pib_ss+1)/PI_ss)*sigmab*pib_hat(+1) + PI_hat(+1));

// 14. FOC Newly Issued Reserves
-(((pib_ss + 1)^(-sigmab))*Rm_ss)*(Rm_hat - (pib_ss/(pib_ss+1))*sigmab*pib_hat) +
        ((pib_ss + 1)^(-sigmab))*(pib_ss/(pib_ss+1))*sigmab*pib_hat = Rm_ss*eeta_ss*(Rm_hat + eeta_hat);

// 15. FOC Short Term Bonds
((pib_ss + 1)^(-sigmab))*(1/Rb_ss)*(-Rb_hat - (pib_ss/(pib_ss+1))*sigmab*pib_hat) =
           betta_b*((pib_ss + 1)^(-sigmab))*(1/PI_ss)*(-PI_hat(+1) - (pib_ss/(pib_ss+1))*sigmab*pib_hat(+1)) +
           betta_b*(kappas*eeta_ss/PI_ss)*(-PI_hat(+1) + eeta_hat(+1)) +
           (pib_ss/(pib_ss+1))*sigmab*pib_hat - ((pib_ss/(pib_ss+1)/PI_ss)*sigmab*pib_hat(+1) + PI_hat(+1));

// 16. FOC Long Term Bonds
((pib_ss + 1)^(-sigmab))*(1/(RL_ss-PSI))*(-(RL_ss/(RL_ss - PSI))*RL_hat - (pib_ss/(pib_ss+1))*sigmab*pib_hat) =
        betta_b*((pib_ss + 1)^(-sigmab))*(1/PI_ss)*(-PI_hat(+1) - (pib_ss/(pib_ss+1))*sigmab*pib_hat(+1)) +
        betta_b*(kappal*eeta_ss*RL_ss/((RL_ss - PSI)*PI_ss))*(-PI_hat(+1) +  eeta_hat(+1)
        - (PSI/(RL_ss - PSI))*RL_hat(+1))
        -betta_b*(RL_ss/((RL_ss - PSI)*PI_ss*(pib_ss + 1)^(sigmab)))*(-PI_hat(+1) -
        (pib_ss/(pib_ss+1))*sigmab*pib_hat - (PSI/(RL_ss - PSI))*RL_hat(+1))
        +(RL_ss/((RL_ss - PSI)*(pib_ss + 1)^(sigmab)))*(- (pib_ss/(pib_ss+1))*sigmab*pib_hat
        - (PSI/(RL_ss - PSI))*RL_hat(+1));

// 17. FOC Default
(Ll_ss/(PI_ss*(pib_ss+1)^(sigmab)))*(1 + Ll_hat(-1) - PI_hat - (pib_ss/(pib_ss+1))*sigmab*pib_hat)
        = ddelta + ((wdelta/2)*betta_b*(1-deltta_ss)*(Ll_ss^2)*
        ((pib_ss+1)^(-sigmab)))*(1-(deltta_ss/(1-deltta_ss))*deltta_hat + 2*Ll_hat(-1)
        - (pib_ss/(pib_ss+1))*sigmab*pib_hat(+1));
```

```
// ========================================================================
// CENTRAL BANK
// ========================================================================

// 18. Budget constraint
tr_ss*(tr_hat) - (Bcs_ss/PI_ss)*(Bcs_hat(-1) - PI_hat) + (Bcs_ss/Rb_ss)*(Bcs_hat - Rb_hat) =
        (RL_ss*Bcl_ss/((RL_ss - PSI)*PI_ss))*(Bcl_hat(-1) - (PSI/(RL_ss - PSI))*RL_hat - PI_hat) -
        Bcl_ss/(RL_ss - PSI)*(Bcl_hat - (RL_ss/(RL_ss - PSI))*RL_hat) + mp_ss*Rm_ss*(mp_hat + Rm_hat) -
        ((mp_ss*Rm_ss)/PI_ss)*(mp_hat(-1) + Rm_hat - PI_hat);

// 19. Feedback rule
Rm_hat  = rhoR*Rm_hat(-1) + (1-rhoR)*(rhoPI*PI_hat + rhoy*y_hat + rhody*(y_hat - y_hat(-1))) + em*std_m;

// 20. Eligible assets
I_ss*I_hat  = (kappas*Bs_ss/((PI_ss)*Rm_ss))*(Bs_hat(-1) - PI_hat - Rm_hat) +
        (kappal*Bl_ss*RL_ss/((RL_ss - PSI)*PI_ss*Rm_ss))*(Bl_hat(-1) - (PSI/(RL_ss - PSI))*RL_hat - PI_hat - Rm_hat);

// 21. Newly issued reserves
I_ss*I_hat = mp_ss*mp_hat - (mp_ss/PI_ss)*(mp_hat(-1) - PI_hat) +  emp*std_mp;

// 22. Balanced budget condition
mp_ss*mp_hat = Bcs_ss*Bcs_hat + (Bcl_ss/(RL_ss - PSI))*(Bcl_hat - (RL_ss/(RL_ss - PSI))*RL_hat);


// ========================================================================
// MARKET CLEARING + MISC
// ========================================================================

// 23. Market clearing
y_ss*y_hat = c_ss*c_hat + g_ss*g_hat + pif_ss*pif_hat + pil_ss*pil_hat
        + pib_ss*pib_hat + K_ss*K_hat - (1-varphi)*(K_ss)*K_hat(-1) +
        (wdelta)*((1-deltta_ss)^2)*(Ll_ss^2)*(-2*(deltta_ss/(1-deltta_ss))*deltta_hat(-1) + 2*Ll_hat(-2)) +
        (wpsi/2)*((1-psi_ss)^2)*(Lb_ss^2)*(-2*(psi_ss/(1-psi_ss))*psi_hat(-1) + 2*Lb_hat(-2));

// 24. Law of motion for K_hat
K_ss*K_hat = K_ss*(1-varphi)*K_hat(-1) + (Lb_ss/Rc_ss)*(Lb_hat - Rc_hat);

// 25. Indexing rule
w_hat(+1) - w_hat = (tauw*PI_hat);

// 26. Household BC
(Dl_ss/Rd_ss)*(Dl_hat - Rd_hat) + c_ss*(c_hat) - t_ss*t_hat
        = (w_ss*N_ss)*(w_hat + N_hat) + (Dl_ss/PI_ss)*(Dl_hat(-1) - PI_hat) - tr_ss*tr_hat;

// 27. Firm profit
pif_ss*(pif_hat) = y_ss*(y_hat) - (w_ss*N_ss)*(w_hat + N_hat) - ((psi_ss*Lb_ss)/PI_ss)*(psi_hat + Lb_hat(-1) - PI_hat) -
        (wpsi)*((1-psi_ss)^2)*(Lb_ss^2)*(-2*(psi_ss/(1-psi_ss))*psi_hat(-1) + 2*Lb_hat(-2));

// 28. Deposit bank profit
pil_ss*(pil_hat) = (Dl_ss/Rd_ss)*(Dl_hat - Rd_hat) - (Dl_ss/PI_ss)*(Dl_hat(-1) - PI_hat) +
        ((deltta_ss*Ll_ss)/PI_ss)*(deltta_hat + Ll_hat(-1) - PI_hat) -
        (Ll_ss/Rl_ss)*(Ll_hat - Rl_hat);
```

```
// 29. Merchant bank profit
pib_ss*(pib_hat) = - (I_ss*Rm_ss)*(I_hat - Rm_hat)
        + (Ll_ss/Rl_ss)*(Ll_hat - Rl_hat) - ((deltta_ss*Ll_ss)/PI_ss)*(deltta_hat + Ll_hat(-1) - PI_hat) +
        ((psi_ss*Lb_ss)/PI_ss)*(psi_hat + Lb_hat(-1) - PI_hat) - (Lb_ss/Rc_ss)*(Lb_hat - Rc_hat)  -
        (wdelta)*((1-deltta_ss)^2)*(Ll_ss^2)*(-2*(deltta_ss/(1-deltta_ss))*deltta_hat(-1) + 2*Ll_hat(-2))  +
         + (Bs_ss/PI_ss)*(Bs_hat(-1) - PI_hat) - (Bs_ss/Rb_ss)*(Bs_hat - Rb_hat) +
        (RL_ss*Bl_ss/((RL_ss - PSI)*PI_ss))*(Bl_hat(-1) - PI_hat - (PSI/(RL_ss - PSI))*Rl_hat) -
        (Bl_ss/(RL_ss - PSI))*(Bl_hat - (RL_ss/(RL_ss - PSI))*RL_hat);

// 30. Production function
y_hat = alppha*(K_hat) + (1-alppha)*(N_hat);

// 31 + 32. Balanced budget conditions
Dl_hat = Ll_hat;
Ll_ss*Ll_hat = mp_ss*mp_hat + (RL_ss*Bl_ss/(RL_ss - PSI)*PI_ss)*(Bl_hat - PI_hat(+1)
        - (PSI/(RL_ss - PSI))*Rl_hat(+1)) + Bs_ss*Bs_hat + Lb_ss*Lb_hat;

// ========================================================================
// GOVERNMENT
// ========================================================================

// 33. Gov Budget
g_ss*g_hat + (Bts_ss/PI_ss)*(Bts_hat(-1) - PI_hat) +
    (RL_ss*Btl_ss/(RL_ss - PSI)*PI_ss)*(Btl_hat(-1) - PI_hat - (PSI/(RL_ss - PSI))*Rl_hat)
    = (Bts_ss/Rb_ss)*(Bts_hat - Rb_hat)  + (Btl_ss/(RL_ss - PSI))*(Btl_hat - (RL_ss/(RL_ss - PSI))*RL_hat) + t_ss*t_hat ;

// 34. This is a budget balancing condition, need to include it.
Bts_ss*(Bts_hat) = Bcs_ss*(Bcs_hat) + Bs_ss*(Bs_hat);

// 35. Long run balanced budget condition
Btl_ss*(Btl_hat) = Bcl_ss*(Bcl_hat) + Bl_ss*(Bl_hat);

// 36. Growth rate of short run bonds
Bts_hat = gaama*(Bts_hat(-1) - PI_hat);

// 37. Growth rate of long-term bonds
Btl_hat = (RL_ss/(RL_ss - PSI))*RL_hat + rhob*(Btl_hat(-1) - (RL_ss/(RL_ss - PSI))*RL_hat(-1) - PI_hat) + elb*std_lb;

// 38 + 39. Shock to haircut
//kappas = rho_kap*kappas(-1) + ekp*std_kp;
//kappal*kappal_hat = rho_kapl*kappal*kappal_hat(-1) + ekp*std_kp;
end;

// ========================================================================
// STEADY STATE CHECK
// ========================================================================

resid(1);
steady;
check(qz_zero_threshold=1e-10);
```

```
// ========================================================================
// SHOCKS
// ========================================================================

shocks;
var em;
stderr 1;
end;

stoch_simul(irf=40);

// ========================================================================
// MODEL DIAGNOSTICS
// ========================================================================
// model_diagnostics(M_,options_,oo_)
```