Conventional and Unconventional Monetary Policy in a DSGE Model with an Interbank Market Friction

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Submitted for the degree of
Doctor of Philosophy (Economics)
at the University of St Andrews

October 2013

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For my beloved family

Acknowledgements

I would very much like to thank all the people who helped in my work. Professor Alan Sutherland supervised and mentored me for the final two years of my PhD research. I am immensely grateful for all his tireless input and encouragement over the years. The level of dedication and energy that he devotes into this thesis is remarkable. I have learnt and been inspired a lot from him. I would like to take this opportunity to thank him for all the great help and support. I would like to thank Dr. Ozge Senay for subsequently becoming my second supervisor in 2011, who inspired me after the previous presentations in school. I am also thankful to my previous supervisors Professor Christoph Thoenessen, Professor Charles Nolan and Dr. Tatiana Damjanovic, who guided and supervised me in the early stages of my research. I would also like to thank the School of Economics and Finance in general. I always enjoyed discussing my work with interested members of the faculty and I am grateful for the questions they asked and observations they made at my PhD presentations. I would like to in particular thank Professor Rod McCrorie, Professor Marco Mariotti, Professor Paola Manzini, Professor Kaushik Mitra, Dr. Alex Trew, Dr. Peter Macmillan and Dr. Jinhyun Lee. I would also very much like to thank my PhD colleagues, past and present. I immensely enjoyed their company and learnt a lot from them. I would like to particularly thank Morten Dyrmose, Orachat Niyomsuk, Min-Ho Nam, Ning Zhang, Bei Qi, Yu-Lin Hsu, Ansgar Rannenberg, Shona Munro and Liang Cao. I would like to thank the Scottish Institute for Research in Economics (SIRE) who supported me with a full PhD scholarship during my study. Thanks also to the Centre for Dynamic Macroeconomic Analysis (CDMA) where I learnt a lot as research associate.

I would like to dedicate this thesis to my dearest family, who support me and stand on my side no matter what happens.

Abstract

This thesis examines both conventional and unconventional monetary policies in a DSGE model with an interbank market friction. The recent crisis during 2007-2009 affected economies worldwide and forced central banks to implement not just conventional monetary policies, but also direct interventions in financial markets. We investigate a DSGE model with financial frictions, to test conventional and unconventional monetary policies.

The thesis starts by using the Gertler and Kiyotaki (2010)'s modelling framework, to examine eight different shocks under imperfect interbank market conditions. Unlike Gertler and Kiyotaki (2010) who consider the two extreme cases for the banking system, I firstly extend the analysis to a case in between the two extreme cases that they examined. The shocks considered include supply and demand shocks and also two shocks from the financial system itself (an interbank market shock and a shock to the deposit market). It is found that a negative shock to the interbank market has only a moderate impact to the banking system. However, a shock to the deposit market has a much stronger impact. Even though the impacts of these shocks are not large it is shown that the financial frictions magnify the effects of other shocks.

The model is extended to include price stickiness. A modified Taylor rule is analysed to test how conventional monetary policy should respond to the shocks in the presence of financial frictions. Specifically the credit spread is added as a third term in the monetary policy rule. The stabilising properties of the policy rule are analysed and a welfare analysis is conducted. The model is further developed to include unconventional monetary policy in the form of direct lending to private sector firms from the central bank. A policy rule for unconventional policy is tested and its stabilising and welfare properties are analysed.

Key Words: Financial Intermediation, Interbank Market Friction, Interbank Market Shock, Price Stickiness, Conventional and Unconventional Monetary Policies, Welfare Analysis.

Contents

Chapter 1
Financial Frictions and Monetary Policies during the Financial Crisis

1.1 The 2007 Financial Crisis

The literature on monetary policy has greatly expanded since the financial crisis of 2007. If we go back to the summer of 2007, when the crisis first started, the global economy has suffered from a severe shock in financial markets, which in turn affected all goods markets. It has been widely agreed that the crisis was started by the unexpected increase in delinquencies in the U.S. subprime mortgage market, which sequentially caused an enormous shock to investor's confidence in credit markets all over the world. Much recent research has focused on the modelling of the crisis. This research is either looking backwards or forwards. Backward looking research has concentrated on the prior weakness of the financial markets and has been investigating the underlying reasons for the sudden shock. On the other hand, forward looking research has focused on the follow-up chain reactions and damage to the economy and therefore investigates the fiscal and monetary responses of governments and central banks. Christiano et al. (2010) conclude that the recent research focuses on five areas, including the possibility for shocks to return unexpectedly in the future, asymmetric information in financial contracts, private banks' funding decisions, credit supply adjustments and intervention policies implemented by central banks during crisis times in the credit market. Whichever way current research is grouped, the motivation is the same——the avoidance of future crises and stabilization of the economy if crises do occur.

As is widely known, the current crisis started with the sudden jump in U.S. subprime mortgage delinquencies. However, Bernanke (2009c) argues that this is not the only reason for the sudden and fast collapse of the credit market, though it was an important trigger event. As argued in Elliott and Baily (2009), it was not just a bubble in the housing market. Before the rise of delinquencies in U.S. subprime mortgage market, financial markets in most countries were already quite fragile. Prior to the onset of the crisis, general credit standards in financial markets had been decreased gradually; average compensation for risky securities was falling; market reliance had been shifting to more complicated credit instruments; and furthermore, credit rating agencies broke down.

From historical experience, a full blown financial crisis can impact a great deal in both human and economic terms. The corresponding chain reactions create a large amplification from the shock, and therefore, damage the economy even further. Brunnermeier and Sannikov (2012) illustrated the severe follow-up reactions with a qualitative model. Other papers which analyse this ‘endogenous risk’ and amplification loop are Bernanke, Gertler and Gilchrist (1999) and Kiyotaki and Moore (1997).

The primary function of the interbank market is to transfer liquidity among banks. As stated in Allen and Gale (2000), the financial distress of a single financial institution may affect other financial institutions through contagion via the interbank market and may eventually have impacts on the rest of the financial system and the state of the total economy. Right after the crisis, in early September 2007, the rate at which British banks lend to each other – known as the London Interbank Offered Rate (LIBOR) – rose to its highest level in almost nine years. The three-month loan rate hit 6.7975%, above the Bank of England’s emergency lending rate of 6.75%, suggesting that banks were reluctant to lend money in the interbank market. Facing this difficulty in borrowing the interbank market, the Northern Rock Bank experienced serious funding problems in 2007. Similar problems happened in the two large US mortgage financial institutions the Countrywide and the IndyMac. Each party had to hold further funds to protect itself against possible risks and this further reduced the liquidity in the market. This 'gridlock' occurred in the interbank lending market during the crisis and reduced the funds available in the economy and was a major factor in the slowdown of economic activity during the crisis.

Monetary authorities faced high demand to ease the serious liquidity drought in financial markets. Both conventional and unconventional monetary policies were adopted during the crisis in 2007. The conventional monetary policies concerned the traditional tools of adjusting liquidity conditions, for example the short term policy interest rate as set by the Taylor rule function. Unconventional monetary policies related to other forms of monetary policy, which are particularly used when the policy interest rate are at or near the zero lower bound. Examples of unconventional monetary policies include credit easing, quantitative easing and signalling. In credit easing, central banks purchase private sector assets in order to improve liquidity and improve access to credit. During the credit crisis, the US Federal Reserve adopted several quantitative easing policies. The Bank of Canada made a "conditional commitment" to keep the interest rates at the lower bound until the end of the second quarter of 2010 (which is an example of the policy signalling).

There have been many research literatures about crises both before and after the 2007 financial crisis. In this thesis, I focus on a particular area. Starting with Chapter 2 I focus on a model of an imperfect interbank market under nine different types of shocks.

There are two major financial frictions considered in the model: the interbank market friction and a general friction in the banks' ability to raise funds from retail depositors. I consider shocks that arise from the interbank market and the deposit market and compare these financial shocks with all other supply and demand shocks to the model. Chapter 3 builds on the baseline model in Chapter 2 but adds price stickiness. Chapter 3 focuses on conventional monetary policies in the form of a modified Taylor rule function. I extend the Taylor rule to make the nominal interest rate respond to inflation, output and the spread between deposit and lending interest rates. The model is then tested with different policies and a welfare analysis is presented. Chapter 4 extends the analysis further to consider unconventional monetary policies in the form of direct lending by the central bank to private borrowers. Again a welfare analysis is presented.

In this chapter, I will summarise some relevant key literatures and highlight the extensions I present later in this thesis. The next sub-section firstly summarises key developments in DSGE modelling and financial markets. Section 1.3 provides a summary of key literatures relating to Chapter 2 about interbank market frictions. Section 1.4 summarises research on conventional monetary policy and thus provides some background to Chapter 3. Lastly Section 1.5 summarises the motivations and literatures on unconventional monetary policies, which relates to the modelling in Chapter 4.

1.2 DSGE Models with Financial Intermediation

Research in Dynamic Stochastic General Equilibrium (DSGE) models has developed rapidly to include financial intermediation and different types of frictions. This sub-section summarises some of the key papers in DSGE modelling history.

King and Plosser (1984) derived a standardised model integrating money and banking into a typical real business cycle (RBC) framework which is based on the models of Tobin (1963) and Fama (1980). Unlike the usual RBC model with financial intermediaries, the model distinguishes between inside and fiat money. It is still based on the traditional policies that central banks normally adopt to control the credit market, for instance, portfolio regulations, where it is restricted that private banks can only hold a certain fraction of their nominal asset portfolio in the form of non-interest-bearing reserves issued by the central bank. Alternative regimes are also discussed including reserve requirements for private banks and a regime of controlling the sum of currency and commercial bank reserves. By controlling this high-powered money, the price level can be stabilised, and consequently, real activity can be neutral with respect to price level changes. Additionally, King and Plosser's model includes price stickiness and transaction costs of services provided by financial intermediaries. It is used to discuss the correlations between the quantity of internal money and real economic activity. Rather than maximising utility, individuals make decisions based on minimising total transaction costs. This total transaction cost includes the cost of obtaining labour income and the cost of purchasing transaction services provided by the financial intermediary.

Labadie (1995) introduced a basic general equilibrium model with a traditional banking system, where private banks are restricted by reserve requirements. In the model Labadie focuses on open market operations and changes in nominal reserves of private banks. Similar to the statement from Boyd and Prescott (1986), the existence of financial intermediaries is motivated by the monitoring abilities and technology that banks have. This monitoring technology provides the private banks with a comparative advantage in issuing loans and gathering returns from lending. The key element in this model comes from the monitoring costs. It is learnt from this model that, when commercial banks are able to provide state-contingent standard debt contracts and when monitoring costs are fixed in real terms, the real return from loans will be unaffected by inflation. However, a different assumption about monitoring costs would cause variation in real lending and thus affect nominal transfers.

Modelling of monetary policies with financial markets has been a major focus of the recent DSGE research. Among the main research outcomes in recent years, Christiano, Eichenbaum and Evans (2005) have become the foundation for others to follow for this specific topic. However, their modelling was based on largely frictionless financial markets. Moreover, the monetary policies being considered were all conventional in nature, which could only capture some features for the start of the crisis, where traditional monetary policies were used. Another important contribution to the DSGE literature is Smets and Wouters (2007), who constructed a quantitative model to capture the effects of conventional monetary policies, again with frictionless financial markets.

Adding financial frictions into DSGE models with financial sectors has developed in a number of directions. Here we list some recent literature. Bernanke et al. (1999) introduce a financial friction into the typical DSGE model. They develop a model in which there is a two-way link between the borrowing costs of firms and the firms' net worth. This link is known as the "financial accelerator". It is shown that with asymmetric information, the external finance premium depends inversely on the net worth of potential borrowers. The friction arises from this asymmetric information. When potential borrowers have little net worth, providers of loanable funds expect higher agency costs and thus raise the external finance premium. Additional frictions also include price stickiness and lags in investment decision making. Using a sticky-price model calibrated to post-war US data, Bernanke et al. (1999) show that a different setup for the financial-accelerator mechanism both amplifies the impact of shocks and provides a quantitatively important mechanism that propagates shocks at business cycle frequencies.

Subsequent work using Bernanke et al.(1999) derive similar results. Hall (2001) used the Bernanke et al.'s framework for the U.K.'s data. Fukunaga (2002) test for the data of Japan. They have provided similar results. Based on Bernanke et al. (1999), Christensen and Dib (2008) estimates and simulates a sticky-price DSGE model to test for the effect of financial accelerator on economy. Differently from Bernanke et al. (1999), Christensen and Dib have adopted the nominal interest rate in the model. The monetary policy in their model is characterised by a modified Taylor-type rule, under which the monetary authority adjusts short-term nominal interest rates in response to inflation, output, and money-growth changes.

Differently from Bernanke et al. (1999), who have looked at the environments of the financial market (the financial accelerator), Kiyotaki and Moore (2008) focus at the limits of the ability for firms to gather funds.

Kiyotaki and Moore (2008) worked on a model focusing mainly on two constraints, where the borrowers can only make loans to a certain proportion of their investments (a borrowing constraint) and they can only sell a certain proportion of their own equities (the resale constraint). The recent shock in credit markets could be considered as a form of "liquidity shock", which affects both the borrowing constraint and the ability for resale constraint. From Kiyotaki and Moore's experiment with these constraints, it was found that when both the constraints bind, which would be the case where both the proportion of investment can be borrowed and the proportion of equity can be sold are very low, monetary policy could then play an essential role in the credit market. This would be another way to illustrate the recent crisis. Similarly in Bernanke and Gertler (1989) and Kiyotaki and Moore (1997), the credit constraints affect non-financial borrowers. Kiyotaki and Moore have therefore successfully included the liquidity shock in a model with two additional constraints.[1]

The modelling framework in Kiyotaki and Moore (2008) is a compact and tractable framework for modelling liquidity especially. But there are still some limitations in it. It has an incomplete contract based credit system. The collateral is set proportional to a bank's net worth. The instruments for monetary policy do not include the interest rate.

Based on Kiyotaki and Moore (2008), Bigio (2010) studies the properties of an economy subject to a random liquidity shock. In their model, liquidity shocks affect the ease with which the equity can be used to finance the down-payment for firms' new investment projects. They have found that, the liquidity shocks have the similar effects of investment shocks. Liquidity shocks are not an important source of business cycle fluctuations in absence of other frictions affecting the labour market. Hirano and Inaba (2010) examine the effect of asset price bubbles in the Kiyotaki and Moore's model. They have shown that, the dynamic interactions between asset prices and output will generate powerful bubbly dynamics. Based on the structure of the model followed Kiyotaki and Moore (2005, 2008), Kurlat (2013) analyse a model where the key friction in financial markets is asymmetric information about asset qualities. He introduces a wedge between the return on saving and the cost of funding.

[1] Liu et al. (2010) focuses on this constraint and provides a more detailed analysis for the impact of this particular friction. Other relevant contribution to modelling of the liquidity shocks can be found in Kiyotaki and Moore (2003, 2005).

More recent monetary DSGE models incorporating financial sectors can also be found in Gilchrist et al. (2009), Christiano et al. (2009), Boyd and Gertler (2004) and Del Negro et al. (2010).

Del Negro et al. (2010) extended the model in Kiyotaki and Moore (2008) to include nominal wage and price frictions, and also explicitly incorporated the zero bound on the short-term nominal interest rate. Their model shows that the irrelevance result of Wallace (1981) (where it is found that non-standard open market operations in private assets are irrelevant) breaks down.[2] Del Negro et al embed Kiyotaki and Moore credit frictions in a relatively standard DSGE model along the lines of Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007). This model contains standard frictions, such as wage and price rigidities and aggregate capital adjustments costs. Standard monetary policy then takes the form of variations in the nominal interest rate. Non-standard policy is open market operations in private assets that increase the overall level of liquidity in the economy. In this paper they break Wallace's irrelevance result incorporating a particular form of credit frictions, proposed by Kiyotaki and Moore (2008). Based on the Kiyotaki and Moore model, Driffill and Miller (2013) consider the source of the crisis of 2007/8 to be a shock to the resaleability of private assets. This causes the private market for credit to freeze which causes a sudden decrease in asset prices. This captures central aspects of the crisis of 2007/8. It has also been found that once the zero bound on the short-term nominal interest rate is introduced, and in the absence of unconventional policy intervention, the economy may suffer a Great Depression-style collapse.[3] However, Del Negro et al (2010)'s model has disadvantages in mainly three ways: first,

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[2] This irrelevance result has been extended and supported by a range of researches, including Eggertsson and Woodford (2003) and Taylor and Williams (2009).

[3] Similar results can be found in: Christiano et al. (2011) and Eggertsson (2011). They report that the 'multiplier of government spending' is unusually large at zero interest rates.

the model has only "reduced form" liquidity constraints; secondly, the lack of an incentive structure for the private sector which may endogenously change the reduced form liquidity constraints; and lastly, the model does not include the cost of non-conventional government intervention.

Christiano et al. (2010) have developed a standard monetary DSGE model to include a banking sector and financial markets. They found that agency problems in financial contracts, liquidity constraints facing banks and shocks that alter the perception of market risk and hit financial intermediation are prime determinants of economic fluctuations. They consider four kinds of shocks to the economy, a "price of investment shock", a "marginal efficiency of investment shock", a "financial wealth shock" and a "risk shock". In fact, the liquidity provided by the central bank can be considered as a substitute for market liquidity when private credit vanishes during a crisis. Evidence on liquidity replacement could also be found in many other works, including Brunnermeier (2009), Brunnermeier and Pederson (2009), Bernanke (2009b) and Trichet J.C. (2010). These contributions show that the liquidity policies implemented by central banks during the crisis have greatly reduced the impact of the financial panic.

Other macro models incorporate financial frictions by introducing an agency problem between borrowers and lenders. Relevant examples of this method can be found in Williamson (1987), Kehoe and Livene (1993), Holmstorm and Tirole (1997), Carlstrom and Fuerst (1997), Caballero and Kristhnamurthy (2001), Kristhnamurthy (2003), Christiano, Motto and Rostagno (2005), Lorenzoni (2008), Geanakoplos and Fostel (2008), Brunnermeir and Sannikov (2009). Among these contributions, the agency problem creates a wedge between the cost of external finance and the opportunity cost of internal finance, which therefore adds to the overall cost of credit that a particular borrower faces when demanding funds.

1.3 Interbank Market Frictions

As already explained, the interbank market played an important role in the financial crisis in 2007. For this reason the interbank market is the major focus in this thesis. In Chapter 2, using a variant of the model developed by Gertler and Kiyotaki (2010) I illustrate in more detail how interbank market frictions affect the economy and demonstrate the effects of a shock arising from the interbank market itself. In this section, I summarise some literatures and facts relating to the interbank market and frictions which relate to interbank borrowing and lending.

Right after the crisis, borrowing in financial markets became tougher and interest rates higher, reflecting increasing risk premiums. The elevated risk premiums on interbank market loans are of particular importance. The London interbank offered rate (LIBOR) is considered to be an indicative rate for interbank market loans and can be used to measure the risk premium on interbank loans. McAndrews et al. (2008) compared LIBOR to the expected overnight interest rate over matched terms. They used the short-term one-month and three-month LIBOR rates and the Overnight Index Swap (OIS) rate from mid-2007 to mid-December 2008. In the first half of 2007, the one-month and three-month LIBOR-OIS spreads were both very small.[4] In August 2007, both the one-month and the three-month LIBOR-OIS spreads increased sharply to almost 100 basis points. The raised spread indicates the increased risk premium on the

[4] Before the crisis in 2007, the one-month LIBOR-OIS spread was about 5 to 6 basis points; the three-month spread was about 7 to 9 basis points.

interbank market. This could also be viewed as an increase in the interbank friction. The combination of uncertainty in banks' credit and evaporating liquidity in the interbank market was also a huge drag in the banking sector, and in turn on the economy. The tightening of banks' credit availability and financial conditions further strained the fragile economy after the crisis. Thus, in Chapter 2, we focus especially on the tightening in interbank market credits, the interbank market frictions and investigate a shock originating in the interbank market. Our modelling framework follows the ones described in Gertler and Kiyotaki (2010).

Gertler and Kiyotaki (2010) have structured a model with interbank market frictions. This friction is created by dividing private banks into two types: the banks based on investing islands and the banks based on islands without any investing opportunities. Those banks located on investing islands would not be able to satisfy the large demand for financial supports on their islands solely by using deposits. They have to borrow from the other banks which are located on non-investing islands. By the end of the period, banks on investing islands should pay back the amount they borrowed from the banks on non-investing islands. However, it is assumed that borrowing banks have the incentive to divert a certain fraction of these interbank loans for personal use. If they divert assets, the bank defaults on its debt and shut down. Lending banks could only reclaim a fraction of interbank loans. Because lenders recognise banks' incentive to divert funds, the lending amount will be restricted. This friction in the banking system potentially magnifies the damage to the economy from a crisis. Gertler and Kiyotaki (2010) examine how the economy responds to a capital quality shock in two extreme cases of the banking system, one with a perfect interbank market and one with an imperfect interbank market. For the perfect interbank market, all of the interbank loans are returned to the lending banks by the end of each period. However, for the imperfect interbank market, lending banks are no more efficient than depositors in recovering their assets from the borrowing banks.

Unlike Gertler and Kiyotaki (2010) who consider the two extreme cases for the banking system, we have extended their model to a case in between the two extreme cases. We also consider two other shocks which might represent possible trigger for the crisis. We consider the possibility that the crisis came from a shock to the efficiency of financial markets rather than the quality of the real capital. The model in Chapter 2 extend the model further with two new shocks to simulate the shock to the efficiency of financial markets: one is a shock to the fraction of funds that can be diverted by bankers in the deposit market (the overall financial market shock); another one is a shock to the fraction of funds that can be diverted by bankers in the interbank market (the interbank market shock). By introducing these two shocks it can be seen how a sudden rise in financial frictions affects the economy.

1.4 Conventional Monetary Policy Regimes

The monetary authority's response to a crisis is obviously a very important factor in determining how a crisis develops. Thus, monetary policy is an important topic of research. Chapter 3 of this thesis focuses particularly on the conventional monetary policies, i.e. policies based on the use of the short term interest rate. The analysis in Chapter 3 is built on the baseline modelling framework presented in Chapter 2. This section describes some key developments from existing literature on the conventional monetary policy response to the crisis.

Inflation targeting has been widely adopted and has successfully controlled the inflation rate in many countries. In Bernanke and Mishkin (1997), inflation targeting has been described as a monetary policy where publicly announced medium-term inflation targets provide a nominal anchor for inflation expectations, while allowing the central bank some flexibility to help stabilise the real economy in the short run. The inflation-targeting approach dictates that central banks should adjust monetary policy actively and pre-emptively to offset incipient inflationary or deflationary pressures. Since adopted by central banks, the inflation-targeting policy has generally performed well in practice, in controlling the inflation rate and stabilising the real economy.

However, though this policy has successfully brought inflation rate under control, financial markets continued to display instability. This was particularly evident in early stages of the crisis in 2007, with the financial crisis originating from the sub-prime mortgage market. During the early stages of the crisis, asset prices deteriorated very sharply, which effectively caused the external finance premium to jump. The conventional inflation-targeting monetary policy approach did not performed well during this period. Under the conventional inflation-targeting regime, variations in asset prices would only affect the policy to the extent of affecting the monetary authority's forecast of inflation. When monetary policy initially remained unresponsive and focused on the inflation-targeting pressures only, the asset price crash did major damage to the economy. Thus, the 2007 crisis has highlighted the overconfidence in the self-adjusting ability for the economy and financial system itself and the lack of monetary policy control for financial stability.[5]

[5] For instance, the Bank of England and the ECB were slow to respond to the crisis, because of a continued concern with the relatively high inflation rate. Stock markets in the US, Europe and the UK started to decline sharply from October 2007 onwards. However, policy interest rates in the Eurozone and the UK did not start to be reduced until late 2008, by which time the main stock market indexes had already

Since the crisis economic research has not only started to develop new thinking on the role of financial intermediaries but has also started to examine the appropriate monetary policy regimes that could be adopted to reduce the damage from the crisis. It has been argued that focusing on inflation control only is not sufficient for monetary authorities to stabilise financial markets. In the context of short-term monetary policy management, central banks should view price stability and financial stability as highly complementary and mutually consistent objectives, to be pursued within a unified policy framework.

Before the crisis in 2007, policymakers concentrated on analysing many developments in inflation-targeting policy, of which one important dimension is how to adopt a policy which includes monitoring the volatility of asset prices. Bernanke and Gertler (1999) provide a good example of an analysis which extends the focus of monetary policy to stabilise financial markets rather than just inflation-targeting. They employed simulations of a macroeconomic model to examine how an inflation-targeting policy might face problems in a "boom-and-bust" cycle in asset prices. They addressed the issue of how should monetary authorities respond to asset price volatility. In Bernanke and Gertler (2001) they extended the policy regime to one including responses of the nominal interest rate to inflation, output and stock prices in a Taylor rule.[6] They found that an

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fallen by over 25%. The reason for the delayed reaction was the fact that inflation was well above target in the Eurozone and the UK throughout 2008 (at around 4%). The Fed reacted more quickly to the crisis by reducing its policy rate from early 2008 onwards, but still not immediately after the stock market falls. Central banks' delays in cutting policy rates and introducing other non-conventional policies contributed to the severity of the crisis. GDP in Eurozone, US and UK began to contract sharply from early 2008, well before policy began to ease in these areas. Had monetary authorities responded to the asset price falls in 2007 (rather than waiting for inflation forecasts to decline), the crisis may not have had such a large impact on real activity.

[6] Bernanke and Gertler's (2001) model is based on Bernanke et al. (1996) and includes credit market frictions which depend on initial financial conditions. The extent to which an asset price contraction weakens the private sector's balance sheets depends on the degree and sectoral distribution of initial risk exposure. They found that, if the balance sheets are initially strong, with low leverage and strong cash flows, then even large declines in asset prices are unlikely to push households and firms into financial

aggressive inflation-targeting policy rule (where the coefficient relating the instrument interest rate to expected inflation is 2.0) substantially stabilizes both output and inflation to both the asset price and technology shocks. In other words, inflation-targeting central banks automatically accommodate productivity gains that lift asset prices. Bernanke and Gertler (2001) concluded that inflation-targeting central banks need not respond to asset prices, except when the asset prices affect the inflation forecast. They argued that the best policy framework for attaining both price-stabilising and financial market stabilisation is a regime with flexible inflation targeting.

Curdia and Woodford (2009) adopt a model with imperfect financial intermediation to test both conventional and unconventional monetary policies. They introduce imperfections in the private banking sector and the possibility of disruptions to the efficiency of intermediation as exogenous disturbance to the model. They also introduce "non-trivial heterogeneity" in bank's spending opportunities in the model. The credit frictions in their model complicate the relationship between the central bank's policy rate and financial conditions more broadly. Considering these frictions, they conclude that, the traditional interest-rate monetary policy should continue to be a central focus of monetary policy deliberations, despite the existence of time-varying credit frictions.

Since Bernanke and Gertler (1999, 2001) have extended the original Taylor rule to include stock prices as a variable in the Taylor rule, the result gives a zero response to the stock prices as the best policy. Unlike Bernanke and Gertler (2001), we address the question of how central bankers ought to respond to asset price volatility and financial instability, with another extension of the Taylor rule. Chapter 3 analyses a Taylor where the credit market spread is included rather than asset prices (as in Bernanke and Gertler,

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distress.

1999 and 2001). The structure of the model of Chapter 3 follows the monetary DSGE model explained in Chapter 2, but also includes price stickiness. After adopting the credit spread (i.e. the spread between the return on banks' assets and the return to households' deposits) as a new variable in the Taylor rule, I test the implications of the rule for output and inflation variability. Additionally, by carrying out a consumption-based welfare analysis, I illustrate the optimal policy regime.

1.5 Unconventional Monetary Policies

Because of the severity of the crisis in 2007 many unconventional monetary policies were adopted in an attempt to stabilise financial markets and stimulate the economy. These policies played a very important role. Chapter 4 of the thesis investigates the use of unconventional monetary policy. Again, this analysis is conducted using the model of interbank market frictions presented in Chapter 2. This section summarises the key facts and literatures relating to unconventional monetary policies.

After the crisis, there is a need for fast and sound fiscal and monetary policies to heal the damage caused by the shock and to avoid further damage to the economy. There have been many examples in history where the monetary and fiscal policy responses to financial crisis have been slow and inadequate. In these cases the initial problems caused by the crisis are not solved and, moreover, the ultimate result is greater damage to the economy and massive fiscal costs and problems.

During the recent crisis, most countries have been aware of these historical lessons and, with some delay, responded with significant falls in policy interest rate. The initial response involved a sharp decline of central banks' policy interest rates. For example, the

U.S. Federal Reserves decreased their federal funds rate from 5.25% to a range of 0%-0.25% from January 2008 to January 2009, which has been extended till current periods. The Bank of England decreased its interest rate from 5.0% to 0.5% from October 2008 to March 2009. Additionally, in order to ease the fund in the interbank market, the interbank offered rate had also decreased in the recovery period after the crisis.

Figure 1.1 shows a rough trend for the interbank market rate in normal times and in crisis. The figure contains three significant financial crisis happened in the past. The shadow areas cover the main crisis periods in recent history. The first shadow area representing the US 1989-1992 Saving and Loan crisis between March 1990 to September 1992, which caused a corresponding recession both in the domestic economy and internationally. This recession lasted for approximately three years from 1989 to 1992. The second shadow area shows the stock market crash which happened in 2000 with a loss of 5 trillion US dollars in market value from March 2000 to October 2002. The impact from the bursting of dot-com bubble expanded to the whole economy. The third shadow area shows the recent financial crisis of 2007-2010, which caused the LIBOR to fall to a new low level of nearly 0% after the shock.

Immediately following the crisis the monetary easing reflected in significant reductions in policy interest rates has offset to some degree the financial turmoil. However, the stabilising effect of interest rate cuts has been considered incomplete, as widening credit spreads, more restrictive lending standards, investors' low expectations and credit market dysfunction have worked against the monetary easing and led to tighter financial conditions overall. In particular, many traditional funding sources for financial institutions and markets have dried up.

Obviously, the financial crisis that occurred in 2007 highlighted the constraints implied by the zero lower bound on nominal interest rates as an important motivation for unconventional monetary policy. It has also highlighted the role that financial frictions play as a source of shocks in the transmission and amplification of non-financial shocks. Models of financial frictions, such as the model introduced and analysed in chapters 2 and 3, show that financial frictions create a spread between deposit rates and bank lending rates. This credit spread plays an important role in transmitting and amplifying all types of shocks and it may be a source for shocks itself. The existence of this credit spread creates a second motivation (i.e. in addition to the zero lower bound) for considering unconventional monetary policy. Unconventional policy creates the possibility for policymakers directly to tackle the credit spread. A policy tool which directly offsets the financial frictions which create the credit spread may offer a useful means directly to offset the effects of financial shocks and directly to reduce the amplification and transmission role of the credit spread.

Central banks in most countries have adopted unconventional policies to assist the recovery process. As shown in Del Negro et al. (2010)'s model, once the zero bound on the short-term nominal interest rate has been reached, the economy suffers a 'Great Depression-style' collapse in the absence of more direct policy intervention. In reality, during the period 2007-2009, in addition to traditional tools, most central banks have worked to support credit markets and also to reduce financial strains by providing liquidity to the private sector. In Bernanke (2009a)'s speech about the financial crisis, he confirmed that the Federal Reserve would adopt further powerful tools to fight the financial crisis and the continuing recession, even though the federal funds rate had reached its lower bound and could not be reduced any further. In the years after Bernanke's speech, the Federal Reserve has made a number of unconventional interventions to help with the downturn in the economy and has gone some way to solve major problems in the financial market. These examples show that there have been many cases of unconventional monetary policies, where central banks and governments intervene directly in the financial markets.

Table 1.1 summarizes unconventional monetary policies into three groups: assisting financial institutions and commercial banks, assisting credit markets directly, and assisting in long-term securities. One example of the first group of assisting financial institutions would include discount window lending to private banks. The second group would include central banks' direct lending to firms. The last group includes government equity injection into private financial intermediaries. These policy tools were adopted one after another at various times during the crisis. Policy of this type will be analysed in Chapter 4.

Among these additional policy tools, some were already available prior to the crisis and some were just created as the need arose during the crisis. Practically, we have seen these interventions in many cases. For example, the investment bank Merrill Lynch has agreed to be acquired by Bank of America. The very large commercial bank Wachovia agreed to be sold. Two largest remaining freestanding investment banks, Morgan Stanley and Goldman Sachs, were stabilized when the central bank approved, on an emergency basis, their applications to become bank holding companies. On 18th September 2008, the U.K. mortgage lender HBOS was forced to merge with Lloyds TSB. In mid-October 2008, the Swiss authorities announced a rescue package for UBS, one of the world's largest banks, which consisted of a capital injection from the authority and a purchase of assets. In July and August 2007, two German banks IKB and Sachsen LB, that had relied heavily on market funding through asset-backed commercial paper (ABCP) conduits, received assistance from public-sector owners to cope with severe funding pressures. In September 2007, Northern Rock, the large mortgage lender who also used to rely heavily on securitisations for funding, was nationalized by U.K. authorities after experiencing a run by retail depositors. Moreover, in February 2008, West LB, another German bank with large ABCP conduits, received protection against losses from its owners, including the state of North Rhine-Westphalia. In March 2008, the U.S. Treasury and the Federal Reserve facilitated the acquisition of the investment bank Bear Stearns by JPMorgan Chase & Co. Obviously, these central banks were not providing funds to all the private financial intermediaries with liquidity problems during the crisis. The direct intervention and liquidity facilities were only allocated to a range of financial intermediaries and lenders in financial market, which were considered to be "insolvent" intermediaries or institutions.

Gertler and Karadi (2009) derived a monetary DSGE model with financial intermediation to test central banks' unconventional monetary policies during a simulated financial crisis. An agency problem with endogenous constraints on intermediary leverage ratios is introduced, which constrains the overall credit flows to equity capital. The advantage processed by the central bank comes from the agency problem, where the central bank does not have such a restriction, thus does not face any constraints on its leverage ratio. Therefore, when financial shocks hit the market, the central bank can intervene to support credit flows. However, a trade-off arises from the efficiency of adopting such policies. Intermediation carried out by the central bank is assumed to be less efficient than ordinary private intermediation. The experiment by Gertler and Karadi (2009) shows that welfare benefits arise from unconventional policy implemented directly by central bank. However, although this model creates a framework for unconventional monetary policies in a quantitative way, it does not include interbank credit market frictions, and thus the model can not comprehensively explain the default risk and the chain reaction that was part of the current crisis. Gertler and Kiyotaki (2010) have followed the unconventional monetary policy in Gertler and Karadi (2009), extended with interbank market frictions. However, they have not considered price stickiness into the model. In chapter 4 we demonstrate the unconventional monetary policy with price stickiness. Thus, the unconventional monetary policy is compared and examined with the existing conventional policy under a Taylor rule. We adopt the welfare analysis to test for the welfare-optimised unconventional monetary policy parameter under different Taylor rule policies.

It is important to note that, in common with Gertler and Karadi (2009), the motivation for considering unconventional policy is that financial frictions create a credit spread which may be tackled via directly lending by the central bank. As explained above, this motivation is separate from the existence of the zero lower bound on the nominal interest rate, which creates an additional important reason for considering unconventional policy (but not directly analysed in this thesis).

1.6 Conclusion

Since the 2007 financial crisis, there have been much new research about the crisis. In this thesis, I focus on interbank market frictions and both conventional and unconventional monetary policies. Starting in Chapter 2, I describe the baseline modelling framework with an interbank market friction and shocks that arise from financial markets. Compared to Gertler and Kiyotaki (2010), the thesis analyses an intermediate level of the interbank market friction. The model also considers a much wider set of demand and supply shocks than consider by Gertler and Kiyotaki. From the impulse response functions (IRFs) of the model, the analysis shows how the financial frictions amplify the effects of these shocks. Among these shocks I have introduced two new shocks — an interbank market shock and a shock to the fraction of divertable funds in deposit market. From the IRF analysis, it is shown how the shocks originating in the financial market may be transmitted to the real economy via financial frictions.

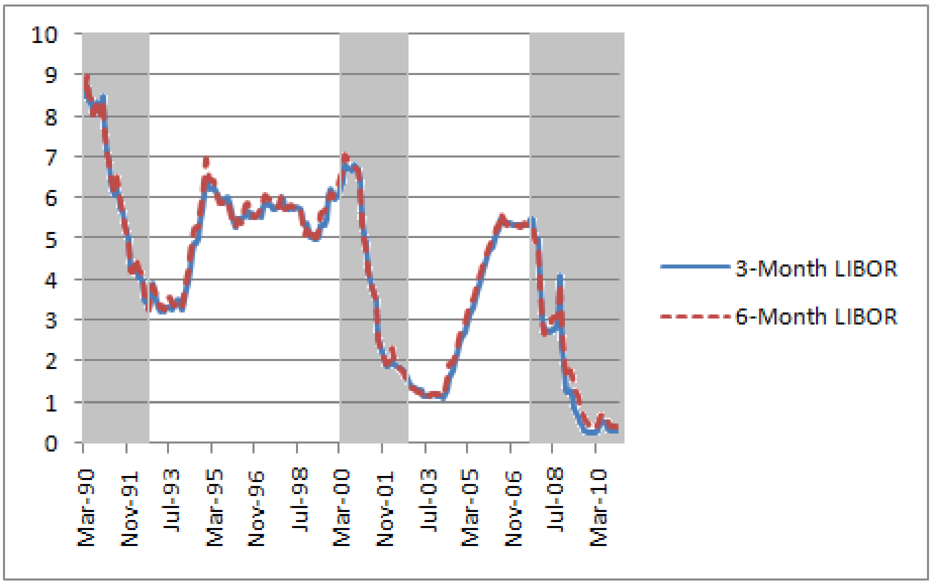
Chapter 3 builds on the baseline model in Chapter 2 and adds price stickiness to the model. This chapter focuses on conventional monetary policy on the form of a modified Taylor rule. It analyses the positive and normative implications of adding the credit spread to the Taylor rule in the presence of a wide set of shocks. Chapter 3 investigates not only the IRFs under several different cases of the model, it also investigates the optimal conventional monetary policy and welfare analysis in the model. The analysis is based on IRFs, the unconditional second moments of the model and a welfare function based on a second order approximation of aggregate utility.

Chapter 4 analyses unconventional monetary policy in the presence of interbank market frictions. This chapter investigates unconventional monetary policy in the form of direct lending by the central bank in the presence of the supply and demand shocks with different cases for the model. It also incorporates the conventional monetary policy together with this unconventional policy to illustrate the optimal regime to respond to the shocks under several important cases. Chapter 4 analyses the positive and normative implications of these policies with welfare analysis based on a second order approximation of aggregate utility.

Table 1.1 : Grouping of Unconventional Intervention Policies

Lender of Last Resort	creating new facilities	eg. UK, US
	discount window lending	eg. US, ECB
	bilateral currency swap	eg. US, China
Liquidity to Borrowers in Key Credit Markets	purchase of highly rated paper	eg. ECB, US
	backup liquidity for mutual funds	eg. US
	facility against AAA securities	eg. EU, US, Canada
Purchase of Longer Term Securities for Central Banks' Portfolio		eg. US, Canada

Figure 1.1 : LIBOR Historical Trend



Source : Bank of England Statistics.
3 − month and 6 − month LIBOR data from March 1990 to March 2011.

Chapter 2
Financial Intermediation with Interbank Market Frictions

Abstract

The global economy experienced a serious crisis starting in 2007. This has led to a major recession and has been widely transmitted into almost every market in the global economy. Economic researchers has started to consider what was wrong with our global economic structure, what types of risks were hiding prior to the occurrence of the crisis and what should be done to minimise the damage from such crises. A wide range of monetary models have been developed in the macroeconomics literature. They incorporate detailed consideration of the banking system and financial intermediation. Among recent contributions, Gertler and Kiyotaki (2010) have considered a monetary DSGE model where a shock to the quality of the capital stock is the initial cause of the crisis. They examine how the economy responds to the shock in two extreme cases: a perfect and an imperfect interbank market. This chapter extends their analysis to a case in between the two extreme cases. It also introduces a range of demand and supply shocks along with two financial shocks which represent possible initial causes of the crisis. One of the financial shocks is a shock to the fraction of funds that can be diverted by private bankers in the deposit market, the other is a shock to the fraction of funds that can be diverted by bankers in the interbank market. These represent shocks to the efficiency of financial markets.

2.1 Introduction

Starting in 2007 the economy experienced a severe crisis in financial and credit markets which has led to a major recession. This has been widely transmitted to almost every market in the global economy. After this painful experience economists started thinking about what was wrong with our globally connected economic structure, what kinds of risks were hiding prior to the occurrence of the crisis and what should be done in order to minimise the damage from such crises in the future. The macroeconomic literature has developed rapidly to consider a wide range of monetary DSGE models which incorporate detailed consideration of the banking system and financial frictions. One important contribution to this new literature is Gertler and Kiyotaki (2010) who have considered a model where a shock to the quality of the capital stock is the initial cause of the crisis. Using a monetary DSGE model with interbank market frictions, they examine how the economy would respond to the shock in two different cases, one with a perfect interbank market and one with an imperfect interbank market. In this chapter I have extended their model to a case in between the two extreme cases that they examined. In addition I consider two financial shocks which may represent possible causes of the crisis. So, unlike Gertler and Kiyotaki (2010), I consider the possibility that the crisis came from a shock to the efficiency of financial markets rather than the quality of real capital. I introduce two financial shocks to simulate the shock to the efficiency of financial markets—— one is a shock to the fraction of funds that can be diverted by bankers in the deposit market and one to the fraction of funds that can be diverted in the interbank market. From simulation of the model I have found that both these shocks have an impact to the economy. But the shock to the deposit market has a much larger impact than the shock to the interbank market. Furthermore, I have also included four demand shocks to the economy.

There have been many other research literatures focusing on the crisis. It has been quite widely agreed that, the crisis was started by the unexpected rise in delinquencies on sub-prime mortgages in the US mortgage market, which caused an enormous shock to the confidence of various investors in credit markets not only in U.S. but involving markets all over the world sequentially. A whole new set of macroeconomic models has been developed after the crisis, some of which build on previously existing literature. Bernanke et al. (1999) introduced a "financial accelerator" into the typical DSGE model. This approach has inspired many different models of credit market frictions and the corresponding role of these frictions. The key mechanism is the "financial accelerator", which captures a basic idea of the link between the external finance premium and the net worth of potential borrowers. They found that with asymmetric information, external finance premium depends inversely on the net worth of potential borrowers. The friction mainly rises from the asymmetric information. When potential borrowers are believed to have very little net worth, providers of loanable funds normally expect higher agency costs with larger external finance premium. Additional credit market frictions also include price stickiness, lags in investment decision makings and heterogeneity among firms. Investment decision lags generate not only the "hump-shaped" output responses, but also a lead-lag relationship between price level and the investment. And last, the heterogeneity among firms comes from the reality that debtors normally have differential access to capital markets.

Similarly to Bernanke et al (1998), many macro models have adopted financial frictions by introducing the agency problem between borrowers and lenders. By doing this, the financial market frictions have been endogenised inside the model. Relevant models with this method can be found in Williamson (1987), Kehoe and Livene (1994), Holmstorm and Tirole (1997), Carlstrom and Fuerst (1997), Caballero and Kristhnamurthy (2001), Kristhnamurthy (2003), Christiano, Motto and Rostagno (2005), Lorenzoni (2008), Geanakoplos and Fostel (2008), Brunnermeir and Sannikov (2009). Among these approaches, the agency problem creates a wedge between the cost of external finance and the opportunity cost of internal finance. It has been added to the overall cost of credit that a particular borrower faces when demanding funds.

Kiyotaki and Moore (2008) developed two types of frictions in credit market. One relates to the ability of firm's resale constraint. During a specific period, a firm can sell only a limited fraction of the illiquid assets to improve the liquidity of the firm. They have developed another credit friction by introducing a standard borrowing constraint.

With this constraint, a borrower can only borrow up to a fraction of the present net return of the investment.

Gertler and Karadi (2009) have considered a model where a shock to the quality of real capital is the initial cause of the crisis. They have included financial intermediation to fund firms' new investment. However, they have not introduced the interbank market within the banking system. Without the interbank market frictions, the model would not be able to comprehensively explain the defaulting risk and the economy's corresponding reaction under different conditions of the banking system. This has been extended with Gertler and Kiyotaki (2010) with interbank market frictions. This friction is created by dividing private banks into two types: the banks based on investing islands and the banks based on islands without any investing opportunities. Those banks located on investing islands would not be able to satisfy the large demand for financial supports on their islands solely by using deposits. They have to borrow from the other banks which are located on non-investing islands. By the end of the period, banks on investing islands should pay back the amount they borrowed from the banks on non-investing islands. However, it is assumed that borrowing banks have the incentive to divert a certain fraction of these interbank loans for personal use. If they divert assets, the bank defaults on its debt and shut down. Lending banks could only re-claim a fraction of interbank loans. Because lenders recognise banks' incentive to divert funds, the lending amount will be restricted. This friction in the banking system potentially magnifies the damage to the economy from a crisis. Gertler and Kiyotaki (2010) examine how the economy responds to a capital quality shock in two extreme cases of the banking system, one with a perfect interbank market and one with an imperfect interbank market. For the perfect interbank market, all of the interbank loans are returned to the lending banks by the end of each period. However, for the imperfect interbank market, lending banks are no more efficient than depositors in recovering their assets from the borrowing banks.

Unlike Gertler and Kiyotaki (2010) who consider the two extreme cases for the banking system, in this chapter I have extended their model to a case in between the two extreme cases that they examined. I also consider two other shocks which might represent possible initial causes of the crisis. Unlike Gertler and Kiyotaki (2010), I consider the possibility that the crisis came from a shock to the efficiency of financial markets rather than the quality of the real capital. I thus extend the model further with two new shocks to simulate the shock to the efficiency of financial markets: one is a shock to the fraction of funds that can be diverted by bankers in the deposit market (the overall financial market shock); another one is a shock to the fraction of funds that can be diverted by bankers in the interbank market (the interbank market shock). By introducing these two shocks it can be seen how a sudden rise in financial frictions affects the economy.

From simulation of the model I have found that both these shocks to the efficiency of financial markets have an impact to the economy. The shock to the friction in the deposit market has a much larger impact than the shock to the interbank market. The interbank market shock has limited impact to the whole economy compared to the capital quality shock and the shock to the deposit market.

The remainder of this chapter is structured as follows: Section 2.3 describes the features and the construction of the monetary DSGE model with interbank market frictions in detail. Section 2.4 describes the quantitative results for the model and analysis of the results. Section 2.5 provides a sensitivity analysis for the model and Section 2.6 concludes this chapter.

2.2 Model

This section explains the construction of the model in detail. The model consists mainly of three parts: households, firms and financial intermediaries. Households act as workers and bankers. In each period, a certain fraction of households switch from workers to bankers. Firms demand loans from the private banks to fund their investment. By the end of each period, firms return the financial loans back to their local banks. Financial intermediaries, which are commercial banks, issue loans to firms. They also borrow or lend to the banks in the interbank market. If the bank defaults, the banker can abscond with a certain fraction of the bank's assets. Thus, there is an incentive constraint in the model to prevent the banker diverting funds when the bank defaults. This incentive constraint limits the size of the banks' balance sheets so the bankers would prefer to keep operating the banks rather than abscond.

This limit in the size of banks' balance sheets implies that the capital stock is lower than it would otherwise be, which in turn implies that the marginal product of capital and the rate of return on the capital stock (R_{kt}) is higher than the deposits interest rate (R_t). In other words, there is a credit spread ($SP_t = R_{kt} - R_t$). This credit spread is endogenous in the model, which amplifies the effects of demand and supply shocks on the economy.

In addition to the financial friction originated from the banker's diverting assets when the bank defaults and the limit in the banks' balance sheets described above, there is also an interbank market friction in the model. In the imperfect interbank market, banks may also abscond with the funds borrowed from the interbank market. This adds another dimension to the financial friction and further adds to the credit spread. Shown in the later sections, shocks to the deposit market and the interbank market can also be transmitted to the real economy via the credit spread.

The following sub-sections describe the three parts of the model in detail and discuss the calibration and steady states for the model.

2.2.1 Goods Production Firms

To describe the framework of the model for firms and financial intermediaries, we firstly need to make clear the structure of this economy. In order to simulate an interbank market friction, it is assumed there is a continuum of islands in the economy. Investment opportunities randomly arrive to a proportion π^i of the islands (the "investing islands") at the beginning of each period. It is assumed the arrival of the investment opportunities is i.i.d. across islands. Firms locating on investing islands extend their production lines and acquire new capital stock in the period. Thus, a large demand for loans arises in financial markets on investing islands. It is assumed that firms can only borrow from the banks locating on the same island. Investing islands' banks therefore face high demand for loans. However, they are not able to satisfy these needs unless they borrow from the other banks based on non-investing islands, which do not face large loan demands from firms located on their islands. On the non-investing islands, firms do not have any investment opportunities and no new capital is created on those islands. Banks located on the non-investing islands would not face any demand for loans and can lend their excess funds to the banks on investing islands in the interbank market.

The production side of the economy consists of two types of producers: the goods production firms and the capital goods firms. Goods production firms purchase capital stocks from the capital goods firms and produce final goods for the economy. Both goods production firms and capital goods firms locate on the continuum of islands. Goods production firms follow a production function in the form of a Cobb-Douglas function with capital and labour as inputs. It is assumed that capital is immobile across firms and islands, but labour is perfectly mobile. The production function is expressed as the following:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \tag{2.1}$$

where A_t captures the productivity shock assumed to follow a first-order autoregressive process: $A_t = \rho^A A_{t-1} + \varepsilon_t^A + news_t$. There is also a "news shock" $news_t$. This news shock is also assumed to follow a first-order autoregressive process: $news_t = \rho^n news_{t-1} + \varepsilon_t^n$. In expression (2.1), K_t and L_t represent aggregate capital and labour respectively. If i_t^i denotes investment on investing-islands and k_t^i the capital stock on these islands, the law of motion for firms on investing islands would be:

$$k_{t+1}^i = \psi_{t+1} \left[i_t^i + (1-\delta) k_t^i \right] \tag{2.2}$$

where the capital stock remaining at the end of the period, k_{t+1}^i, is composed of accumulated capital from last the beginning of the period minus depreciation, δk_t^i, plus the new investment made during the period, i_t^i. There is an exogenous shock to the quality of real capital, denoted ψ_{t+1}. The law of motion for the capital stock of firms locating on non-investing islands is:

$$k_{t+1}^n = \psi_{t+1} (1-\delta) k_t^n \tag{2.3}$$

where, as explained above, there is no new investment happening on non-investing islands. The capital stock remaining at the end of the period, k_{t+1}^n, is therefore only an inheritance from the beginning of the period minus depreciation. Similarly, there is a shock to the quality of capital, ψ_{t+1}. Combining of expressions (2.2) and (2.3) gives the aggregate law of motion for real capital:

$$K_{t+1} = \psi_{t+1} \left[I_t + (1 - \delta) K_t \right] \tag{2.4}$$

where $I_t^i = I_t$.

The shock to the quality of the capital stock originally comes from Merton (1973). Intuitively speaking, when the goods produced from the production function have become obsolete and unpopular in the goods market, goods producers will upgrade their capital stocks to produce popular goods. However, not all capital stock is "shiftable" or easy to update immediately. This "un-shiftable" capital stock would then damage the economy, which can therefore be considered to be a "capital quality shock". Gourio (2009) has defined this idea more widely as the risk of disaster affecting business cycles. When the economy is hit by a disaster, a certain proportion of capital stock is destroyed. This could be considered as a physical shock to the capital stock, such as a war. It could also be interpreted as expropriation of capital users, the inefficient use for capital stock, a “technical revolution” creating a large share of worthless capital stock, or even intangible shocks such as a loss in matches between producers and households in this economy.

In Gertler and Kiyotaki (2010), the capital quality shock is emphasized as the major shock that hits this model economy and is considered to be a good representation of the damage to the economy that triggered the recent financial crisis. In this chapter, rather than arising from a capital quality shock, I consider the possibility that the crisis came from a shock to the efficiency of financial markets. I introduce two new shocks in order to capture the shock to the efficiency of financial markets in the economy: a shock to the interbank market and a shock to the overall banking system. These alternative shocks will be described later.

The profit for goods production firms is given by $Y_t - W_tL_t - Z_tK_t$, which is simply the total output minus total wage payment W_tL_t and the cost for capital Z_tK_t for the period. Goods production firms maximise profits by optimised choices for labour and capital.

$$\max_{\{K_t,L_t\}} \{A_tK_t^{\alpha}L_t^{1-\alpha} - W_tL_t - Z_tK_t\}$$

The first order condition for the choice of labour from firm's profit maximisation is:

$$W_t = (1-\alpha)\frac{Y_t}{L_t} \tag{2.5}$$

and the first order condition for the capital stock is:

$$Z_t = \alpha A_t \left(\frac{L_t}{K_t}\right)^{1-\alpha} \tag{2.6}$$

where Z_t is the gross return per unit of capital in period t.

2.2.2 Capital Goods Firm

For simplicity, the capital goods firms are located outside the investing or non-investing islands. They are indifferent between the two types of islands. Thus, no matter how the investing opportunity randomly changes across islands, capital goods firms sell their capital stocks to all the goods production firms that require new capital. Capital goods firms face the following profit maximization problem:

$$\max_{\{I_t\}} E_t \sum_{\tau=t}^{\infty} \frac{1}{R_{t,\tau}} \left\{Q_{\tau}^{i} I_{\tau} - \left[1 + \phi\left(\varrho_t \frac{I_{\tau}}{I_{\tau-1}}\right)\right] I_{\tau}\right\}$$

The discounted profit is maximized with respect to new investment decisions. The adjustment cost of capital stock is represented by $\phi\left(\varrho_t \frac{I_{\tau}}{I_{\tau-1}}\right) I_{\tau}$, where ϱ_t denotes a capital adjustment cost disturbance (a shock to the investment cost function) following a first-order autoregressive process with an i.i.d. normal error term:$\varrho_t = \rho^{\varrho}\varrho_{t-1} + \varepsilon_t^{\varrho}$. It is assumed that $\phi(1) = \phi'(1) = 0$ and $\phi''(1) > 0$ at the steady state. With these properties, $\phi\left(\varrho_t \frac{I_\tau}{I_{\tau-1}}\right)$ is assumed to be strictly concave. Capital goods firms sell new capital stock only to goods production firms locating on investing islands at the price of Q_τ^i.

The first order condition for this profit maximization gives:

$$Q_t^i = 1 + \phi\left(\varrho_t \frac{I_\tau}{I_{\tau-1}}\right) + \frac{I_t}{I_{t-1}}\phi'\left(\varrho_t \frac{I_\tau}{I_{\tau-1}}\right) - E_t \frac{1}{R_{t+1}}\left(\frac{I_{t+1}}{I_t}\right)^2 \phi''\left(\varrho_{t+1}\frac{I_{\tau+1}}{I_\tau}\right) \quad (2.7)$$

Recall that there is no investment opportunity on non-investing islands. Thus, the price of capital stock is just the price on investing islands, Q_τ^i.

2.2.3 Individual Households

It is assumed a representative household has a continuum of members. Both workers and bankers come from the households. Within each household, a certain proportion f of people are workers, another proportion $1-f$ are bankers. Workers supply labour to firms. They earn labour income from firms and deposit their savings in banks. Bankers manage financial intermediaries. They collect deposits from households and issue loans to firms. However, a person cannot stay in his/her worker or banker's position forever. It is possible for a banker to become worker in each new period, and a worker could become a banker. Assume that at the end of each period, a proportion $1-\sigma$ of existing bankers randomly step out from their banking positions and become workers. This gives a banker's survival rate of $\frac{1}{1-\sigma}$.

Consider a situation where this assumption does not apply. In this case the banker could stay in his/her position forever. This banker would accumulate assets to the point where the financial constraint (to be discussed below) for this bank would no longer be binding. The assumption that bankers randomly switch to being workers is therefore necessary to ensure that the financial constraint is always binding.

When bankers exit the financial system, they transfer retained earnings to the household while the household transfers some funds to new bankers (i.e. those workers who become bankers). Under the above assumptions, there are $(1-\sigma)\,f$ workers who become bankers in each period. Simultaneously, there are $(1-\sigma)\,f$ bankers who become workers in the period. This assumption therefore keeps the number in each position constant.

Apart from acting as workers and bankers, households also hold shares of the firms. They can collect dividends from these shares at the end of each period. The following expression shows the flow of budget constraint for a representative household i:

$$c_t^i + d_{t+1}^i = W_t l_t^i + \Pi_t^i + t_t^i + R_t d_t^i$$

where c_t^i represents the household's consumption, d_{t+1}^i represents the stock of deposits at the current period. $R_t d_t^i$ denotes the interest revenue plus the principal of last period's deposit ($R_t \geq 1$). This captures the fact that saving decisions are normally made one period in advance. The right hand side of the flow budget constraint reflects the total income received by this household during the period. W_t represents real wage payment to households. $W_t l_t^i$ gives the real wage income from workers. Π_t^i is the dividend income generated from ownership of banks. t_t^i denotes a lump-sum transfer from the government. In Smets and Wouters (2003)'s model, the capital income also enters the budget constraint of the households directly. Here it is assumed that capital is not owned by the household, thus no direct capital earnings appear in the constraint. But the earnings from real capital enter the budget constraint indirectly via the dividend income generated from the ownership of banks. It is worth noting that there is no nominal rigidities in this model so all variables should be considered as real variables.

Households maximise intertemporal utility which is given by

$$\sum_{t=0}^{\infty} \beta^t U_t$$

where the instantaneous utility function for the household takes the form:

$$U_t = \tau_t \left\{ \ln \left(c_t^i - \gamma c_{t-1}^i \right) - \frac{X}{1+\varphi} \left(l_t^i \right)^{1+\varphi} \right\} \tag{2.8}$$

This expression contains a preference shock, τ_t, which represents a shock to the discount rate. This shock is assumed to follow a first-order autoregressive process with an i.i.d. normal error term: $\tau_t = \rho^{\tau} \tau_{t-1} + \varepsilon_t^{\tau}$. A representative household i maximises utility subject to the flow budget constraint. The first order conditions for optimization for the choice of $(c_t^i, l_t^i, d_{t+1}^i)$ are:

$$\mu_t = \frac{\tau_t}{c_t^i - \gamma c_{t-1}^i} - \frac{\beta \gamma \tau_{t+1}}{c_{t+1}^i - \gamma c_t^i} \tag{2.9}$$

$$\mu_t W_t = X \tau_t \left(l_t^i \right)^{\varphi} \tag{2.10}$$

$$R_{t+1} = \frac{\mu_t}{\beta \mu_{t+1}} \tag{2.11}$$

It is worth noting that banks can only raise deposits from households on the same islands. In the sequence of decisions, the choice of d_{t+1}^i is made one period in advance. Households must therefore make deposit decisions for the next period only, whereas deposits in the current period have already been decided and fixed during the last period. Financial intermediaries collect the amount of deposits d_t from households at the beginning of each period. By the end of the period, the amount of $R_{t+1} d_t$ will be returned to households, including the interest earnings and the principal. Deposits decisions are made before the realisation of the shock which determines the type of the island (i.e. investing or non-investing).

2.2.4 Financial Intermediation via the Banking Sector

In this thesis, the financial intermediaries are banks. There is no other types of financial intermediaries in this model. As described in previous sections, there is a continuum of islands in the economy. Investment opportunities arrive randomly to a proportion π^i of the islands at the start of each period. Firms and financial intermediaries are located on different types of islands, either investing or non-investing. Firms located on the investing islands have the opportunity to acquire new capital stocks. These firms have high demand for loanable funds in the credit market. Financial intermediaries cannot satisfy all the demand only using deposits collected from the households on their island. There is an assumption that firms can only borrow from the banks on the same island. Thus, lack of loanable funds available in the credit market force private banks to borrow from the other banks that have outstanding funds and do not face large loan demands. Firms located on non-investing islands do not face investment opportunities. They do not need to buy new capital stock during the period. Banks located on these non-investing islands therefore do not face any demand for loans in the credit market. They can therefore lend the funds collected from households' deposits to the banks locating on investing islands that need extra funds.

Under such circumstances, the interbank market becomes necessary for banks on island with new opportunities (investing islands) to borrow from those on islands with no new project arrivals (non-investing islands). To keep the simplest way to adopt an interbank market friction, it is assumed that there is no cost in transferring the funds from a bank to a firm. It is also assumed there is no friction between banks on the same type of islands.

The financial friction in this model comes from the possibility that a banker could divert a certain fraction of bank's assets both in the deposits market and possibly also the interbank market.

Banks need to decide the volume of lending to non-financial firms and the volume that needs to be borrowed from the interbank market based on the budget constraint. The flow of funds constraint that they have to obey is the following expression:

$$Q_t^h s_t^h = n_t^h + b_t^h + d_t \tag{2.12}$$

where h denotes the different island types ($h = i, n$ for investing and non-investing islands respectively), Q_t^h represents the price of loans to production firms in the financial market, s_t^h is the volume of loans issued to non-financial firms, $Q_t^h s_t^h$ gives the value of funds available to the loanable funds market, n_t^h is bank's net worth from previous accumulation, b_t^h denotes the funds borrowed from or lent to (depending on the type of the bank) the other banks in the interbank market, and finally d_t is the total amount of deposits collected from households. Thus, the right-hand-side of this expression gives the total amount of assets in the financial intermediary, while the left-hand-side gives the total amount of funds available to the loanable funds market. This is the fundamental budget constraint for a representative bank.

Apart from this flow of funds constraint, in order to avoid bankers diverting banks' assets in equilibrium, banks also need to satisfy the incentive constraint. The incentive constraint is:

$$V\left(s_t^h, b_t^h, d_t\right) \geq \theta_t \left(Q_t^h s_t^h - w_t b_t^h\right) \tag{2.13}$$

where $V\left(s_t^h, b_t^h, d_t\right)$ represents bank's value, $w_t\theta_t$ represents the fraction that bank cannot divert from the interbank loans borrowed from previous period. As described in previous flow of funds constraint, $Q_t^h s_t^h$ is the value of loans funded within the period, which can be also recognised as the value that a bank received from making loans to firms in the financial market. Therefore, $Q_t^h s_t^h - w_t b_t^h$ represent the divertable assets of the bank. This gives the total amount of assets that are divertable to banker's own family. Thus the divertable assets consist of the total gross assets ($Q_t^h s_t^h$) net a fraction w_t of interbank borrowing (b_t^h). The product $w_t b_t^h$ gives the amount of interbank loans that is excluded from the "divertable" assets. θ_t represents the fraction that a banker might divert from bank's divertable assets. It is assumed that, after the bank obtains funds, the banker managing the bank might transfer a fraction θ_t of the "divertable" assets ($Q_t^h s_t^h - w_t b_t^h$) to his/her family. When a banker diverts bank's assets for personal use, the bank defaults on its debts and shuts down. If this happens, deposits (the households who deposit in the bank) could reclaim the remaining fraction $1-\theta_t$ of the bank's assets; and lending banks could reclaim a fraction $1-\theta_t\left(1-w_t\right)$ of defaulting bank's assets, with $0 < w_t < 1$. When $w_t = 1$, private banks cannot divert assets financed by borrowing from other banks in the interbank market. In this case the interbank market operates frictionlessly. Lending banks are able to recover all their assets from the borrowing banks perfectly. In this case, financial intermediaries are not constrained in borrowing from one another. In the other extreme case, when $w_t = 0$, there is an imperfect interbank market. Lending banks are no more efficient than depositors in recovering their assets from borrowing banks. The level of friction in the interbank market is the same as the friction in the deposit market. In this case banks' ability of obtaining funds is constrained both in the interbank market and the deposit market.

Since creditors recognise the bank's incentive to divert assets, they restrict the amount they lend to the bank. The banks are constrained not only in obtaining funds from depositors but also in obtaining funds from the interbank market. From this incentive constraint, there are two types of financial frictions being introduced in the model—— one is the interbank market friction, another is the deposit market friction. The interbank market friction arises in the sense where lending banks restrict the amount they lend since they recognise borrowing banks' incentive to divert funds. The second financial friction comes from the deposit market where depositors recognise banks' incentive to divert their assets. This incentive constraint summarises this idea and binds the bank's behaviour, in order to avoid banks defaulting. The value of the bank $V\left(s_t^h, b_t^h, d_t\right)$ is set to be no less than the amount of funds that a banker may divert from bank's net assets.

In the structure of this model, two new variables are introduced in order to illustrate the different conditions for above incentive constraint on investing and non-investing islands. Variable DVA_t^h is the total value of bank's divertable assets on a particular type of islands ($h = i, n$). It is defined as:

$$DVA_t^h = Q_t^h S_t^h - w_t B_t^h \tag{2.14}$$

where B_t^h represents the aggregate interbank loans on each type of islands, S_t^h gives the loans to non-financial firms in aggregate value. This variable DVA_t^h illustrates the value of financial intermediaries' divertable assets as shown in the incentive constraint. Another new variable EBV_t^h gives the excess value of banks, defined as the following:

$$\begin{aligned} EBV_t^h &= V_t^h - \theta_t \left(Q_t^h S_t^h - w_t B_t^h\right) \\ &\Rightarrow EBV_t^h = V_t^h - \theta_t DVA_t^h \end{aligned} \tag{2.15}$$

From the incentive constraint (2.13), it is known that $EBV_t^h \geqslant 0$. The value of banks should always be larger than or equal to the value of divertable funds. Thus, excess bank value should be at least zero. But when will it be larger than or equal to zero? From the previous discussion, it is known that only firms on investing islands have new opportunities and would have high demand for loans from banks. Only the banks on investing islands will borrow from the interbank market. Banks on non-investing islands act as lenders in the interbank market. Thus the incentive constraint binds only on investing islands, which means $EBV_t^i = 0$. For banks on non-investing islands, $B_t^n < 0$ and the incentive constraint is not binding on non-investing islands, hence $EBV_t^n > 0$. By defining the two variables DVA_t^h and EBV_t^h, the binding conditions of incentive constraint on different types of islands can be distinguished clearly within the model.

The value function for a bank located on island h is expressed as:

$$V_t = E_t \sum_{\tau=1}^{\infty} (1-\sigma)\, \sigma^{\tau-1} \frac{1}{R_{t,t+\tau}} n_{t+\tau}^h \tag{2.16}$$

where $n_{t+\tau}^h$ represents the "net worth" for the bank on island h ($h = i, n$ distinguish banks on investing islands i and those on non-investing islands n). σ gives the probability that the banker stays in the position and keeps running this bank during the current period. $1-\sigma$ gives the probability that the banker exits the banking position and becomes a worker. The dividend to the banker is assumed to be paid only once at the time when a banker exits the banking system and returns to be a worker. The exogenous discount factor $\frac{1}{R_{t,t+\tau}}$ is the same as the one from the household's first order conditions, which represents the marginal rate of substitution between consumption in period $t+\tau$ and the consumption from period t for this representative household. This value function is the objective for the banker to optimise with subject to the flow of funds constraint and the incentive constraint described previously.

From the above expression it can be seen that the value of a bank is a discounted function of the bank's net worth. The net worth of this bank is made up of three parts: revenue from the previous period's loan to firms, deposits and interest payable to households for last period's deposits, and interbank loan interest and principal to be paid back for the previous interbank borrowings. Bank's net worth is therefore given by:

$$n_t^h = \left[Z_t + (1-\delta) Q_t^h\right] \psi_t s_{t-1} - R_{bt} b_{t-1}^h - R_t d_{t-1} \tag{2.17}$$

Here, the expression $\left[Z_t + (1-\delta) Q_t^h\right]$ represents the interest earnings plus principal (after depreciation) payable to the bank for the loans issued to firms in previous period. s_{t-1} denotes the amount of last period's loans made to firms. ψ_t is the shock to the quality for the loan assets (i.e. the capital quality shock). A sudden drop in quality of capital goods firstly affects production in this economy and in turn has an impact in the bank's net worth. R_{bt} is the interest rate on interbank loans. $R_{bt} b_{t-1}$ denotes the amount to be returned in the interbank market for loans borrowed in last period. The amount of funds to be returned to households for their deposits from last period is shown in the term $R_t d_{t-1}$.

2.2.5 The Interbank Friction

From the previous sub-section, the fundamental structure of financial intermediation has been illustrated. As stated before, Gertler and Kiyotaki (2010) introduced the model with interbank frictions, but they only focused on the extreme conditions where $w = 0$ or 1. From the incentive constraint described in the previous sub-section, $w = 0$ means lending banks are no more efficient than depositors in recovering assets from borrowing banks; and $w = 1$ means banks cannot divert assets financed by borrowing from other banks (i.e. there is a perfect interbank market). Everything else equal, the higher value of w, the higher the credibility of banks, and the more efficient is the interbank market. This chapter firstly extends the analysis of their model to a generalised modelling structure, where the interbank market is in-between the two extreme cases.

As described before, it is assumed that after a bank obtains funds, the banker managing the bank may transfer a fraction θ of the "divertable" assets to his/her family. If bank defaults, the fraction of assets that depositors can recover is $1-\theta$, while the lending banks in the interbank market can recover the fraction $1-\theta\,(1-w)$. In Gertler and Kiyotaki (2010), when $w = 1$, $\theta > \theta\,(1-w) = 0$, the interbank market is privileged over the deposit market at the friction status; when $w = 0$, $\theta = \theta\,(1-w)$, the interbank market is the same as the deposit market, private lenders (depositors) face the same diverting risk as the lending banks in the interbank market.

However, this chapter firstly extends the analysis of the model to a generalised case, with $0 < w < 1$. In this generalised model, since $0 < w < 1$, $\theta > \theta\,(1-w) > 0$, $1-\theta < 1-\theta\,(1-w)$, which means that the lending banks can recover a higher fraction of assets than the depositors if the borrowing bank defaults. Thus, as long as $0 < w < 1$, the interbank market could not perform worse than the deposit market. This chapter firstly explores the responses of the economy with this generalised model structure.

Based on the generalised model, I also consider two new shocks which may represent the possible causes for the crisis of 2007. Recall in Gertler and Kiyotaki (2010), the financial distress is simulated as a decline in the quality of the capital stock, which forces a decline in the value of assets that banks hold. Unlike Gertler and Kiyotaki (2010), I consider the possibility that the crisis came from a shock to the efficiency of financial markets rather than the quality of real capital. As described before, depositors can recover a fraction $1-\theta$ of their assets in the deposit market, and lending banks can recover the fraction $1-\theta(1-w)$ of their assets in the interbank market. Any factor that might reduce the fraction of assets that lenders can expect to recover in a default will induce a tightening of margins, and therefore reduce the efficiency of financial markets.

In the model θ_t is related inversely to the efficiency of the deposit market; the product $\theta_t(1-w_t)$ is related to the efficiency of the interbank market. An increase in θ_t or a reduction in w_t clearly tightens the bank's incentive constraint, affecting the efficiency of financial markets. Thus, two new shocks are introduced to represent the shock that tightens the incentive constraint. The first shock is one affecting the interbank market, w_t. When w_t suddenly falls the interbank market becomes less perfect. The second shock is one to the fraction of funds that can be diverted by bankers in the deposit market, θ_t. Both the increase in θ_t and the decrease in w_t cause creditors (depositors and lending banks) to be able to recover a lower fraction of assets in a default. Lenders will permit less borrowing for any given level of net worth. This leads to tightening of margins, and less efficiency in either the deposit market or the interbank market.

Moreover, as described before, with the limitation of $0<w_t<1$, the interbank market could not be worse than the deposit market under such assumption. Therefore it is found in the model simulation that, even a 100% decrease in w_t would for instance change w_t from a steady state value of 0.5 to the value of 0.25. This is a very small shock. Thus in addition to introducing the two new shocks, I have extended the analysis further to analyse the case where w_t drops outside the 0-1 range. Three cases are considered for the shock—– a shock in w_t which changes it from 0.5 to 0, a shock in w_t which change it from 0.5 to -0.25, and a shock to w_t which changes it from 0.5 to -0.75.

In Gertler and Kiyotaki (2010), w always stays within the range between 0 and 1. However in this chapter, I do consider a case where w_t is outside this range. The interpretation of moving w_t outside the 0-1 range will be discussed further below.

The following sections describe further details the model structure.

2.2.6 Optimisation for Financial Intermediaries

Financial intermediaries facing the previously described constraints make their optimisation choices for loans and deposits. They have to maximise their value subject to both the budget constraint (shown in equation (2.12)) and the incentive constraint (shown in equation (2.13)). Maximization of the value function with respect to the decision on loans to firms, s_t^h and the decision on collecting households' deposits, d_t, is based on the following Lagrangian:

$$\mathcal{L} = V_t^h + \lambda_t^h \left[V_t^h - \theta_t \left(Q_t^h s_t^h - w_t b_t^h \right) \right]$$

The objective function for maximisation is the value function of the bank. λ_t^h represents the Lagrange multiplier for the incentive constraint. The shadow price λ_t^h is the marginal value of the incentive constraint. It gives the rate of change of the objective function (the bank's value) from one extra unit on the right hand side of the constraint (the value of divertable assets). There is a complementary slackness condition, where the above equation holds with equality if $\lambda_t^h > 0$, and holds with strict inequality when $\lambda_t^h = 0$. This complementary slackness condition is shown in the following expression:

$$\lambda_t^h \left[V_t - \theta_t \left(Q_t^h s_t^h - w_t b_t^h \right) \right] = 0 \tag{2.18}$$

When the incentive constraint is not binding, $V_t\left(s_t^h, b_t^h, d_t\right) > \theta_t\left(Q_t^h s_t^h - w_t b_t^h\right)$ and $\lambda_t^h = 0$. On the other hand, when the incentive constraint is binding, $V_t\left(s_t^h, b_t^h, d_t\right) = \theta_t\left(Q_t^h s_t^h - w_t b_t^h\right)$ and the shadow price is strictly positive ($\lambda_t^h > 0$).

In the construction of the model, only investing islands' banks face high demand for loans and therefore borrow in the interbank market. Thus, only the banks on investing islands have a binding incentive constraint, with $\lambda_t^i > 0$. For non-investing islands, there are no new investment opportunities. They act as lending banks in the interbank market. The value of $w_t b_t^n$ is negative and $\theta_t\left(Q_t^n s_t^n - w_t b_t^n\right)$ is bigger compared to the value for banks on investing islands. Thus, $\lambda_t^n = 0$ and the incentive constraint is not binding.

In order to calculate the first order conditions for the above maximising problem, we adopt a more explicit form for the value of the bank. The bank's expected value V_t^h is postulated to be of the following form:

$$V_t^h = v_{st} s_t^h - v_{bt} b_t^h - v_t d_t \tag{2.19}$$

Thus, from this postulated form, the bank's value is positively related to the quantity of loans made to firms during this period, negatively related to the amount of funds obtained from interbank market, and negatively related to the deposits gathered for current period. In this postulated linear value function, we have three time-varying parameters, v_{st}, v_{bt} and v_t, where v_{st} indicates the marginal value of bank loans to goods production firms, v_{bt} represents the marginal cost for interbank debts and v_t gives the marginal cost for deposits from households.

After inserting the above value function into the previous Lagrangian, the first order conditions can be obtained as the following:

$$\begin{aligned} \left(1+\lambda_t^h\right)\left(\frac{\upsilon_{st}}{Q_t^h}-\upsilon_{bt}\right) &= \lambda_t^h \theta_t \left(1-w_t\right) \\ &\Rightarrow \frac{\upsilon_{st}}{Q_t^h}-\upsilon_{bt}=\frac{\lambda_t^h \theta_t \left(1-w_t\right)}{1+\lambda_t^h} \end{aligned} \tag{2.20}$$

$$\begin{aligned} \left(1+\bar{\lambda}_t\right)\left(\upsilon_{bt}-\upsilon_t\right) &= \theta_t w_t \overline{\lambda}_t \\ &\Rightarrow \upsilon_{bt}-\upsilon_t=\frac{\theta w_t \bar{\lambda}_t}{1+\bar{\lambda}_t} \end{aligned} \tag{2.21}$$

$$\left(\upsilon_{st}-\upsilon_{bt}Q_t^h\right)s_t^h+\upsilon_{bt}n_t^h+\left(\upsilon_{bt}-\upsilon_t\right)d_t \geq \theta_t\left[\left(1-w_t\right)Q_t^h s_t^h+w_t n_t^h+w_t d_t\right] \tag{2.22}$$

From expression (2.20), under the assumption that the interbank market is imperfect ($w_t < 1$), the marginal value of the bank's assets in the terms of goods ($\frac{\upsilon_{st}}{Q_t^h}$) will be larger than the marginal cost of interbank loans (υ_{bt}). This expression gives the shadow price associated with the bank's incentive constraint expressed as:

$$\lambda_t^h=\frac{\frac{\upsilon_{st}}{Q_t^h}-\upsilon_{bt}}{\theta\left(1-w_t\right)-\left(\frac{\upsilon_{st}}{Q_t^h}-\upsilon_{bt}\right)} \tag{2.23}$$

As the Lagrange multiplier, λ_t^h represents the shadow price, which gives the marginal value of the incentive constraint. Since the deposits collected by this individual bank do not depend on which type of island this bank is based on, here in the second first order condition, $\bar{\lambda}_t$ is a representation for a weighted average parameter between islands, where $\bar{\lambda}_t = \sum_h \pi^h \lambda_t^h = \pi^i \lambda_t^i + \pi^n \lambda_t^n$. Here $\bar{\lambda}_t$ gives the average marginal value of the incentive constraint of the whole economy, which represents the rate of change of the bank's value from a one unit increase in the amount of divertable funds for exiting bankers. From equation (2.21), when $\bar{\lambda}_t > 0$, which means the incentive constraint is expected to bind for some islands[7], the marginal cost of interbank loans (v_{bt}) will exceed the marginal cost for deposits (v_t). Intuitively, under the assumption that the interbank market operates more efficiently than the deposits market ($w_t > 0$), the marginal cost for interbank borrowing will be larger than the cost for deposits when banks are facing a binding constraint. The third first order condition shows the optimised condition for the shadow price λ_t^h.

As explained before, the shadow price λ_t^h gives the change in optimised value for the bank with respect to a change in the incentive constraint. Theoretically, the marginal cost of interbank borrowing would exceed the marginal cost of deposits if and only if the incentive constraint is binding for some state. Under such circumstance, the interbank market would operate more efficiently than the retail deposit market.

2.2.7 Marginal Value for the Bank's Net Worth and the Calculation of the Time-Varying Parameters

The previous sub-section illustrates the optimisation problem of financial intermediaries, based on the assumed linear value function for the banks (shown in expression (2.19)). In the linear value function (2.19), the time-varying parameters v_{st}, v_{bt} and v_t are unknown. However, based on the first order conditions in the previous sub-section, these parameters can be calculated. In this sub-section, I will show how the marginal value for the bank's net worth is derived from the first order conditions and how the time-varying parameters are calculated.

As described before, in order to calculate the three time-varying parameters, the optimised marginal value of bank's net worth should be derived first. The optimised

[7] Recall in the complementary slackness condition (2.18), banks on investing islands have a positive shadow price and a binding incentive constraint; banks on non-investing islands have a zero shadow price and a positive excess bank value.

marginal value of the bank's net worth can be derived from the first order conditions in the previous sub-section. From the flow of funds constraint: $d_t = Q_t^h s_t^h - n_t^h - b_t^h$, the optimised incentive constraint becomes:

$$v_t n_t^h \geq \left[\theta_t - \left(\frac{v_{st}}{Q_t^h} - v_t\right)\right] Q_t^h s_t^h - \left[\theta_t w_t - (v_{bt} - v_t)\right] b_t^h \tag{2.24}$$

This expression shows that the bank's net worth ($v_t n_t^h$) should be at least as large as the weighted average value of the bank's assets ($\left[\theta_t - \left(\frac{v_{st}}{Q_t^h} - v_t\right)\right] Q_t^h s_t^h$) net of the returned amount of interbank loans ($\left[\theta_t w_t - (v_{bt} - v_t)\right] b_t^h$). This expression can be viewed as an endogenous incentive constraint on banks with the budget constraint included.

The first order conditions can also be used to derive an expression for the value of loans issued to firms as follows:

$$Q_t^h S_t^h \leq \frac{(v_{bt} - \theta_t w_t)\, n_t^h - \frac{\theta_t w_t}{1+\lambda_t} d_t}{\theta_t (1 - w_t) - \left(\frac{v_{st}}{Q_t^h} - v_{bt}\right)} \tag{2.25}$$

This expression provides the upper bound for the value of loans to non-financial firms on the two types of islands. This is also another reformulation of the incentive constraint of an individual bank. Thus, by optimising the bank's value with respect to the preceding described two constraints, the value of the loans issued by this bank should not be larger than the right-hand-side of above expression. The ceiling on the value of loans is expressed in terms of the bank's net worth minus the bank's deposits.

In the case of $0 < w_t < 1$, the above expression will hold as an equality on the investing islands, while it will hold as an inequality on the non-investing islands. This is because when there is an imperfect interbank market, security prices across different islands will not be equal and the price of a security on the investing islands is lower than the one on the non-investing islands due: i.e. $Q_t^i < Q_t^n$.

The bank's three first order conditions ((2.20), (2.21) and (2.22)) derived in previous sub-section can be used to derive the following expression for the value of loans to non-financial firms:

$$Q_t^h s_t^h = \frac{\lambda_t^h}{\frac{v_{st}}{Q_t^h} - v_{bt}} \left[(v_{bt} - \theta_t w_t) n_t^h - \frac{\theta_t w_t}{1+\bar{\lambda}_t} d_t \right]$$

$$\Rightarrow Q_t^h s_t^h = \frac{1+\lambda_t^h}{\theta_t (1-w_t)} \left[(v_{bt} - \theta_t w_t) n_t^h - \frac{\theta_t w_t}{1+\bar{\lambda}_t} d_t \right] \quad (2.26)$$

It is obvious here that if $\lambda_t^h > 0$, the complementary slackness condition implies a binding incentive constraint. This expression is derived in order to derive an expression for the relationship between the value function of the bank and its net worth. By substituting the flow of budget constraint (2.12), the first order conditions (2.20) and (2.21) into the value function (2.19) gives:

$$V_t^h = \frac{\lambda_t^h \theta_t (1-w_t)}{1+\lambda_t^h} Q_t^h s_t^h + v_{bt} n_t^h + \frac{\theta_t w_t \bar{\lambda}_t}{1+\bar{\lambda}_t} d_t \quad (2.27)$$

Combining the above two expressions (2.26) and (2.27) gives the following expression for the optimised value of the bank:

$$V_t^h = \left[v_{bt} + \lambda_t^h (v_{bt} - \theta_t w_t) \right] n_t^h + \theta_t w_t \frac{\bar{\lambda}_t - \lambda_t^h}{1+\bar{\lambda}_t} d_t \quad (2.28)$$

This expression gives the optimal value of the bank as a function of its net worth and current deposits. All other terms, such as the value of loan assets and the value of liabilities in the interbank market, have been substituted out. The term in the bracket multiplying net worth gives the marginal value of net worth for a bank that continues to exist in the next period. The bank continues to exist in the next period with probability σ. With probability $1-\sigma$ the banker becomes a worker and returns its net worth to the household. In this case the marginal value of net worth is unity. The total marginal value of bank's net worth is therefore:

$$\Omega_t^h = 1 - \sigma + \sigma \left[\upsilon_{bt} + \lambda_t^h \left(\upsilon_{bt} - \theta_t w_t \right) \right] \tag{2.29}$$

where Ω_t^h represents the marginal value of bank's net worth.

Recalling the bank's discounted value function in (2.16), the objective for the bank's optimisation can be expressed using the marginal value of bank's net worth, as follows:

$$V_t^h = \underset{h}{E_t} \Lambda_{t,t+1} \Omega_{t+1}^h n_{t+1}^h \tag{2.30}$$

where $\Lambda_{t,t+1} = \beta \frac{\mu_{t+1}}{\mu_t}$ is the augmented stochastic discount factor which same as the discount factor for the household. From this expression, it can be seen that the value function is just the discounted expected bank's value in the next period, which is denoted by the product of the net worth and its marginal value, $\Omega_{t+1}^h n_{t+1}^h$. The major components of the financial intermediary's optimisation problem have now been derived.

The marginal value for the bank's net worth can be used to derive the unknown time-varying parameters υ_{st}, υ_{bt} and υ_t. These parameters can be found by the method undetermined coefficients, by using the marginal value for bank's net worth, as follows

$$\begin{aligned} V_t^h &= \upsilon_{st} s_t^h - \upsilon_{bt} b_t^h - \upsilon_t d_t = \underset{h}{E_t} \frac{1}{R_{t+1}} \Omega_{t+1}^h n_{t+1}^h \\ &= \underset{h}{E_t} \frac{1}{R_{t+1}} \Omega_{t+1}^h \left\{ \left[Z_{t+1} + (1-\delta) Q_{t+1}^h \right] \psi_{t+1} s_t - R_{bt+1} b_t^h - R_{t+1} d_t \right\} \end{aligned} \tag{2.31}$$

The unknown time-varying parameters υ_{st}, υ_{bt} and υ_t are thus:

$$\upsilon_{st} = \underset{h}{E_t} \Lambda_{t,t+1} \Omega_{t+1}^h \left[Z_{t+1} + (1-\delta) Q_{t+1}^h \right] \psi_{t+1} \tag{2.32}$$

$$\upsilon_{bt} = \underset{h}{E_t} \Lambda_{t,t+1} \Omega_{t+1}^h R_{bt+1} \tag{2.33}$$

$$\upsilon_t = \underset{h}{E_t} \Lambda_{t,t+1} \Omega_{t+1}^h R_{t+1} = E_t \frac{R_{t+1}}{R_{bt+1}} \upsilon_{bt} \tag{2.34}$$

From the above three expressions, it can be seen that the parameters from the postulated linear value function have been expressed in terms of the rate of return for each element of the bank's balance sheet, and linked to the marginal value of the bank's net worth. For the two extreme cases studied in Gertler and Kiyotaki (2010), where the interbank market is perfect ($w_t = 1$) and where the frictions in the interbank market are the same as the retail deposit market ($w_t = 0$), these expressions are the analytical solutions given in Gertler and Kiyotaki (2010). For the generalised case analysed in this chapter, where the interbank market is not perfect but better than the retail deposit market ($0 < w_t < 1$), the numerical solutions can be found by using (2.32), (2.33) and (2.34).

2.2.8 Leverage Ratio and the Return on Bank's Assets

Previous sub-sections have illustrated the framework for the generalised model. Three parts of the model have been demonstrated, including the households, firms and financial intermediaries. The above sub-sections have illustrated how these parts are structured in the case of a generalised interbank market, where the interbank market is in-between the two extreme cases $w_t = 0$ and $w_t = 1$. As stated before, the model is also built with two new shocks, one is the shock to the deposit market, which affects θ_t, the other is the shock in the interbank market, which affects w_t. Negative shocks to the efficiency of financial markets illustrate a tightening of the incentive constraint (2.13) and the leverage ratio. Thus, this section will demonstrate how the incentive constraint is tightened and the concept of the bank's leverage ratio.

Recall that expression (2.24) gives the optimised incentive constraint. From this expression, the incentive constraint can also be expressed as:

$$Q_t^h s_t^h - w_t b_t^h \leq \phi_t^h n_t^h \tag{2.35}$$

$$\text{with } \phi_t^h = \frac{\upsilon_t}{\theta_t - \mu_t^h} \tag{2.36}$$

$$\mu_t^h = \frac{\upsilon_{st}}{Q_t^h} - \upsilon_t \tag{2.37}$$

where ϕ_t^h represents the bank's leverage ratio; μ_t^h denotes the excess value of a unit of assets relative to deposits, which is expressed as the marginal value of holding assets ($\frac{\upsilon_{st}}{Q_t^h}$) net of the marginal cost of deposits (υ_t). This constraint applies to the assets intermediated ($Q_t^h s_t^h$) minus the amount of interbank borrowing ($w_t b_t^h$). From this expression it can be seen that, how tightly the constraint binds depends positively on the fraction of net assets the bank can divert (θ_t); and negatively on the excess value of bank's assets (μ_t^h). In other words, the higher the excess value is (μ_t^h), the greater is the value of the bank ($\phi_t^h n_t^h$) and the less likely it is to divert funds, the less binding of the constraint.

If R_{kt+1} denotes the bank's gross rate of return on a unit asset, then from the bank's value equation and the above leverage ratio expression, the rate of return for the bank's issued loans to non-financial firms is:

$$R_{kt+1}^{hh'} = \underset{h}{E_t} \frac{Z_{t+1} + (1-\delta) Q_{t+1}^{h'}}{Q_t^h} \psi_{t+1} \tag{2.38}$$

where h is the current type o island on which the bank is located and h' is the type of island on which it will be located next period. There four possibilities for the combination of h and h' so there are four possible values for $R^{hh'}_{kt+1}$ as follows:

$$R^{in}_{kt+1} = E_t \frac{Z_{t+1} + (1-\delta) Q^n_{t+1}}{Q^i_t} \psi_{t+1} \quad (2.39)$$

$$R^{ni}_{kt+1} = E_t \frac{Z_{t+1} + (1-\delta) Q^i_{t+1}}{Q^n_t} \psi_{t+1} \quad (2.40)$$

$$R^{ii}_{kt+1} = E_t \frac{Z_{t+1} + (1-\delta) Q^i_{t+1}}{Q^i_t} \psi_{t+1} \quad (2.41)$$

$$R^{nn}_{kt+1} = E_t \frac{Z_{t+1} + (1-\delta) Q^n_{t+1}}{Q^n_t} \psi_{t+1} \quad (2.42)$$

The probability of being located on an investing island is π^i and the probability of being located on a non-investing island is π^n so the aggregate return on assets can be written as a weighted average of these four possible values for $R^{hh'}_{kt+1}$, which is:

$$\tilde{R}_{kt+1} = E_t \left\{ \pi^i \pi^n \left(R^{in}_{kt+1} + R^{ni}_{kt+1} \right) + \left(\pi^i \right)^2 R^{ii}_{kt+1} + \left(\pi^n \right)^2 R^{nn}_{kt+1} \right\} \quad (2.43)$$

The net interest spread between the rate of return for loans to non-financial firms and the rate of return to household's deposits is: $\tilde{R}_{kt+1} - R_{t+1}$. This is the credit spread of the model, which plays an important role in the analysis in the following section. As described earlier, a banker can divert a certain proportion of funds if the bank defaults. Thus there is an incentive constraint to prevent the banker defaulting. The incentive constraint limits the size of bank's balance sheet, which implies that the economy's capital stock is less than it would be in the absence of the incentive constraint. Thus the marginal product of capital is higher than it would otherwise be, which implies the rate of return on capital is higher than the interest rate on deposits. This means the credit spread ($SP_t = R_{kt} - R_t$) will be positive in the model. As shown in the later section for quantitative analysis on IRFs, the credit spread can act as an amplifying mechanism for the supply and demand shocks. It can also transmit shocks from financial markets to the real economy.

In previous sub-sections, the value function of financial intermediaries is postulated to be linear. Also from the previous sub-section, the time-varying parameters of this value function have been derived as shown in expressions (2.32), (2.33) and (2.34). Thus, substituting these expressions and the return on bank's assets $R_{kt+1}^{hh'}$ into the expression (2.37) gives:

$$\mu_t^h = \underset{h'}{E_t} \Lambda_{t,t+1} \Omega_{t+1}^{h'} \left(R_{kt+1}^{hh'} - R_{t+1} \right) \tag{2.44}$$

where the excess value of a unit of assets relative to deposits is expressed in terms of the rates of return on bank's assets and deposits. The product $\Lambda_{t,t+1}\Omega_{t+1}^{h'}$ represents the augmented stochastic discount factor, which is defined as the stochastic discount factor $\Lambda_{t,t+1}$ weighted by the stochastic marginal value of bank's net worth $\Omega_{t+1}^{h'}$. The marginal value of bank's net worth ($\Omega_{t+1}^{h'}$) is derived in the previous sub-section and expressed in (2.29). The above expression (2.44) illustrates that, the excess value of bank's assets per unit (μ_t^h) is the expected product of the augmented stochastic discount factor ($\Lambda_{t,t+1}\Omega_{t+1}^{h'}$) and the excess return ($R_{kt+1}^{hh'} - R_{t+1}$).

If the optimised incentive constraint (given in (2.27)) is binding, the banks' balance sheet constraints are binding in both the deposit market and the interbank market, in which case both the leverage ratio shown in (2.36) and the excess value of unit assets shown in (2.44) will be positive. Thus there will be excess returns on assets over interbank rates and over deposits. Moreover, since only the banks located on investing islands face high demand for loans in the credit market, asset supply per unit of bank net worth is larger on investing islands than on non-investing islands, thus the asset price is lower on investing islands ($Q_t^i < Q_t^n$). Intuitively, given that the leverage ratio constraint limits banks' ability to acquire assets, prices will clear at lower values on investing islands where the supply of asset per unit of bank's net worth is greater. The interbank market frictions limit the degree of arbitrage, and keep the asset price on investing islands (Q_t^i) below the asset price on non-investing islands. The lower asset price on investing islands (Q_t^i) means a higher expected return (R_{kt}^i). Thus, the excess value of assets on investing islands will be larger than the excess value of asset on non-investing islands ($\mu_t^i > \mu_t^n \geq 0$). Then from expression (2.44), there will be excess returns on assets over interbank rates and over the deposits shown as the following:

$$\underset{h}{E_t}\frac{1}{R_{t+1}}\Omega_{t+1}^h R_{kt+1}^i > \underset{h}{E_t}\frac{1}{R_{t+1}}\Omega_{t+1}^h R_{kt+1}^n \geq \underset{h}{E_t}\frac{1}{R_{t+1}}\Omega_{t+1}^h R_{bt+1} > \underset{h}{E_t}\frac{1}{R_{t+1}}\Omega_{t+1}^h R_{t+1} \tag{2.45}$$

where there is a strict inequality if the excess return on unit assets of non-investing banks is positive ($\mu_t^n > 0$) and a strict equality if $\mu_t^n = 0$. From the expression (2.45) it can be seen that the interbank rate (R_{bt}) lies between the return on loans (R_{kt}) and the deposit rates (R_t). This situation continues as long as the interbank market is imperfect but has a less severe friction than the retail deposit market, i.e. where $0 < w_t < 1$.

Recall the bank's incentive constraint given by: $V\left(s_t^h, b_t^h, d_t\right) \geq \theta_t\left(Q_t^h s_t^h - w_t b_t^h\right)$. By substituting using the bank's budget constraint we have: $V \geq \theta_t\left(D_t^h + n_t^h\right) + \theta_t\left(1 - w_t\right) b_t^h$. Thus, it is clear from this expression, that the fraction of divertable funds in the deposits market is θ_t, while the fraction of divertable funds that a banker might divert in the interbank market is $\theta_t\left(1 - w_t\right)$. Under the assumption of $0 < w_t < 1$, $\theta_t > \theta_t\left(1 - w_t\right)$, $1 - \theta_t < 1 - \theta_t\left(1 - w_t\right)$, so lending banks would be able to recover a greater fraction of borrowing banks' assets than depositors in the case of a default. Intuitively, one unit of interbank credit would tighten the incentive constraint by less than one unit of deposits. Therefore, the interbank rate (R_{bt}) would exceed the deposit rate (R_t) in such case. On the other hand, since the interbank market is still imperfect ($w_t < 1$), lending banks are not able to recover their assets perfectly in a default, there is imperfect arbitrage keeping the expected interbank rate (R_{bt}) below the expected rate of return to loans in the wholesale financial market (R_{kt}). Therefore, as demonstrated in this sub-section, an increase in θ_t or a reduction in w_t tightens the bank's incentive constraint and the leverage ratio. This will affect the binding condition of the incentive constraint and affect the efficiency of financial markets.

2.2.9 Net Worth of Banks

Net worth, as denoted by n_t^h, represents individual private bank net worth. This sub-section derives the dynamics of aggregate net worth of banks in this economy. As described in a previous sub-section, in each period, with probability σ an individual bankers continues as a banker in each period. Thus, the total net worth for all "old" banks for this economy can be written as:

$$N_{ot}^h = \sigma\pi^h \left\{ \left[Z_t + (1-\delta) Q_t^h \right] \psi_t S_{t-1} - R_t D_{t-1} \right\} \tag{2.46}$$

There is also a probability $1-\sigma$ a banker will switch to be a worker to be replaced by a new bank. Thus in each period proportion $1-\sigma$ of banks are newly created. In order to start banking, it is assumed that an amount of net worth is transferred to the each "new" bank by households. The amount of net worth transferred to each new banks is $\frac{\xi}{1-\sigma}$, which gives an expression for the net worth of new banks as follows:

$$\begin{aligned} N_{nt}^h &= \frac{\xi}{1-\sigma} (1-\sigma) \pi^h \left[Z_t + (1-\delta) Q_t^h \right] \psi_t S_{t-1} \\ &= \xi\pi^h \left[Z_t + (1-\delta) Q_t^h \right] \psi_t S_{t-1} \end{aligned} \tag{2.47}$$

It is worthwhile noting that in the expression for "new" bank's net worth, there is no term in households' deposits. This is because as a starter, this new bank would have no accumulated deposits from the previous period, but only the transferred assets from exiting bankers. In the current period households only place deposit in existing financial intermediaries. At the aggregate level, the total value of bank net worth is the combination of both "old" and "new" banks' net worth.

$$N_t^h = (\sigma + \xi)\, \pi^h \left[Z_t + (1-\delta)\, Q_t^h\right] \psi_t S_{t-1} - \sigma \pi^h R_t D_{t-1} \tag{2.48}$$

The net worth of the bank is shown as a combination of the discounted value of loans to non-financial firms from last period that could be collected in this period, minus the value of deposits from last period that should be returned.

2.2.10 Model Equilibrium

Both security and labour markets must clear in equilibrium. Firms on both investing and non-investing islands borrow funds from their corresponding banks on the same islands. This implies that the equilibrium in each type of island can be written as the following:

$$S_t^i = I_t + (1-\delta)\, \pi^i K_t \tag{2.49}$$

$$S_t^n = (1-\delta)\, \pi^n K_t \tag{2.50}$$

To close the model, the aggregate accounting identity gives the following:

$$Y_t = C_t + \left[1 + \phi\left(\varrho_t \frac{I_\tau}{I_{\tau-1}}\right)\right] I_t + G_t \tag{2.51}$$

where $\phi\left(\varrho_t \frac{I_\tau}{I_{\tau-1}}\right) I_t$ represent a capital adjustment cost. Here C_t denotes the aggregate consumption of the economy. The government spending shock G_t is assumed to follow a first-order autoregressive process with an i.i.d. normal error term: $G_t = \rho^G G_{t-1} + \varepsilon_t^G$.

2.2.11 Calibration and Steady States

The calibration of the model follows Smets and Wouters (2003,2007), Villa and Yang (2011) and Corsetti et al (2011). Tables 2.1 and 2.2 list the parameter values calibrated in the model. For the shock parameters, carefully comparing the model framework for each shock, I calibrate the values of the shocks using examples from relevant papers.

For the interbank shock and fraction of divertable funds shock, since they are newly added shocks in this model, there is no existing relevant calibration for these shocks and there is no obvious empirical means to tie down benchmark values. In the absence of clear empirical evidence I use 0.25 for the standard deviation for the interbank market shock and 0.05 for the standard deviation of the deposit market shock. There is no clear empirical basis for these values, thus, the numerical exercises reported in this and later chapters are repeated for a range of values for the variances of these shocks.

Parameters include α (the share of capital stock in the production function), β (the discount factor), δ (the rate of depreciation for capital stock), ϕ (the labour elasticity parameter), σ (the surviving rate of financial intermediaries), π^h (the probability that an island is an investing or non-investing island) and γ (habit parameter). The probability that an island is an investing island, π^i, is assumed to be 0.25, which implies new investment opportunities on an island arise once a year on average. The other parameters are set to the following values $\alpha = 0.33$, $\beta = 0.99$, $\delta = 0.025$, $\phi = 0.333$, $\sigma = 0.972$ and $\gamma = 0.5$. This model uses a small value for the capital adjustment cost parameter $s = 1.5$ to limit the impact of capital adjustment costs on the dynamics. Gertler and Kiyotaki (2010) selected the values of ξ and θ under two conditions, where an average credit spread is one hundred basis points annually and an economy-wide leverage ratio of 4. It is assumed that the steady state value of households' labour input is 1/3. Thus, L is 0.33 in the steady state.

The final parameter which needs to be calibrated is w, which determines the size of the friction in the interbank market. Gertler and Kiyotaki (2010) consider two extreme values for this parameter, 0 or 1, but they do not offer any way to tie this parameter down with reference to empirical evidence. In the absence of any clear empirical evidence on this parameter, in the exercises which follow w is set at 0.75 as a benchmark value. This implies that the friction in the interbank market exists (i.e. $w < 1$) but is less severe than in the deposit market (which seems reasonable since banks are more able than depositors to monitor the behaviour other banks). Because there is no clear basis on which to tie down the value of $w,$ the numerical exercises reported in this and later chapters are all repeated for a wide range of alternative values of $w.$

The IRFs results in the next section are calculated using a first-order approximation of the model solved using Dynare with the calibrated parameters shown in this sub-section. Appendix A at the end of this thesis shows the Dynare model code used to generate all the results reported in Chapters 2, 3 and 4. Dynare automatically solves the model into linearised equations, thus, the equations I put into Dynare are the original non-linearised model equations as shown in the appendix.

In the section for sensitivity analysis, I also experiment with a range of values for major parameters to check the sensitivity of the main results to parameter variations.

2.3 Quantitative Results

In the previous sections, the model framework has been illustrated in detail. The two financial frictions in this model come from both the deposit market and the interbank market. In the model, the banker can default and abscond with a fraction of the bank's assets. In order to prevent the banker absconding, there is an incentive constraint imposed in the model. The incentive constraint ensures the bank contains sufficient amount of funds to repay its debts, which limits the size of the bank's balance sheet. The limit on the bank's balance sheet causes the capital stock to be lower than it would be if there is no incentive constraint in the model. This implies that the marginal product of capital and the rate of return on capital stock is higher than the interest rate on deposits. Thus, the credit spread is positive. This endogenous positive credit spread in the model amplifies the effects of demand and supply shocks on the economy.

Moreover, bankers could also abscond with funds borrowed from the interbank market. This interbank market friction adds another dimension to the financial friction and further adds to the credit spread. As will be shown in this section, shocks to the deposit market and the interbank market can also be transmitted to the real economy via the credit spread.

This section illustrates quantitative results from the model. As described before, Gertler and Kiyotaki (2010) examined how this model economy would respond to the capital quality shock in two extreme cases, one with a perfect interbank market and one with an imperfect interbank market. As described before, this chapter firstly extends the analysis to the case of a generalised model between the two extreme cases that Gertler and Kiyotaki (2010) examined. The generalised model considers a more realistic situation where the possibility for bankers to divert funds in the interbank market is set to be an intermediate value of $w = 0.75$. In addition to this the model described above also includes a broader set of structural shocks than considered by Gertler and Kiyotaki —– the technology shock, the capital quality shock, four "demand" shocks (which include a news shock, a preference shock, an investment shock and a government spending shock) and two financial market shocks (which include the interbank market shock and the shock to the fraction of divertable funds in the deposit market).

This section analyses the IRFs of the model, which show clearly how the economy responds to the supply and demand shocks under different cases. There are cases for different levels of financial frictions in the model. Thus, it can be seen from these IRFs how the economy with different level of financial frictions responds to the different types of shocks. I adopt the IRFs analysis particularly to determine the extent to which the two financial frictions amplify the effects of typical shocks and to determine of the shocks to financial frictions can create large effects on the real economy.

This section includes five sub-sections to demonstrate simulation of the eight shocks to the model. Sub-section 2.3.1 presents and discusses the impulse response functions for the technology shock. Sub-section 2.3.2 investigates the capital quality shock. Sub-section 2.3.3 presents and discusses the set of "demand" shocks in this model economy. Sub-section 2.3.4 demonstrates the simulation results for the interbank market shock. Sub-section 2.3.5 examines the results for a large interbank market shock. And finally, sub-section 2.3.6 shows the impulse response functions for the shock to the fraction of divertable funds in the retail deposit market.

2.3.1 Technology Shock Responses

The model includes shocks to total factor productivity (TFP). The TFP shocks refer to the changes in the economy's output that cannot be accounted for by the changes in the measured factors of production (i.e. labour and capital stocks). TFP shocks also capture all sorts of things that are not technologically-related in a strict sense. In this quantitative analysis section I firstly illustrate a technology shock in order to highlight some of the difference between a typical RBC model and the model with financial frictions. Figure 2.1.1 presents the IRFs to a positive TFP shock to the economy. There are four cases illustrated in each figure. The lines with stars show the IRFs in the RBC form of the model. The solid lines show the IRFs for the benchmark model, where $w = 0.75$ and $\theta = 0.383$. The dashed lines present the IRFs for the model with $\theta = 0.5$. And the dash dotted lines illustrate the IRFs for the model with $w = 0.25$.

As shown in the figure, output rises immediately and strongly in response to this positive TFP shock. Higher output induces an increase in investment and the capital stock. Consumption increases with the rise in productivity of the economy. The hump-shaped consumption response is caused by the capital adjustment cost. With higher total factor productivity, real wages increase immediately, and this partially stabilises the real marginal cost of production. This causes the initial decrease in employment, which rises again afterwards because of the rise in marginal utility of consumption.

The model with financial frictions responds more to the TFP shock than the RBC version of the model, showing a clear amplification mechanism arising from the financial frictions. In RBC model there is no financial friction so the deposit interest rate is the same as the interest rate on bank loans. The spread therefore is zero by definition. However, with financial market frictions, the spread drops, making it relatively less expensive for firms to borrow funds in the financial market. Investment and output is therefore stimulated to a higher level than in the RBC model. The impact of the shock to the economy is therefore amplified by financial frictions.

This amplification effect from financial frictions gets smaller with lower w or higher θ. For the benchmark model where there is medium level of deposit market friction and interbank market friction (with $w = 0.75$ and $\theta = 0.383$), the economy respond most to the TFP shock. The spread drops by nearly 0.02 percentage points in the benchmark model with financial frictions. For the model with a high interbank market friction (where $w = 0.25$), the spread drops less than the model with a high deposit market friction (where $\theta = 0.5$). The effect on the economy from the deposit market friction is larger than the effect from the interbank market friction. Recall from the bank's incentive constraint (2.13), that if the bank defaults, the fraction that the banker could divert from the interbank market is $\theta(1 - w)$, while the fraction that the banker could divert from the retail deposit market is θ. Thus, an increase in θ has a larger impact on the model than a decrease in w.

2.3.2 The Capital Quality Shock Responses

Gertler and Kiyotaki (2010) analyse the capital quality shock for the two extreme interbank market cases. In this chapter, I also simulate the model response to this shock. However, rather than the two extreme cases that they considered, I test the model with an "intermediate" level of interbank market friction. I also compare the model with a different level of friction in the retail deposit market. Figure 2.1.2 shows the responses of the economy to the capital quality shock under four different conditions for the financial market.

Firstly it can be seen that, the economy suffers more from the capital quality shock when there are financial market frictions. Output drops by around 0.5% for the cases with frictions. For the RBC model however, it only decreases by 0.2%. The impact on output is therefore more than double the size with the financial market friction. The drop in capital quality decreases investment by more than 1% in cases with frictions. In these cases, the spread jumps up, this makes it more costly for firms to borrow funds from banks. This amplifies the impact of the initial negative shock. For model with a larger interbank or deposit market friction, this amplification effect is smaller.

The case with a high interbank market friction (where $w = 0.25$) has a larger response of the economy with respect to the capital quality shock. For the case with a higher deposit market friction (where $\theta = 0.5$), the decrease in output, labour and investment is not so large as in the benchmark case. Since capital quality directly affects bank's net worth, a sudden drop in capital quality initially decreases bank's net worth by a large amount. With an interbank market friction, where it is harder for banks to borrow from the interbank market, the bank's net worth would be affected more by this capital quality shock. The drop in value of banks' assets does not affect the household's deposits on impact. Household's deposits do however decrease later. Deposits drop to a much lower level and the negative effect lasts for quite a long time after the shock.

2.3.3 Demand Shocks

In this model, I have included four typical demand shocks to the economy, including a preference shock, an investment shock, a news shock and a government spending shock. Figure 2.1.3 illustrates the impulse responses of the economy to a preference shock. Figure 2.1.4 presents the IRFs to an investment shock. Figure 2.1.5 gives the responses of models to a news shock. Figure 2.1.6 demonstrates the responses to a government spending shock. In each figure, there are four different cases —— the benchmark model with an intermediate level of financial frictions, the model with a high deposit market friction, the model with a high interbank market friction, and the RBC model. The vertical axis in each graph measures the percentage deviation of a relevant variable from its steady state value.

The preference shock in the model is a shock to the overall utility function for consumers (see expression (2.8)). A sudden drop in τ_t decreases consumption on impact. This decrease is amplified with financial frictions. Obviously the volatility of variables in RBC model is much less than the volatilities in models with interbank market frictions. The decrease in consumption does not last long following the preference shock. In cases with financial frictions, the unanticipated drop in the taste of consumers τ_t decreases the consumption deeply by around 0.3%. As discussed in Baxter and King (1991) and Hall (1997), in DSGE models, the positive preference shock has a strong crowding-out effect for investment. Here with a negative preference shock, investment raises while consumption drops down. This opposite response in investment is also amplified with financial market frictions. This increase in investment raises employment and output, which in turn causes an increase in consumption in the later periods after the shock. The difference between the higher interbank market friction and the higher deposit market friction is not very obvious in response to this preference shock.

The investment shock comes from a sudden drop in the capital adjustment cost (ϱ_t) (see expression (2.7)). This investment shock is a source of exogenous variation in the efficiency with which the final good can be transformed into physical capital, and thus into tomorrow's capital input. Here in the model, a drop in ϱ_t induces a decrease in the capital adjustment cost, and thus stimulates the economy.

The shock to the adjustment cost increases investment and the capital stock. The drop in consumption implies a rise in the marginal utility of income, which shift labour supply to the right. Similar to Justiniano et al (2009), the responses to investment shock shows a significant change in the transmission mechanism. With standard preference and productivity, the marginal rate of substitution depends positively on consumption and labour, while the marginal product of labour depends negatively on hours worked. Thus, any shock that boosts labour supply on impact without shifting the marginal product of labour, would finally generate a fall in consumption at the new equilibrium. This is precisely what happens in response to the investment shock in this model shown in Figure 2.1.4. The increase in firms' investment also increases the demand for funds both in the retail financial market and the interbank market. However, the financial market friction blocks the market. The increase in interbank borrowing and bank lending in the frictional case is quite limited. Thus, the increase in investment in models with financial frictions is much less than the response in RBC model. So is the output response. The difference between high interbank friction and the high deposit market friction is again quite small for this shock.

Figure 2.1.5 presents the IRFs for the economy in response to a positive news shock. The news driven business cycle hypothesis was originally advanced in Pigou (1927) and restated in Beaudry and Portier (2004). They posited that business cycles might arise on the basis of expectations of future fundamentals. In this chapter I have followed Corsetti et al (2011)'s framework by assuming that the news shock is a forecast of future technology development. This specification allows agents to know the shock to technology one quarter in advance. "News" become available in quarter 0, but the technology level would not start to change until the end of quarter one. As shown in the model responses, when there is favourable news about future total factor productivity, the economy firstly is stimulated with a rise in output and consumption. Similarly to the investment shock, the positive impact to the economy is limited by financial frictions. The rise in output and investment in the model with financial frictions is smaller than the RBC model. In the frictional models, the spread increases and this limits the increase in loans, which in turn limits the increase in investment.

Finally, Figure 2.1.6 demonstrates the IRFs in response to a contractionary government spending shock. In the RBC model, the contractionary government spending shock causes a small drop in output. The capital stock and consumption rise by a very little amount. The drop in labour supply is caused by a small rise in the real wages. Consistent with the empirical analysis in Berument and Dogan (2004), Kandil (2001) and Wane (2010). The IRFs for the models with financial frictions are quite similar to the IRFs in RBC model, except for the amplified variation in investment and deposits.

For these demand shocks, the financial frictions do lead to a small amplification for the shocks. However, the degree of the interbank friction does not affect much the size of the amplification. There are limited impacts to the model under different levels of financial frictions under these demand shocks.

2.3.4 Shock to the Interbank Market

This sub-section shows the simulation results for the interbank market shock. Gertler and Kiyotaki (2010) considered the capital quality shock as the trigger of the crisis. Here in this model, in addition to the above conventional demand and supply shocks to the model, I consider two new shocks occurring in the financial market. This section investigates the impulse responses to the interbank market shock, as shown in Figure 2.1.7.

Firstly it can be seen that the effects on the economy from this interbank market shock are quite limited. The mechanism in the IRFs is very small. According to the incentive constraint (expression (2.13)), if the bank defaults, the fraction that a banker can divert from the interbank market is $\theta\,(1-w)$. Thus, a decrease in w has a very limited impact on the fraction of divertable funds in the interbank market. In Figure 2.1.7, I illustrate the effects of an absolute decrease in w_t of 0.25. In the benchmark model, $w_t = 0.75$, so a 0.25 absolute drop in w_t would decrease it to 0.5. In the model with high interbank market friction, $w_t = 0.25$, so a 0.25 decrease would bring w_t to 0 (which is the extreme imperfect interbank market case). Since the model originally has an imperfect interbank market, the interbank shock would only bring it to a more imperfect condition. This is why the interbank shock has limited impact on the economy.

The shock causes loans to non-financial firms to drop initially. This creates a contraction in the bank lending market, which in turn causes a drop in the interbank borrowing. The contraction in the financial market decreases the net worth of bank by around 3%. This decreases investment and output in the economy.

It is obvious that the shock has a larger effect on output in the high θ case compared to the low w case. The model with a higher friction in the deposits market (where $\theta = 0.5$) has amplified responses comparing to the other two frictional cases. As described before, θ affects both the fraction of divertable funds in the deposit market and in the interbank market. When the bank defaults, bankers can divert $\theta\,(1-w)$ of the interbank borrowing funds. For the model with higher θ, a drop in w_t is amplified. Thus, modelling with a more severe friction in the deposit market causes a further contraction in the financial market, and causes a larger drop in the interbank borrowing.

Deposits decrease later than the interbank market contraction. The deposit market is not affected on impact with respect to the interbank market shock. However, once the impact is transferred to the deposits market, the contraction in deposits last longer than the contraction in the interbank market.

2.3.5 Large Interbank Market Shock

As shown in the previous sub-section, the interbank market shock appears to have a relatively limited effect to the economy. Thus, rather than the negative 0.25 shock in w_t, in Figure 2.1.8, I illustrate the effect of a decrease in w_t by -2, (i.e. a fall in w from 0.25 to -1.75) to illustrate a much larger interbank market shock. Comparing to the benchmark case, a -2 shock in w_t has a much larger impact to the economy.

In Gertler and Kiyotaki (2010) model, they limit w to the 0-1 range and examined the two extreme cases for w. When $w = 0$, the interbank market is not better than the deposit market, they face the same risk of diverting funds. When $w = 1$, the interbank market is better than the deposit market. Interbank market faces less diverting risk than the deposit market.

However, it can be argued that, while it may be reasonable to suppose that the friction in the interbank market is usually less severe than in the deposit market, there is no logical reason to assume that this is always the case. For instance, it can be argued that at the height of the financial crisis in 2007 and 2008, concerns about losses in interbank lending became much more severe than concerns about losses by retail depositors. For instance, it was effectively the complete loss of access to the interbank market which first triggered the crisis for banks such as Northern Rock and RBS. Until problems in the interbank market arose, neither of these institutions faced particular problems in attractive retail deposits. A case where the friction in the interbank market is more severe than in the deposit market logically requires w to be less than zero.

In this sub-section I therefore consider a large interbank market shock which reduces w_t suddenly from 0.75 to -1.25. This would make the interbank bank much worse than the deposit market.

Since the banker can divert a fraction $\theta\,(1-w)$ of interbank borrowed funds when the bank defaults, in the benchmark case the banker can divert about 9.6% of the interbank loans if there is a default (i.e. $\theta\,(1-w) = 0.383 \times (1-0.75) = 0.09575$). In the benchmark model with the negative 0.25 shock to the interbank market, the fraction that a banker can divert from the interbank borrowing would increase to approximately 19.2%. This has some impacts on the economy. But as described in the previous sub-section, these effects are very limited. In Figure 2.1.8, with the large interbank market shock, w_t decreases by -2, which would increase the fraction of divertable funds in the interbank market to 86.2%. This means that, when the bank defaults, the banker could divert over 80% of the interbank borrowing funds.

As shown in the figure, this large increase in risk in the interbank market decreases interbank lending by nearly 20% of its steady state level. This large shock in the interbank market also reduces output by about 2%, and investment by about 14%. There is also a large decrease in employment by about 3%. Thus it can be seen that a large increase in the interbank market risk can cause a large recession in the economy.

2.3.6 Shock to the Fraction of Divertable Funds in the Deposit Market

Figure 2.1.9 shows the impulse responses of the model to a shock to the fraction of divertable funds in the retail deposit market. As explained before, θ_t represents the fraction of the funds supplied by private retail lenders that a banker could divert in a default. Thus, the fraction of assets that depositors could expect to recover in a default is $1 - \theta_t$. Thus, an increase in θ_t tightens the incentive constraint and causes a shock to the real economy.

The response magnitudes shown in Figure 2.1.9 are much larger than Figure 2.1.7. The figure shows that the fraction of divertable funds shock has larger impact to the economy than the interbank market shock. As described in previous sections, from the bank's incentive constraint (expression (2.13)), $\theta(1 - w)$ represents the fraction of interbank funds that a banker can divert when the bank defaults. Thus, a shock in θ affects the interbank market as well. This explains why the shock in θ_t have much larger impact than the shock in the interbank market. Though the impacts of the shock is much stronger than that of the shock from the interbank market, the shape of responses for the economy is approximately the same. Compared to the capital quality shock, the initial disruption of financial markets leads to several endogenous factors in the economy, such as on the price and quantity of loans issued to firms and the interbank borrowing. These deteriorations in both bank loans and interbank financial assets would make it much more difficult for depositors to recover their funds after a default. These endogenous responses to the shock in the fraction of divertable funds magnify the crisis.

As shown in the figure, a sudden increase in θ initially decreases the bank's net worth by 2%. Deposits and the interbank market are both affected by this shock, which causes a decrease in both interbank borrowing and deposits. The decrease in the bank's net worth also causes a decrease in the loanable funds in the financial market. The decline in the loans to non-financial firms also causes further contraction of the interbank market. Firms' investment is decreased by 1% because of lack of bank credit for investment and this reduces output. The rise in the rate of return raises the real wage rate on impact. Consumption initially rises and then decreases afterwards because of the contraction of output.

Differently from the demand shocks illustrated in the Sub-section 2.3.3, the financial frictions lead to a clear amplification of these two financial shocks. It is however not so obvious with the small interbank market shock illustrated in the Sub-section 2.3.4. However, with the large interbank market shock shown in Sub-section 2.3.5, the large increase in the interbank market risk causes a large recession in the economy. The sudden increase in the deposit market friction also causes an obvious recession to the economy. It has therefore shown that the financial frictions shock do potentially have a significant effect on the real economy.

2.4 Sensitivity Analysis

The quantitative results explained above are based on the fixed set of parameters values described in section 2.2.11. To test the robustness of the benchmark calibration, I consider a range of the values for some key parameters. This section carries out a sensitivity analysis of the model around the benchmark solution to examine how the results would vary with different parameter values. Here I consider variations in six parameters, the capital adjustment cost (s), consumer's habit parameter (γ), the inverse Frisch elasticity of labour supply (ϕ), the survival rate of bankers (σ), the probability of new investment opportunities (π^i), and the transfer from households to new bankers (ξ). Figures 2.2.1 to 2.2.6 illustrates the IRFs for five key shocks to the model with different parameter values. The shocks chosen here include the TFP shock, capital quality shock, the interbank market shock, the shock to the fraction of divertable funds, and the government spending shock (which represents a typical demand shock).

Figure 2.2.1 illustrates the IRFs for the change in the capital adjustment cost (s). In the benchmark model, $s = 1.5$, which is compared with $s = 1.6$. As can be seen in the figure, the change in s has relatively little impact on the way these shocks affect the variables shown. A larger value for the capital adjustment cost causes the response of output, consumption and interbank borrowing to be larger. The response of the interest rate spread is however smaller with a larger s. This explains why the response of other variables is amplified.

Figure 2.2.2 presents the IRFs of the economy for a higher value of the consumer's habit parameter (γ). As can be seen from the figure, there is not much change in the response of output to shocks. However, there is quite a large effect on the response of consumption. When γ increases, consumption responds less to the shocks. According to the consumer's utility function (expression (2.8)), a higher γ makes the consumption from the previous period more important. A shock in the current period therefore has a smaller effect on the consumer's habit stock from the previous period. Thus, the increase in parameter γ decrease the variation in consumption after shocks.

Figure 2.2.3 shows the IRFs for a different value of the elasticity of labour supply (ϕ). For most of the shocks, there is not much difference between for different values of ϕ, except for the government spending shock. With the contractionary government spending shock, when the labour supply becomes more elastic, consumption increase more than in the benchmark model. The elastic labour supply limits the negative effects from this shock.

For different survival rates of bankers (σ), the IRFs are shown in Figure 2.2.4. In the benchmark model, $\sigma = 0.972$. Here I illustrate the effects of a lower value of σ. The effects of the lower value of σ are larger than the other parameter variations discussed above. From Figure 2.2.4 it can be seen that, decreasing the banker's survival rate decreases the impact of the shocks to the economy. However, the lower survival rate amplifies the response of the interest rate spread to shocks.

Figure 2.2.5 gives the IRFs of the economy with a different probability of new investment opportunities (π^i). When π^i increases, there are more islands with investment opportunities and the response of interbank borrowing to the shocks is diminished. When investment opportunities are narrowed in a smaller group of banks (with lower $\pi^i = 0.25$), investing banks need to borrow more in the interbank market following a shock.

Lastly, Figure 2.2.6 presents the IRFs of the model with different transfer parameter from old to new bankers (ξ). As ξ increases from 0.0025 to 0.005, more net worth is transferred from the exiting bank to new bankers. However, from the figure, it appears that the models' responses are not much affected by the change in this parameter.

2.5 Conclusion

The global economy has experienced a serious crisis in financial markets starting from 2007. This led to a major recession. The crisis has also been widely transmitted to almost every market in the global economy. The macroeconomic literature has developed rapidly to study a wide range of monetary models considering the banking system and financial frictions. Among these, Gertler and Kiyotaki (2010) have considered a model where a shock to the quality of capital stock is the initial cause of the crisis. They have examined how the economy responds to this capital quality shock in two extreme cases, one with a perfect interbank market and one with an imperfect interbank market. This chapter firstly extended the analysis of their model to a "generalised" one in between the two extreme cases that they examined. In addition, I consider shocks to the efficiency of financial markets as the initial cause of the crisis rather than the capital quality shock. I introduce two new shocks in this chapter to simulate the shock to the efficiency of financial markets: one is a shock to the fraction of funds that bankers can divert in the deposit market and one to the fraction of funds that bankers can divert in the interbank market.

It is found that, a negative shock to the interbank market has only a moderate impact to the banking system, and its impact on the wider economy is diluted through the incentive constraint for financial intermediaries. I extended the analysis to include a large interbank market shock, which implies that the interbank market friction is worse than the deposit market friction and the shock almost closes down the interbank market entirely. It is shown that this large increase in the interbank market risk can cause a large recession in the economy.

Though the shape of IRFs for the financial market shocks are basically similar to those for the capital quality shock, most of the variables take a much longer period to return to their steady state values. From the IRFs for variables relating to the banking sector, it is also found that dynamic changes occur in banks' value, bank lending financial market and the interbank market. For the deposit market shock bank lending experiences a longer recovery period compared to the interbank market, which causes a variation in bank's excess value to shift from negative to positive effects. Even though the impacts of these shocks are not as large as the capital quality shock introduced by Gertler and Kiyotaki (2010), it is shown that these endogenous impacts to the economy would magnify the effects of other shocks.

From the analysis in this chapter, it can be seen that financial frictions would lead to a general amplification for the effects of the shocks. This amplification mechanism is small under the demand shocks comparing to the supply shocks of the model. The small interbank market shock has limited effect to the economy. However with a very large interbank market shock, the real economy would suffer from a severe recession following this shock. The deposit market shock has more obvious effect than the small interbank market shock.

It would be useful in future research to focus on the size of interbank market shock and compare this against real data for the effects of the crisis on interbank lending.

Table 2.1. Shock Parameters

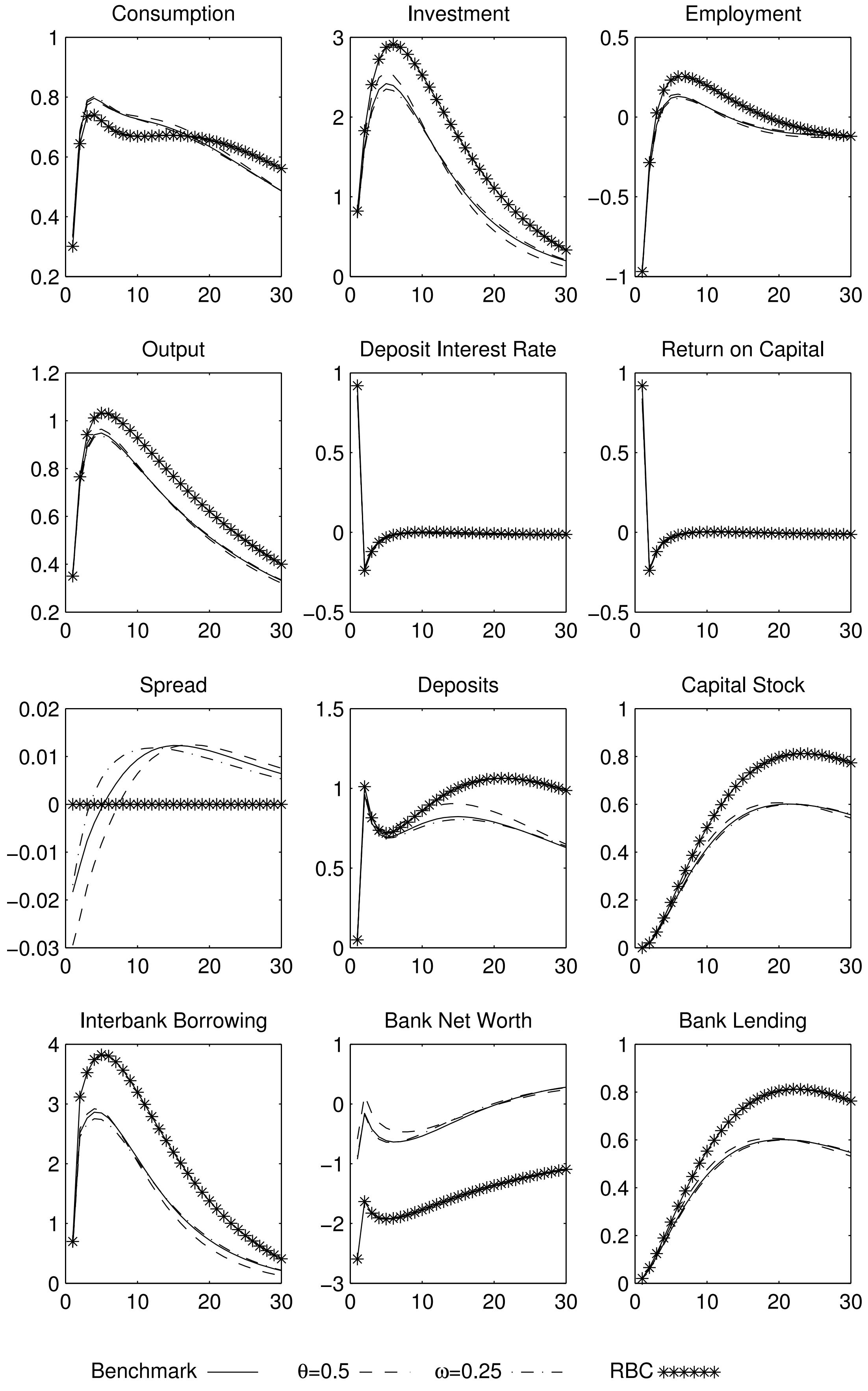
Technology	ρ_A	0.95	σ_A	0.01	Smets and Wouters (2007)
Capital Quality	ρ_ψ	0.4	σ_ψ	0.01	Villa and Yang (2011)
Interbank	ρ_w	0.9	σ_w	0.25	n/a
Divertable Funds	ρ_θ	0.9	σ_θ	0.05	n/a
Preference	ρ_τ	0.838	σ_τ	0.00407	Smets and Wouters (2003)
Investment	ρ_m	0.91	σ_m	0.00113	Smets and Wouters (2003)
News	ρ_n	0.9	σ_n	0.1414	Corsetti et al 2011
Gov Spending	ρ_G	0.943	σ_G	0.00335	Smets and Wouters (2003)

Table 2.2. Model Parameters

share of capital stock in production function	α	0.33
discount factor	β	0.99
depreciation rate	δ	0.025
labour elasticity	ϕ	0.333
surviving rate of private banks	σ	0.972
probability for non-investing island	π^n	0.75
habit parameter	γ	0.5
probability for investing island	π^i	0.25
capital adjustment level	s	1.5
level of disutility of work	χ	2.045

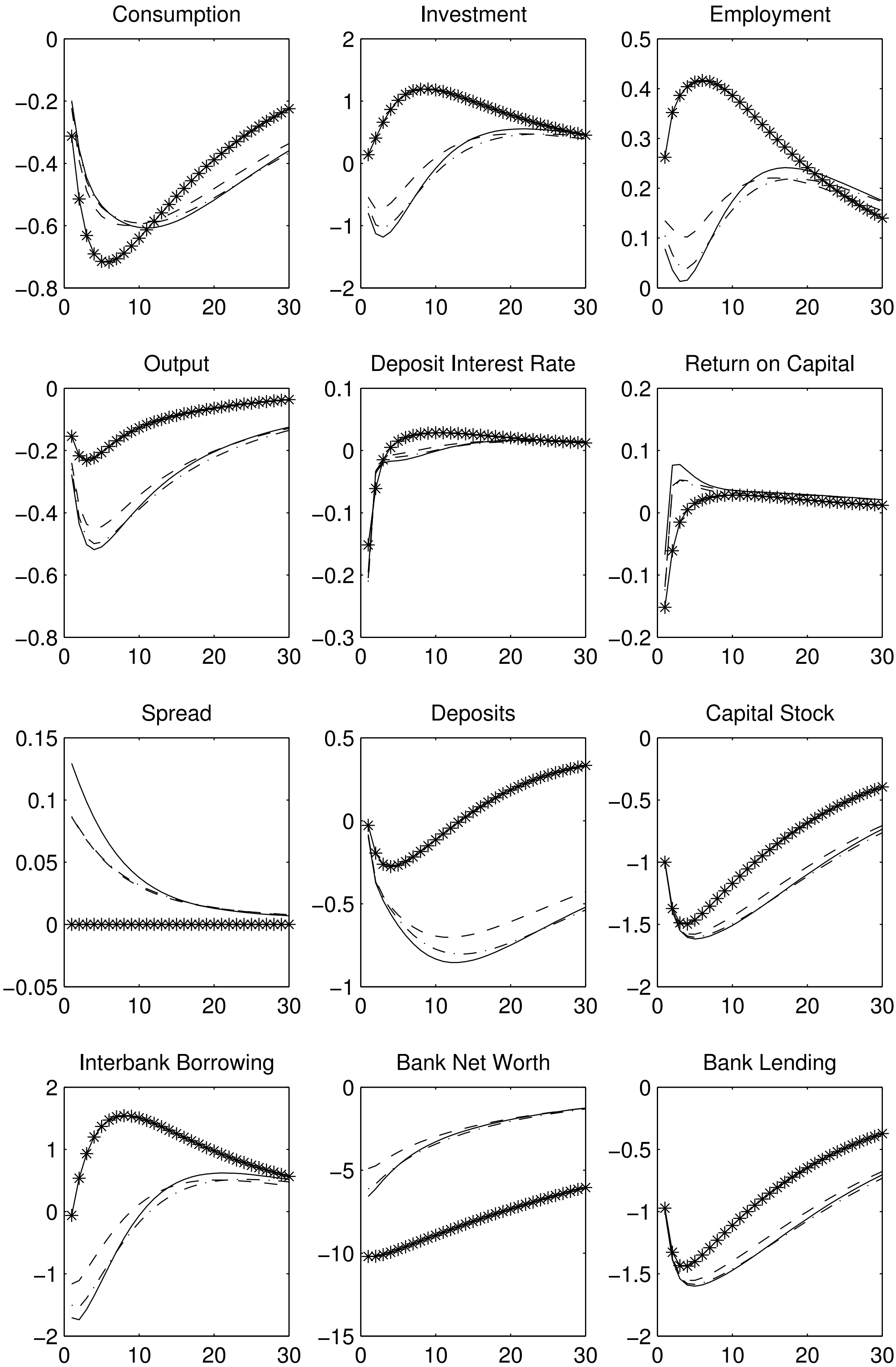
from Gertler and Kiyotaki 2010

Figure 2.1.1 : TFP Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital and the spread, which show the percentage point difference from the steady state.

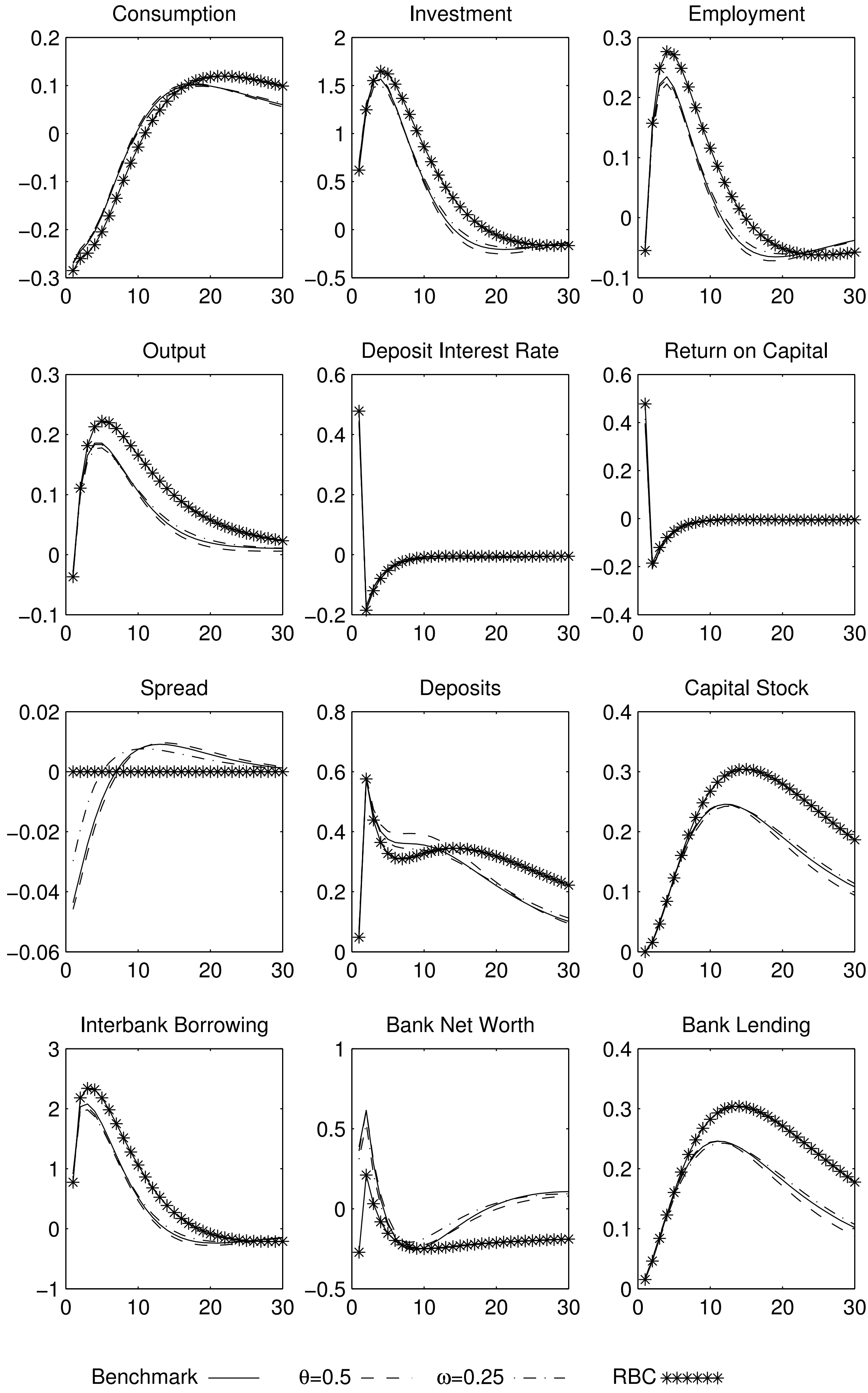
Figure 2.1.2 : Capital Quality Shock IRFs



Benchmark ——— θ=0.5 – – – ω=0.25 · – · – RBC ******

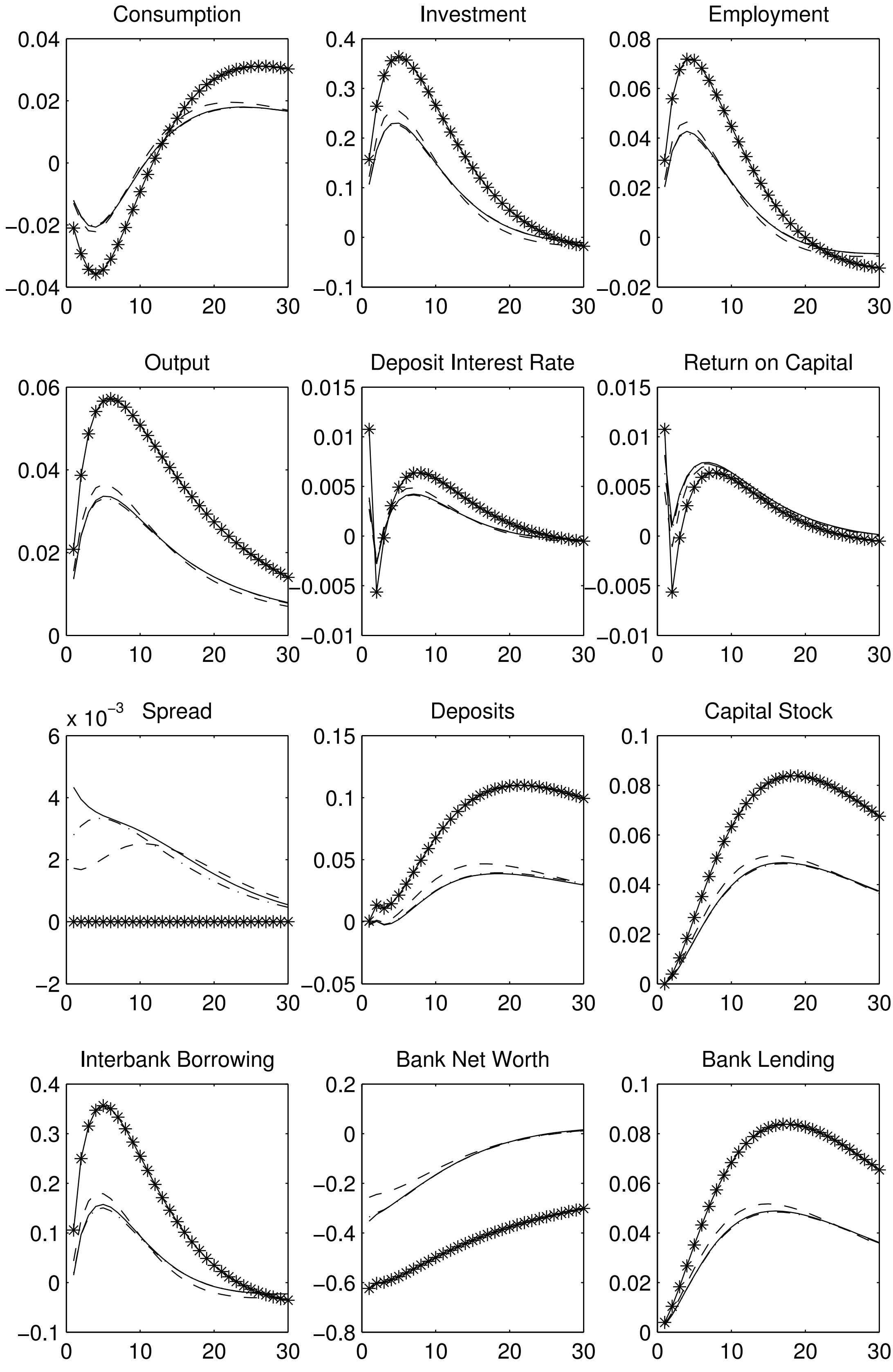
Plots show the percentage difference from the steady state,
except those for the deposit interest rate, the return on capital and the spread,
which show the percentage point difference from the steady state.

Figure 2.1.3 : Preference Shock IRFs



Plots show the percentage difference from the steady state,
except those for the deposit interest rate, the return on capital and the spread,
which show the percentage point difference from the steady state.

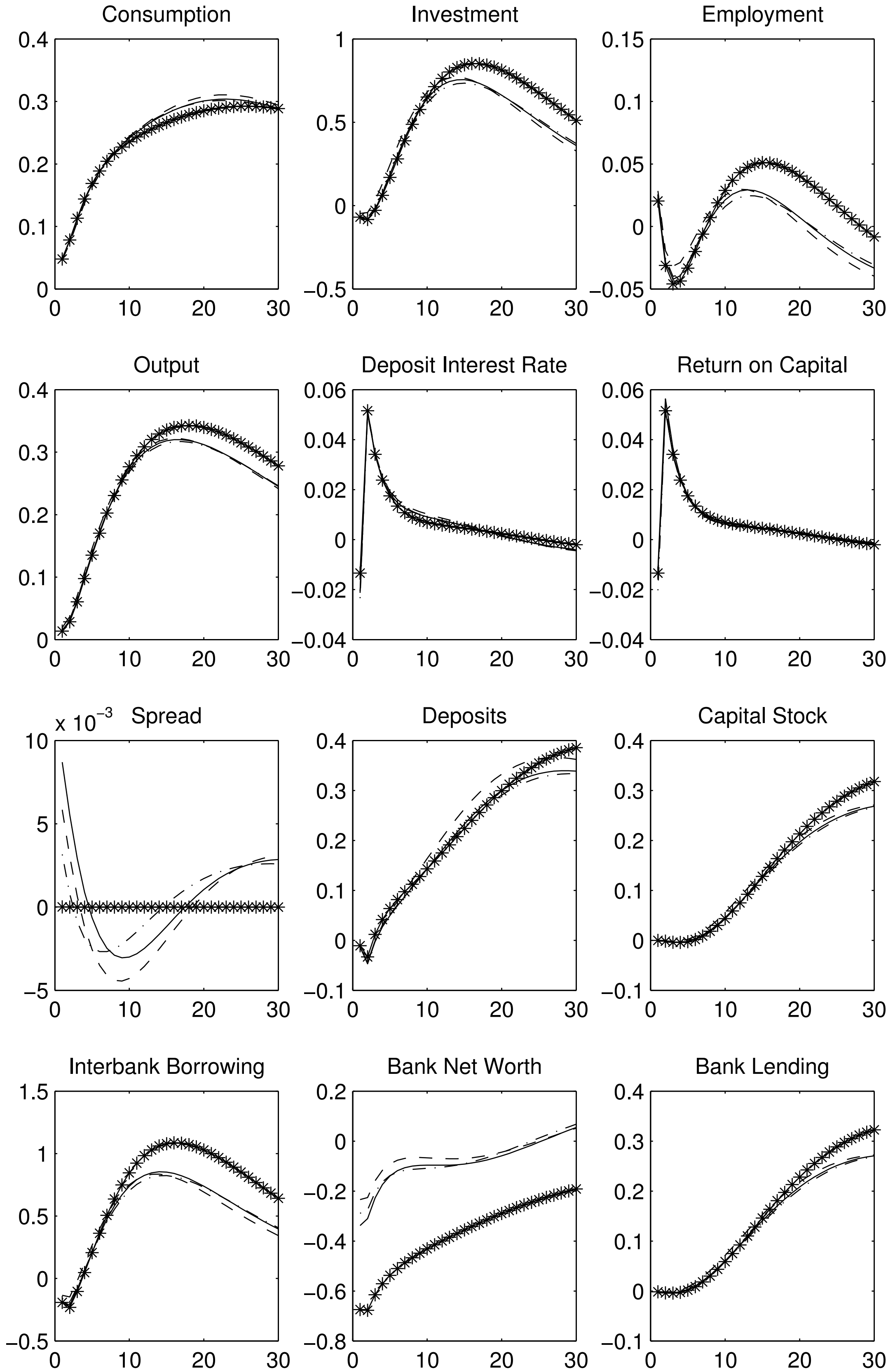
Figure 2.1.4 : Investment Shock IRFs



Benchmark ——— θ=0.5 – – – ω=0.25 ·–·– RBC ✳✳✳✳✳

Plots show the percentage difference from the steady state,
except those for the deposit interest rate, the return on capital and the spread,
which show the percentage point difference from the steady state.

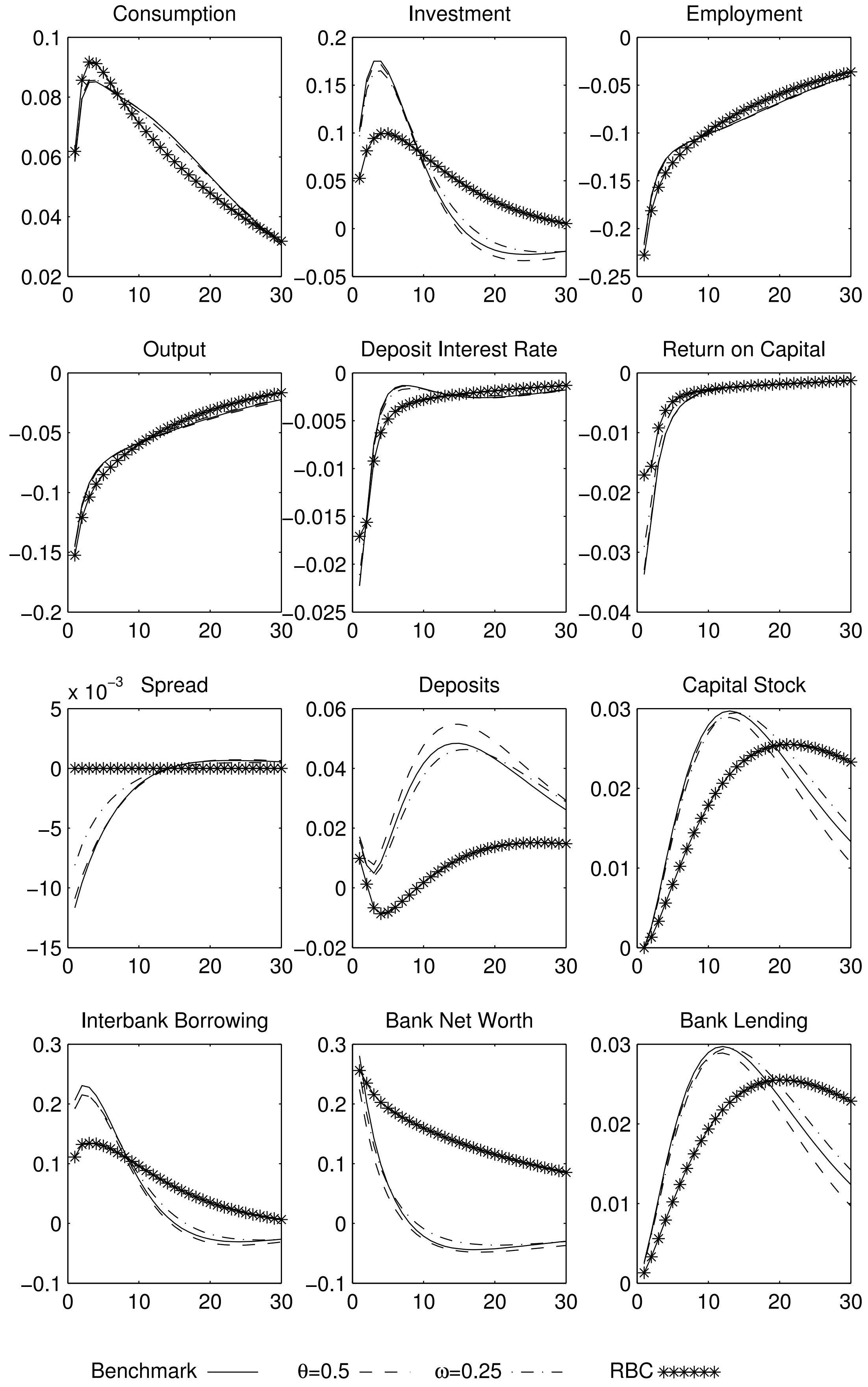
Figure 2.1.5 : News Shock IRFs



Benchmark ——— θ=0.5 – – – ω=0.25 · – · – RBC ✳✳✳✳✳

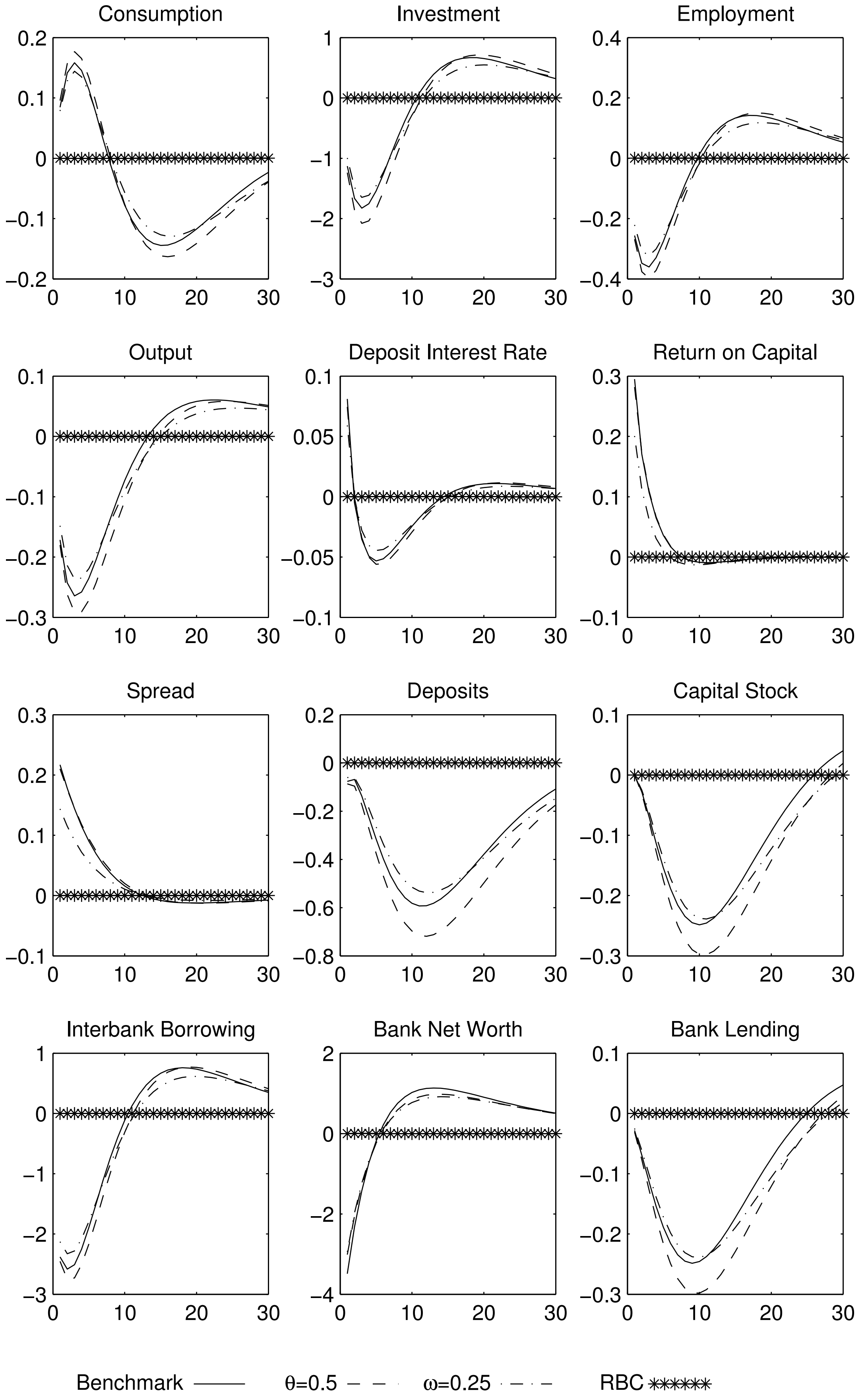
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital and the spread, which show the percentage point difference from the steady state.

Figure 2.1.6 : Government Spending Shock IRFs



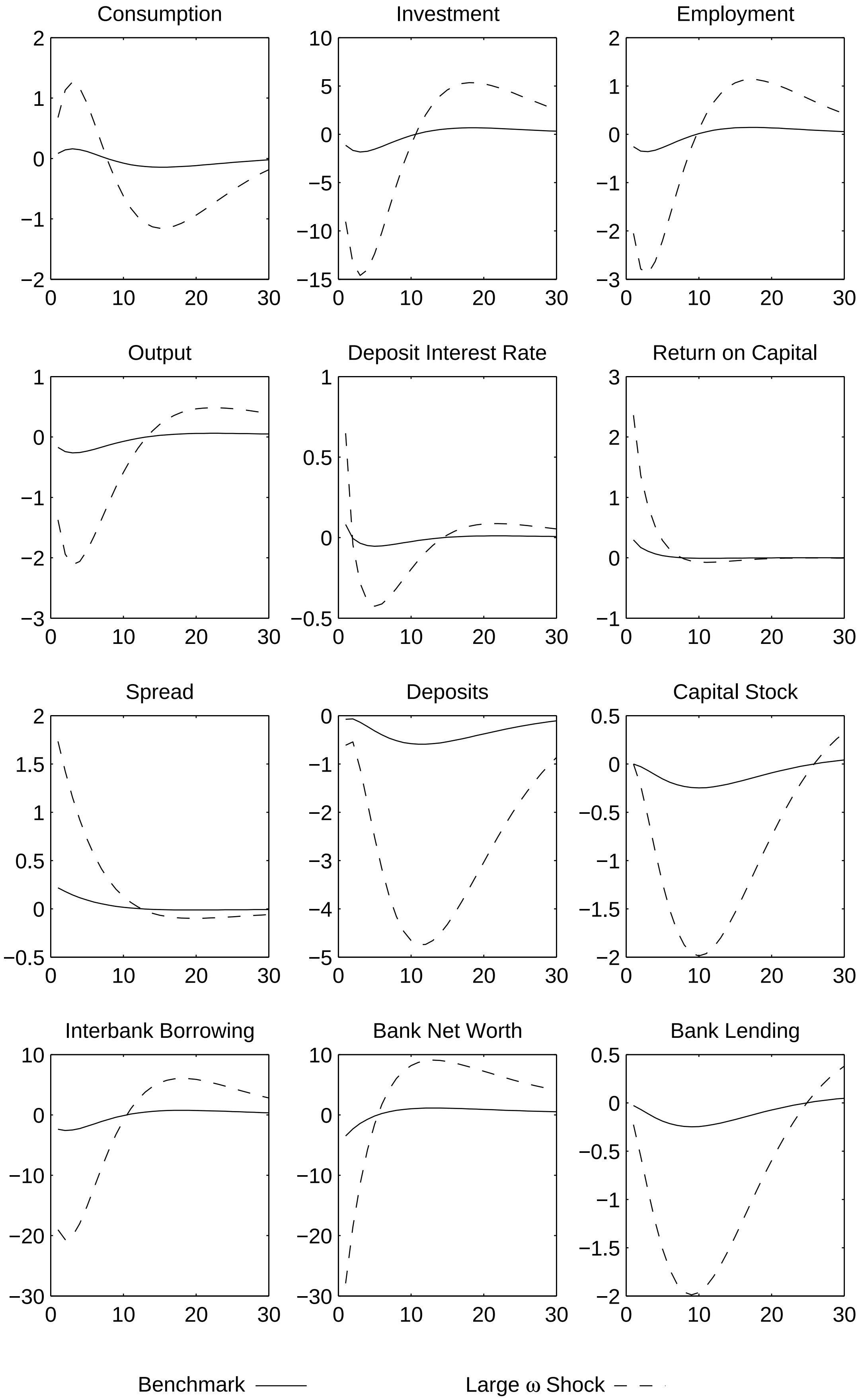
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital and the spread, which show the percentage point difference from the steady state.

Figure 2.1.7 : Interbank Friction Shock IRFs



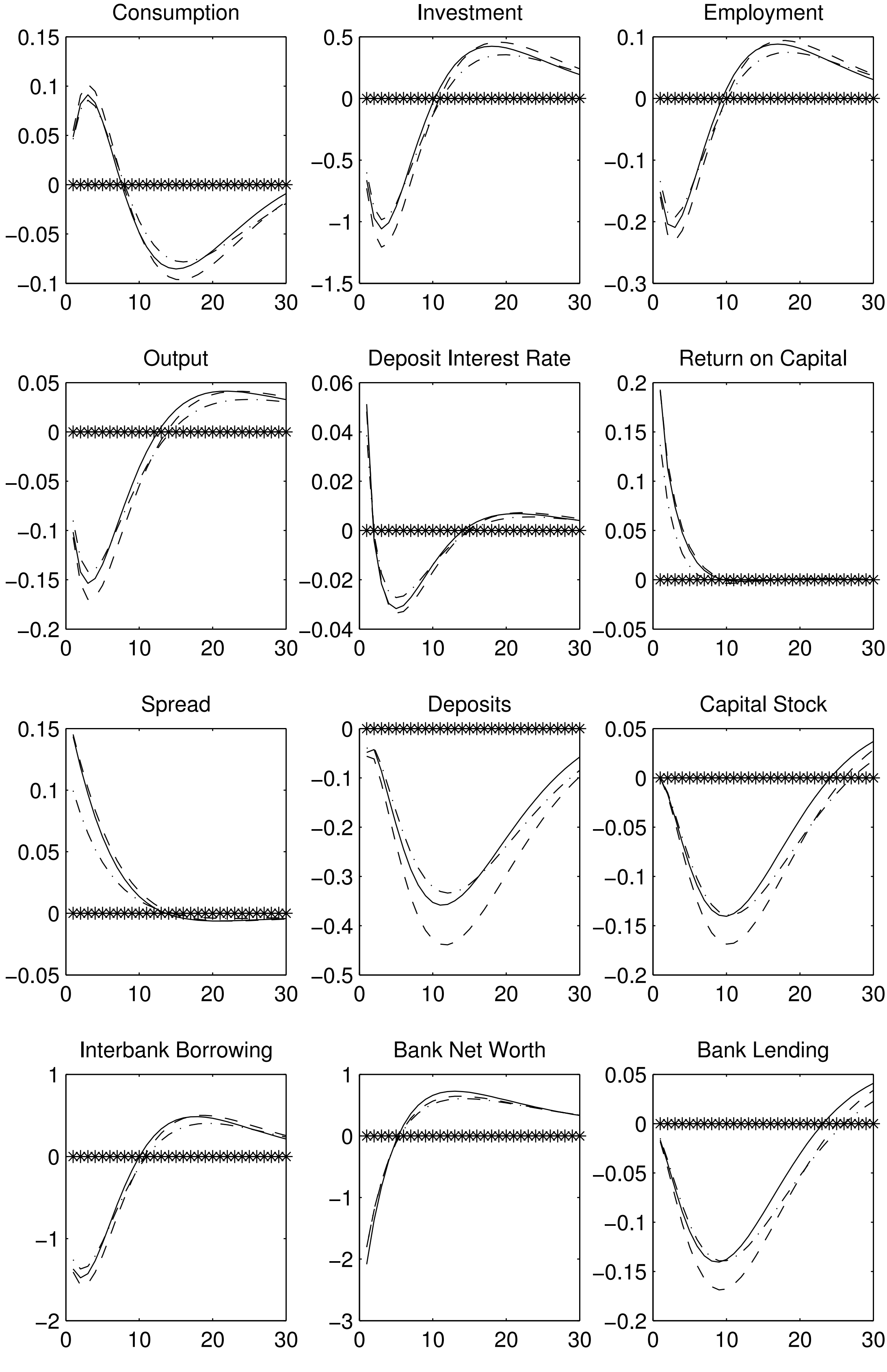
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital and the spread, which show the percentage point difference from the steady state.

Figure 2.1.8 : Large Interbank Friction Shock IRFs



Plots show the percentage difference from the steady state,
except those for the deposit interest rate, the return on capital and the spread,
which show the percentage point difference from the steady state.

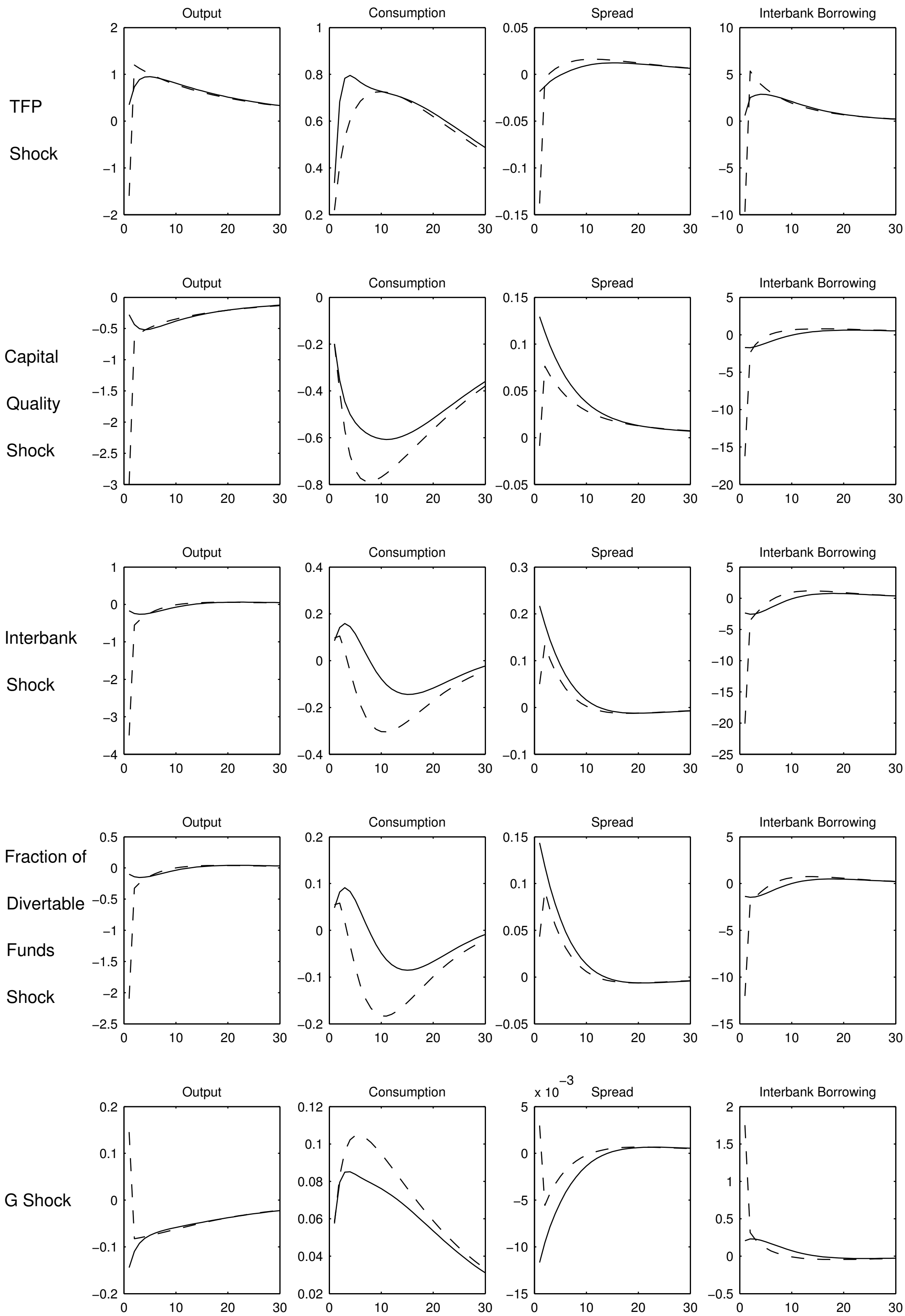
Figure 2.1.9 : Fraction of Divertable Funds Shock IRFs



Benchmark —— θ=0.5 – – ω=0.25 · – · – RBC ✳✳✳✳✳

Plots show the percentage difference from the steady state,
except those for the deposit interest rate, the return on capital and the spread,
which show the percentage point difference from the steady state.

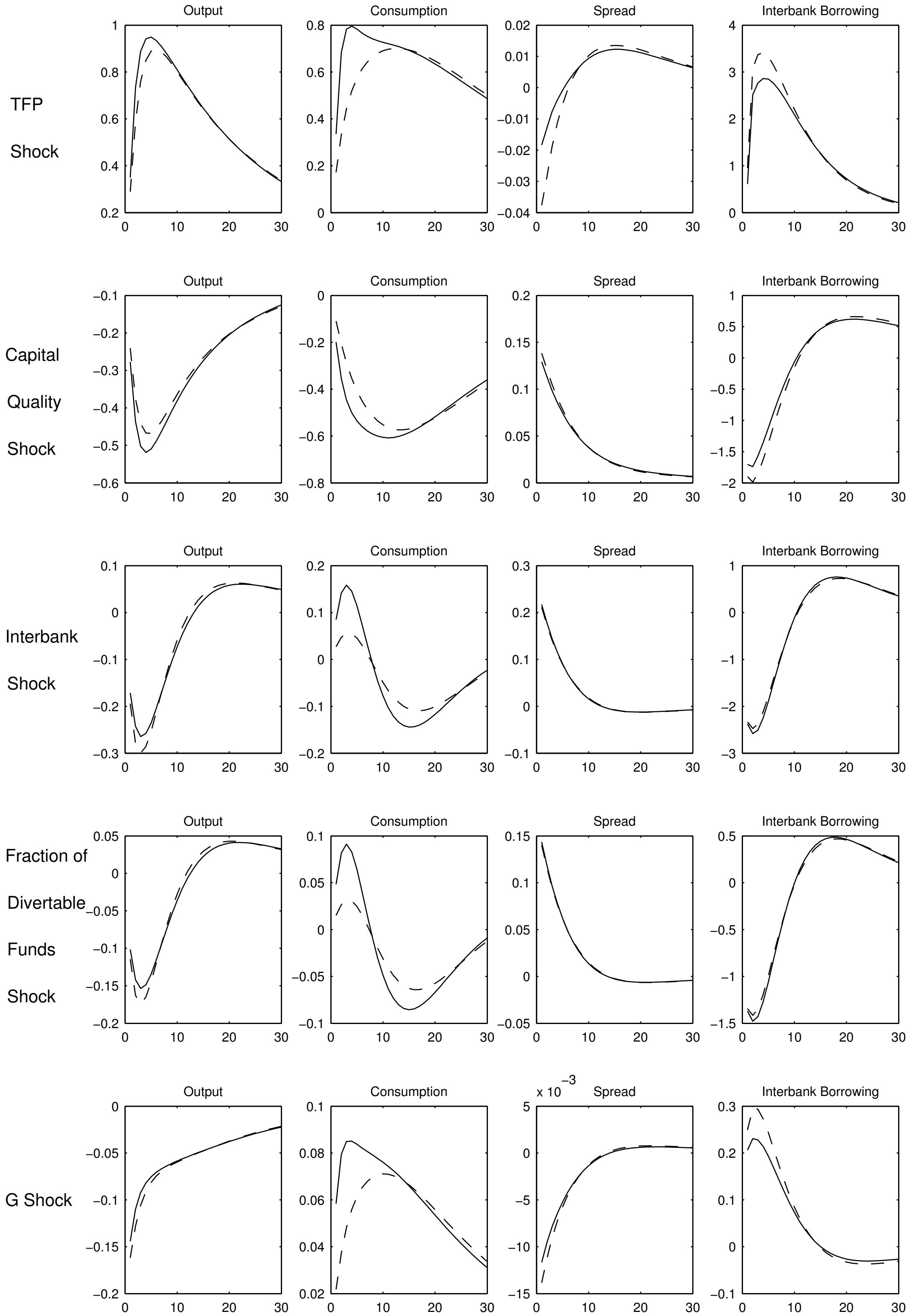
Figure 2.2.1 : IRF Comparison for Different Capital Adjustment Cost



Benchmark ——   s=1.6 – –

Plots show the percentage difference from the steady state, except for the spread, which shows the percentage point difference from the steady state.

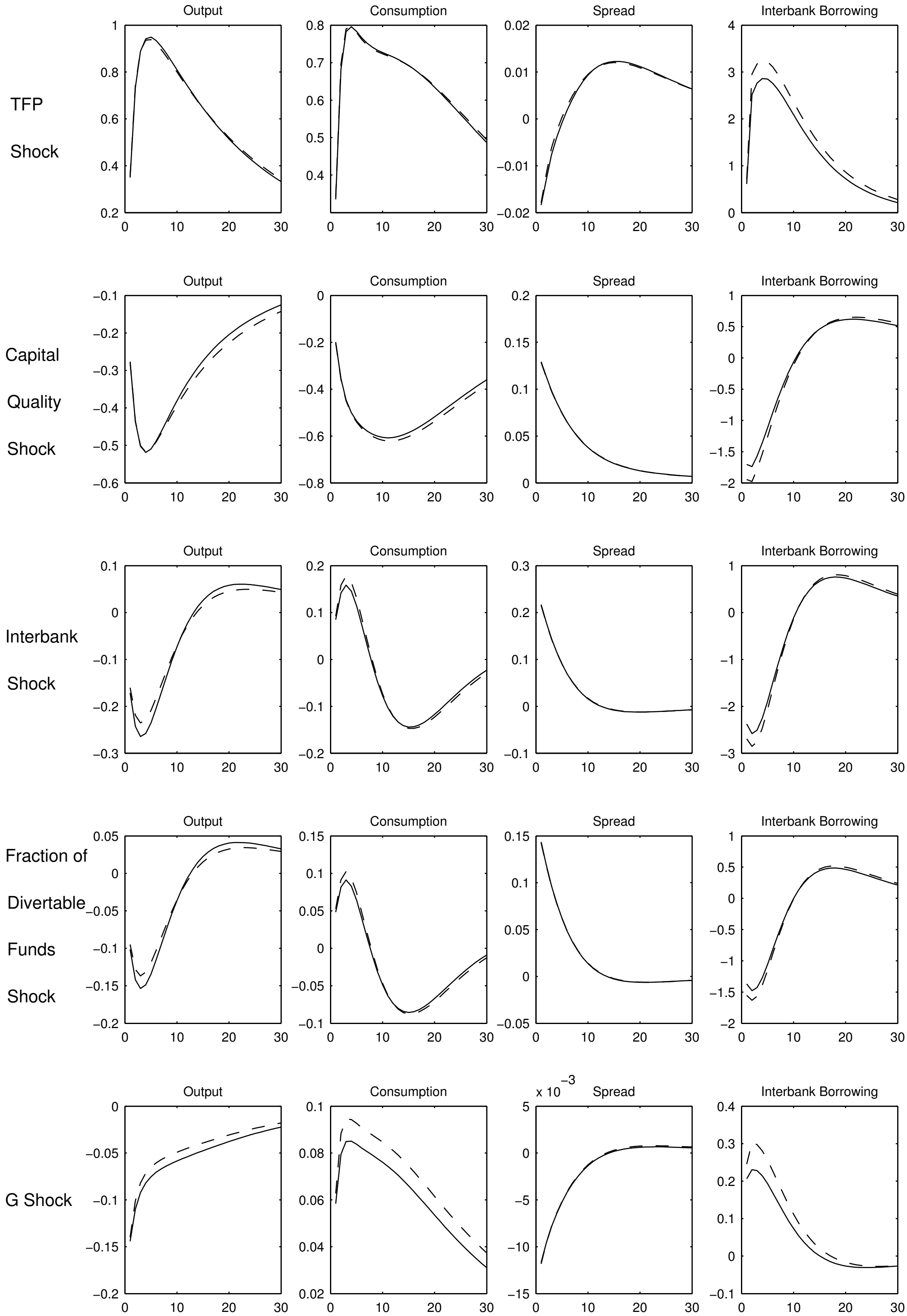
Figure 2.2.2 : IRF Comparison with Different Values in γ



Benchmark —— γ=0.8 – –

Plots show the percentage difference from the steady state, except for the spread, which shows the percentage point difference from the steady state.

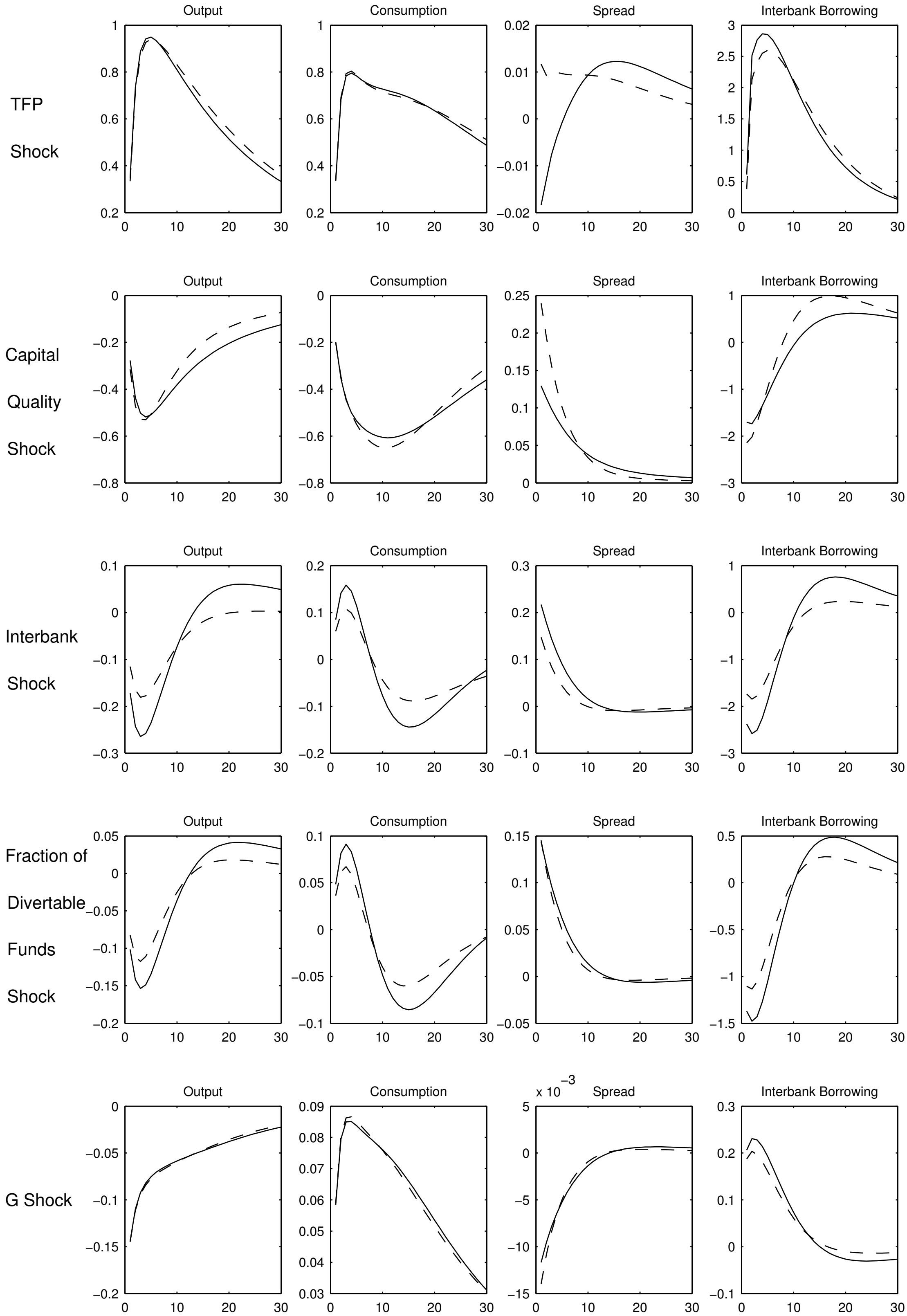
Figure 2.2.3 : IRF Comparison for Different Values in ϕ



Benchmark ——— ϕ=0.5 – –

Plots show the percentage difference from the steady state, except for the spread, which shows the percentage point difference from the steady state.

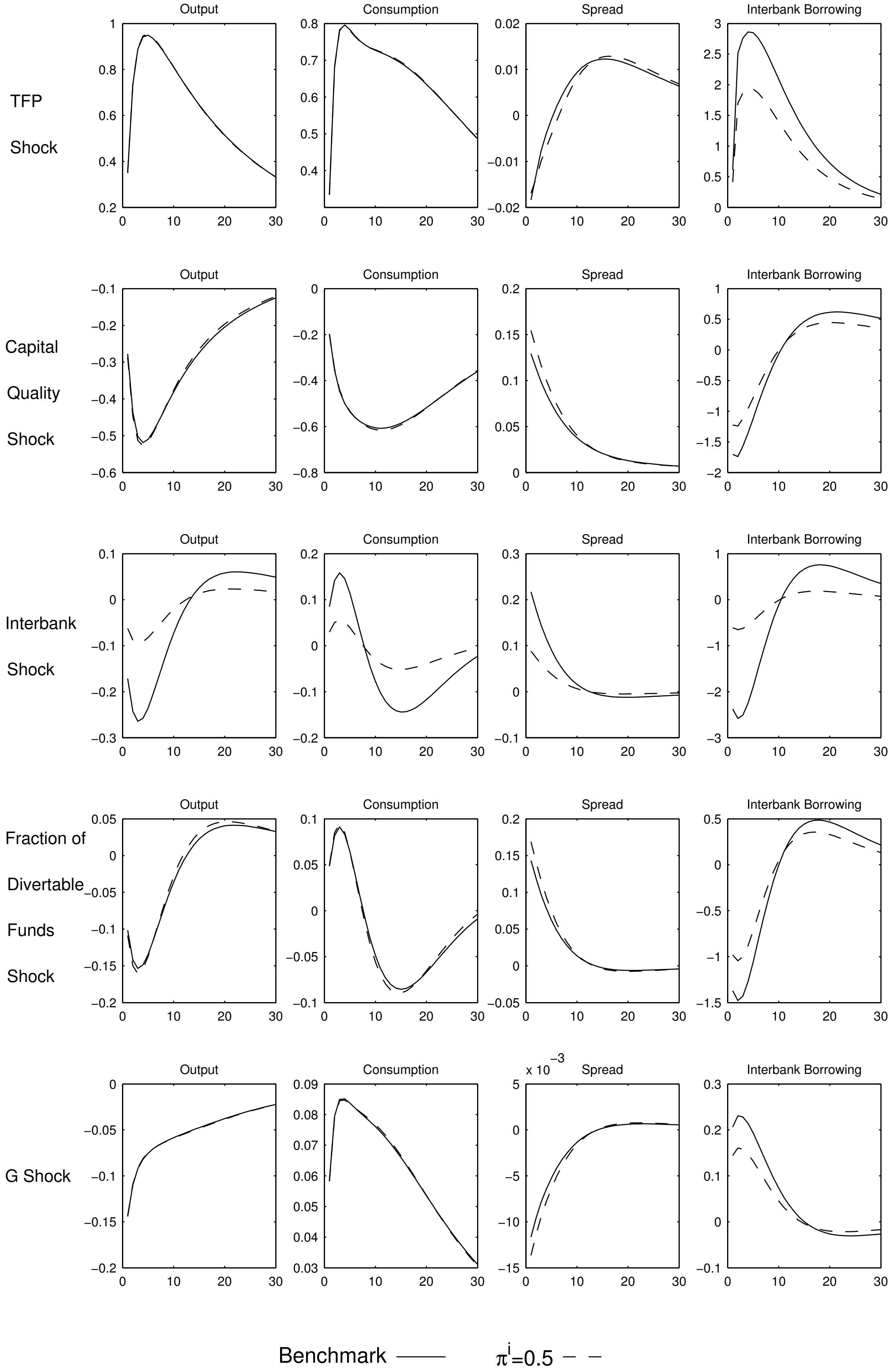
Figure 2.2.4 : IRF Comparison for Different Values in σ



Benchmark —— σ=0.95 – –

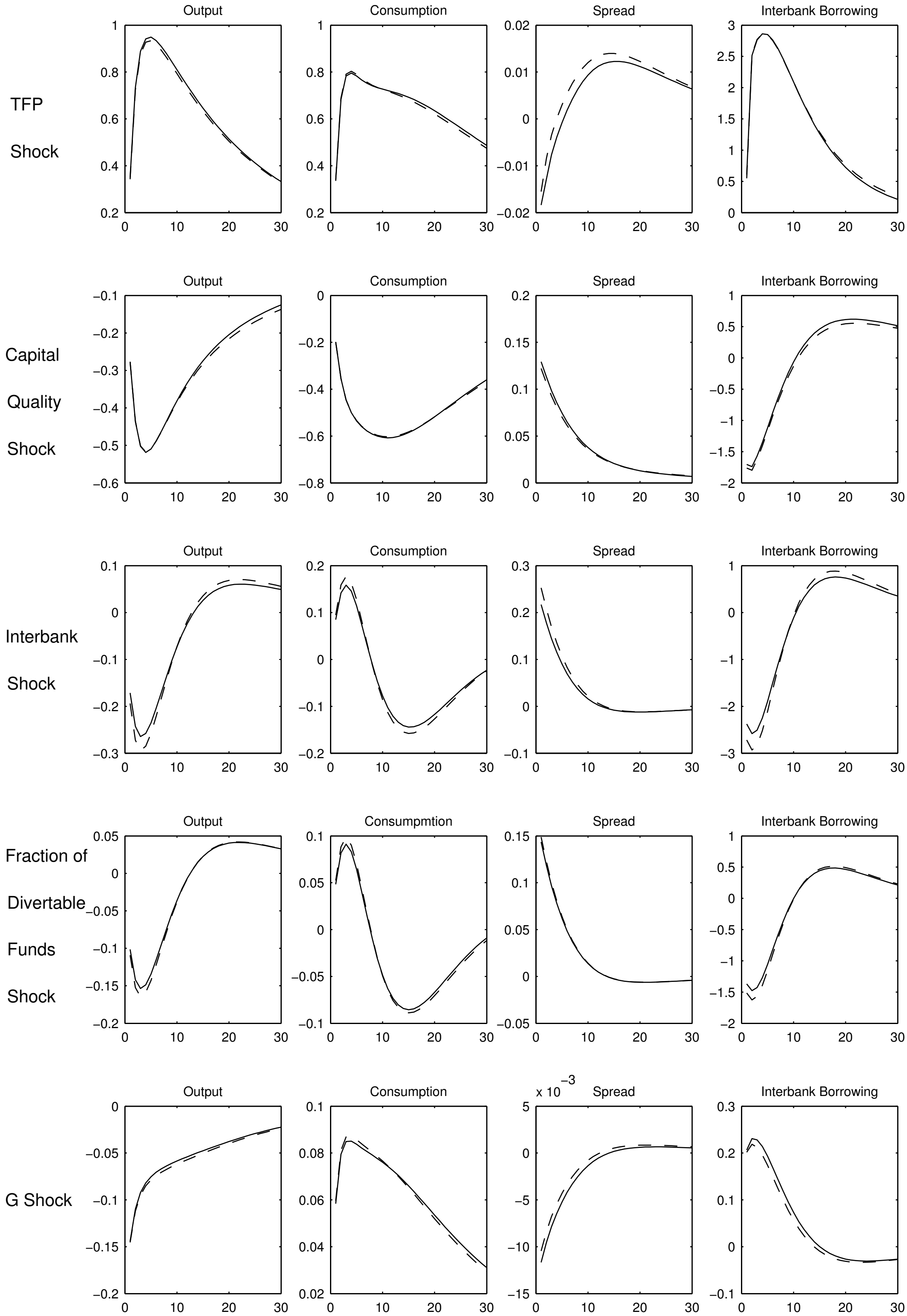
Plots show the percentage difference from the steady state, except for the spread, which shows the percentage point difference from the steady state.

Figure 2.2.5 : IRF Comparison for Different Values in π^i



Plots show the percentage difference from the steady state, except for the spread, which shows the percentage point difference from the steady state.

Figure 2.2.6 : IRF Comparison for Different Values in ξ



Benchmark —— ξ=0.005 – –

Plots show the percentage difference from the steady state, except for the spread, which shows the percentage point difference from the steady state.

Chapter 3
Price Stickiness and Conventional Monetary Policy

Abstract

Inflation-targeting monetary policy has been widely adopted and has successfully kept the inflation rate under control in many countries. However, the financial crisis starting in 2007 has revealed the disadvantages of the focus on inflation-targeting. Economists have suggested rethinking monetary policy so that it also monitors financial market stability. Bernanke and Gertler (1999,2001) have shown a good example of monitoring asset prices using conventional Taylor rules. They concluded that inflation-targeting central banks need not respond to asset prices except when the asset prices affect the inflation forecast. Unlike Bernanke and Gertler (2001), I add the credit spread as a third term in the monetary policy rule. The structure of this chapter's model follows the monetary DSGE model explained in the previous chapter, but includes price stickiness. After adopting the credit spread as a new term in the monetary policy rule, I assess the rule's implications for the variability of output and inflation under each of the 9 shocks to the model. Additionally, by applying a utility-based welfare analysis, I derive and analyse the optimal policy rule.

3.1 Introduction

The policy of inflation-targeting has been widely adopted by major central banks in the global economy. In Bernanke and Mishkin (1997), inflation-targeting policy is described as the monetary-policy where publicly announced medium-term inflation targets provide a nominal anchor, while allowing the central bank some flexibility to help stabilise the real economy in the short run. The inflation-targeting approach dictates that central banks should adjust monetary policy actively and pre-emptively to offset incipient inflationary or deflationary pressures. The experience of inflation-targeting in the period up to the financial crisis in 2007/8 appeared to show that it generally performed well at controlling the inflation rate and stabilising the real economy.

Although this policy has been successful at bringing down inflation, the recent crisis has shown that this policy has been unable to stabilise financial markets. This disadvantage was shown clearly in 2007, when the financial crisis emerged in the subprime mortgage market. During the crisis and the following long-lasted recession, asset prices declined very sharply. Monetary policy (in the form of inflation targeting) however continued to focus on stabilising inflation rate only. Under a conventional inflation-targeting regime, variations in asset prices would only affect policy to the extent that they affected the monetary authority's forecast of inflation. When monetary policy remained unresponsive and focused on the inflation-targeting pressures only, the asset price crash did sustained damage to the economy. Thus, there is a case for arguing that monetary authorities should take more direct account of asset prices and the stability of financial markets, rather than just the inflation rate. The 2007 crisis has highlighted the overconfidence in the self-adjusting ability of the economy and financial system itself and the lack of monetary policy response to financial instability.

Economic researchers have started to revise their approach to modelling economy and have also begun to rethink the role of financial intermediaries and have started to look for the appropriate monetary policy regimes that could be adopted to reduce the damage from the financial crisis. Thus, inflation-targeting regime would not be sufficient enough for monetary authorities to stabilise the financial markets. In the context of short-term monetary policy management, central banks should view price stability and financial stability as potentially complementary and mutually consistent objectives, to be pursued within a unified policy framework.

Before the crisis in 2007, some research did consider modifications to the inflation-targeting policy, of which one important dimension is how to adopt a policy that monitors the volatility of asset prices. Bernanke and Gertler (1999) is a good example of extending the focus of monetary authorities to stabilise financial markets rather than just inflation-targeting. They simulated a macroeconomic model to examine how an inflation-targeting policy might face troubles in a "boom-and-bust" cycle in asset prices. They addressed the issue of how should monetary authorities respond to asset price volatility. Bernanke and Gertler (2001) extended the policy regime to one including responses of nominal interest rate to inflation, output and stock prices as terms in a monetary policy rule. They found that an aggressive inflation-targeting policy rule (where the coefficient relating the instrument interest rate to expected inflation is 2.0) substantially stabilizes both output and inflation in the face of asset price and technology shocks. In other words, inflation-targeting central banks automatically accommodate productivity gains that lift asset prices. Bernanke and Gertler (2001) concluded that inflation-targeting central banks need not respond to asset prices, except when the asset prices affect the inflation forecast. They believe that the best policy framework for attaining both price-stabilisation and financial market stabilisation is a regime with flexible inflation targeting.

Bernanke and Gertler (1999,2001) extended the original Taylor rule to include the stock prices as a term in the Taylor rule, and the result shows that a zero response to the stock prices is the best policy. Unlike Bernanke and Gertler (2001), I address the question of how central bankers ought to respond to asset price volatility and financial instability, with another extension of the monetary policy rule. In contrast to Bernanke and Gertler (1999,2001), this chapter adopts the banker's premium instead of the stock prices as a new term in the monetary policy rule. The structure of this chapter's model follows the monetary DSGE model explained in the previous chapter, but also includes nominal price stickiness. After including the credit spread (the spread between the return on bank's assets and the return to household's deposits) in the monetary policy rule, I report and analyse the variabilities for output and inflation for different parameter values in the policy rule under the 9 shocks in the model. Additionally, by applying a consumption-based welfare effect analysis, I derive and analyse the optimal policy regime.

As explained previously in Chapter 2, bankers can potentially divert a certain fraction of banks' assets if banks default. There is therefore an incentive constraint to prevent bankers absconding with the funds borrowed. This constraint limits the size of banks' balance sheets, which causes the capital stock to be lower than if there is no incentive constraint. Thus, the marginal product of capital and the return of capital stock is higher than the interest rate on deposits, which means a positive credit spread. Thus, the credit spread is a direct measure for the severity of financial frictions. The shocks originated from the financial market can also be transmitted to the real economy via the credit spread. Thus, in order to examine the ways in which conventional monetary policy should respond to the amplifying effects of financial frictions, especially for the shocks originated from the financial markets, it would be useful to include a response to the credit spread in the Taylor rule. By including the credit spread in the Taylor rule, conventional monetary policy could be extended to adjust for the financial frictions in the model. This chapter thus considers how including such a term in the Taylor rule would alter the dynamic response of the economy, and how it alters the volatility of the key variables in the model. It also shows how the parameter on the credit spread (a_{sp}) should be set optimally with respect to different supply and demand shocks.

The remainder of the paper is organized as the follows: Section 3.2 describes the structure of the model, especially the price stickiness structure that has been added into the model; Section 3.3 derives the quantitative results with respect to nine different shocks; Section 3.4 concludes. The appendix of the paper provides details of some derivations, and lists of variables and the equations of the model.

3.2 Model

The model of this section is built on the benchmark model explained in the previous chapter. As in the previous chapter, the model follows Gertler and Kiyotaki (2010)'s modelling framework with interbank market frictions. In this chapter, I incorporate nominal price stickiness into the model and also include an extended Taylor rule for monetary policy. The model includes three supply shocks and six demand shocks. I firstly evaluate the different monetary policy rules under distinct shocks, and then adopt a consumption-based welfare analysis to illustrate the best monetary policy in this modelling framework. The following sub-sections describe the details of the model structure.

The production side of the economy is divided into two parts: intermediate goods producers and final goods producers. The intermediate goods firms use labour and capital to produce the intermediate goods. Intermediate goods are then collected by final goods firms and are used to produce the final goods. The structures for households and financial sectors are the same as in the previous chapter.

3.2.1 Final Goods Firms

Final goods firms produce a homogeneous final good by using differentiated intermediate goods. A competitive final goods producer aggregates a continuum of intermediate inputs from the intermediate goods firms. The production function for the final goods firm is the following:

$$Y_{Ft} = \left[\int_0^1 Y_{It}(j)^{\frac{\psi-1}{\psi}} \, dj \right]^{\frac{\psi}{\psi-1}} \tag{3.1}$$

where $\psi > 1$. $Y_{It}(j)$ denotes input of intermediate good j, and Y_{Ft} represents the output of final good being produced with a continuum of intermediate goods. The profits for the final goods firm is therefore the value of the output of final goods less the cost of the production for final goods:

$$\Pi_{Ft} = P_t Y_{Ft} - \int_0^1 P_t(j) \, Y_{It}(j) \, dj \tag{3.2}$$

By substituting the production function of final goods (3.1) into the profit objective for the final goods firm (3.2), the optimisation problem faced by the final goods firm can be written as the following:

$$\max_{\{Y_{It}(j)\}} P_t \left[\int_0^1 Y_{It}(j)^{\frac{\psi-1}{\psi}} \, dj \right]^{\frac{\psi}{\psi-1}} - \int_0^1 P_t(j) \, Y_{It}(j) \, dj \tag{3.3}$$

Thus the final goods firm decides the amount of inputs $Y_{It}(j)$ to purchase from intermediate goods firms in order to maximise its final profits subject to the production function constraint. The first order condition from maximisation is:

$$P_t(j) = P_t \left[\int_0^1 Y_{It}(j)^{\frac{\psi-1}{\psi}} \, dj \right]^{\frac{1}{\psi-1}} Y_{It}(j)^{-\frac{1}{\psi}} \tag{3.4}$$

Substituting the final goods production function (3.1) into the above first order condition yields:

$$\begin{aligned} P_t(j) &= P_t Y_{Ft}^{\frac{1}{\psi}} Y_{It}(j)^{-\frac{1}{\psi}} \\ &\Rightarrow \; Y_{It}(j) = Y_{Ft} \left(\frac{P_t(j)}{P_t} \right)^{-\psi} \end{aligned} \tag{3.5}$$

The above expression represents the demand function for intermediate goods. Use the definition of Y_{Ft} and the solution for $Y_{It}(j)$ we can derive the following expression:

$$Y_{Ft} = \left[\int_0^1 \left[Y_{Ft} \left(\frac{P_t}{P_t(j)} \right)^{\psi} \right]^{\frac{\psi-1}{\psi}} dj \right]^{\frac{\psi}{\psi-1}} = Y_{Ft} \left\{ \int_0^1 \left(\frac{P_t}{P_t(j)} \right)^{\psi-1} dj \right\}^{\frac{\psi}{\psi-1}} \tag{3.6}$$

The production function has constant returns to scale, thus Y_{Ft} drops from both sides of the above expression. The expression for the price level of final goods can be derived as the following:

$$P_t = \left\{ \int_0^1 P_t(j)^{1-\psi} dj \right\}^{\frac{1}{1-\psi}} \tag{3.7}$$

where P_t represents the optimised price for final goods, which is also the minimum cost of producing one unit of the final-goods bundle Y_{Ft}. Because of the constant-returns-to-scale assumption, P_t is independent of the quantity of final goods produced. Based on this reason, P_t can be interpreted as the aggregate price index. It indicates the optimised value for the final goods firm of relaxing the constraint on production.

3.2.2 Intermediate Goods Firms

The intermediate goods sector is made up by a continuum of monopolistically competitive firms, indexed by $j \in (0, 1)$. As shown in the previous sub-section, each intermediate goods firm faces a downward sloping demand for its product. It uses labour and capital goods to produce the intermediate goods according to the following production function:

$$Y_{It}(j) = A_t K_t^{\alpha}(j) L_t^{1-\alpha}(j) \tag{3.8}$$

where $L_t(j)$ and $K_t(j)$ represent the labour inputs and capital goods inputs for one representative intermediate-goods firm j. As illustrated in the previous sub-section, each intermediate goods producer chooses its own sale price $P_t(j)$ taking as given the demand curve for intermediate goods. I follow the Calvo (1983) assumption that every period only a random fraction of intermediate goods firms is optimally setting their prices. Each firm can reset its price only when there is a chance to do so, which only occurs with a probability $1-\rho$ in every period. There are two constraints that an intermediate producer faces: the production constraint (3.8) and the demand function (3.5). The intermediate goods sector faces two optimisation problems simultaneously, which includes both minimisation the firms' production costs subject to the Cobb-Douglas production function, and maximisation in firms' profits. Therefore, the following two sub-sections describe the intermediate goods sector as a cost minimiser and as a price setter.

3.2.3 The Intermediate Goods Producer as a Cost Minimiser

Consider cost minimisation conditional on the output $Y_{It}(j)$ produced. This optimisation involves minimising the total cost of production $Z_t K_t(j) + W_t L_t(j)$ subject to the production function (3.8):

$$\min_{\{K_t(j), L_t(j)\}} Z_t K_t(j) + W_t L_t(j) - \mu_t \left[A_t K_t^{\alpha}(j) L_t^{1-\alpha}(j) - Y_{It}(j) \right]$$

where W_t and Z_t represent the wage payments and capital payments in real terms. μ_t is the multiplier associated with the production constraint. Thus, intermediate goods firms minimise their costs of production in order to decide the quantity of capital and labour to input in the production process for the current period. The first order conditions can be written as:

$$\begin{aligned}
\frac{\partial \mathcal{L}}{\partial K_t(j)} &= 0 \Rightarrow \mu_t = \frac{Z_t}{A_t \alpha K_t^{\alpha-1}(j) L_t^{1-\alpha}(j)} \\
\frac{\partial \mathcal{L}}{\partial L_t(j)} &= 0 \Rightarrow \mu_t = \frac{W_t}{A_t (1-\alpha) K_t^{\alpha}(j) L_t^{-\alpha}(j)}
\end{aligned}$$

$\Rightarrow$

$$\frac{(1-\alpha) Z_t}{\alpha W_t} = \frac{L_t (j)}{K_t (j)} \tag{3.9}$$

The above expression gives a simplified first order condition for the intermediate goods firm's minimisation of production costs. The optimal labour and capital inputs can be derived by substituting this first order condition into the production function. This yields the following:

$$L_t^* (j) = \frac{Y_{It} (j)}{A_t} \left[\frac{(1-\alpha) Z_t}{\alpha W_t}\right]^{\alpha} \tag{3.10}$$

$$K_t^* (j) = \frac{Y_{It} (j)}{A_t} \left[\frac{(1-\alpha) Z_t}{\alpha W_t}\right]^{\alpha-1} \tag{3.11}$$

where $L_t^* (j)$ and $K_t^* (j)$ denote the critical quantities of labour and capital inputs respectively for intermediate goods firms. The minimised objective function for all the intermediate goods firms therefore is:

$$COST_{jt} = Z_t K_t^* (j) + W_t L_t^* (j) = \frac{W_t}{(1-\alpha) A_t} \left[\frac{(1-\alpha) Z_t}{\alpha W_t}\right]^{\alpha} Y_{It} (j) = MC_t \cdot Y_{It} (j) \tag{3.12}$$

where $MC_t = \frac{W_t}{(1-\alpha)A_t} \left[\frac{(1-\alpha)Z_t}{\alpha W_t}\right]^{\alpha}$ represents the real marginal cost of production for intermediate goods. This expression gives the minimised total cost of production. Given cost minimisation, the intermediate goods producers take MC_t as given when choosing the output price as shown in the following sub-section.

3.2.4 The Intermediate Goods Producer as a Price Setter

As stated before, I follow the Calvo (1983) approach and assume that in every period only a random fraction $1-\rho$ of intermediate goods producers can optimally set their prices. It is also assumed that this random fraction is independent across periods. The intermediate goods sector faces two optimisation problems simultaneously. One is minimising firms' production costs subject to the Cobb-Douglas production function, which has been illustrated in the previous sub-section. The other is maximising firms' profits by choice of output price. This choice is only available for the proportion of intermediate goods firms which can adjust their prices freely during the period. This sub-section illustrates this second maximisation problem.

At any point in time, some intermediate goods producers can change their prices and others cannot, thus the average price level will be a constant elasticity of substitution (CES) aggregate of all prices in the economy:

$$P_t^{1-\psi} = \rho P_{t-1}^{1-\psi} + (1-\rho)\left[P_t^*(j)\right]^{1-\psi} \tag{3.13}$$

where P_{t-1} is the previous period's price level, and $P_t^*(j)$ is the price level chosen by the intermediate goods firm j, which is able to reset price. In equilibrium, all the firms that reset the price in period t choose the same price and face the same demand, hence, $P_t^*(j) = P_t^*$. For those intermediate goods firms which could not adjust their prices freely, they follow the rule that the previous period's price continues to hold. Thus, the proportion $1-\rho$ of the intermediate goods firms maximise profits with respect to the choice of price adjustment. The following objective function represents the expected profit of the intermediate goods producers:

$$\max_{P_t(j)} E_t \sum_{i=0}^{\infty} (\beta\rho)^i \left\{P_t(j)\, Y_{t+i}(j) - P_{t+i} Z_{t+i} k_{t+i}(j) - P_{t+i} W G_{t+i} L_{t+i}(j)\right\}$$

Intermediate goods firms maximise their profit shown in the above expression subject to the production function (3.8) and the demand function for intermediate goods (3.5). By substituting the optimisation results derived in the cost minimisation problem (expressions (3.10) and (3.11)), we can then derive the price-setting first order condition:

$$P_t^*(j) = \left(\frac{\psi}{\psi - 1}\right) \frac{E_t \sum_{i=0}^{\infty} (\beta\rho)^i P_{t+i} Y_{t+i}(j) \cdot MC_{t+i}}{E_t \sum_{i=0}^{\infty} (\beta\rho)^i Y_{t+i}(j)} \tag{3.14}$$

The optimal prices that are chosen by the $1 - \rho$ of intermediate goods firms is given by the above expression, where $\frac{\psi}{\psi-1} > 1$ represents the steady state gross markup for a particular intermediate goods firm j's price on the ratio of discounted total nominal production costs over the discounted quantity of real output.

3.2.5 Monetary Policy with the credit spread

In the previous chapter the monetary authority does not play any role in the real economy. In this chapter, because of nominal price frictions, the monetary authority plays a major role in the real economy. Here the monetary authority is assumed to be following the Taylor rule. R_{t+1}^n represents the nominal interest rate on bank deposits, i.e. $R_{t+1}^n = E_t R_{t+1} \frac{P_{t+1}}{P_t}$, where R_{t+1} is the real rate of return on bank deposits. By the Taylor rule, it is assumed that the target for the nominal interest rate R_{t+1}^n is governed by:

$$\frac{R_{t+1}^n}{\bar{R}^n} = \beta^{\frac{1}{\varrho-1}} \cdot (R_t^n)^{\varrho} \left[\left(E_t \frac{P_{t+1}}{P_t}\right)^{a_\pi} \left(\frac{Y_t}{\bar{Y}}\right)^{a_Y} \left(\frac{SP_t}{\overline{\overline{SP}}}\right)^{a_{SPR}} \right]^{1-\varrho} \cdot \varepsilon_t^R \tag{3.15}$$

where a bar over a variable indicates its value at the steady state (i.e. the approximation point), $0 < \varrho < 1$ denotes the persistence parameter, $a_\pi > 1$ represents the response of the nominal interest rate to inflation, and $a_Y > 0$ denotes the response of nominal interest rate to output (relative to its steady state value). ε_t^R is a random monetary policy disturbance with zero mean and normally distributed with standard deviation σ_R. The above Taylor rule allows for a degree of partial adjustment in monetary policy, determined by the parameter ϱ.

In one exercise reported below I follow Bernanke and Gertler (1999) by investigating the effects of adjusting the feedback parameters on inflation and output (a_π and a_Y). The higher value of a_π indicates higher level of inflation stabilisation.

The key innovation in the monetary rule in (3.15) is that I have added the credit spread as a new policy indicator, where SP_t denotes the spread between the rate of return on real capital and the rate of return on deposits ($SP_t = E_t(R_{kt+1} - R_{t+1})$). This spread can be seen as the excess return of banks, and represents the premium that banks earns on their assets. Thus, the parameter a_{SPR} represents the policy response of nominal interest rate to this spread (relative to its steady state value).

As described before, the incentive constraint in the model limits the size of banks' balance sheets and causes the capital stock to be lower than it otherwise would be. This implies a positive credit spread of the economy. The credit spread is therefore a direct measure for the severity of financial frictions. It is obviously interesting to consider ways in which conventional monetary policy should respond to the amplifying effects of financial frictions. Thus, I add a nominal interest rate response to the credit spread in the Taylor rule. By doing so, conventional monetary policy can be extended to adjust better for the financial frictions in the model.

Taylor (1993) has discussed the conflict among monetary policy goals, where for instance inflation is above its target rate while output is below full employment. The Taylor rule specifies the relative weights given to reducing inflation versus raising output. Bernanke and Gertler (1999) have added a term in stock prices in the Taylor rule. By including the spread as a new term into the monetary policy rule, I evaluate the variabilities for output and inflation under 27 different combinations of a_π, a_Y and a_{SPR} for each of the 9 shocks in the model. Additionally, by applying a consumption-based welfare analysis, I derive and analyse the optimal policy rule for each of the shocks. These results are described in the next sub-section.

3.2.6 Calibration and Steady States

Similarly to the previous chapter, the calibration of the model mostly follows Gertler and Kiyotaki (2010). The model parameters include α (the share of capital stock in production), β (the household's discount factor), δ (the rate of depreciation of capital), ϕ (the labour elasticity parameter), σ (the survival rate of financial intermediaries), π^h (the probability that an island is an investing or non-investing island) and γ (habit parameter). The probability for investment opportunities to arrive on a typical island π^i is fixed to be 0.25, which implies new investment opportunities on an island arise once a year on average. The other parameters are set to conventional values where $\alpha = 0.33$, $\beta = 0.99$, $\delta = 2.5\%$, $\phi = 0.333$, $\sigma = 0.972$ and $\gamma = 0.5$. The capital adjustment cost parameter s is set to be 1.5 to limit the impact of capital adjustment costs on the dynamics. The model is sensitive to the parameters χ (the level of disutility of work) and ξ (the amount that transferable for banks entering the market). The model is also sensitive to the fraction of assets that a banker could divert in a default θ and the fraction of divertable funds in the interbank market w. Gertler and Kiyotaki (2010) selected the values of ξ and θ under two conditions, where an average credit spread is one hundred basis points annually and the economy-wide leverage ratio is 4. The baseline calculation for the steady state values of the model follow Hansen (2008) where it is assumed that the steady state of households' labour input is 1/3 (which is normally 8 hours per day). In a later section a sensitivity analysis the model is reported for a range of values for major parameters.

For the monetary policy rule, I consider rules relating the central bank's nominal interest rate to the expected inflation, output and the spread between the rate of return in bank's assets and the rate of return in bank's deposits. Similarly to Bernanke and Gertler (2001), the response of the nominal interest rate to expected inflation varies between 1 and 3, the response of the nominal interest rate to output varies between 0 and 1. I set the response of the nominal interest rate to the spread to be between -5 and 0. In section 3.3, for each choice of the policy rule parameters, I calculate the unconditional variances of the inflation and output to illustrate a comparison between different policy rules.

It is assumed the shocks in the model obey first order autoregressive process. Consistent with the calibrations for the shocks in Smets and Wouters (2003, 2007), the autoregressive factor for the technology shock, monetary policy shock, taste shock, investment adjustment shock and government expenditure shock are set to be 0.95, 0.15, 0.838, 0.91 and 0.943 respectively. The standard deviation for the above five shocks are set to be 0.01, 0.24, 0.407, 0.113, 0.335 respectively. The calibration for the capital quality shock follows Villa and Yang (2011), where the autoregressive factor is 0.4. The calibration for the news shock is consistent with Corsetti et al (2011), where the standard deviation and autoregressive factor of the shock are set to be 0.1414 and 0.9 respectively.

Similarly to Chapter 2, this chapter also analyses the IRFs of the model under different cases. The IRFs are calculated using a first-order approximation of the model solved using Dynare. Appendix A at the end of this thesis reports the Dynare model codes. The IRFs include cases with different levels of financial frictions, with different settings of the monetary policy rules, and with a "welfare-optimised" value of interest rate response to spread in the Taylor rule. These IRFs show clearly how the economy responds to the supply and demand shocks under these different cases of the model.

From these IRFs, it can be seen the extent to which the financial frictions amplify the effect of typical shocks in the model with price stickiness, comparing to the IRFs in Chapter 2. It also can be seen how the financial frictions can affect the real economy with price stickiness. Moreover, the IRFs show which conventional monetary policy should be preferred to minimise the negative effects from the shocks.

There is also a welfare analysis included in this chapter. Welfare is calculated using the household's utility function. The welfare results shown in the tables are based on a second-order approximation of the model solved using Dynare.

3.3 Quantitative Results

This chapter focuses on the analysis of conventional monetary policy rules in an economy subject to different shocks. In the following sub-section 3.3.1, I firstly analyse the impulse response functions (IRFs) for the model for a benchmark setting of the monetary policy rule. There are three sets of IRFs in this chapter. Figures 3.1.1 to 3.1.9 provide the IRFs for cases with different levels of financial friction. The second set of IRFs, contained in the Figures 3.2.1 to 3.2.9, provide the IRFs for different settings of the monetary policy rule. Afterwards, sub-section 3.3.2 shows the detailed analysis of the standard deviation of key variables, including an analysis of welfare. Tables 3.1 and 3.2 report the standard deviations in cases with different setting of the monetary policy rule and in cases with different levels of financial friction. Tables 3.3 to 3.5 and Figures 3.3.1 to 3.3.8 provide an analysis of the welfare optimised policy rule under different settings for key parameters of the model.

IRFs for Different Levels of Financial Friction

As explained above, the IRFs in this chapter show how the economy responds to different types of shocks under several different cases, including the cases with different levels of financial frictions, cases with different settings of the monetary policy rule, and cases with a "welfare-optimised" value of nominal interest rate response to spread in the Taylor rule. By examining the IRFs, it is possible to see how price stickiness and the Taylor rule interact with financial frictions. They show whether the frictions amplify the shocks in the model with price stickiness, and whether price stickiness increases the importance of the financial friction shocks. The IRFs also show the optimal conventional monetary policy to minimise the negative effects from the shocks with the Taylor rule.

The first set of IRFs (shown from Figure 3.1.1 to Figure 3.1.9) provide a comparison of how the model responds to the different shocks for different levels of the financial friction. The comparison between the benchmark case and the case with no financial frictions are also shown in these figures (i.e. the case with price stickiness but with perfectly functioning financial markets).

Firstly it can be seen that, the IRFs do not change much with different levels of friction. In Figure 3.1.1, the immediate rise of output in model with price stickiness is not as strong as the no financial friction case. The effect of frictions in financial market is not very obvious. Compared to the benchmark model, the spread decreases immediately for the positive TFP shock in models with financial frictions. The fraction of divertable funds, θ, seems to have more effect on the spread than the friction in the interbank market (measured by ω).

In the case of the capital quality shock, shown in Figure 3.1.2, with higher financial frictions, the initial decrease in output is smaller than in the benchmark model. However, the length of the recession for the cases with higher financial frictions is longer than for the benchmark model. In the case of the capital quality shock, the spread increases immediately after the shock. For models with financial frictions, this rise in spread is less than the benchmark model. Consumption and output drops less than the benchmark model but take longer to return to the steady state.

In addition to the eight shocks simulated in Chapter 2, this chapter includes a monetary policy shock, shown in Figure 3.1.3. This is a negative shock to the nominal interest rate in the Taylor rule function. As shown in the figure, cases with financial frictions respond more to the shock than the no financial friction case. In the benchmark case, the spread jumps by 0.6% after the shock. This makes it more expensive for firms to borrow in the financial market. Both the level of interbank borrowing and the level of bank loans drop by a large amount. Bank loans decrease by nearly 2.4%. This large decrease in financial liquidity causes investment and output to decrease further than in the no financial friction case. However, there is not much difference between the different levels of financial frictions in the model. It seems that the model with a higher interbank market friction or a higher deposit market friction respond a little less than the benchmark case.

Figures 3.1.4 to 3.1.7 show the four demand shocks to the model. The economy does not respond very differently with different level of financial friction. As shown in the case of the preference shock, for the cases with financial frictions, both interbank borrowing (B_t^i) and bank loans (S_{pt}) increase less than the no financial friction case. This causes output and investment to increase less than in the no financial friction case. The effect is similar in the case of a positive investment shock. With a sudden drop in the investment adjustment cost, the economy is stimulated with more investment and output. In the cases with financial friction, this stimulation is more limited comparing to the no financial friction case. In the case of a positive news shock, the difference between the four cases of the model is quite small. Though it still can be seen that the financial frictions limit the positive impact to the economy from this shock. In the case of a government spending shock, the spread drops slightly in the frictional cases and deposits rise more than in no financial friction case, and so do interbank borrowing and bank loans.

Figure 3.1.8 and Figure 3.1.9 show the IRFs in the case of the two financial market shocks — the interbank market shock and the shock to deposits market. For the model with higher frictions in the deposits market (where $\theta = 0.5$), output drops more following these shocks. For the model with a higher friction in the interbank market however, the output drops less, but it takes a longer period to get back to steady state. As discussed in Chapter 2, the change in θ affects not only the deposit market but also the friction in the interbank market. Thus, a larger value for θ makes the economy respond more to the shock than a higher interbank friction.

Compared to the IRFs in Chapter 2, adding price stickiness has diminished the amplification mechanism of financial frictions to both supply and demand shocks. However, with price stickiness, the shocks originating from the financial market have a larger impact on the economy compared to the ones in Chapter 2. The importance of the financial friction shocks is thus increased by including price stickiness in the model.

The financial frictions lead to an obvious amplification of the Taylor rule shock. Compared to no financial friction case, the model with different levels of financial frictions creates a larger impact on the economy from this shock.

IRFs for Different Monetary Policies

As explained above, since the credit spread shows a direct measure of the severity of the financial frictions, the nominal interest rate response to the credit spread is also included in the Taylor rule. In this sub-section the IRFs are used to examine how varying the policy parameters of the Taylor rule may help to damp the effects of various shocks in the face of financial frictions.

The second set of IRFs (shown in Figure 3.2.1 to Figure 3.2.9) shows the results for different values of $a_\pi$and a_y in Taylor rule. Comparing to the first set of IRFs, variations in a_π and a_y have larger impacts on the real economy. The real economy responds more with high a_π and zero a_Y. The effects from the shocks are amplified by these extreme parameter values.

The real economy responds strongly to the TFP shock, especially in the case with zero a_Y in the Taylor function. With a zero nominal interest rate response to output in the Taylor rule function, the spread responds strongly to the shock. In the figure, the spread decreases by about 0.1%. This makes it easier for firms to borrow funds and stimulates investment and output to a much higher level. For the case with large a_π, this amplification mechanism is smaller than in the zero a_Y case, but still larger than the benchmark case and no financial friction case. In the benchmark case, where $a_\pi = 1.5$ and $a_Y = 0.125$, the spread does not change much. Thus the economy is not stimulated so much as the two extreme cases. Moreover with financial frictions, the benchmark case even responds less than the no financial friction case with respect to this positive TFP shock.

Similarly to the TFP shock, it is also very obvious that, in the case of the capital quality shock (shown in Figure 3.2.2), a large a_π and zero a_y makes the economy respond much more than the benchmark case. For example, output decreases by 0.4% in the benchmark case, but when $a_\pi = 3$, output drops by 0.6%, and decreases by 0.8% when $a_y = 0$. Compared to the high a_π value case, the economy responds the most in the zero a_y case. Since there is no frictions in the no financial friction case, the economy is least affected with this negative capital quality shock. The extreme values in a_π and a_Y amplify the impact from this shock to the economy.

The impact of the Taylor shock is diminished with $a_\pi = 3$ comparing to the other two frictional cases (the benchmark case and the zero a_Y case). From Figure 3.2.3, with a higher a_π, the nominal interest rate is more sensitive to the inflation rate and output responds less in the shock. The spread does not increase so much as the other cases.

Figures 3.2.4 to 3.2.7 show the results for the four demand shocks. In the case of the preference shock, the economy responds least in the case with $a_\pi = 3$. In this case, the spread drops by a large amount, which eases the costs of loans for firms. This stimulates investment, employment and output in the economy. In the case of the positive news shock, for the case where $a_y = 0$, the spread drops by the most comparing to the other cases. This decrease in spread makes it easier for firms to borrow funds, which causes output to increase by nearly 0.4% after this shock. With a positive investment shock, as shown in Figure 3.2.5, the spread increases in the benchmark case and in the high a_π case. This causes the economy to respond less to this shock. However in the zero a_Y case, the spread decreases on impact, stimulating the economy to respond more to this positive investment shock. The impact on the economy is also amplified with the extreme values in a_π and a_Y with respect to the positive news shock. It is most amplified in the zero a_Y case. In this case, the spread decreases, which makes it easier for firms to borrow which means that investment is stimulated after the shock and output increases by nearly 0.04%. In the case of a negative government spending shock however, the spread in the zero a_Y case is almost unchanged after the shock. Investment and output are therefore less affect compared to the other cases. The ability of the spread to adjust is diminished compared to the benchmark model. This leads to a larger decrease in output. Output decreases by 0.2%, and investment also affected by a large amount.

Figures 3.2.8 and 3.2.9 present the IRFs for the shock in financial markets. In the case of these two shocks, it seems that the large value of a_π does not make much difference compared to the benchmark case. In the case of these financial market shocks, the nominal interest rate response to inflation is not so important as the nominal interest rate response to output in the Taylor rule. In the case of the interbank market shock, a zero a_y causes a deeper recession for the economy. When $a_y = 0$, the spread increases by more than the benchmark case after the shock, which implies a larger decrease in output. The change in the value of a_π however does not have much impact in this case.

Generally speaking, for almost all the shocks, adopting extreme values for a_π and a_Y amplifies the impacts from the shocks to the economy, especially comparing to the benchmark case. Adopting extreme values for a_π and a_Y causes the spread to respond more to the supply shocks, but respond a little less to the demand shocks. The zero a_Y case shows the largest amplification mechanism for the shocks.

This section only considers the IRFs for different parameter values of a_π and a_Y. The effects of setting a non-zero value of a_{SPR} on the IRFs are considered in a later section (which will also consider the optimal choice of parameters for the Taylor rule).

3.3.1 Standard Deviation of Critical Variables

In order to examine further the stabilising properties of the various settings of the Taylor rule, this sub-section analyses the standard deviations of important macro variables under different Taylor rule parameters. By examining the standard deviation for critical variables, it can be shown whether changing the Taylor rule parameters improves the response of the economy to the shocks.

As described in the model section, this chapter models conventional monetary policies in terms of a modified Taylor rule. It is important to analyse the model under different settings of monetary policy and under different levels of financial frictions. In this sub-section, I analyse the standard deviation of some critical variables for different values of the parameters of the Taylor rule and for different levels of financial friction. The results are reported in Table 3.1 and Table 3.2.

Table 3.1 shows the standard deviation of output, inflation and the spread for different values of the parameters in the Taylor rule. The first column in the table reports the parameters of the Taylor rule. The three numbers shown in each row of this column represent the parameters a_π, a_y and a_{SPR}. Thus, the first number gives the response of the nominal interest rate to expected inflation, the second number represents the response of nominal interest rate to output, and the third number denotes the response of nominal interest rate to the spread. The second to the fourth columns reports the unconditional standard deviations of output (σ_Y), of inflation (σ_π) and of the spread (σ_{SPR}) respectively. The results shown are derived from stochastic simulation for the model with the 9 shocks simultaneously.

Firstly it can be seen that, increase the response of the nominal interest rate to output (a_y) would decrease the variance of output (σ_Y), increases the variance of inflation

(σ_π) and decreases welfare. The standard deviation of the spread (σ_{SPR}) increases when the response of the nominal interest rate to the spread (σ_{SPR}) is non-zero. For example, compare rows (1, 0, 0), (1, 0.5, 0) and (1, 1, 0) in the table.

From the above results, it seems that monetary policy should respond to the output as well, at least if the purpose of policy is to reduce the variability of output. Adding an output response ($a_y \neq 0$) in the policy rule, compared to a rule that targets only inflation, typically leads to a small reduction in the variability of output.

Secondly, an increase in the response of the nominal interest rate to inflation (a_π) decreases the variation of inflation (σ_π). This aggressive anti-inflation monetary policy increases the standard deviation of output (σ_Y) and welfare when the policy response to output (a_y) is non-zero. For example, compare the rows (1, 0.5, 0), (2, 0.5, 0) and (3, 0.5, 0) in the table.

When the response to inflation is $a_\pi = 3$, there is a higher variability of the spread (which is increasing the absolute value of a_{SPR}) and a lower standard deviation in output. This only happens when the response to inflation equals is 3. In all cases, an increase in the response to spread decreases the variability in the spread.

Lastly, in almost all cases, the reduction in variability of output coincides with an increase in the variability of inflation. There is a clear trade-off between inflation and output stabilisation. Thus, for instance, when the policy (1, 0.5, 0) is compared to the policy (1, 1, 0) the reduction in the variability of output is accompanied by an increase the variability of inflation.

Table 3.2 summarises the standard deviations for the key variables and welfare with different levels of financial friction. There are two types of financial frictions illustrated in the table —– the interbank market friction (w) and the friction in the deposit market

(θ). Their values are listed in the first column of the table. The second to the fourth columns provide the unconditional variance of the output (σ_Y), of inflation (σ_π) and of the spread (σ_{SPR}) respectively. Similarly to Table 3-1, the results shown in the table are simulated under the nine shocks simultaneously. As explained previously, the sizes of the shocks are calibrated following Smets and Wouters (2003, 2007).

From this table it can be seen that an increase in the fraction of divertable funds (higher θ), which is also an increase in the level of friction in deposit market, decreases the variability of output and inflation and increases the variability of the spread. For example, compare the rows (0, 0.3), (0, 0.35) and (0, 0.4). In the model with a perfect interbank market ($w = 1$), the higher the level of friction in deposit market the lower the variability of the spread (compare rows (1, 0.3), (1, 0.35) and (1, 0.4)).

However, an increase in the level of the interbank market friction increases the standard deviations of output and the spread. This change in the interbank market friction does not affect the standard deviation of inflation. For example, compare the rows (0, 0.35), (0.5, 0.35) and (1, 0.35).

From the results shown in this sub-section, there is clear trade-off between inflation and output stabilisation among different policies. The results also show that the spread would respond differently for the different types of financial frictions. The interbank market friction does not affect the variation of inflation but affects output and spread.

3.3.2 Welfare Optimisation

The model of this chapter includes a utility–based welfare measure, shown in the following expression:

$$Welfare_t = E\left\{\ln\left(C_t - \gamma C_{t-1}\right) - \frac{X}{1+\varphi}\left(L_t\right)^{1+\varphi}\right\} \tag{3.16}$$

which is the unconditional expectation of aggregate household flow utility. This makes it possible to analyse the welfare maximising choice of the parameters of the Taylor rule. The welfare results shown in the tables in this chapter are based on a second-order approximation of the model solved by using Dynare.

In this section, the welfare optimisation is obtained by a grid search of the parameters of the Taylor rule. Ideally, it would be desirable to jointly optimise all three parameters of the Taylor rule, i.e. jointly choose a_Y, a_π and a_{SPR} to maximise utility. This is, however, a very time-consuming numerical problem which is beyond the scope of this thesis. I therefore focus on two restricted sets of optimisation exercises. In one set of optimisation exercises the values of a_Y and a_π are fixed at their benchmark values (i.e. $a_Y = 0.5/4$ and $a_\pi = 1.5$) and a_{SPR} is chosen to maximise welfare.

In the other set of exercises, a_π and a_{SPR} are jointly chosen to maximise welfare while a_Y is fixed at zero. In this second set of exercises, the assumption that a_Y is fixed at 0 is based on Schmitt-Grohé and Uribe (2006)'s work where they analyse a welfare maximising Taylor rule in a basic New Keynesian model. Their analysis showed that the welfare-maximising a_Y is close to zero for a wide range of calibrations of their model. Since the basic structure of goods and labour markets in their model is very similar to the structure of goods and labour markets in the model of this chapter, I set $a_Y = 0$ when running the joint optimisation for a_π and a_{SPR}. Some limited additional experiments with my model show that $a_Y = 0$ is indeed very close to optimal, so my second set of optimisation exercises appears to be a reasonably good approximation for joint optimisation of all three parameters of the Taylor rule.

The optimisation is carried out via a grid search. The grid search for a_{SPR} is set between -10 and 0. The welfare maximising value for a_{SPR} is generally negative indicating that it is optimal for the nominal interest rate to be reduced in response to an increase in the spread. In the case of joint optimisation over a_{SPR} and a_{π}, the grid search for a_{π} is set to be quite wide, i.e. from 1.5 to 100.

It is assumed that by choosing an optimal Taylor rule the monetary authority is able to eliminate all monetary policy shocks so, for all optimisation exercises, the variance of the Taylor rule shock is set to zero.

The optimal Taylor rule in the benchmark case

For the benchmark set of parameter values, optimisation over a_{SPR} while fixing $a_Y = 0.5/4$ and $a_{\pi} = 1.5$ yields the result that the optimal value of a_{SPR} is -2.9 and the maximised value of welfare is -2.7541.

For the second optimisation problem, when a_{π} and a_{SPR} are optimised jointly and a_Y is fixed at zero (and all other parameters are set at their benchmark values), the welfare-maximised values are $a_{SPR} = -1.4$ and $a_{\pi} = 56$ and the maximised value of welfare is -2.2187. Note that the welfare-optimal value of a_{π} in this second exercise implies almost complete inflation stabilisation. This result is consistent with the results in Schmitt-Grohé and Uribe (2006). In their model, they chose a search grid for a_{π} with a maximum value of 3 and in all their cases the optimum is at this maximum value. They pointed out however that the true optimal value of a_{π} in their model is much higher (i.e. close to 60) and the welfare difference between their $a_{\pi} = 3$ and the true optimum is very small.

IRFs for the Welfare Optimised a_{SPR}

The IRFs in this sub-section provide a comparison between the benchmark cases and the case adopting the "welfare-optimised" a_{SPR}. By examining these results, we can assess the effects of adding the credit spread to the Taylor rule on the responses to the various shocks. It also can be shown how the new term in the Taylor rule can dampen the response of the spread and how it can reduce the amplification effects of the financial frictions.

The IRFs shown in Figure 3.3.1 to Figure 3.3.8 are based on the welfare optimised value of a_{SPR}. In these figures, the dashed lines show the case with $a_{SPR} = -2.9$ (i.e. where only a_{SPR} is optimised) and the lines with dashes and dots show the case where $a_{SPR} = -1.4$ and $a_{\pi} = 56$ (i.e. where both a_{π} and a_{SPR} are optimised jointly and a_Y is fixed at zero). In this section I compare these cases to the benchmark case where $a_{SPR} = 0$ and $a_Y = 0.5/4$ and $a_{\pi} = 1.5$ and also the case with no financial frictions (and the benchmark Taylor rule).

The impact of adopting the welfare maximising value of a_{SPR} is not very obvious in the case of the positive TFP shock shown in Figure 3.3.1. Compared to the benchmark case, the spread decreases slightly in the case with optimal a_{SPR}. This leads to a slightly higher increase in the investment, labour and output after this shock. The case where both a_{SPR} and a_{π} are optimised is however quite different. Here inflation is almost completely stabilised and this is partly achieved by allowing a large fall in the spread. This helps to stimulate a large increase in investment and output in response to the positive productivity shock.

In the case of a negative capital quality shock, shown in Figure 3.3.2, the negative impact to the economy is diminished in the optimal a_{SPR} case compared to the benchmark case. With this welfare-optimised value of a_{SPR}, the spread increases less than in the benchmark case. The increase in the spread is less than half of the increase in the benchmark case, which causes an opposite response in interbank borrowing after the shock. In the benchmark model, with a 0.13% increase in the spread, bank loans decrease by more than 1.5% and interbank loans decrease. This drags investment down by around 0.8% and causes a 0.4% decrease in output. However in the case with $a_{SPR} = -2.9$, bank loans to firms also decreased, but by less than the drop in the benchmark case. The $a_{SPR} = -2.9$ case has the same response direction in interbank borrowing as with the case with no financial frictions. Compared to the benchmark case, this stimulates investment and employment and therefore reduces the impact of the shock on output.

The case with both a_{SPR} and a_{π} are optimised is again quite different. Optimisation of a_{π} results in inflation being almost completely stabilised. This requires a more severe fall in investment and output and this is partly achieved by causing the spread to rise by more in response to the shock than in the benchmark case.

In the IRFs for the four demand shocks shown in Figures 3.3.3 to 3.3.6, the spread increases less when $a_{SPR} = -2.9$ and investment and output increase more than the benchmark model and consumption decreases by a smaller amount. Bank's net worth also drops by a smaller amount. The impact of adopting $a_{SPR} = -2.9$ is not so obvious in the preference shock. It shows more obviously in the case of the investment shock, where the spread increases by only a little amount after the shock in the $a_{SPR} = -2.9$ case. The economy is stimulated more than the benchmark case with respect to the sudden drop in investment adjustment cost. For the news shock shown in Figure 3.3.5, there is not much difference between the benchmark case and the $a_{SPR} = -2.9$ case. Except for inflation, in the $a_{SPR} = -2.9$ case, the inflation rate returns back to steady state faster than the other two cases. Differently from the other shocks, the government spending shock shows a negative impact by adopting $a_{SPR} = -2.9$. It can be seen from Figure 3.3.6 that, in the $a_{SPR} = -2.9$ case, the spread decreases less than the benchmark case, which blocks the increase in investment after the shock and causes a larger decrease in labour and output.

The differences between the two optimised Taylor rules are less obvious in the case of the four demand shocks. In all cases the rule with optimised a_{SPR} and a_{π} all result in stabilisation of inflation. This tends to result in a larger movement in the spread in each case compared to the rule where only a_{SPR} is optimised. The larger movement in the spread helps to offset the effects of the demand shocks on output and inflation.

Similarly to the other cases analysed above, the interbank shock (Figure 3.3.7) and the shock to the fraction of divertable fund (Figure 3.3.8) have the same shape of responses to the shocks. The interbank market shock has a more limited impact than the fraction of divertable funds shock. In the case where only a_{SPR} is optimised (i.e. where $a_{SPR} = -2.9$) there is an obvious impact in cases of these two financial shocks. The spread increases less and results in larger increases in interbank borrowing and bank loans. This stimulates investment and thus output in this economy.

In the case where both a_{SPR} and a_{π} are optimised, inflation is stabilised but this version of the optimal Taylor does less to stabilise the spread in response to financial friction shocks. In fact the spread behaves in a very similar way to the benchmark case.

In summary, from the results reported above it can be seen that, by adopting the Taylor rule with only a_{SPR} optimised, the amplification effect of the financial frictions has been dampened for most of the shocks relative to the benchmark case. This is especially true for the two financial market shocks, where by adopting this optimised a_{SPR} the negative impact to the economy has been reduced very significantly compared to the benchmark case. For the case where $a_Y = 0$ and a_{π} and a_{SPR} are jointly optimised ($a_{\pi} = 56$ and $a_{SPR} = -1.4$), the results are more complicated. In this case the welfare benefits of stabilising inflation imply that a_π is very high while the spread is allowed to move by more than in the case where only a_{SPR} is optimised.

The optimal Taylor rule and financial frictions

Here in this section I find the optimal value of a_{SPR} for different cases of the model with different levels of financial friction. Both versions of optimised Taylor rule are examined in this section. The first version optimises welfare by running the grid search on a_{SPR} only. The second version optimises welfare by running the joint grid search on a_{SPR} and a_π together. In all cases where a_{SPR} and a_π are optimised jointly, a_Y is set to 0 (following Schmitt-Grohé and Uribe, 2006). Table 3.3 presents the results for welfare maximisation in cases with different levels of financial friction. There are two parts in each cell of the table. The top part represents welfare optimisation running the grid search for a_{SPR} only. The second part in each cell represents welfare optimisation running the joint grid search for a_{SPR} and a_π. The first line of the second part in each cell provides the welfare-optimal value of a_π, the second line provides the welfare-optimal value of a_{SPR} and the third line provides the optimal welfare value.

The first column of Table 3.3 shows three different levels for the interbank market friction. It can be seen that when the interbank market friction is decreasing (which corresponds to a rise in w), the maximised welfare decreases and the absolute value of the optimal nominal interest rate response to the spread ($|a_{SPR}|$) decreases. The same is true for the other two columns in Table 3.3. Thus, it is clear that when the interbank market friction is reduced, the optimal response to the spread in the Taylor rule is reduced.

The first row of Table 3.3 represents three different levels for the deposit market friction. A higher value of θ implies a more severe deposit market friction. By increasing the value of θ, the absolute value of the optimal nominal interest rate response to the spread ($|a_{SPR}|$) decreases in the case where only a_{SPR} is optimised. Thus an increase in the value of θ results in a lower optimal nominal interest rate response to the spread. However, when both a_π and a_{SPR} are jointly optimised the opposite is the case. In this case the optimal response to the spread increases as the deposit market friction becomes more severe.

The optimal inflation response in Taylor rule (a_π) decreases when the interbank friction decreases. For example, compare the column where θ is 0.3, when $w = 0$, the optimal $a_\pi = 47$; when w increases to 0.5 (which means a decrease in the interbank market friction), optimal a_π drops slightly to 46; when w increases further to 1 (which represents a perfect interbank market), optimal a_π drops further to 41.

The same effect is apparent for the deposit market friction. Thus, the optimal inflation response in Taylor rule (a_π) increases when the deposit market friction level increases (i.e. as θ increases). For example, compare the elements in the row where w is fixed at 0, when $\theta = 0.3$, the optimal $a_\pi = 47$; when θ increases to 0.35 (which is an increase in the deposit market friction), optimal a_π increases to 53; when θ increases further to 0.4, optimal a_π increases further to 59. Therefore, when the deposit market becoming more frictional, interest rate could respond to inflation more in a Taylor rule in order to approach the optimal welfare level. For the case where both a_π and a_{SPR} are optimised, the overall result appears to be that an increase in financial frictions, either in the interbank market or in the deposit market, implies that it is optimal for monetary policy to respond more to both inflation and the spread.

Optimal a_{SPR} and the other parameters of the Taylor rule

In this section, I discuss the effects of different values of a_Y and a_π for the optimal choice of a_{SPR}. In this case I focus on the case where only a_{SPR} is optimised (where a_Y and a_π are fixed at $0.5/4$ and 1.5 correspondingly).

In Table 3.4 the first column shows three different values for the interest response to inflation (a_π). The first row of the table shows three different values of the interest response to output (a_Y). There are two numbers contained in each cell of the table. The top number gives the optimal interest response to the spread (a_{SPR}), while the bottom number in each cell gives the optimal welfare in the economy.

Firstly from this table it can be seen that, an increase the nominal interest response to inflation (a_π) increases welfare. For example, compare the bottom elements in the second column. When $a_\pi = 1$ and $a_Y = 0$, optimal welfare is -2.6621, this has been increased to -2.2391 when a_π changes to 2 but a_Y stays unchanged. Welfare increases further to -2.2274 when $a_\pi = 3$. This increase in a_π decreases the absolute value of the optimal a_{SPR}. Thus, an increase in the nominal interest rate response to inflation would improve the economy resulting in a higher maximised welfare (as is consistent with the results for the joint optimisation of a_π and a_{SPR} where it is found that the optimal value of a_{SPR} is much higher than 3).

Changes in the value of a_Y show a significant impact on the maximised welfare. As shown in the table an increase in a_Y decreases the maximised welfare significantly. This is partial confirmation of the assumption that $a_Y = 0$ is close to the optimum value.

It can further be seen that, an increase the value of a_Y increases the absolute value for the optimal nominal interest rate response to spread (a_{SPR}). For example when $a_\pi = 2$, $a_Y = 0$, the value for $|a_{SPR}| = 0.9$. When $a_Y = 0.5$, the absolute value $|a_{SPR}|$

changes to 4.7. The value of the welfare-optimised nominal interest rate response to the spread changes to 5.9 when $a_Y = 1$. Thus when the nominal interest rate responds more to output in the Taylor rule, it also needs to respond more to the spread.

The optimal Taylor rule and shock variances

In this section I analyse how different values of the shock variances affect the optimal choice of a_π and a_{SPR}. Table 3.5 shows the welfare optimisation in cases with different variances of the shocks. In each row in turn I double the variance of one of the shocks relative to its variance in the benchmark. There are two columns of results in the table. The first column shows the case where a_{SPR} only is optimised and the second column shows the case where a_π and a_{SPR} are jointly optimised.

As shown in the first column of Table 3.5, a_{SPR} is smallest in the case where the variance of the financial friction shock (θ) is doubled. When this variance is doubled, the nominal interest rate responds by a small amount to the spread in order to achieve welfare maximisation. In the case of doubling the variance of the news shock, $|a_{SPR}|$ is the largest as 5.4. Thus with when the news shock is more important, the nominal interest rate should respond by a large amount to the spread.

The second column of Table 3.5 provides the welfare optimisation results by jointly optimising a_π and a_{SPR}. The absolute values $|a_{SPR}|$ are much smaller than the case when optimising a_{SPR} only and the effect of changes the shock variances on the optimal a_{SPR} is much smaller. Doubling the variance of the capital quality shock appears to have the largest positive effect on the optimal (absolute value) of a_{SPR}. Doubling the variance of the news shock now reduces the absolute size of the optimal a_{SPR}. This is the opposite to the effect that occurred when just a_{SPR} is being optimised. It appears that jointly optimising a_π and a_{SPR} implies that much of the effect of changing the variances of shocks works through the impact on the optimal a_π. When only a_{SPR} is being optimised then this parameter has to do all the work of dealing with the increase in the variance of each shock. When both parameters are being optimised some of the work of dealing with the increase in the shock variance can be handled by increasing a_π.

The optimal a_π values are quite large in all cases. The largest value (where $a_\pi = 63$) can be found in the case with doubled the capital quality shock. The value $|a_{SPR}| = 2.2$ is also the biggest in this case. Therefore quite aggressive conventional policy needs to be adopted in order to achieve the optimal welfare value in this case. The smallest value of $a_\pi = 46$ appears in the doubled financial friction shock case. The interest rate does not need to respond to inflation so much as the other shock cases in order to achieve the optimum.

3.4 Conclusion

The world economy suffered a severe financial crisis starting in 2007, which has led to a major recession. It is very important to study how the monetary authority should respond after such a crisis. The inflation-targeting approach dictates that central banks should adjust monetary policy actively and pre-emptively to offset incipient inflationary or deflationary pressures. Since adopted by central banks, the inflation-targeting policy has generally performed well in practice, in controlling the inflation rate and stabilising the real economy.

However, though this policy successfully brought inflation under control, financial markets continued to display instability. This was particularly evident in 2007, with the financial crisis originating from the subprime mortgage market. During the crisis and the following long-lasted recession, asset prices deteriorated very sharply, which caused the external finance premium to jump. The conventional inflation-targeting monetary policy approach did not performed well during this period of the large swings in asset prices. Under the conventional inflation-targeting regime, variations in asset prices would only affect monetary policy to the extent they affect the monetary authority's forecast of inflation. When monetary policy remained unresponsive and focused on the inflation-targeting pressures only, the asset price crashes did major damage to the economy. Thus, the 2007 crisis has highlighted the overconfidence in the self-adjusting ability for the economy and financial system itself and the lack of monetary policy control for financial stability. It has been argued that focusing on inflation control only is not sufficient for monetary authorities to stabilise financial markets. In the context of short-term monetary policy management, central banks should view price stability and financial stability as highly complementary and mutually consistent objectives, to be pursued within a unified policy framework.

Bernanke and Gertler (2001), using a model based on Bernanke et al (1996) which includes credit market frictions, considered the extent to which monetary policy should take account of asset prices. They found that, if balance sheets are initially strong, with low leverage and strong cash flows, then even large declines in asset prices are unlikely to push households and firms into financial distress. Bernanke and Gertler (1999,2001) concluded that monetary policy should have a zero response to stock prices.

Unlike Bernanke and Gertler (2001), I address the question of how central bankers ought to respond to asset price volatility and financial instability with another extension of the Taylor rule. This chapter analyses a Taylor rule where the credit market spread is included rather than asset prices. After adopting the credit spread as a new variable in the Taylor rule, I evaluate the implications of the rule for output and inflation variability. This chapter also adopts a consumption-based welfare analysis. There are two versions of optimal Taylor rule being considered in this analysis. One optimal Taylor rule is found by running the grid search for the nominal interest rate response to the spread (a_{SPR}) in the Taylor rule only. Another optimal Taylor rule is found by running a joint grid search for both the nominal interest rate response to spread (a_{SPR}) and the nominal interest rate response to inflation (a_{π}).

By using a grid search for the nominal interest rate response to the spread (a_{SPR}) in the Taylor rule, I have found the "welfare-optimised" value of this parameter. The results show that in the case of almost all shocks, adopting the welfare-optimised a_{SPR} improves the response of the economy and limits the negative impacts from the shocks. I also analysed the optimal a_{SPR} in cases with different financial friction levels, in cases with different nominal interest rate responses to output and inflation in the Taylor rule, and in cases with different variances of the shocks.

By using the joint grid search for both the nominal interest rate response to spread (a_{SPR}) and the nominal interest rate response to inflation (a_{π}), the economy's optimal welfare has been improved comparing to the previous version. The optimal nominal interest response to spread (a_{SPR}) decreases to a lower value.

The simulation results in this chapter have shown some interesting results for conventional monetary policies. Firstly from the IRFs it can be seen that adding price stickiness has diminished the amplification mechanism of financial frictions to both supply and demand shocks. However, with price stickiness, the shocks originating from the financial market have a larger impact on the economy compared to the IRFs in Chapter

2. Thus the importance of the financial friction shocks is increased by including price stickiness into the model. The financial frictions lead to an obvious amplification of the Taylor rule shock. Comparing to the model without financial frictions, the model with different levels of financial frictions create a larger impact to the economy from this shock.

For almost all the shocks, adopting extreme values for a_π and a_Y amplifies the impacts from the shocks to the economy, especially compared to the benchmark case. Adopting extreme values for a_π and a_Y causes the spread to respond more to the supply shocks, but respond a little less to the demand shocks. In the zero a_Y case it is found that the amplification mechanism is strongest to the shocks.

Adopting the welfare-optimised a_{SPR} in the Taylor rule dampens the amplification effect of the financial frictions for most of the shocks. Especially for the two financial market shocks, by adopting this a_{SPR} the negative impact to the economy has been reduced significantly compared to the benchmark case.

From the standard deviation results it can be seen that there is clear trade-off between inflation and output stabilisation among different policies. This analysis also shows that the spread would act differently between different types of financial frictions. The interbank market friction does not affect the variation in inflation but affects the output and spread in the economy.

Overall, the conventional monetary policy rule containing a_{SPR} improves the response of the economy to shocks. The response of the economy can be further improved by adopting the welfare-optimised value of a_{SPR} in the Taylor rule. The amplification effects of the financial frictions can be diminished. However, including the spread in the Taylor rule function does not prevent all the negative impacts to the economy from financial frictions. The response in both interbank borrowing and loans to firms still causes some amplification of shocks despite the inclusion of the spread in the Taylor rule with an optimised coefficient. Thus, in the next chapter, I examine unconventional monetary policy in the form of direct lending by the central bank to examine how the economy might be improved further. It might also be interesting in future research to look at some other elements that could be included in the Taylor rule in order to improve the response of this model economy to shocks.

3.A Appendix to Chapter 3

3.A.1 Derivation of Price Setting Equations

Recall that the first order condition for intermediate goods firms gives:

$$\begin{aligned} P_t^*(i) &= \left(\frac{\psi}{\psi-1}\right)\frac{E_t\sum_{\tau=0}^{\infty}\beta^\tau\rho^\tau P_{t+\tau}Y_{t+\tau}(i)\,\frac{W_{t+\tau}}{(1-\alpha)A_{t+\tau}}\left[\frac{(1-\alpha)Z_{t+\tau}}{\alpha W_{t+\tau}}\right]^\alpha}{E_t\sum_{\tau=0}^{\infty}\beta^\tau\rho^\tau Y_{t+\tau}(i)} \\ &\Rightarrow\ P_t^*(i)\,E_t\sum_{\tau=0}^{\infty}\beta^\tau\rho^\tau Y_{t+\tau}(i) \\ &= \left(\frac{\psi}{\psi-1}\right)E_t\sum_{\tau=0}^{\infty}\beta^\tau\rho^\tau P_{t+\tau}Y_{t+\tau}(i)\,\frac{W_{t+\tau}}{(1-\alpha)A_{t+\tau}}\left[\frac{(1-\alpha)Z_{t+\tau}}{\alpha W_{t+\tau}}\right]^\alpha \end{aligned} \tag{a.a1}$$

Left hand side of expression a.a1 could be linearised to:

$$LHS = P^*(i)\,Y(i)\,E_t\sum_{\tau=0}^{\infty}\beta^\tau\rho^\tau\left[\widehat{P}^*(i)+\widehat{Y}_{t+\tau}(i)\right] \tag{a.a2}$$

Right hand side of the expression a.a2 gives:

$$\begin{aligned} &RHS \\ = &\left(\frac{\psi}{\psi-1}\right)E_t\sum_{\tau=0}^{\infty}\beta^\tau\rho^\tau\frac{PY(i)\,W}{(1-\alpha)A}\left[\frac{(1-\alpha)Z}{\alpha W}\right]^\alpha\left\{\begin{array}{c}\widehat{P}_{t+\tau}+\widehat{Y}_{t+\tau}(i)\\ +(1-\alpha)\widehat{W}_{t+\tau}-\widehat{A}_{t+\tau}+\alpha\widehat{Z}_{t+\tau}\end{array}\right\} \end{aligned} \tag{a.a3}$$

From the first order condition a.a1, we could have the expression at steady states to be written as:

$$\begin{aligned} P(i) &= \left(\frac{\psi}{\psi-1}\right)\frac{\frac{1}{1-\beta\rho}PY(i)\,\frac{W}{(1-\alpha)A}\left[\frac{(1-\alpha)Z}{\alpha W}\right]^\alpha}{\frac{1}{1-\beta\rho}Y(i)} \\ \Rightarrow\ \frac{\psi}{\psi-1} &= \frac{1}{\frac{W}{(1-\alpha)A}\left[\frac{(1-\alpha)Z}{\alpha W}\right]^\alpha} \end{aligned} \tag{a.a4}$$

Thus, if we equalise the expressions for LHS and RHS in a.a2 and a.a3 and substituting in the steady state levels in a.a4, the following log-linearised expression for the original first order condition could be achieved:

$$\frac{1}{1-\beta\rho}\widehat{P}^{*}(i)=E_t\sum_{\tau=0}^{\infty}\beta^{\tau}\rho^{\tau}\left\{\widehat{P}_{t+\tau}+(1-\alpha)\widehat{W}_{t+\tau}-\widehat{A}_{t+\tau}+\alpha\widehat{Z}_{t+\tau}\right\} \tag{a.a5}$$

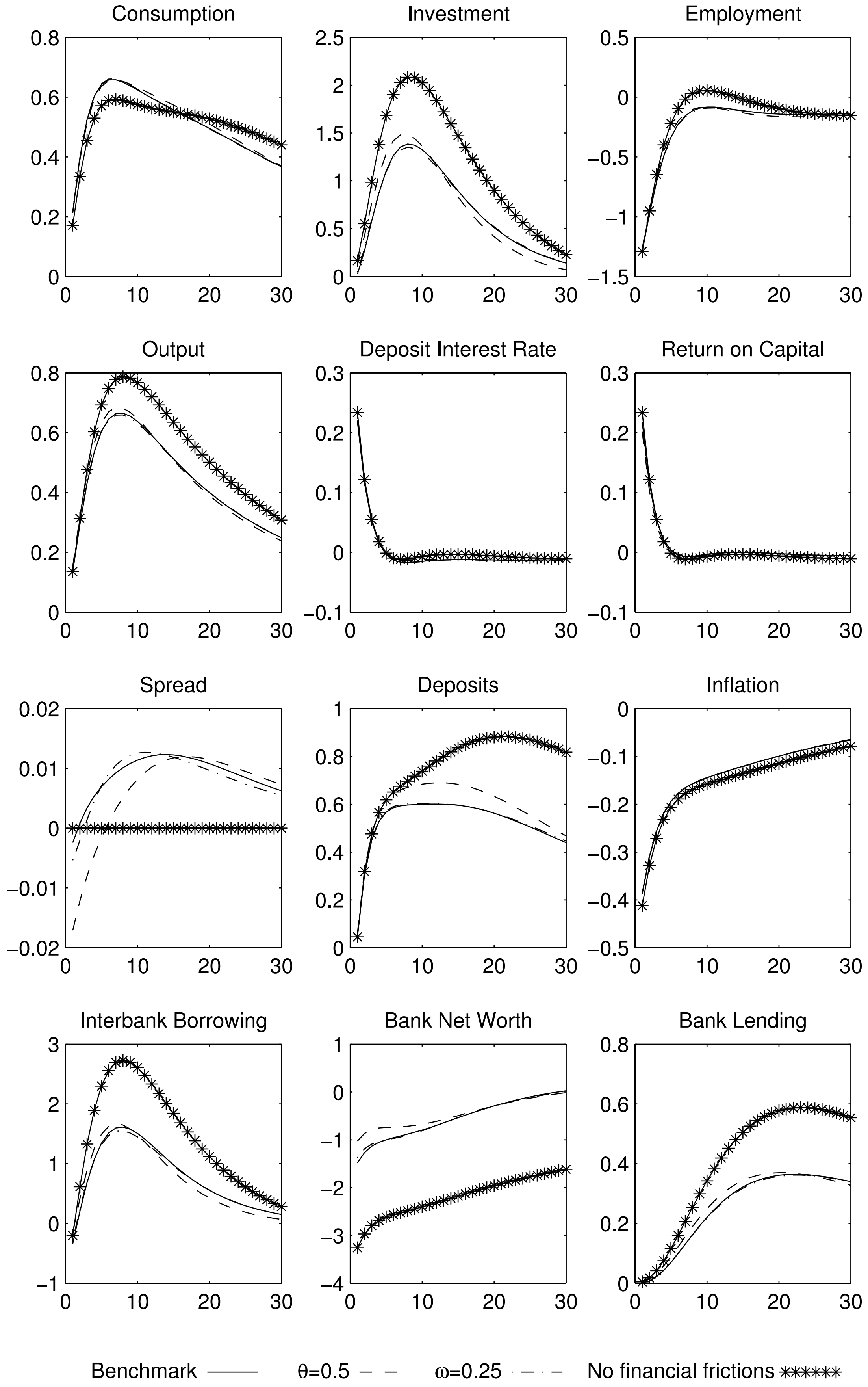
Recall the pricing rule in expression sp.5: $P_t^{1-\psi}=\rho P_{t-1}^{1-\psi}+(1-\rho)\left[P_t^{*}(i)\right]^{1-\psi}$, we could then derive the log-linearised form of the expression to:

$$\begin{aligned}\widehat{P}_t &= \rho\widehat{P}_{t-1}+(1-\rho)\widehat{P}_t^{*}(i)\\ &\Rightarrow \widehat{P}_t^{*}(i)=\frac{\widehat{P}_t-\rho\widehat{P}_{t-1}}{1-\rho}\end{aligned} \tag{a.a6}$$

Substitute the expressions for the log-linearised optimal price $\widehat{P}_t^{*}(i)$ into the linearised expression a.a5 could have:

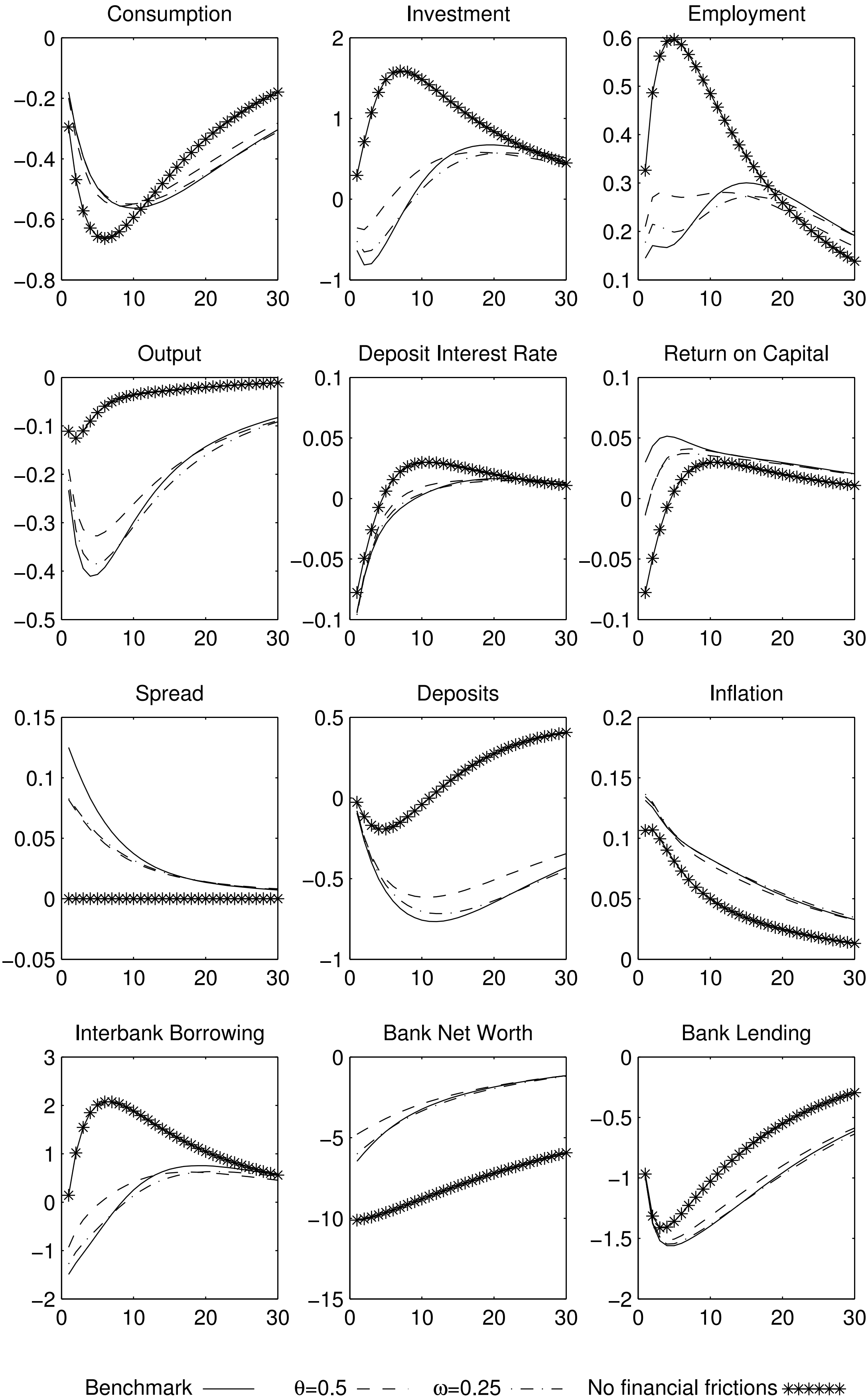
$$\begin{aligned}\widehat{P}_t-\widehat{P}_{t-1} &= \beta\left[\widehat{P}_{t+1}-\widehat{P}_t\right]+\frac{(1-\rho)(1-\beta\rho)}{\rho}\left[(1-\alpha)\widehat{W}_t-\widehat{A}_t+\alpha\widehat{Z}_t\right]\\ &\Rightarrow \ln\pi_t=\beta\ln\pi_{t+1}+\frac{(1-\rho)(1-\beta\rho)}{\rho}\ln RMC_t\end{aligned} \tag{a.a7}$$

Figure 3.1.1: TFP Shock IRFs



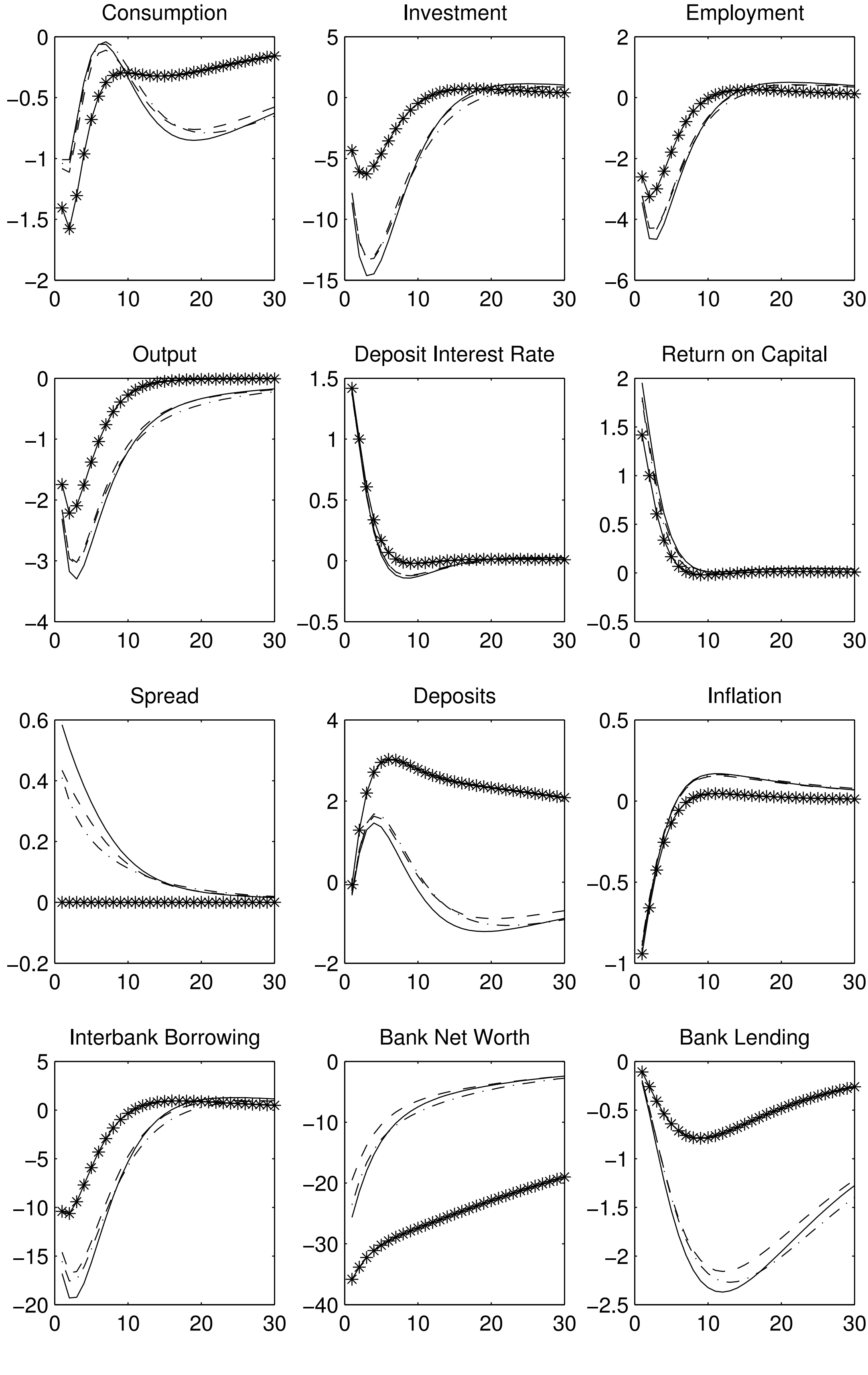
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.2: Capital Quality Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

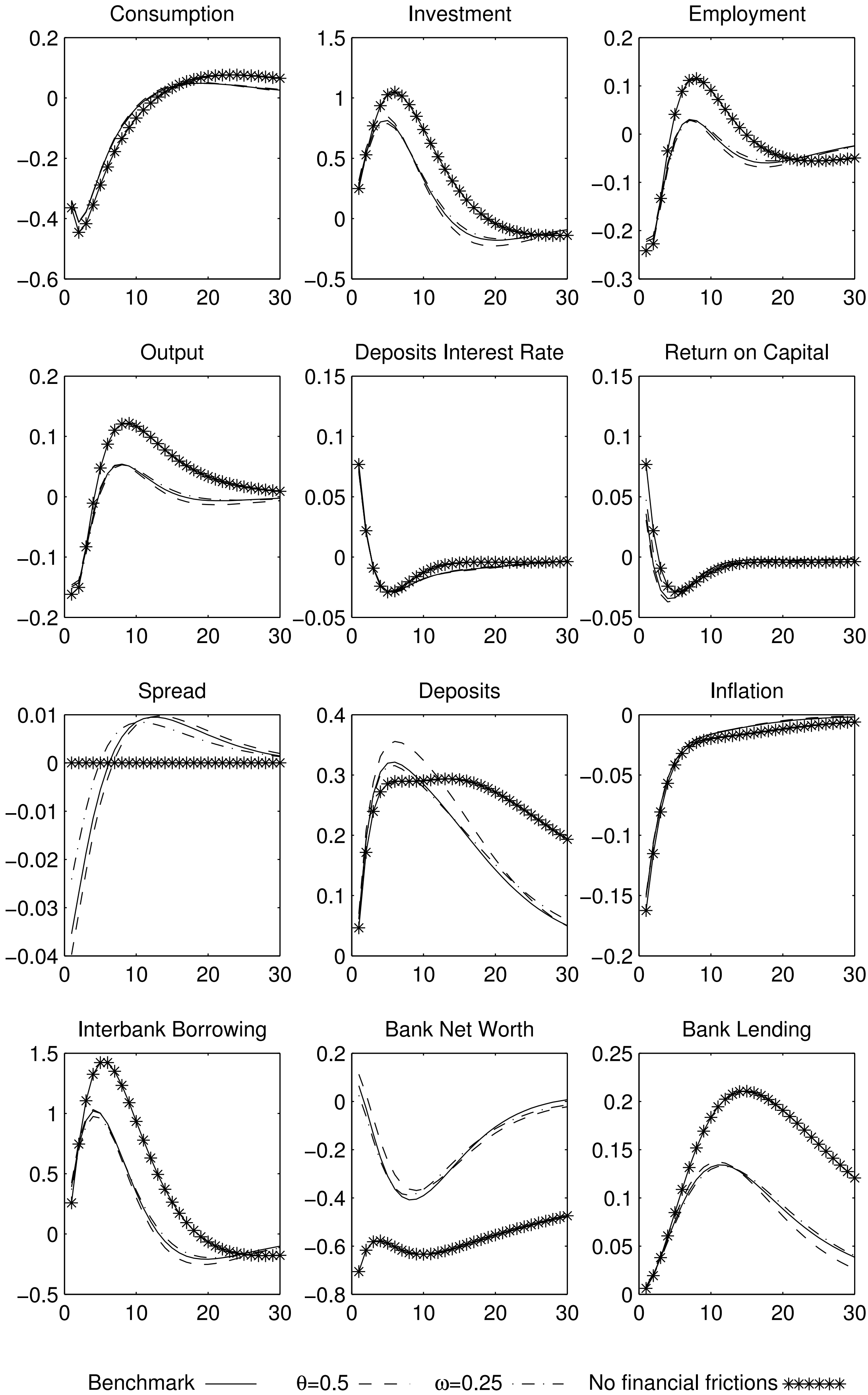
Figure 3.1.3: Taylor Shock IRFs



Benchmark ——— θ=0.5 – – – ω=0.25 –·–· No financial frictions ✳✳✳✳✳

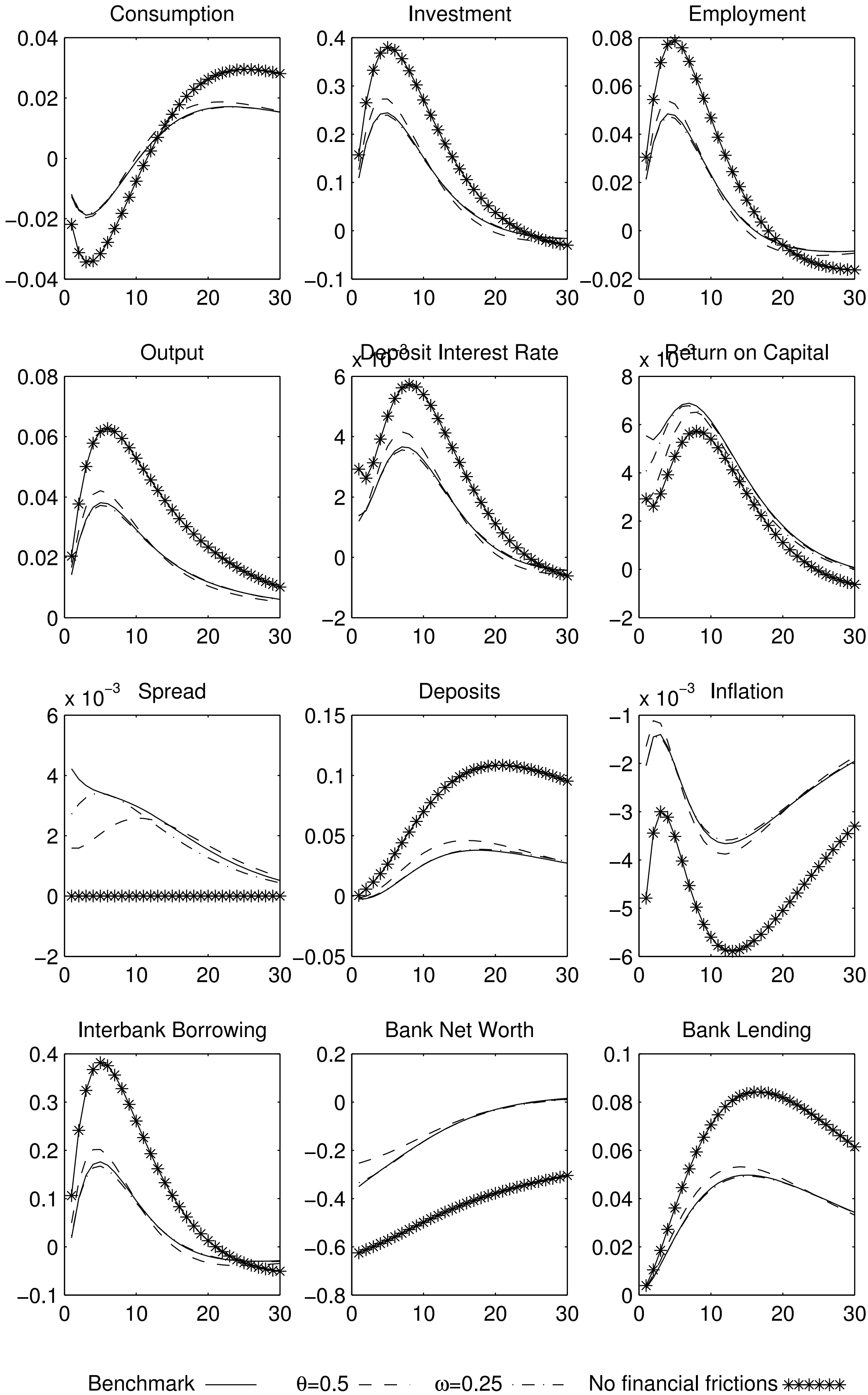
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.4: Preference Shock IRFs



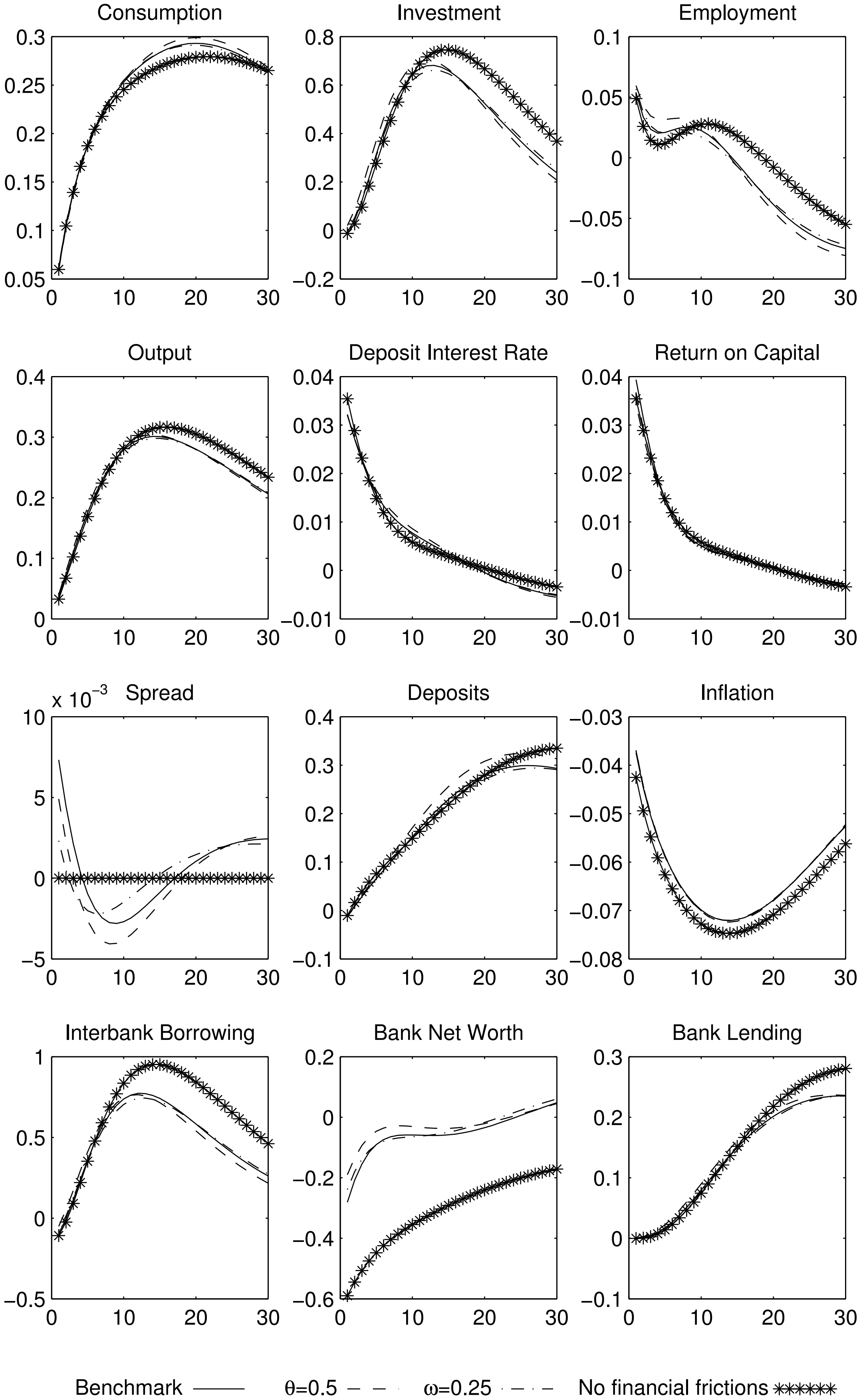
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.5: Investment Shock IRFs



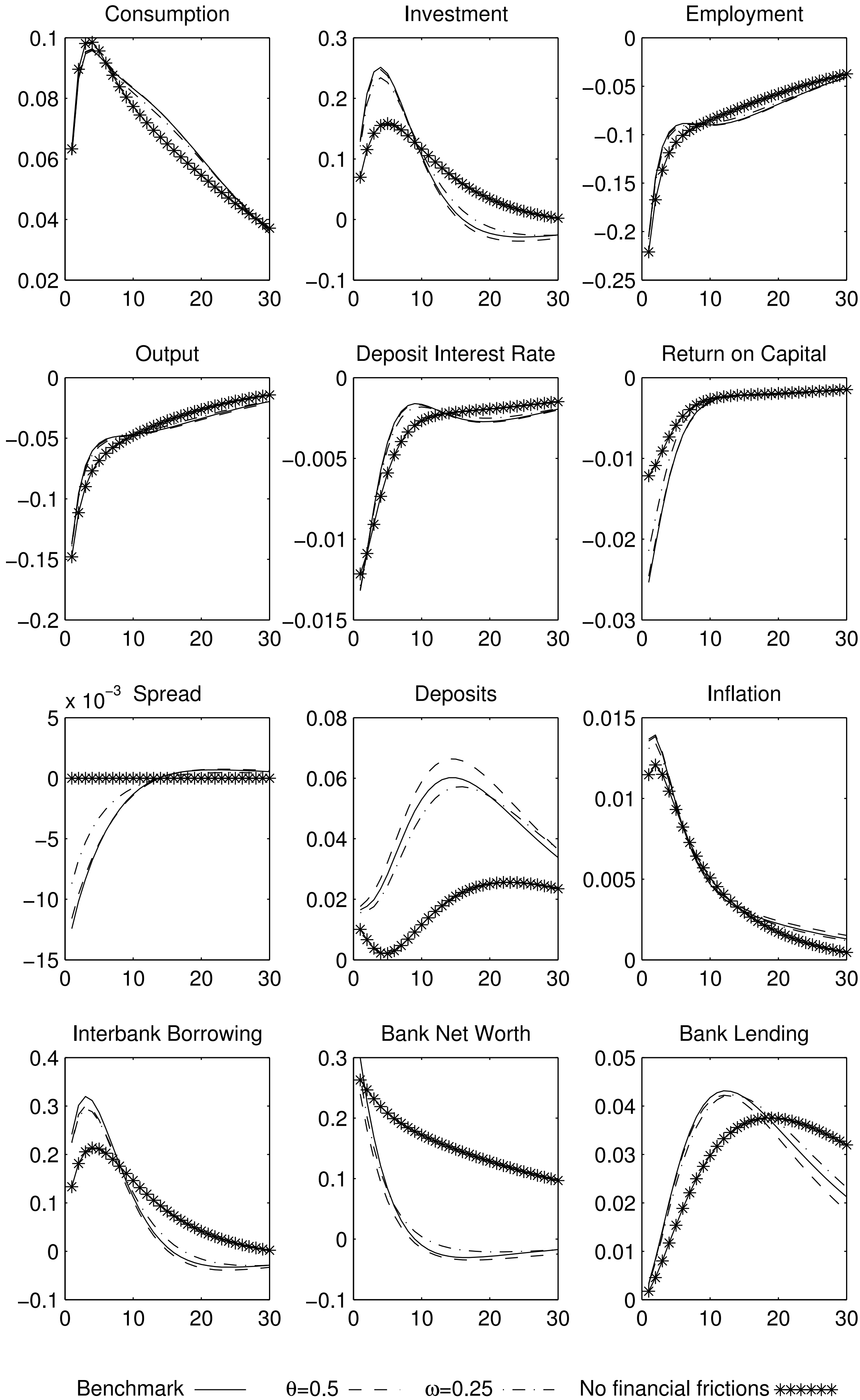
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.6: News Shock IRFs



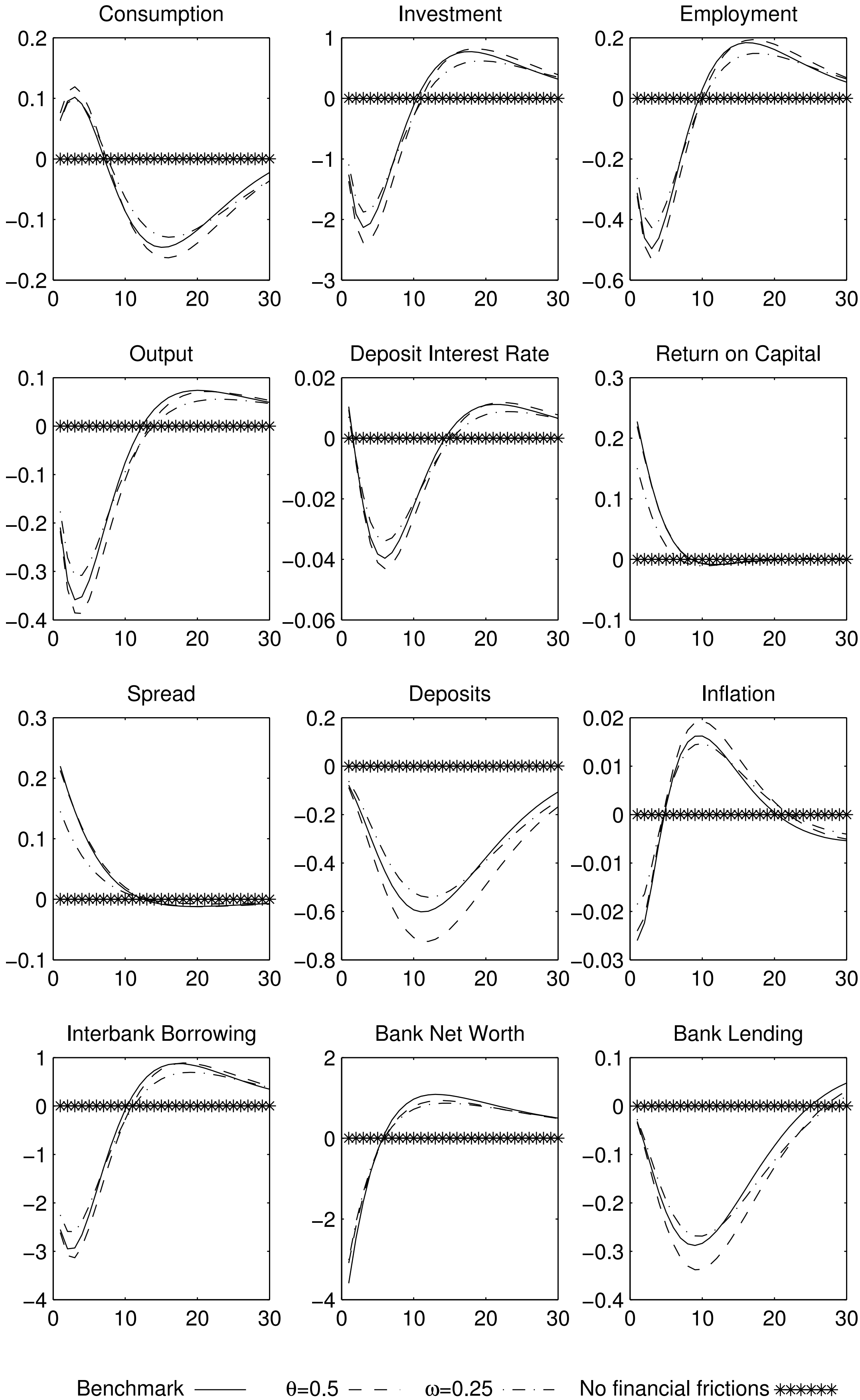
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.7: Government Spending Shock IRFs



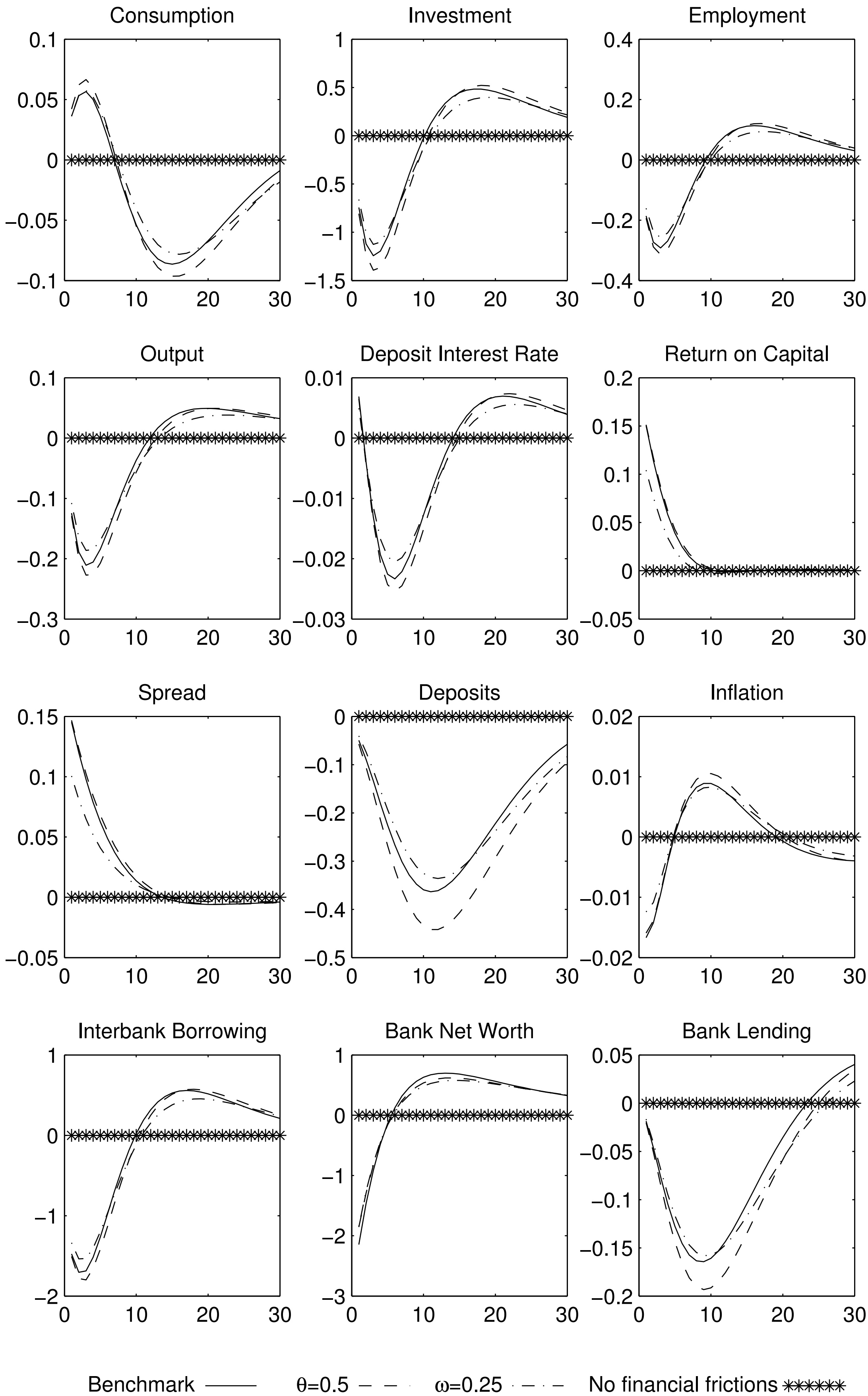
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.8: Interbank Friction Shock IRFs



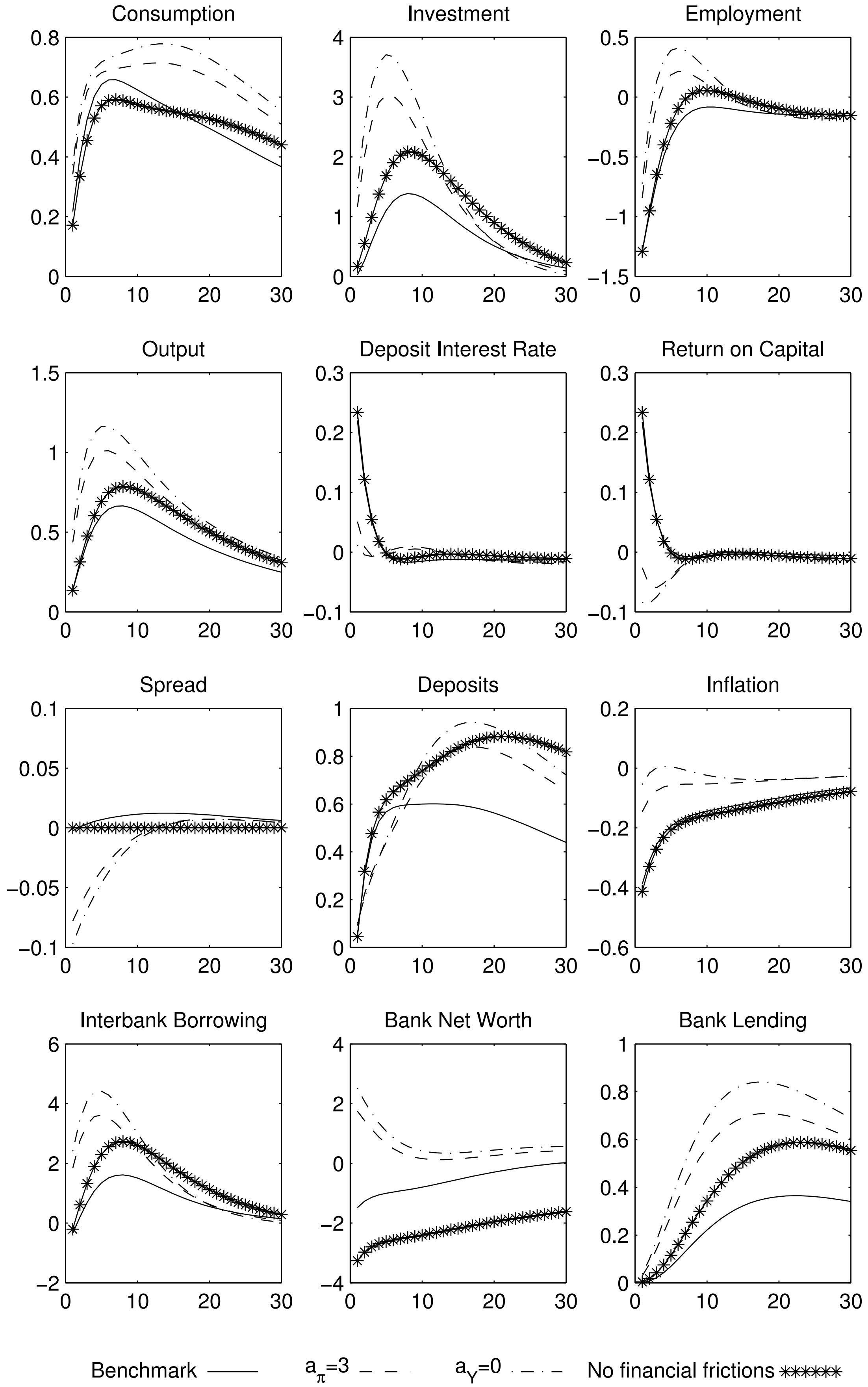
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.1.9: Fraction of Divertable Funds Shock IRFs



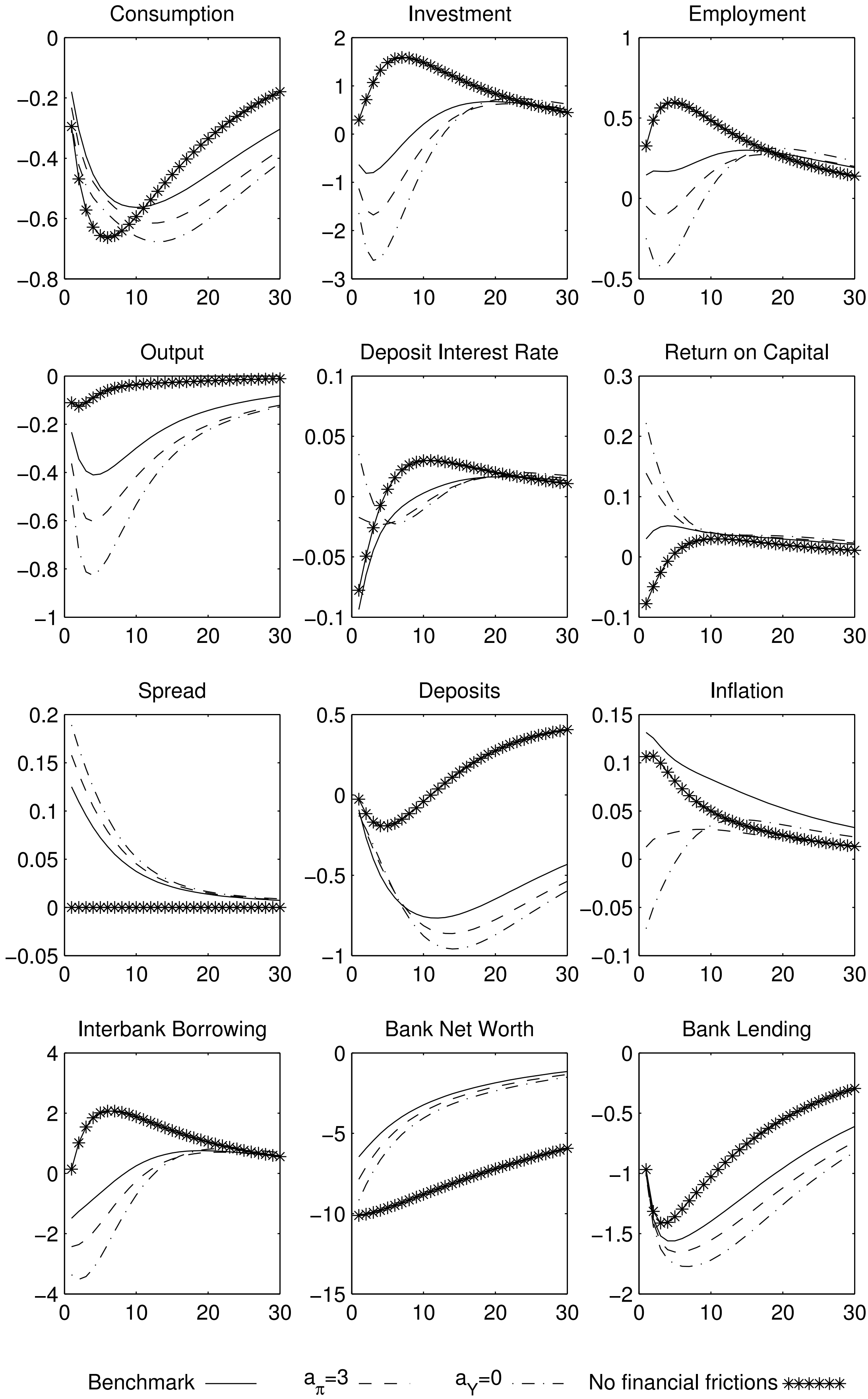
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.1: TFP Shock IRFs



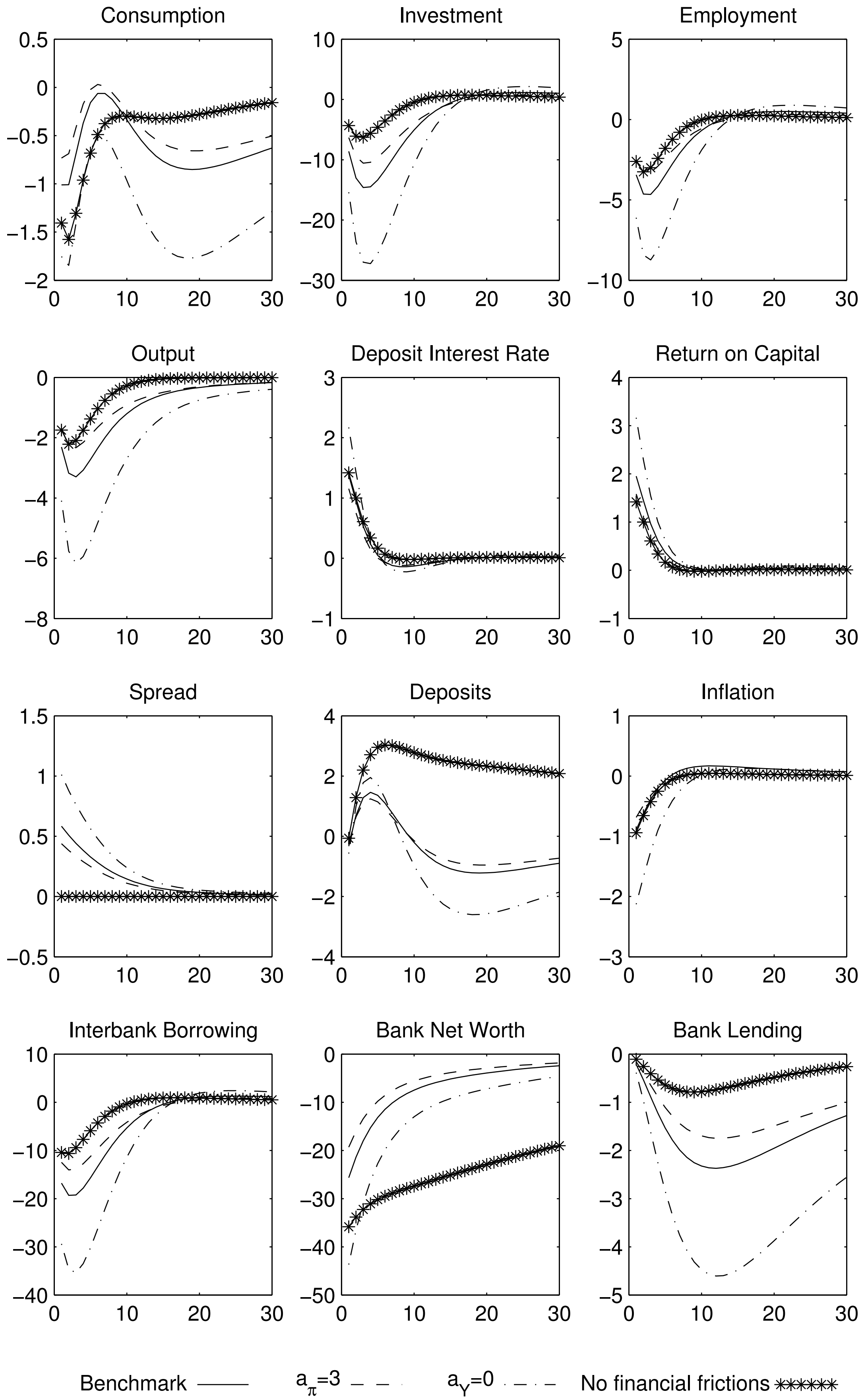
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.2: Capital Quality Shock IRFs



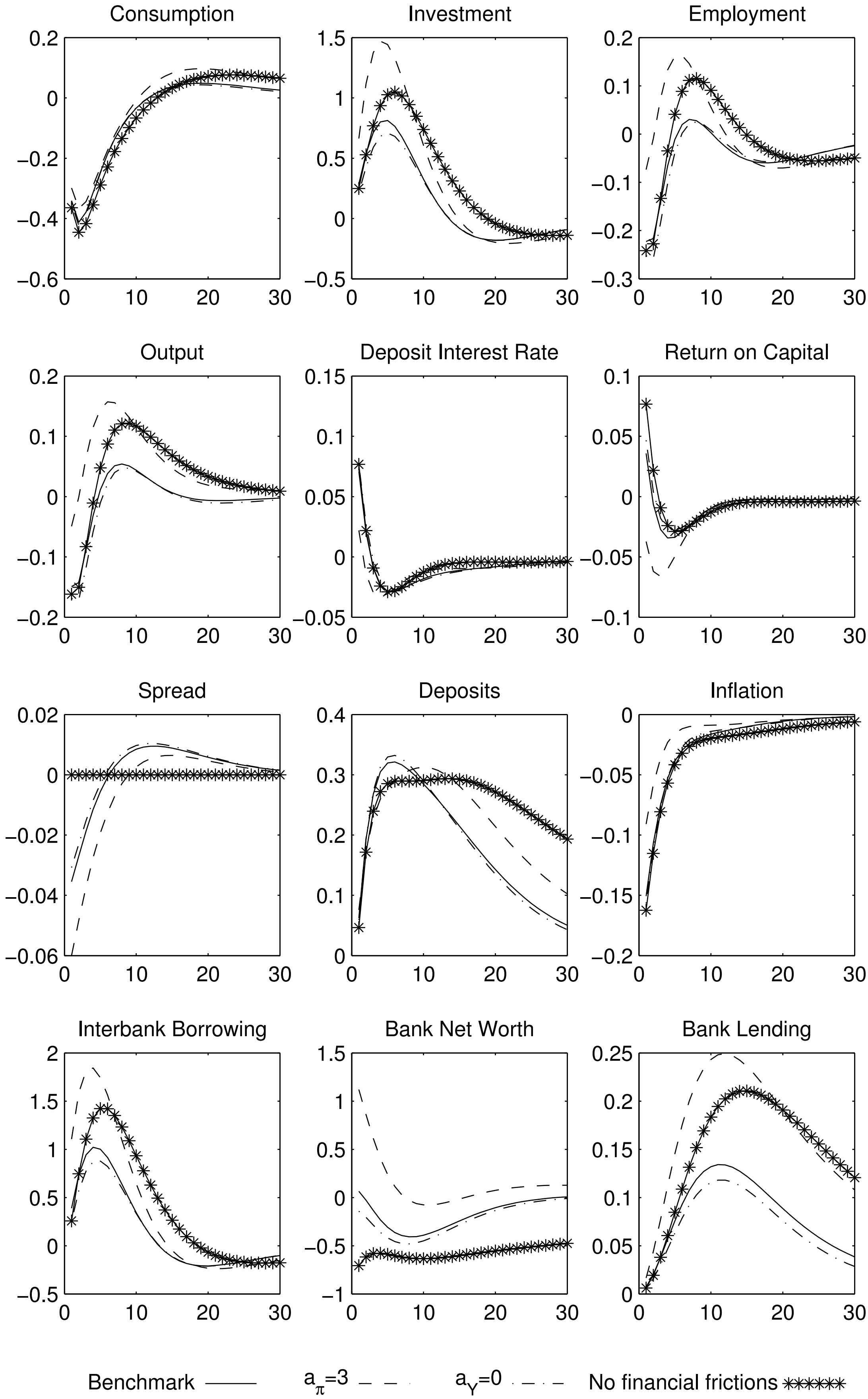
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.3: Taylor Shock IRFs



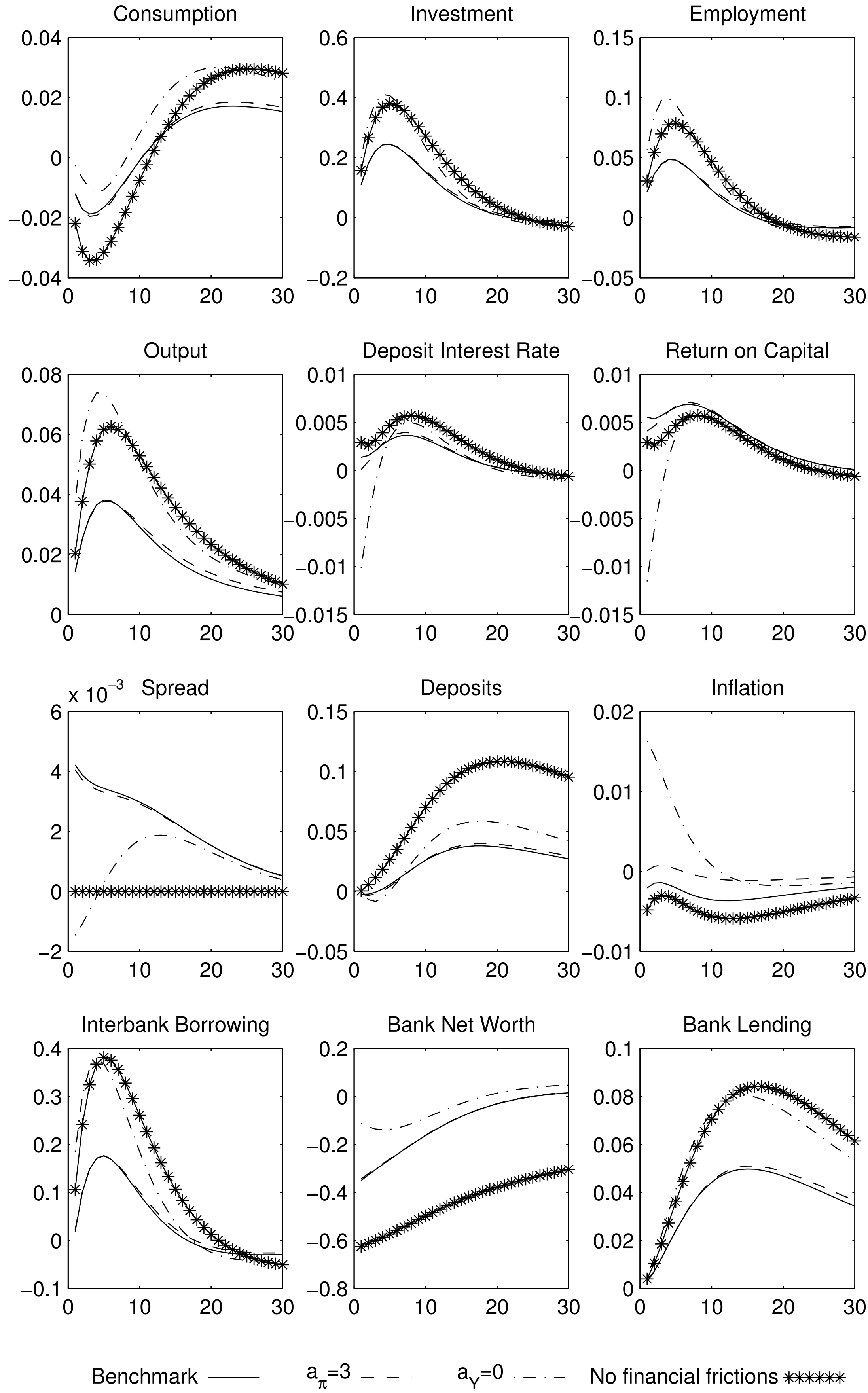
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.4: Preference Shock IRFs



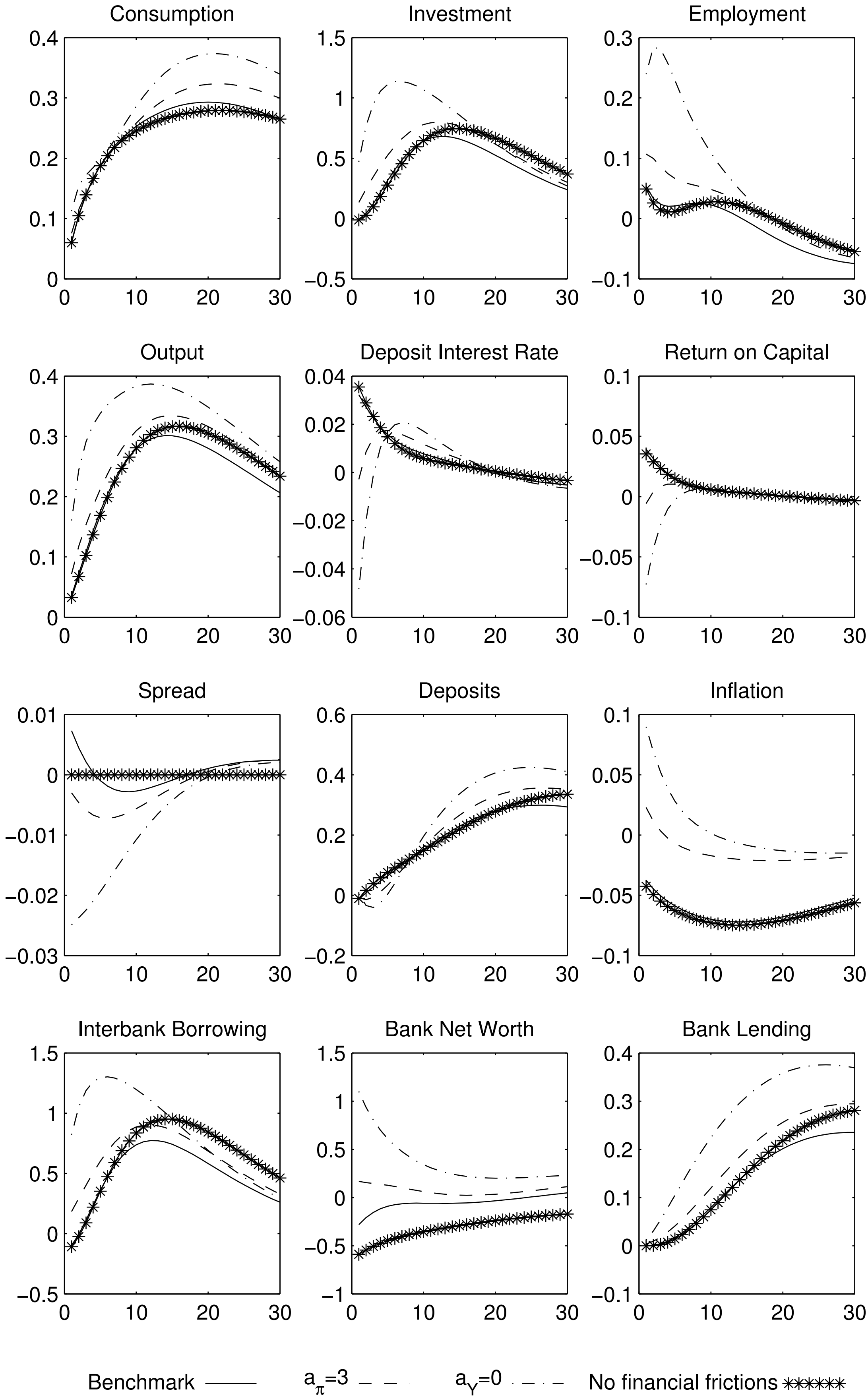
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.5: Investment Shock IRFs



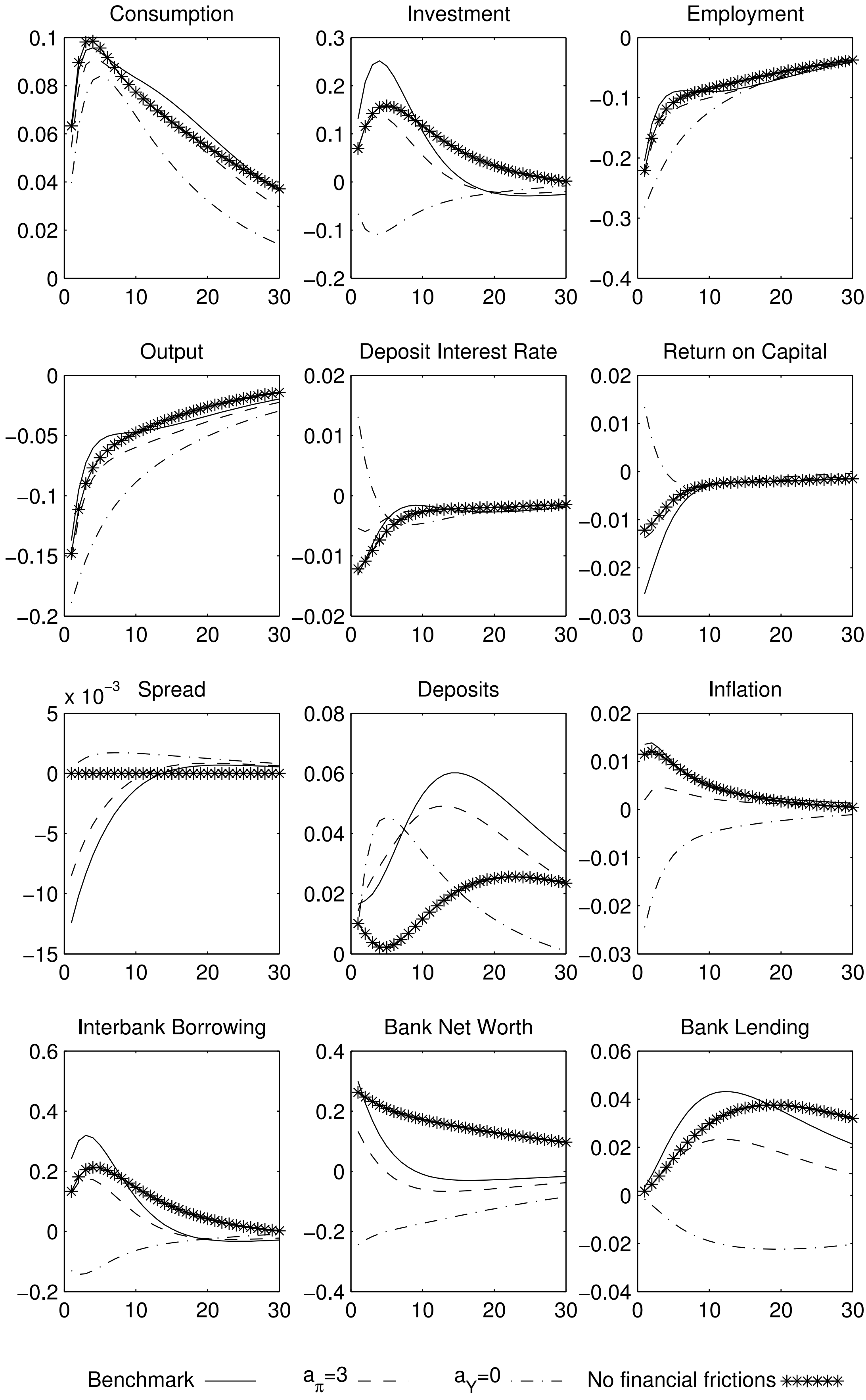
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.6: News Shock IRFs



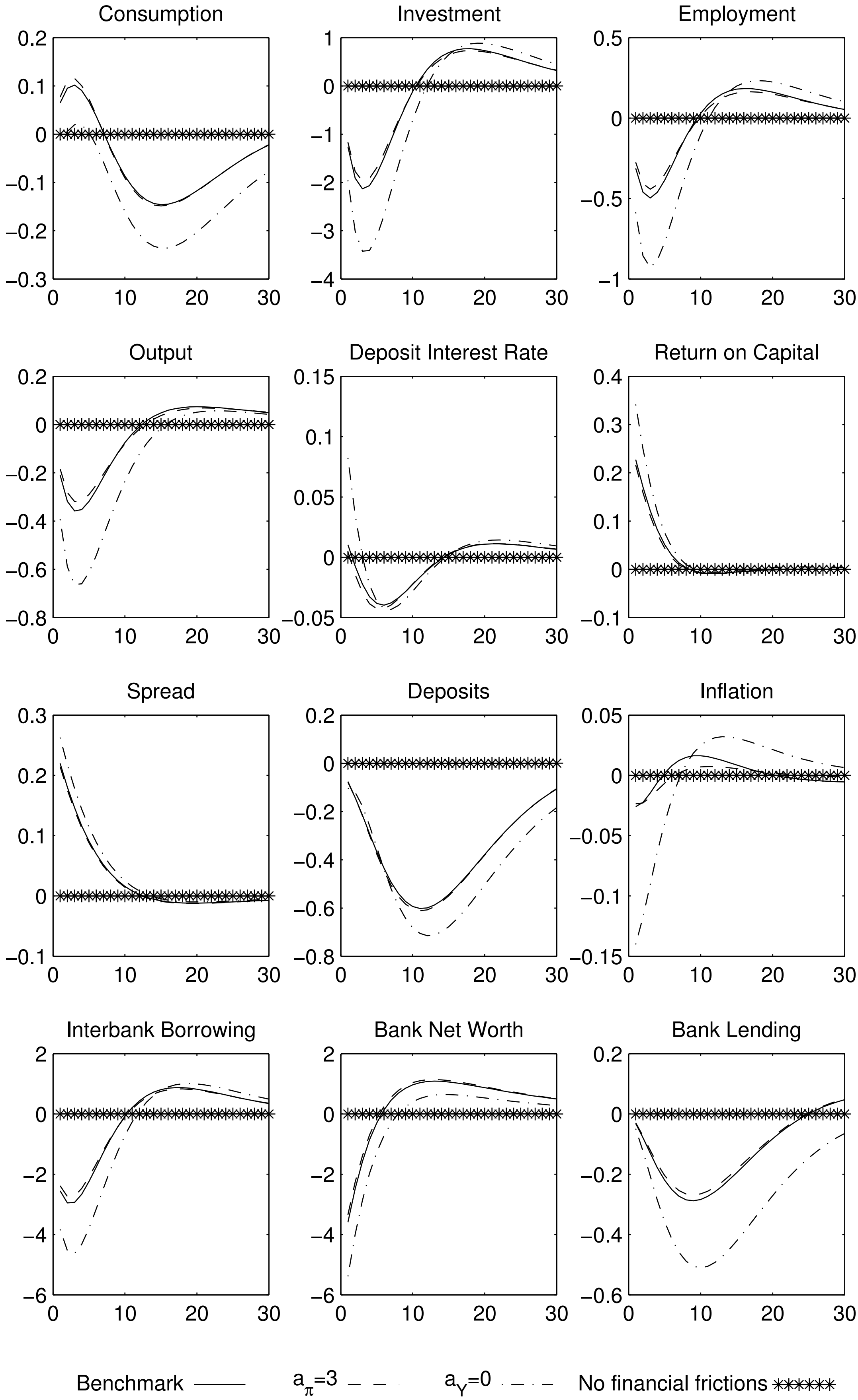
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.7: Government Spending Shock IRFs



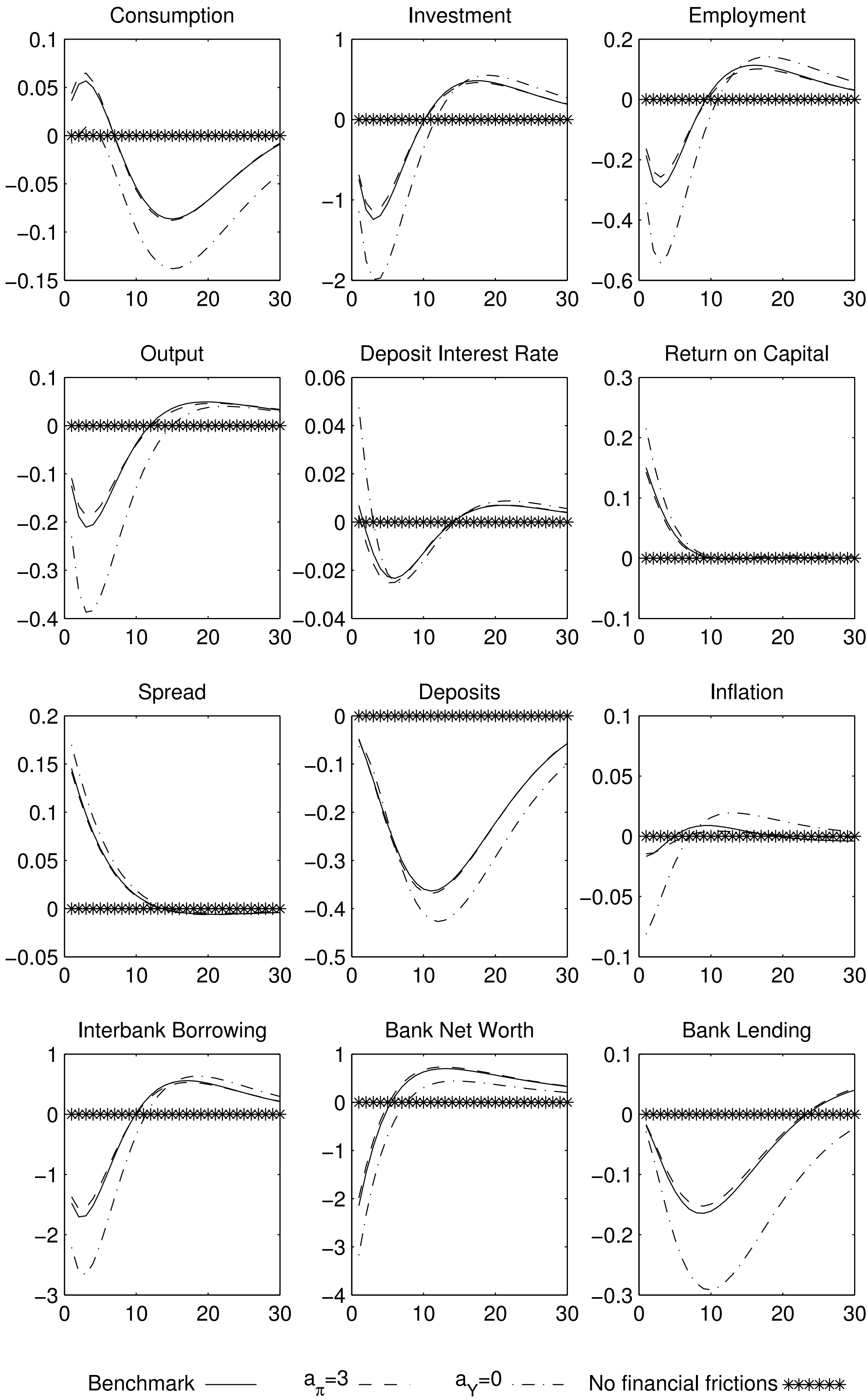
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.8: Interbank Friction Shock IRFs



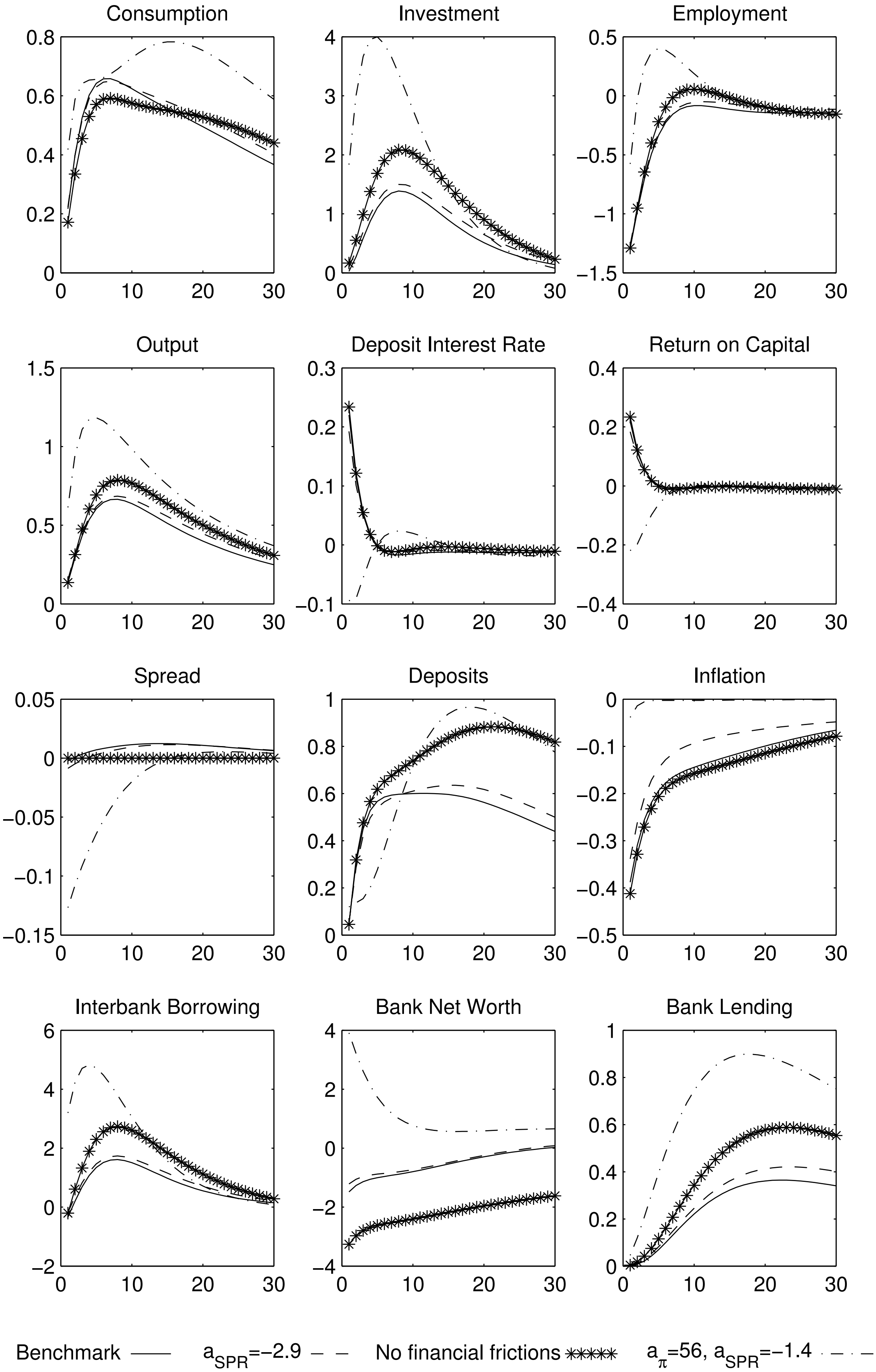
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.2.9: Fraction of Divertable Funds Shock IRFs



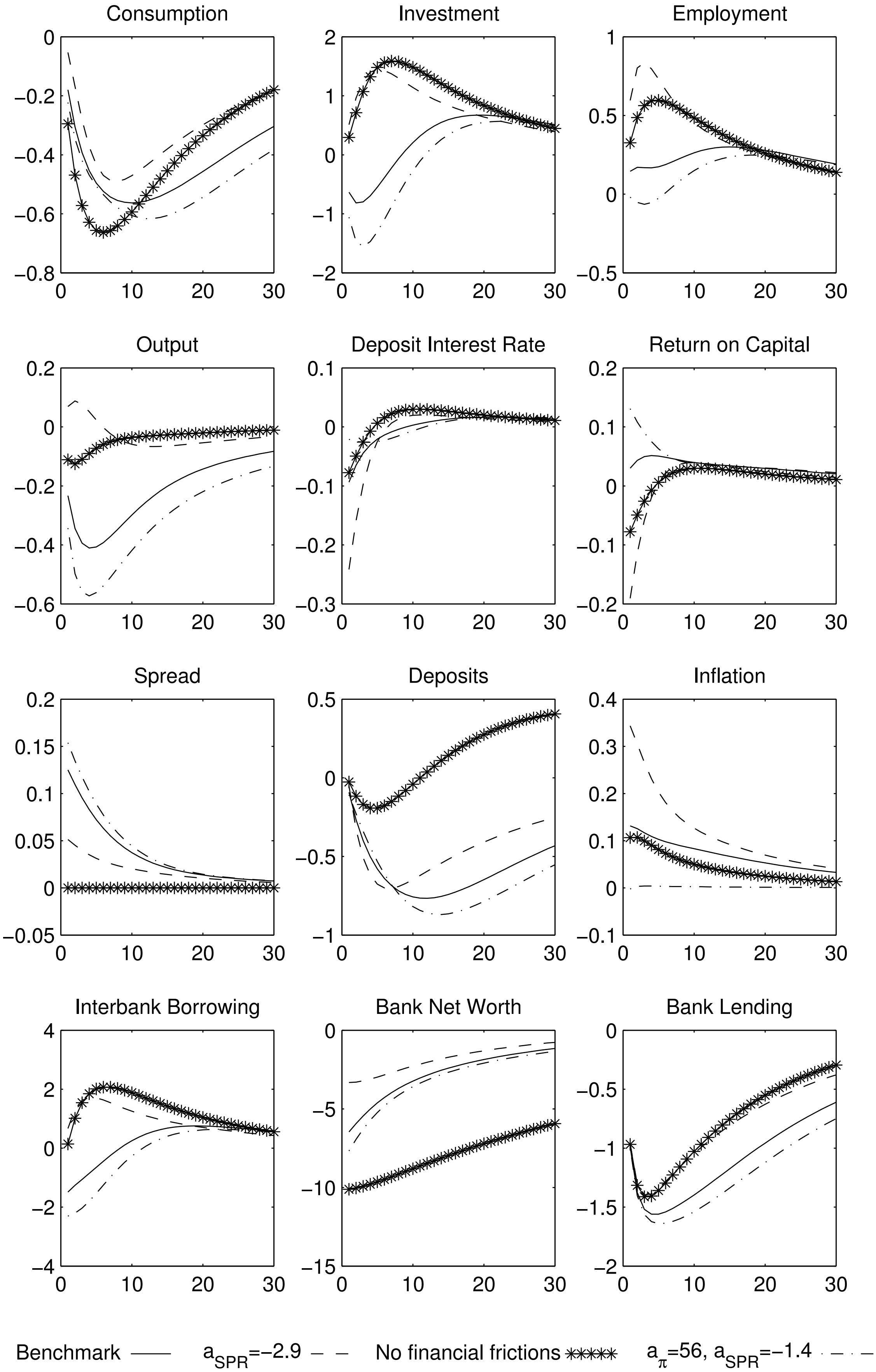
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.1: TFP Shock IRFs



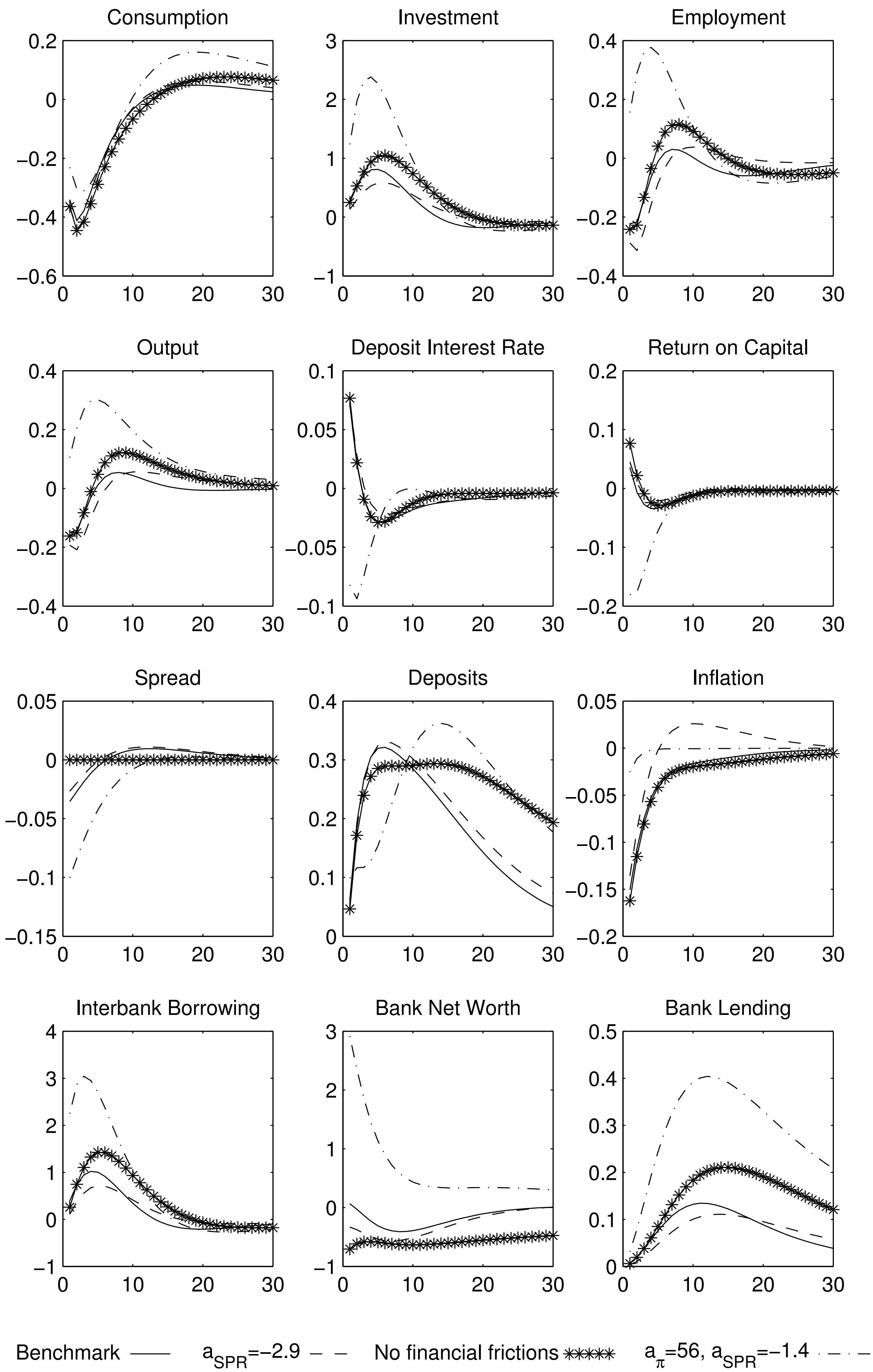
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.2: Capital Quality Shock IRFs



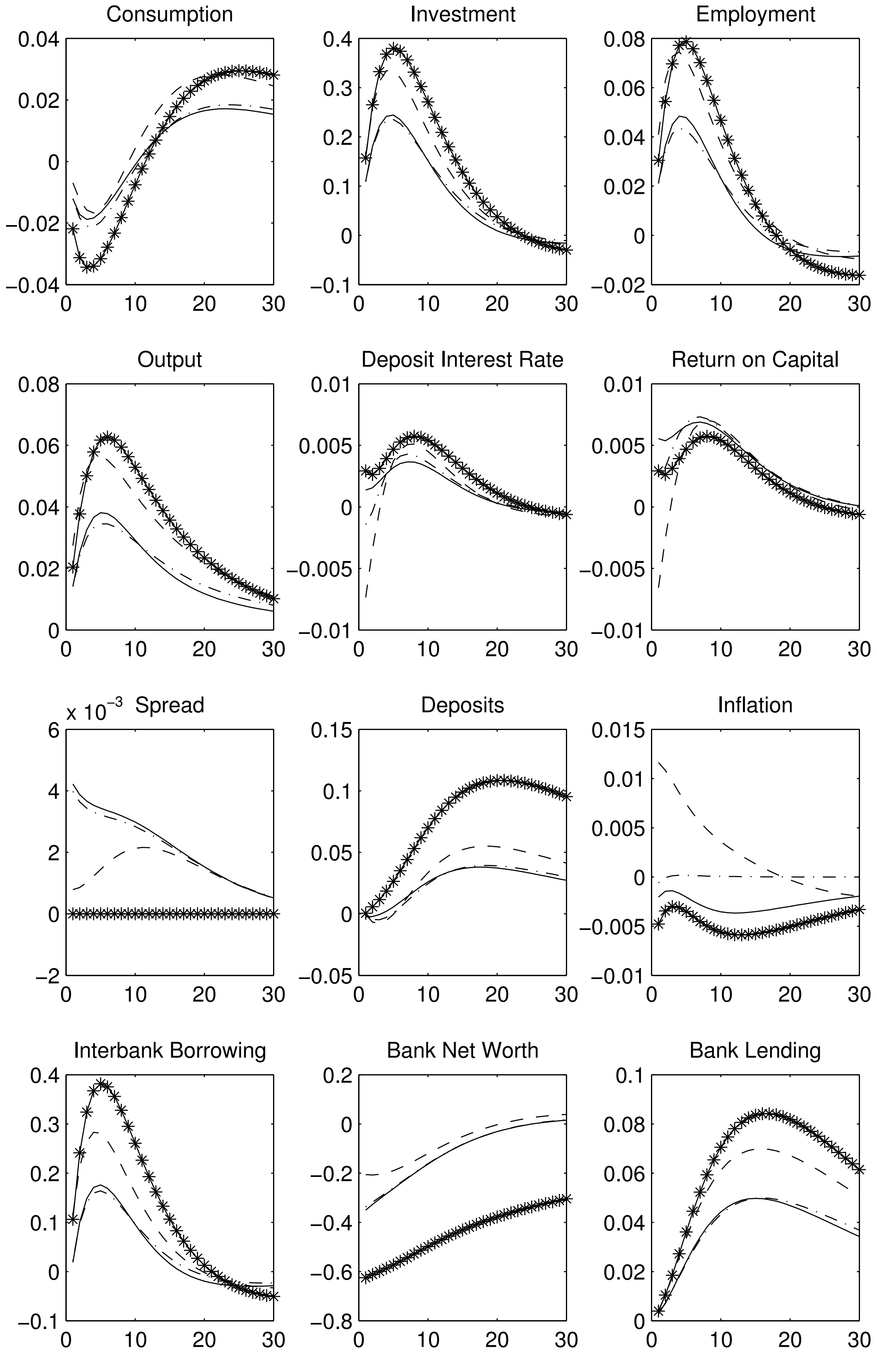
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.3: Preference Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

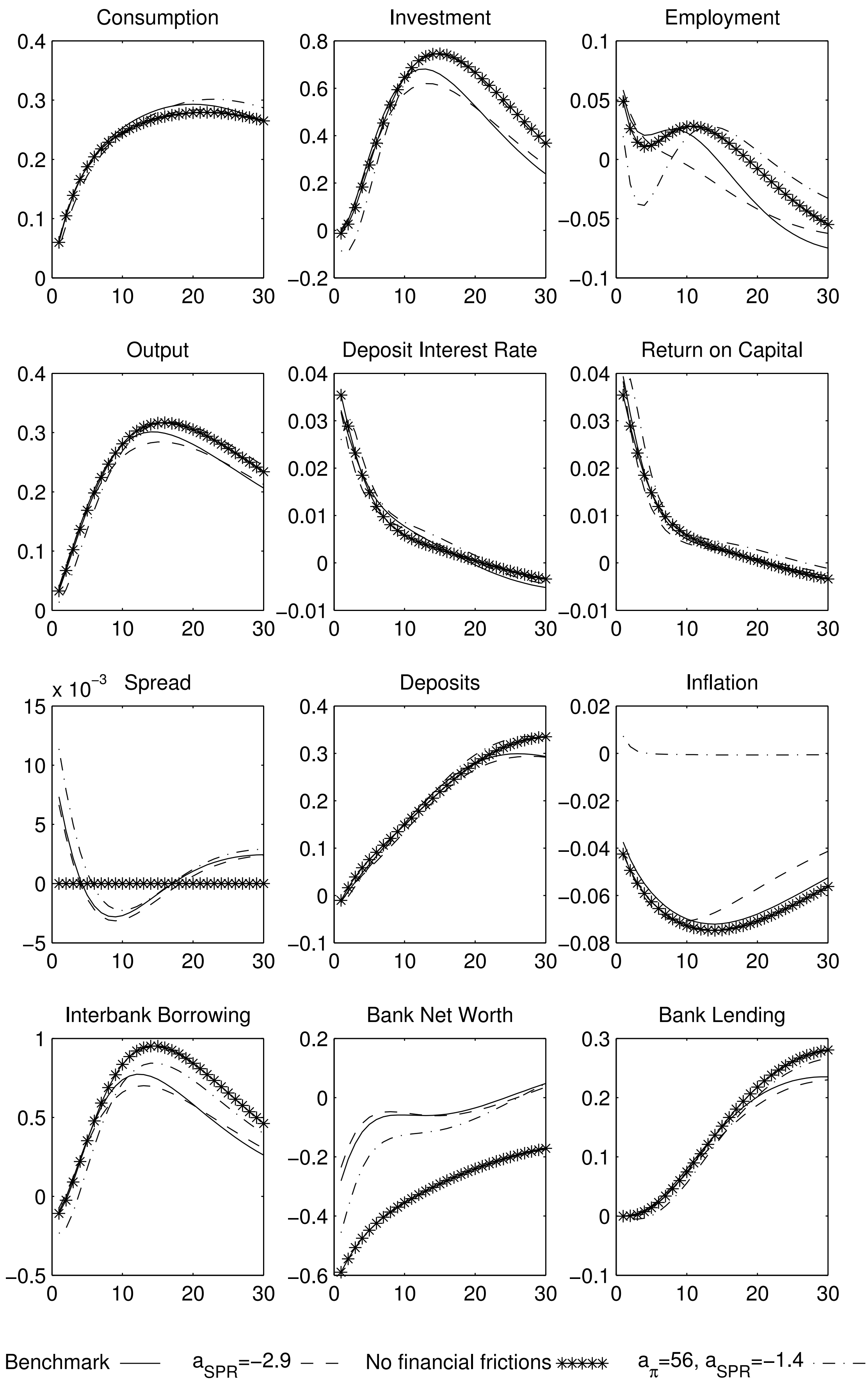
Figure 3.3.4: Investment Shock IRFs



Benchmark —— a_{SPR}=−2.9 – – No financial frictions ∗∗∗∗∗ a_{π}=56, a_{SPR}=−1.4 · – · –

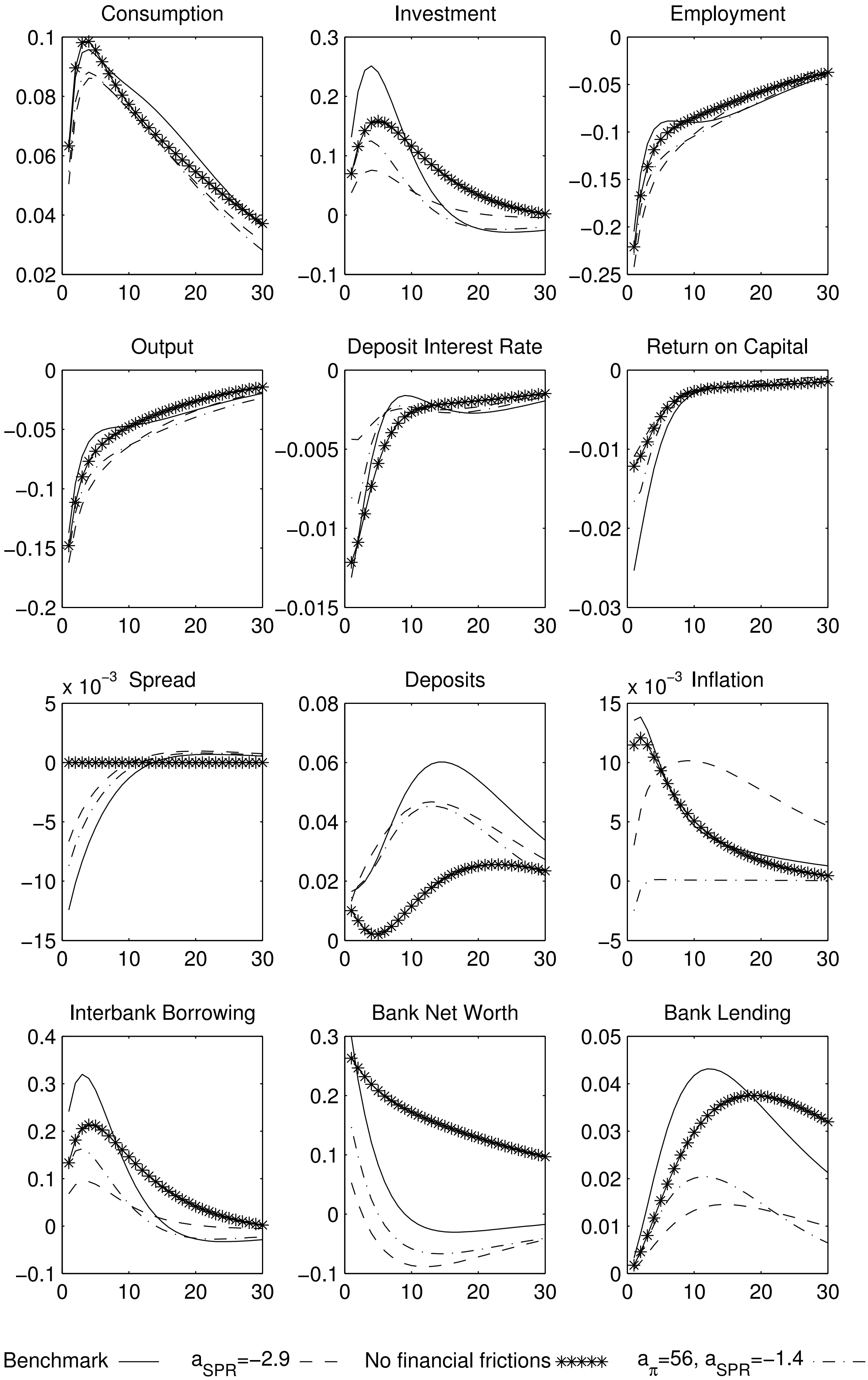
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.5: News Shock IRFs



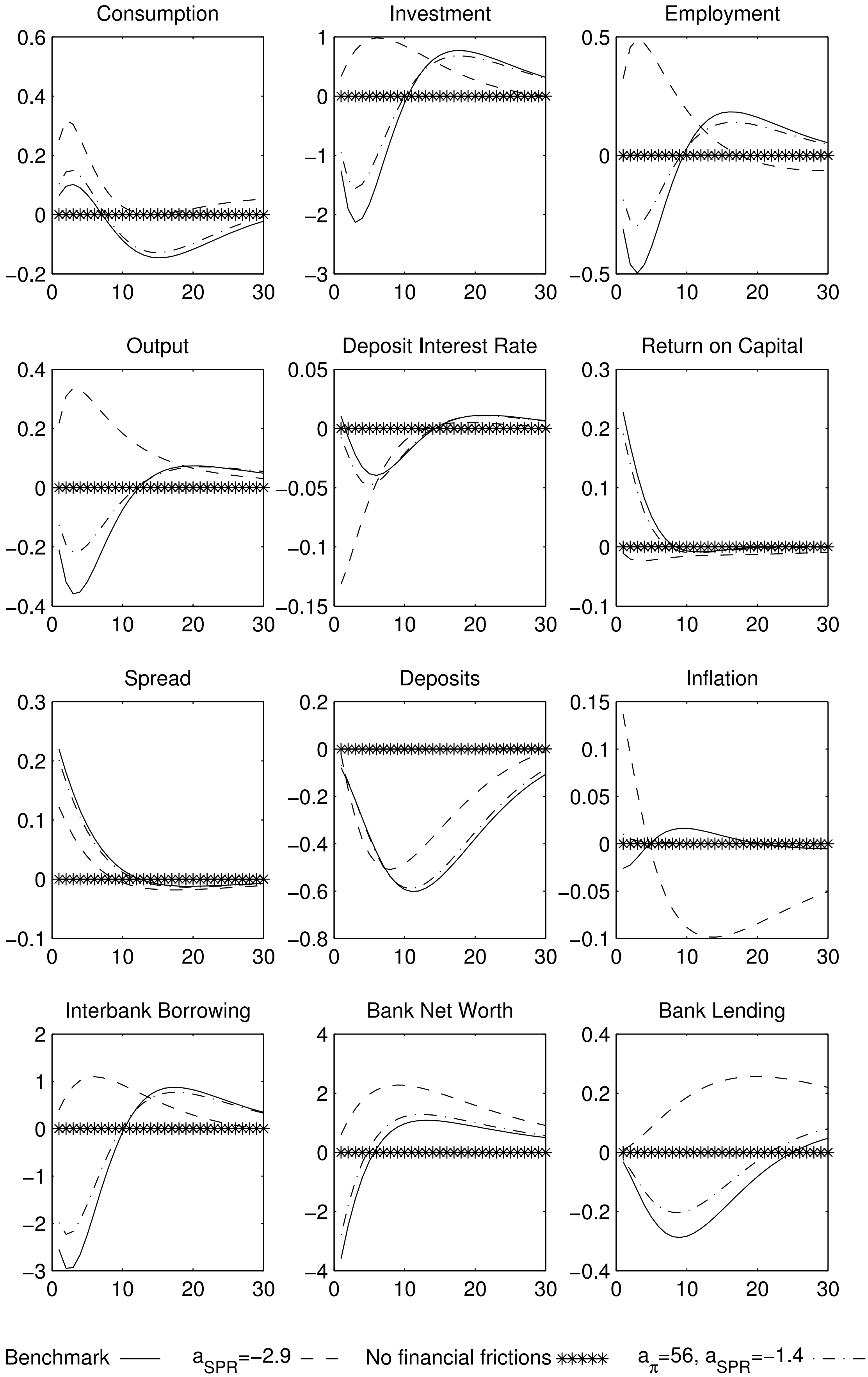
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.6: Government Spending Shock IRFs



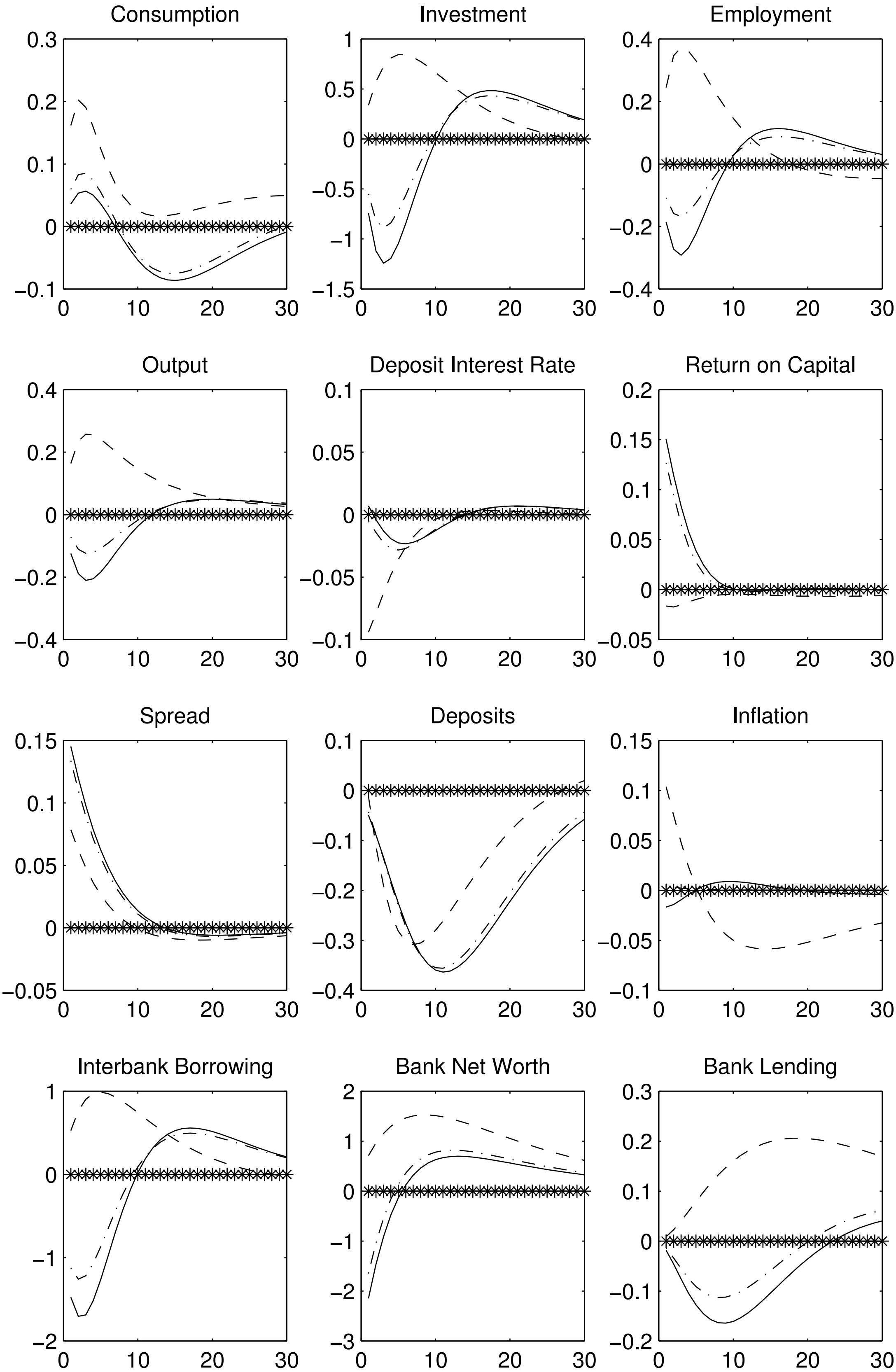
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.7: Interbank Friction Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 3.3.8: Fraction of Divertable Funds Shock IRFs



Benchmark —— a_{SPR}=−2.9 – – No financial frictions ∗∗∗∗∗ a_{π}=56, a_{SPR}=−1.4 · – · –

Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Table3.1: Standard Deviation for Critical Variables under Different Policies

Policy (a_{π}, a_Y, a_{SPR})	σ_Y	σ_{π}	σ_{SPR}	welfare
(1 0.0 0)	0.2162	0.0592	0.0162	−2.8629
(1 0.5 0)	0.0990	0.2155	0.0262	−10.6414
(1 1.0 0)	0.0673	0.2449	0.0235	−13.0738
(1 0.0 −3)	0.2408	0.0533	0.0083	−2.7326
(1 0.5 −3)	0.0720	0.2133	0.0169	−10.4348
(1 1.0 −3)	0.0481	0.2455	0.0177	−13.1095
(1 0.0 −5)	0.2564	0.0791	0.0081	−3.3491
(1 0.5 −5)	0.0786	0.2126	0.0140	−10.3719
(1 1.0 −5)	0.0498	0.2459	0.0153	−13.1354
(2 0.0 0)	0.2772	0.0158	0.0162	−2.2695
(2 0.5 0)	0.1901	0.0971	0.0122	−3.9281
(2 1.0 0)	0.1454	0.1488	0.0124	−6.2294
(2 0.0 −3)	0.2527	0.0153	0.0076	−2.2632
(2 0.5 −3)	0.1921	0.0960	0.0084	−3.8898
(2 1.0 −3)	0.1502	0.1482	0.0096	−6.1961
(2 0.0 −5)	0.2484	0.0211	0.0061	−2.3036
(2 0.5 −5)	0.1933	0.0958	0.0072	−3.8848
(2 1.0 −5)	0.1528	0.1480	0.0084	−6.1868
(3 0.0 0)	0.2616	0.0091	0.0143	−2.2352
(3 0.5 0)	0.2278	0.0578	0.0124	−2.8249
(3 1.0 0)	0.1972	0.1004	0.0116	−4.0461
(3 0.0 −3)	0.2524	0.0117	0.0088	−2.2443
(3 0.5 −3)	0.2242	0.0580	0.0089	−2.8307
(3 1.0 −3)	0.1964	0.1002	0.0091	−4.0403
(3 0.0 −5)	0.2506	0.0158	0.0072	−2.2663
(3 0.5 −5)	0.2232	0.0585	0.0077	−2.8419
(3 1.0 −5)	0.1963	0.1003	0.0080	−4.0427

Table3.2: Standard Deviation for Critical Variables

under Different Friction Levels

(ω,θ)	σ_Y	σ_π	σ_{SPR}
(0.00 0.30)	0.2195	0.0571	0.0076
(0.00 0.35)	0.2194	0.0570	0.0078
(0.00 0.40)	0.2193	0.0570	0.0081
(0.50 0.30)	0.2202	0.0571	0.0107
(0.50 0.35)	0.2200	0.0570	0.0109
(0.50 0.40)	0.2200	0.0569	0.0111
(1.00 0.30)	0.2213	0.0572	0.0183
(1.00 0.35)	0.2210	0.0570	0.0179
(1.00 0.40)	0.2209	0.0569	0.0177

Table3.3: Welfare Optimisation and the Corresponding Optimal a_{SPR}

in Cases with Different ω and θ Values

ω \ θ	0.30	0.35	0.40
0.00	−5.60 −2.6840	−5.10 −2.6883	−4.70 −2.6938
	47.00 −1.70 −2.2152	53.00 −1.80 −2.2175	59.00 −1.90 −2.2197
0.50	−4.40 −2.7243	−3.90 −2.7287	−3.50 −2.7341
	46.00 −1.30 −2.2150	52.00 −1.40 −2.2172	59.00 −1.60 −2.2194
1.00	−2.70 −2.7716	−2.30 −2.7743	−1.90 −2.7774
	41.00 −1.10 −2.2156	48.00 −1.20 −2.2177	54.00 −1.20 −2.2198

Top Half of Each Cell: Optimisation over a_{SPR}
(1st number: optimal a_{SPR}; 2nd number: optimal welfare)

Bottom Half of Each Cell: Optimisation over a_{π} and a_{SPR}
(1st number: optimal a_{π}; 2nd number: optimal a_{SPR}; 3rd number: optimal welfare)

Table3.4: Welfare Optimisation and the Corresponding Optimal a_{SPR} in Cases with Different a_π and a_Y Values

a_π \ a_Y	0.0	0.5	1.0
1.0	−1.90 −2.6621	−6.70 −10.3529	0.00 −13.0730
2.0	−0.90 −2.2391	−4.70 −3.8839	−5.90 −6.1852
3.0	−0.80 −2.2274	−0.50 −2.8240	−3.00 −4.0399

1st Number of Each Cell: Optimal a_{SPR}

2nd Number of Each Cell: Optimal Welfare

Table3.5: Welfare Optimisation and the Corresponding Parameters

in Cases with Different Doubled Shocks

Doubled Shock	a_{SPR}	welfare	a_{π}	a_{SPR}	welfare
TFP	−3.30	−2.7787	57.00	−1.00	−2.2181
Capital Quality	−2.30	−2.7827	63.00	−2.20	−2.2167
Interbank Shock	−2.40	−2.7649	52.00	−1.50	−2.2200
Financial Friction (θ)	−0.70	−2.7966	46.00	−1.30	−2.2231
Preference	−2.90	−2.7545	54.00	−1.30	−2.2187
Investment	−2.90	−2.7541	56.00	−1.40	−2.2187
News Shock	−5.40	−4.0562	56.00	−0.40	−2.2032
Government Spending	−2.90	−2.7542	56.00	−1.40	−2.2187

Chapter 4
Unconventional Monetary Policy

Abstract

The global economy experienced a severe financial crisis starting in 2007, which has led to a major recession in most markets. The Federal Reserve and many other central banks responded rapidly to reduce the loss from the crisis. Rather than the normally used conventional monetary policies, they have also adopted several unconventional monetary policies. These policies have played a significant role in minimising the damage from the crisis. Recent research has started to study the features of these unconventional monetary policies and to record the responses of the economy to such policies. Among these important literatures, Gertler and Kiyotaki (2010) have considered a monetary DSGE model with unconventional policy under two extreme cases: a perfect and an imperfect interbank market. In this chapter, I use the baseline model described in previous chapters with price stickiness and an intermediate level of friction in the interbank markets to examine the consequences for the economy of direct lending by the central bank. I also conduct a welfare analysis to study the welfare-optimal unconventional policy rule. The optimised welfare level and the corresponding optimal policy rule are analysed in cases with different financial frictions, in the cases with different conventional monetary policies and for different shock variances.

4.1 Introduction

Starting in 2007, the global economy has experienced a serious crisis, which has led to recession in almost every market. During and after the crisis there has been a great need for fast and sound fiscal and monetary policies to heal the damage caused by the crisis and to avoid further damage to the economy. Many central banks responded to minimise the damage to the economy from the crisis.

As described in Chapter 3, the initial response involved a sharp decline of central banks' policy interest rates. For example, the U.S. Federal Reserves decreased their federal funds rate from 5.25% to a range of 0%-0.25% from January 2008 to January 2009, which has been extended to the present. The Bank of England decreased its interest rate from 5.0% to 0.5% from October 2008 to March 2009. Following the crisis the monetary easing reflected in significant reductions in policy interest rates has offset to some degree the financial turmoil.

However, the stabilising effect of interest rate cuts has been considered incomplete, as widening credit spreads, more restrictive lending standards, investors' low expectations and credit market dysfunction have worked against the monetary easing and led to tighter financial conditions overall. Particularly, many traditional funding sources for financial institutions and markets have dried up. During 2008, even though central banks' interest rates have dropped to the lowest bound, financial markets continued to suffer a crisis. This demonstrates that it is necessary to use further policy tools to intervene in the market during special crisis times.

The financial crisis that occurred in 2007 has highlighted the constraints implied by the zero lower bound on nominal interest rates as an important motivation for unconventional monetary policy. It has also highlighted the role that financial frictions play as a source of shocks in the transmission and amplification of non-financial shocks. Models of financial frictions, such as the model introduced and analysed in chapters 2 and 3, have shown that financial frictions create a spread between deposit rates and bank lending rates. This credit spread plays an important role in transmitting and amplifying all types of shocks and it may be a source of shocks itself.

The existence of this credit spread creates a second motivation for considering unconventional monetary policy and it is this motivation which is the main focus of this chapter. Unconventional policy, such as direct lending by the central bank to private firms, creates the possibility for policymakers directly to tackle the credit spread. A policy tool which directly offsets the financial frictions which create the credit spread may offer a useful means directly to offset the effects of financial shocks and directly to reduce the amplification and transmission role of the credit spread.

The main aim of this chapter is to use the model introduced and analysed in Chapters 2 and 3 as a framework to examine the role of unconventional policy as a means to tackle the credit spread. Unconventional policy will be compared to the use of conventional policy (i.e. the modified Taylor rule used in Chapter 3) as a response to the credit spread. One question that will be addressed is whether unconventional policy offers a better welfare performance than conventional policy as a way to respond to the credit spread.

It should be noted that, though the zero lower bound is one important reason for considering unconventional monetary policy, this not an issue that is directly considered in this chapter. That is left as an interesting question for potential future research.

During the period 2007-2009, in addition to traditional tools, most central banks have worked to support credit markets and also to reduce financial strains by providing liquidity to the private sector. These policies played a very important role during the financial crisis. For example, the Federal Reserve has made a number of unconventional interventions to help with the downturn in the economy and has gone some way to solve major problems in the financial market. There have been many cases of unconventional monetary policies, where central banks and governments intervene directly in the financial markets. The direct intervention and liquidity facilities were allocated to a range of financial intermediaries and lenders in financial market, which were considered to be “insolvent” intermediaries or institutions. These unconventional interventions from government and central banks had helped to stabilise financial markets, and had helped to limit the decline of real activity after the crisis.

Gertler and Karadi (2009) derived a monetary DSGE model with financial intermediation to analyse central banks' unconventional monetary policies during a simulated financial crisis. An agency problem with endogenous constraints on intermediary leverage ratios is introduced, which constrains the overall credit flows to equity capital. The advantage processed by the central bank comes from the agency problem, where the central bank does not have such a restriction, thus does not face any constraints on its leverage ratio. Therefore, when financial shocks hit the market, the central bank can intervene to support credit flows. However, a trade-off arises from the efficiency of adopting such policies. Intermediation carried out by the central bank is assumed to be less efficient than ordinary private intermediation. The experiment by Gertler and Karadi (2009) shows that welfare benefits arise from unconventional policy implemented directly by central bank. However, although this model creates a framework for unconventional monetary policies in a quantitative way, it does not include interbank credit market frictions, and thus the model can not comprehensively explain the default risk and the chain reaction that was part of the current crisis. Gertler and Kiyotaki (2010) have followed the analysis of unconventional monetary policy in Gertler and Karadi (2009), but extended the framework to include interbank market frictions. However, they have not considered price stickiness in their model.

In this chapter, I focus on the direct lending policy under an intermediate case of interbank market friction, with price stickiness and nine different shocks to the economy. I compare this unconventional monetary policy with conventional monetary policy in the form of a Taylor rule. I also conduct a welfare analysis to analyse the optimal unconventional monetary policy regime under different supply-side and demand-side shocks to the economy. The optimised welfare level and the corresponding optimal policy parameter are derived in cases with different financial friction levels, in cases with different conventional monetary policies and in cases with different shock variances.

As described in previous chapters, the financial frictions in the model cause the private banks to restrict lending below the level that it should be without the frictions. The severity of the endogenous frictions and the limit on capital stock varies in response to shocks. This has been shown to amplify the effect of the shocks. Moreover, the two financial market shocks can also cause fluctuations in the capital stock which would not occur if there were no financial frictions. A policy of direct lending by the central bank to firms might be a way to mitigate the effects of financial frictions by increasing the overall amount of liquidity in the financial market, which also expands the investment in the capital stock and overcomes the limit on the capital stock caused by the frictions. By varying the amount of direct lending it may be possible to offset the effects of the shocks on the overall level of lending in financial market and thus damp the effects of shocks on the real economy.

In the analysis presented below the amount of direct lending is linked by a simple policy rule the credit spread. As explained in Chapter 3, the financial frictions and the corresponding incentive constraint make the capital stock lower than it would otherwise be without the frictions. The credit spread is therefore positive and becomes a direct measure of the severity of the financial frictions. This endogenous credit spread is also part of the amplification and transmission mechanism that links the financial frictions to the real economy. Thus, it is natural to link the credit spread to unconventional monetary policy via a rule of the type analysed below. This chapter investigates the impact of such a rule on the dynamics of the economy. Similarly to Chapter 3, it also investigates the impact of the rule on the volatility of key variables and on welfare.

There are several other possible non-conventional interventions other than direct lending. For example, discount window lending to banks or equity injections to private banks are illustrated in Gertler and Kiyotaki (2010). These alternative ways to ease the effect of the financial frictions and expand the amount of bank's lending to private firms are likely to have very similar effect to the direct lending policy analysed in this chapter. Thus, this thesis focuses on direct lending policy as it is the most straightforward and representative way to model non-conventional monetary policy. Most of the results shown below are likely to carry over to the other forms of non-conventional monetary policies as well.

The remainder of this chapter is structured as follows: Section 4.2 describes the banking sector of the model. Section 4.3 illustrates the quantitative results. Section 4.4 concludes this chapter.

4.2 Model

The model in this chapter builds on the basic model with price stickiness in Chapter 3. As in Chapter 3, the model is based on Gertler and Kiyotaki (2010)'s modelling framework, extended to include price stickiness. Rather than the previous chapter using traditional Taylor rule policies as an anchor to the economy, in this chapter, I have include a direct lending unconventional monetary policy in the model. This model also includes three supply shocks and six demand shocks. I have studied the IRFs for the nine shocks under different cases for the model. In the later section, I examined the welfare-optimal rule for unconventional monetary policy.

Similarly to preceding chapters, it is assumed there is a continuum of islands in the economy. It is assumed that the arrival of the investment opportunity is i.i.d. across islands. At the beginning of each period, investment opportunities arrive to the fraction π^i of islands. These islands become "investing islands" with outstanding investment opportunities. Firms locating on such islands acquire new capital stock in the period. Thus, there is a high demand for banks loans on these investing islands. It is assumed that firms can only borrow from the banks locating on the same islands. Investing-islands' banks therefore face the high demand for loans. However, they are not able to satisfy these needs unless they borrow from the other banks based on non-investing islands, which do not face a large loan demand. The banks on non-investing islands can lend their excess funds to the banks on investing islands in the interbank market.

The structure of the household's problem is the same as described in Chapter 2. The structure of the intermediate and final goods producers' problems are the same as the model described in Chapter 3. Therefore, the following sub-section discusses only the banking sector of the economy, with the added feature that the central bank directly intervenes in the bank loan market and makes loans directly to firms on investing islands. This direct lending is a form of unconventional monetary policy.

4.2.1 Direct Lending, Financial Intermediaries and the Banking Sector

This sub-section illustrates the modelling framework for private financial intermediaries. As there is central bank lending directly into the financial market to firms, the amount of funds available to borrowing firms is:

$$S_t = S_{pt} + S_{gt}$$

where S_{pt} represents the loans issued by private banks, S_{gt} denotes the funds available from the central bank. Without unconventional monetary policy, S_{gt} would just be zero. It is assumed that the central bank chooses to intermediate a fraction φ_t of total credit:

$$S_{gt} = \varphi_t S_t$$

The central bank is assumed to adjust the fraction of credit it intermediates according to a policy rule which relates φ_t to the difference between the credit spread ($E_t R_{kt+1} - R_{t+1}$) and the steady state value of the spread ($ER_k - R$):

$$\varphi_t = v_g \left[(E_t R_{kt+1} - R_{t+1}) - (ER_k - R) \right] \tag{4.1}$$

It can be seen from the above expression, that the amount of direct lending to the financial market is related to the credit spread. As explained above, because of the existence of financial frictions and the incentive constraint, which limits private banks' balance sheet, the capital stock is lower than it would be without the frictions. This implies a positive credit spread and limits the credit flows in the financial market. The spread therefore becomes a direct measure of the severity of the financial frictions. The endogeneity of the credit spread amplifies the effects of shocks and links the financial frictions to the real economy. It is therefore natural to link direct lending, which is designed to offset the financial frictions, to the credit spread.

The private financial intermediation sector is otherwise identical to that described in previous chapters. All the derivations described in Chapter 2 continue to hold in this chapter except that S_t is replaced with S_{pt}. In addition the equilibrium conditions in the bank loan markets on each type of island become the following:

$$S^i_{pt} + S^i_{gt} = I_t + (1 - \delta) \pi^i K_t \tag{4.2}$$

$$S^n_{pt} + S^n_{gt} = (1 - \delta) \pi^n K_t \tag{4.3}$$

4.2.2 Calibration and Steady States

Similarly to the previous chapter, the calibration of the model mostly follows Gertler and Kiyotaki (2010). The model parameters include α (the share of capital stock in production), β (the discount factor), δ (the rate of depreciation of capital), ϕ (the labour elasticity parameter), σ (the survival rate of financial intermediaries), π^h (the probability that an island is an investing island) and γ (habit parameter). The probability for the investment opportunity to arrive on a typical island π^i is fixed at 0.25, which implies new investment opportunities on an island arise once a year on average. Other parameters are set to conventional values as follows $\alpha = 0.33$, $\beta = 0.99$, $\delta = 2.5\%$, $\phi = 0.333$, $\sigma = 0.972$ and $\gamma = 0.5$. The capital adjustment cost parameter s is set to be 1.5. The model is sensitive to the parameters χ (the disutility of work) and ξ (the amount of net worth that is transferred to banks entering the market). The model is also sensitive to the fraction of assets that a banker can divert in a default, θ, and the fraction of divertable funds in the interbank market, w. Gertler and Kiyotaki (2010) selected the values of ξ and θ in order to imply an average credit spread of one hundred basis points annually and an economy-wide leverage ratio of 4. The baseline calculation for the steady state values of the model follows Hansen (2008) so it is assumed that the steady state of households' labour input is 1/3 (which is normally 8 hours per day).

For the monetary policy rule in the benchmark case I set the Taylor rule parameters to their conventional values $a_\pi = 1.5$, $a_Y = 0.125$ and $a_{SPR} = 0$.

It is assumed the shocks in the model obey first order autoregressive process. Consistent with the calibrations for the shocks in Smets and Wouters (2003, 2007), the autoregressive factor for the technology shock, monetary policy shock, taste shock, investment adjustment shock and government expenditure shock are set to 0.95, 0.15, 0.838, 0.91 and 0.943 respectively. The standard deviation for the above five shocks are set to be 0.01, 0.24, 0.407, 0.113, 0.335 respectively. The calibration for the capital quality shock follows Villa and Yang (2011), where the autoregressive factor is 0.4. The calibration for the news shock is consistent with Corsetti et al (2011), where the standard deviation and autoregressive factor of the shock are set to be 0.1414 and 0.9 respectively.

The IRFs are calculated using a first-order approximation of the model solved using Dynare. Appendix A at the end of this thesis reports the Dynare codes. The IRFs include the benchmark case, the case with direct lending, the case with the welfare-optimised a_{SPR} parameter in the Taylor rule described in Chapter 3, and the case with no financial frictions. Thus, it will be possible to examine using these IRFs to see whether the response of the economy can be improved by adopting the unconventional monetary policy rule. It will also be possible to determine whether this type of policy is preferred compared to the welfare-optimised conventional monetary policy with a_{SPR} as shown in the previous chapter. There is also a welfare analysis included in this chapter. The welfare is calculated with the household's utility function. The welfare results shown in the tables are based on a second-order approximation of the model solved using Dynare.

4.3 Quantitative Results

This chapter focuses on unconventional monetary policy under different shocks. In the following sub-section 4.3.1, I firstly analyse the impulse response functions (IRFs) for the model. Sub-section 4.3.2 analyses the standard deviation of key variables under different combinations of the conventional and unconventional monetary policies. Sub-section 4.3.3 analyses the welfare optimisation results under different conditions for the model.

4.3.1 IRFs with Unconventional Monetary Policy

By examining the IRFs presented here, it can be determined whether the direct lending policy helps to stabilise the economy in response to different shocks. This can be compared with the conventional monetary policy rule analysed in Chapter 3 with the welfare-optimised parameter a_{SPR} in the Taylor rule.

In Figures 4.1 to 4.8 there are four cases in each figure. Three of the cases include financial frictions. The benchmark case represents the model without unconventional monetary policy. The second case includes the direct lending unconventional policy in the form of policy rule (4.1) with a policy parameter $v_g = 100$. The third case does not include unconventional policy, but includes the welfare-optimised value of a_{SPR} (which equals -2.9) in the Taylor rule, which is derived from Chapter 3. The last case in the IRFs provides the case with no financial frictions. The model is simulated under the nine shocks described in previous chapters.

This chapter analyses unconventional policy in a similar way to Gertler and Karadi (2009). In their model, they have set the value for v_g at two fixed values (10 and 100). Following Gertler and Karadi (2009), in this chapter, I firstly set v_g at two extreme values (0 and 100), which represent without and with the unconventional policy. In later sections for welfare optimisation, I would run grid search for the values in v_g with the range between -10 to 200.

The comparisons in Figures 4.1 to 4.8 are between the case with conventional policy responding to the spread and a case with unconventional policy responding to the spread. I do not consider a case where both conventional and unconventional policy responding to the spread at the same time.

In the case of the TFP shock shown in Figure 4.1, the spread decreases slightly in the benchmark case, followed with an increase to more than 0.01% afterwards. This initially increases bank loans and interbank borrowing. In the case with the welfare-optimised a_{SPR}, the spread decreases by 0.01%, which caused bank loans and interbank borrowing to increase more than the benchmark case, and stimulates output to a higher level after this positive TFP shock. However, in the case with direct lending policy (where $v_g = 100$), the spread stays quite constant and increases by only a little of less than 0.003% after the shock. This causes an initial decrease in bank loans (S_{pt}) and interbank borrowing (B_t^i). This injection of liquidity into the financial market crowds out deposits to private banks, stimulates consumption and output.

In the case of the capital quality shock shown in Figure 4.2, the negative impact to output from the shock is reduced by adopting the unconventional monetary policy or by adopting the welfare-optimised interest response to spread in Taylor rule. Output even increases slightly by adopting the welfare-optimised parameter a_{SPR} after the shock. In the $v_g = 100$ case, the spread still stays almost unchanged (as in the case of the TFP shock). Bank deposits decrease further in the unconventional monetary policy case and consumption drops further with $v_g = 100$, but takes a shorter time to get back to its steady state. Employment in the benchmark case decreases after the capital quality shock. Thus, with financial frictions but without adopting any conventional or unconventional monetary policy response increases unemployment by a significant amount. Interbank borrowing stays at a low level after the capital quality shock when there is an unconventional policy response.

Figures 4.3 to 4.6 show the IRFs for the four demand shocks in the model. In all figures, as for the previous shocks, by adopting the direct lending monetary policy (shown in the $v_g = 100$ case), the spread stays almost unchanged after the shock. These flat responses in the spread is followed by a lower response in bank loans and interbank borrowing comparing to the cases without unconventional monetary policy.

As shown in these figures, adopting the unconventional monetary policy decreases deposits (D_t) and loans to firms (S_{Pt}) and keeps them at a low level after the shocks, except for the government spending shock. Unlike the other shocks, in the case of a government spending shock, deposits and loans to firms are increased significantly in the $v_g = 100$ case. In the case of the government spending shock, the crowding out effect from the direct lending policy is eliminated by the crowding out effect from the expansionary government shock. This can be seen from the increase in firms' borrowing from the private banks and interbank borrowing after the shock.

Figure 4.7 and Figure 4.8 demonstrates the IRFs in the case of the shocks to financial markets. The IRFs for the shock in the interbank market and the fraction of divertable funds are quite similar. Unconventional monetary policy plays a significant role in eliminating the impacts to the economy under these shocks. The fluctuations to key variables are reduced by adopting the unconventional policy in response to the interbank friction shock. This effect is even more obvious in the case of the shock to the fraction of divertable funds.

Generally speaking, the results presented here show that the direct lending policy dampens the amplification mechanism caused by the financial frictions. However, this improvement in the economy is not so good as adopting the welfare-optimised a_{SPR} policy derived in the previous chapter. The financial frictions' amplification mechanism is more dampened in the case with the welfare-optimised a_{SPR} in Taylor rule. However, the difference between these two types of policy is not large. It should also be noted that in the IRFs just discussed the parameter v_g has not been chosen optimally. The optimal choice of v_g will be analysed below.

4.3.2 Standard Deviation of Critical Variables

After comparing the IRFs between the monetary policies in the previous sub-section, it is interesting to look at the economy's stability properties in more detail. This can be done by looking at the standard deviations for some critical variables in the economy under different policies. The policy variations examined help to determine whether unconventional policy helps to stabilise key variables in the presence of all the shocks. It also allows a comparison between the performance of the unconventional policy rule and the Taylor rule which includes the credit spread.

This sub-section focuses on Table 4.1 which reports the unconditional standard deviations for output, inflation and the spread for different monetary policies. The monetary policies in this table are combinations of conventional Taylor rule policies and the unconventional monetary policy of direct lending.

I analyse the effects of a_π and a_{SPR} in the Taylor rule function. I compare the effect of these parameters with the unconventional monetary policy parameter v_g (shown in expression (4.1)).

The first column in the table represents different combinations of monetary policy rules. The three numbers shown in each row of this column represent the parameters a_π and a_{SPR} in the Taylor Rule and v_g in the unconventional monetary policy rule. The second to the fourth columns represent the unconditional variances of output (σ_Y), of inflation (σ_π) and of the spread (σ_{SPR}) respectively. The last column of the table shows the welfare of the economy under these different policies.

The increase in the absolute value of a_{SPR} decreases the standard deviation of the spread in all cases. It decreases the standard deviation of output only for the cases under "aggressive" inflation-targeting regimes (where $a_\pi = 2$ or 3). For example, compare the rows (2, 0, 0), (2, -3, 0) and (2, -5, 0). An increase in the absolute value of a_{SPR} decreases the standard deviation of inflation only in "accommodative" inflation-targeting cases (where $a_\pi = 1$). For example, compare the rows (1, 0, 0), (1, -3, 0) and (1, -5, 0).

An increase in a_π increases the standard deviation of output, decreases the standard deviation of inflation, and increases welfare. For example, compare the rows (1, 0, 50), (2, 0, 50) and (3, 0, 50). The standard deviation of the spread (σ_{SPR}) in the "accommodative" inflation-targeting regimes (where $a_\pi = 1$) is higher than the standard deviation of the spread in "aggressive" inflation-targeting regimes (where $a_\pi = 2$ or 3).

An increase the unconventional monetary policy parameter v_g decreases the standard deviation of spread. For example, compare rows (1, 0, 0), (1, 0, 50) and (1, 0, 100). It also increases the standard deviation of output in "aggressive" inflation-targeting regimes only. For example, compare the rows (2, -3, 0), (2, -3, 50) and (2, -3, 100).

From these results it can be seen that, adopting the unconventional policy rule does not stabilise output in the "aggressive" inflation-targeting regimes. When the economy is in an aggressive inflation-targeting regime, the direct lending rule makes output responds more to shocks. However, with conventional monetary policies, stabilisation can be achieved in a number of different ways. It can be achieved by adopting an aggressive inflation-targeting regime. It can also be achieved by adopting a higher response to the spread in accommodative inflation-targeting cases.

4.3.3 Welfare Optimisation

I now turn to an analysis of the welfare maximising value of v_g. The welfare maximising value of v_g is derived using a grid search method. The welfare measure is given in (3.16) in the previous chapter. The grid search for welfare-optimised value of v_g is run over the range of -10 to 200. This grid search includes a test to ensure that only values of v_g are considered which are consistent with the correct number of stable eigenvalues for a correct equilibrium.

As explained in chapter 3, two sets of optimisation exercises are considered. In one set of exercises the parameters of the Taylor rule are fixed at their benchmark values, $a_\pi = 1.5$ and $a_Y = 0.5/4,$ while the value of v_g is chosen optimally. In the second set of exercises the value of a_Y is set at zero (which is consistent with the optimisation results of Schmitt-Grohé and Uribe (2006)) while a_π and v_g are jointly optimised. Note that in both sets of exercises a_{SPR} is set to zero, thus only unconventional policy is allowed to respond to the spread.

Optimal v_g in the benchmark case

As described in the previous chapter, when running the grid search for welfare-maximised value of a_{SPR}, the optimised welfare is found to be -2.7527, with the corresponding welfare-optimised value of $a_{SPR} = -2.9$. This optimisation is done using the benchmark parameter values. When the grid search for the optimal value of v_g is performed for benchmark parameter values, the welfare is optimised at the value -2.8036 with the corresponding welfare-optimised unconventional policy parameter $v_g = -1$. It can be seen that under the same benchmark values of a_π and a_Y, the optimal value of v_g provides a lower optimised welfare comparing to the one yielded by the conventional monetary policy with the value of a_{SPR} chosen optimally (i.e. $a_{SPR} = -2.9$). This result implies that with the benchmark model's parameter set, the conventional monetary policy performs better than the unconventional policy.

It is important to notice that, the welfare-optimal v_g is obtained when a_π and a_Y are at their benchmark values and a_{SPR} is zero. Thus, differently from Chapter 3, v_g is not optimised jointly with a_{SPR} here. This is not a case where unconventional policy is trying to improve on an already optimal Taylor rule.

In the case of joint optimisation of a_π and v_g (with $a_{SPR} = 0$ and $a_y = 0$) it is found that the welfare-optimised values are $a_\pi = 93$ and $v_g = -1$ and optimal welfare is -2.2165. Comparing to the case of the joint optimisation of a_π and a_{SPR} (with $v_g = 0$ and $a_y = 0$) in Chapter 3 which gives the welfare-optimised values $a_\pi = 56$, $a_{SPR} = -1.4$ and optimal welfare of -2.2187, unconventional monetary policy does yield a better result in optimised welfare. Comparing to the case with a fixed value of a_π discussed in the above paragraphs, the new case with joint optimisation is marginally better.

In both the optimisation exercises just described the optimal value of v_g is negative. This implies that direct lending by the central bank contracts when the spread rises and expands when the spread falls. This is a surprising result because it implies that unconventional policy is used in a way which magnifies the spread, rather than dampens it.

It is also important to note that, in both optimisation exercises, the optimum value of v_g is at the lower boundary of the range of values of v_g which are consistent with the correct number of stable eigenvalues.

The following sections analyse the effects of different parameters on the optimal value of v_g. To make these exercises more informative it is useful to conduct the analysis based on a set of parameters where the optimal v_g is initially away from the lower boundary of the region with the correct number of stable eigenvalues. Experiments with different values of values of a_π and a_Y show that when the conventional monetary policy is less aggressively anti-inflation (i.e. a_π is lower than about 1.2), the optimal value of v_g moves away from the lower boundary. Therefore, the results reported in the following sections are based on the parameter value $a_\pi = 1.1$ rather than the benchmark value $a_\pi = 1.5$.

When $a_\pi = 1.1$, running the grid search for optimal a_{SPR} derives an optimised welfare of -4.1532, with corresponding optimal $a_{SPR} = -4.6$. The grid search for optimal v_g yields an optimised welfare of -4.6344, with the corresponding optimal $v_g = 26$. Thus, just as in the comparison discussed above, the optimal conventional policy is better than the optimal unconventional policy with the parameter value $a_\pi = 1.1$.

The following analysis shows how variations in other key parameters affect the optimal choice of v_g when $a_\pi = 1.1$.

Optimal v_g and financial frictions

Table 4.2 provides the welfare optimisation results and the corresponding optimal value for v_g in cases with different levels of financial friction. There are two types of financial frictions illustrated in the table - the interbank market friction (w) and the friction in the deposit market (θ).

Each cell of the table is divided into two. The upper part reports the optimal value of v_g and the optimised welfare when a_Y and a_π are fixed at $0.5/4$ and 1.1. The lower part of each cell reports the case where a_π and v_g are optimised jointly and $a_Y = 0$. The first number is the optimal value of v_g, the second number is the optimal value of a_π and the third number is the resulting optimised value of welfare. Note that a_{SPR} is zero throughout these exercises.

This table shows that financial frictions have an obvious impact on the unconventional monetary policy parameter v_g. From the table it can be seen that, by increasing w, the welfare-optimised value of v_g increases. For example, compare the second column of the table. When θ stays unchanged at 0.3, in the extreme imperfect interbank market case where $w = 0$, $v_g = 38$. In the case with $w = 0.5$, the welfare-maximised value of $v_g = 44$. It increases further to 50 when the interbank market becomes perfect (where $w = 1$). The same trend is found with the changes in θ. When the deposit market becomes more frictional (θ increases), the welfare-optimised value of v_g decreases. For example, compare the third row of the table. When w is fixed at 0.5, in the case with $\theta = 0.3$ the optimal value of v_g is 44. When θ increases to 0.3, v_g decreases to 31. And when the deposit market becomes even more frictional with $\theta = 0.4$, the welfare-maximised value of v_g decreases even further to 22.

As described in previous chapters. The increase in w shows a decrease in the level of interbank market friction. The increase in θ represents an increase in the level of deposit market friction. Thus, the above results show consistent results for the two types of financial frictions. When the level of financial friction rises, the central bank intervenes less with unconventional policy in order to achieve the maximised welfare level, no matter whether this friction originates in the interbank market or the deposit market.

The second part in each cell of Table 4.2 provides the welfare optimisation results of jointly optimising a_π and v_g. Comparing to the first part in each cell of the Table 4.2, joint optimising a_π and v_g provides better welfare results. The optimal welfare values in all cases of different friction levels are larger than the optimal welfare values when optimising v_g only.

In cases with an imperfect interbank market (where $w = 0$ or 0.5), the optimal a_π is very large (and is at the top boundary of the grid search), but optimal v_g is negative. This is the opposite when compared to the cases with a perfect interbank market. In the cases with a perfect interbank market (where $w = 1$), the optimal a_π is much smaller than in the imperfect interbank market cases and the optimal value of v_g is large as 200 (i.e. at the top end of the search grid). The optimal a_π is still not small so conventional policy still needs to play an important role to stabilise the inflation.

Different levels of friction in the deposit market however do not appear to make much difference when both a_π and v_g are optimised. When θ changes from 0.3 to 0.4, optimal welfare decreases slightly in all cases in the second part in each cell. However, there is no obvious trend or difference for the optimal policy parameters between the cases with different values of θ.

Note that the above results indicate that the interbank friction has a potentially major effect on the optimal setting of v_g. The optimal value of v_g rises significantly (and even changes sign) as w increases. Gertler and Karadi (2011) only analyse the unconventional policy in a model without an interbank friction (i.e. the case where $w = 1$). However in this chapter, the results in Table 4.2 show that the interbank friction plays a potentially important role.

Optimal v_g and the parameters of the Taylor rule

Table 4.3 provides welfare optimisation results and the corresponding optimal unconventional monetary policy parameter (v_g) in cases with different conventional monetary policy parameters. The first column of the table shows three different values for the interest response to inflation (a_π). The first row of the table shows three different values of the interest response to output (a_Y). There are two elements contained in each cell of the table. The top element gives the welfare-optimised value for the unconventional monetary policy parameter (v_g) and the bottom element in each cell gives the resulting level of welfare.

Firstly, an increase in a_π results in an increase in the optimal welfare in all cases (which is consistent with the benchmark joint optimisation of a_π and v_g, which yields $a_\pi = 93$ and $v_g = -1$).

For example, compare the bottom elements in the second column of the table. When $a_\pi = 1$ and $a_Y = 0$, the optimal welfare is -2.8424. This increases to -2.2380 when a_π changes to 2 but a_Y stays unchanged. It increases further to -2.2251 when $a_\pi = 3$. Thus when the nominal interest rate responds more to the inflation, the optimal welfare level increases.

In the cases where $a_Y = 0.5$ and 1, the increase in a_π decreases the welfare-optimised value of v_g. In the case where $a_Y = 0$ the opposite appears to be the case because the optimal v_g rises from -1 to 200. But experiments with $a_Y = 0$ and values of a_π larger than 3 indicate that as a_π rises above approximately 10 the optimal v_g decreases from 200 to -1. This is consistent with the other columns of Table 4.3 and is also consistent with the joint optimisation of a_π and v_g in the benchmark case which yields $a_\pi = 93$ and $v_g = -1$.

An increase in the nominal interest response to output (a_Y) decreases welfare. For instance, compare the bottom elements in the second row of the table. When $a_\pi = 1$ and $a_Y = 0$, the optimal welfare is -2.8424. With a_π unchanged but $a_Y = 0.5$, welfare decreases to -9.2124. Welfare decreases further to -11.2360 when a_Y increases to 1. These results show that when the nominal interest rate responds more to output in the Taylor rule, welfare decreases. The increase in a_Y increases the welfare-optimised value of v_g only in the case where $a_\pi = 1$. In the cases with $a_\pi = 2$ and 3, an increase in a_Y decreases the welfare-optimised value of v_g.

Optimal v_g and shock variances

Table 4.4 investigates welfare optimisation in cases with different variances for the shocks.

Consider first the case where only v_g is optimised. As shown in the table, the optimal welfare reaches a lowest value of -11.8990 in the case with a doubled variance of the news shock, and the corresponding v_g is 26.8. The news shock seems to have a much larger impact on welfare optimisation in the model. In the case of the financial friction shock to θ, the unconventional policy parameter v_g needs to be as high as 28.6 in order to achieve welfare maximisation. The results in the case where only v_g is optimised suggest that the optimal v_g is relatively unaffected by the variances of the shocks

The last column of Table 4.4 provides the welfare optimisation results by jointly optimising a_π and v_g. By optimising jointly for a_π and v_g, the optimal welfare is much larger than the optimal welfare values when optimising v_g only. It appears again however that the shock variances have very little effect on the optimal value of v_g. In fact the optimal $v_g = -1$ in all cases. On the other hand the effect of shock variances on the optimal a_π values is quite large.

It therefore appears that the conventional policy parameter, a_π, plays the major role in the model compared to the unconventional policy parameter, when optimising them jointly. The optimal a_π is smallest at 81 in the doubled news shock case. However, in the case with the doubled financial friction shock, the optimal $a_\pi = 128$, is the largest.

4.4 Conclusion

The world economy suffered a severe financial crisis in 2007 which has led to a major recession in financial, goods and labour markets. Central banks in many countries responded rapidly to the crisis. The response has not only been with conventional monetary policies, there are also several unconventional monetary policies that have been adopted by central banks. These unconventional policies have played a significant role in minimising the damage to the economy from the crisis. The features of these policies and the responses of the economy to such policies have recently been much studied by economic researchers. Among these important literatures, Gertler and Kiyotaki (2010) have considered a monetary DSGE model with unconventional policy under the two extreme cases: the perfect and imperfect interbank market cases.

In this chapter, I have built on the baseline model described in Chapter 2, with price stickiness as described in Chapter 3, and extended it to include a direct lending unconventional monetary policy.

The model of this chapter also includes a welfare analysis. The model is examined under a wide range of values for the unconventional monetary policy parameter.

The welfare optimisation value and the corresponding optimal unconventional policy parameter have been found in cases with different friction levels, in cases with different conventional monetary policy parameters and in the cases with different variances of the shocks.

From the simulation results, the direct lending policy appears to dampen the amplification mechanism caused by financial frictions. However, this improvement in the economy is not so good as adopting the welfare-optimised a_{SPR} policy derived in the previous chapter. The financial frictions' amplification mechanism is more dampened in the case with the welfare-optimised a_{SPR} in Taylor rule. However the difference between these two types of policies is not big.

Analysis of the standard deviations of key macro variables shows that the unconventional policy rule does not stabilise output in the "aggressive" inflation-targeting regimes. In an aggressive inflation-targeting regime, the direct lending rule makes output respond more to the shocks. However, with conventional monetary policies, stabilisation can be achieved by adopting an aggressive inflation-targeting regime. It can also be achieved by adopting a higher response of unconventional policy to the spread in accommodative inflation-targeting cases.

From the welfare optimisation analysis it can be seen that, for benchmark parameter values, the optimal choice of the unconventional policy parameter v_g is constrained at the lower bound of the range with the correct number of stable eigenvalues. It is found that the optimal v_g rises above the lower bound and becomes positive (in fact strongly positive) either when there is no interbank friction or when conventional monetary policy responds only weakly to inflation (i.e. a_π is very low). The optimal v_g (when only

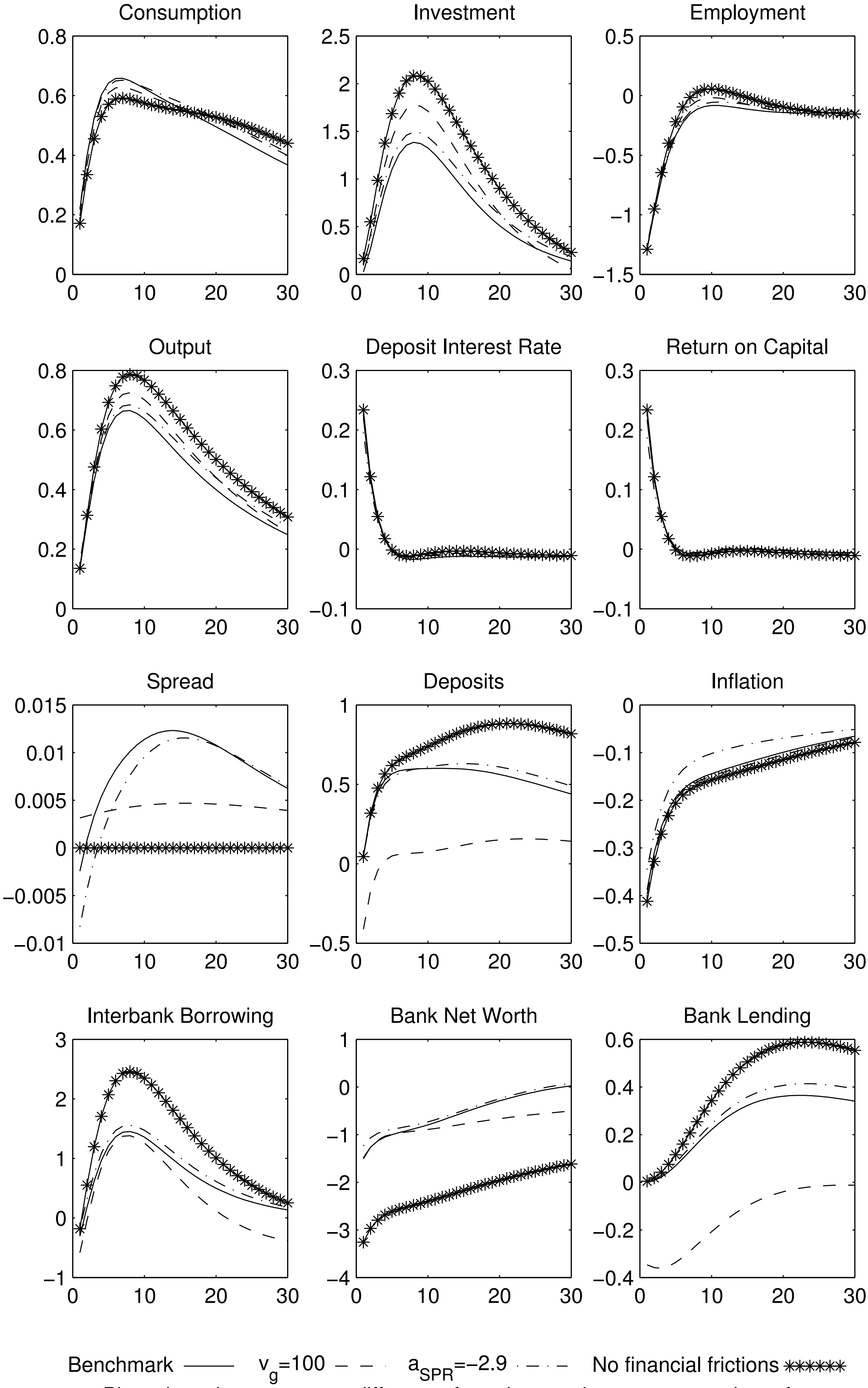
v_g is optimised) yields a lower optimised welfare that the one yield by the conventional monetary policy with optimal choice of a_{SPR} (when only a_{SPR} is optimised).

The joint optimising a_π and v_g provides better welfare results. The optimal welfare values in all cases of different friction levels are larger than the optimal welfare values when optimising v_g only. Moreover, the joint optimisation of a_π and v_g yields slightly higher welfare than joint optimisation of a_π and a_{SPR}. Thus, it appears that unconventional policy yields higher welfare than conventional policy, provided a_π is optimally chosen.

It might be interesting for future research to focus on a wider combination of conventional and unconventional monetary policies. As described in the previous chapter, there might be some other elements that could be added in the Taylor rule. And it would also be interesting to analyse other unconventional monetary policies.

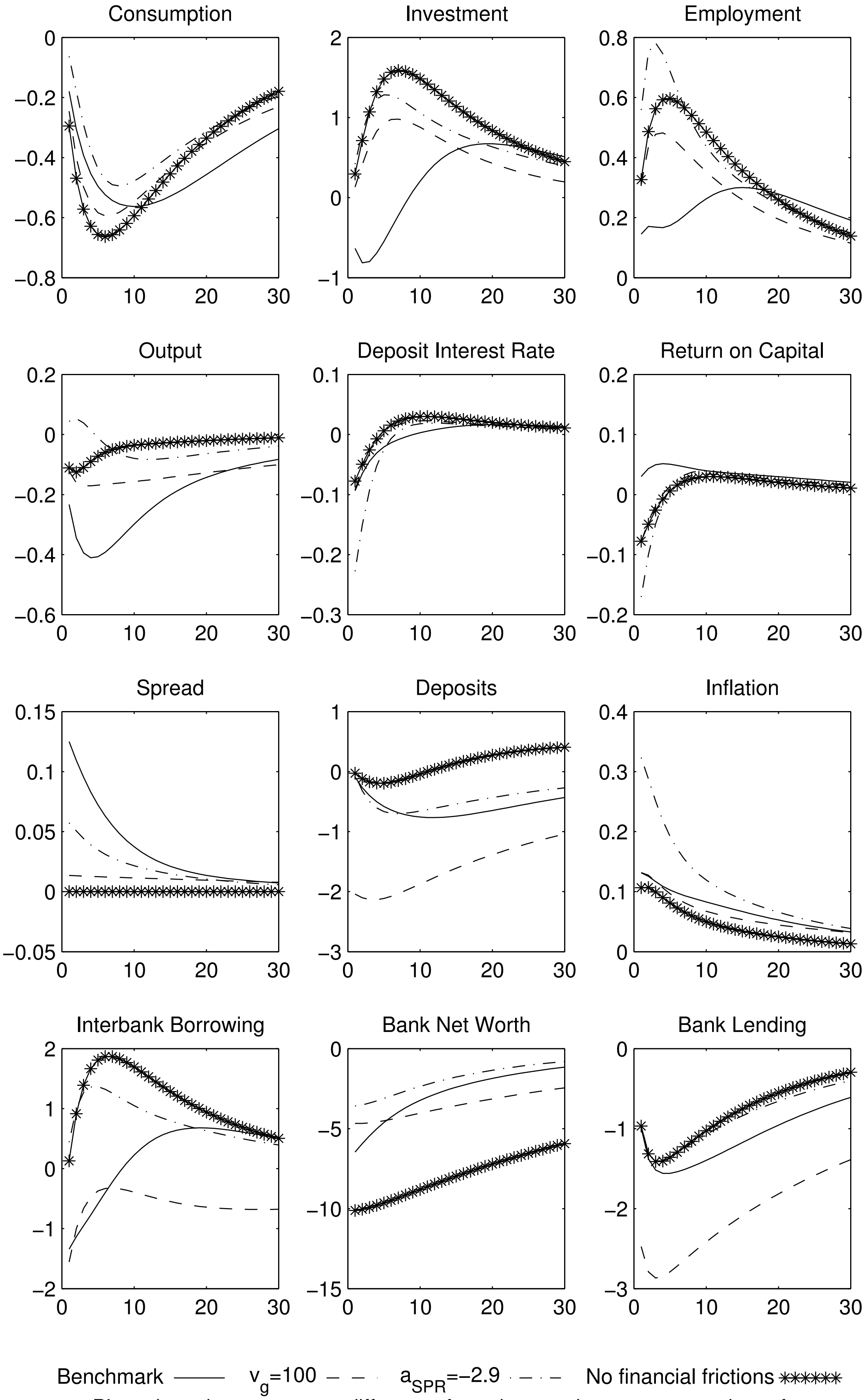
There are limitations to the analysis presented in this chapter. For example, there is no allowance for potential welfare costs of the unconventional monetary policy. Developing a model which includes the welfare costs of unconventional policy would therefore also be a useful line of future research.

Figure 4.1: TFP Shock IRFs



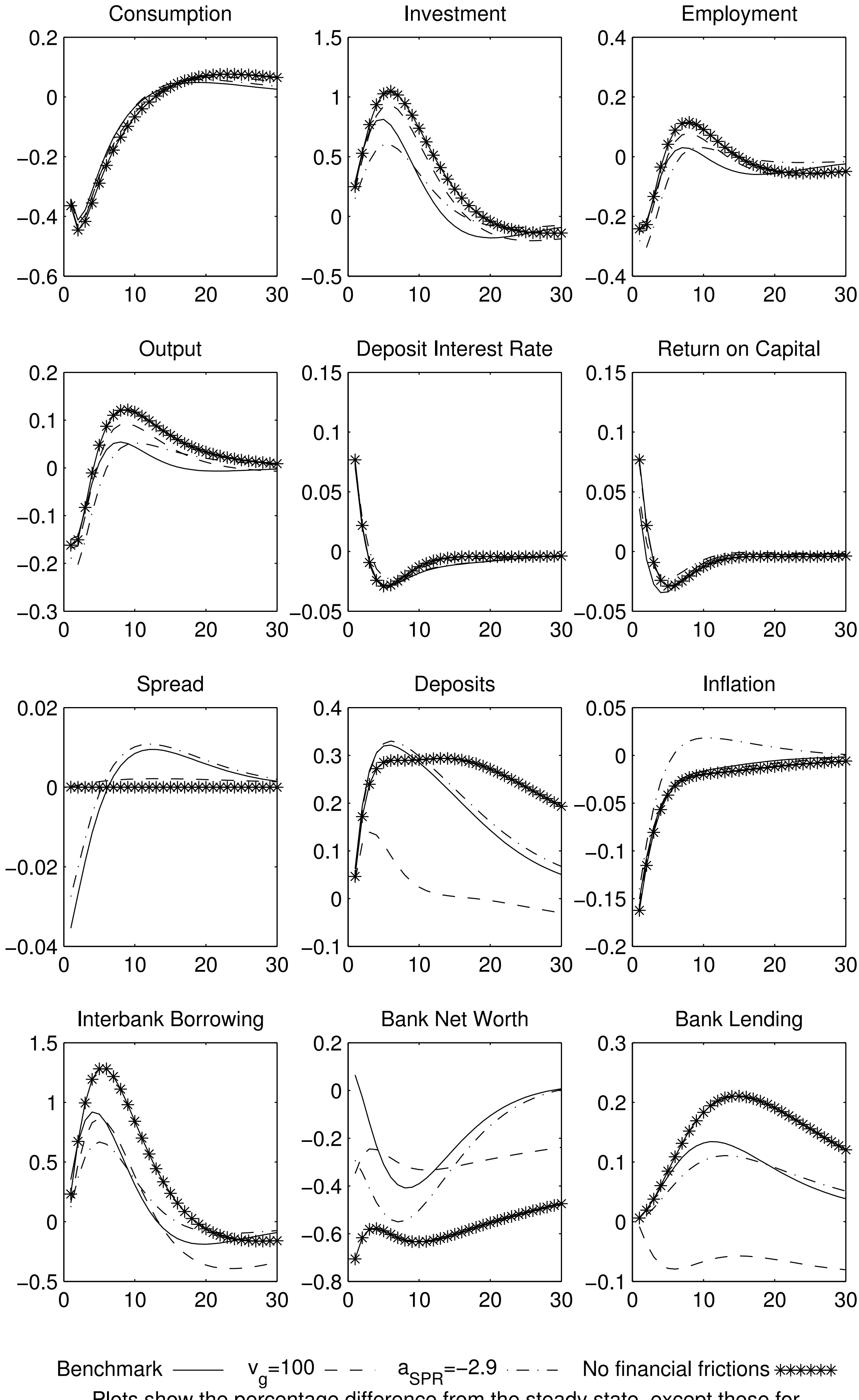
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 4.2: Capital Quality Shock IRFs



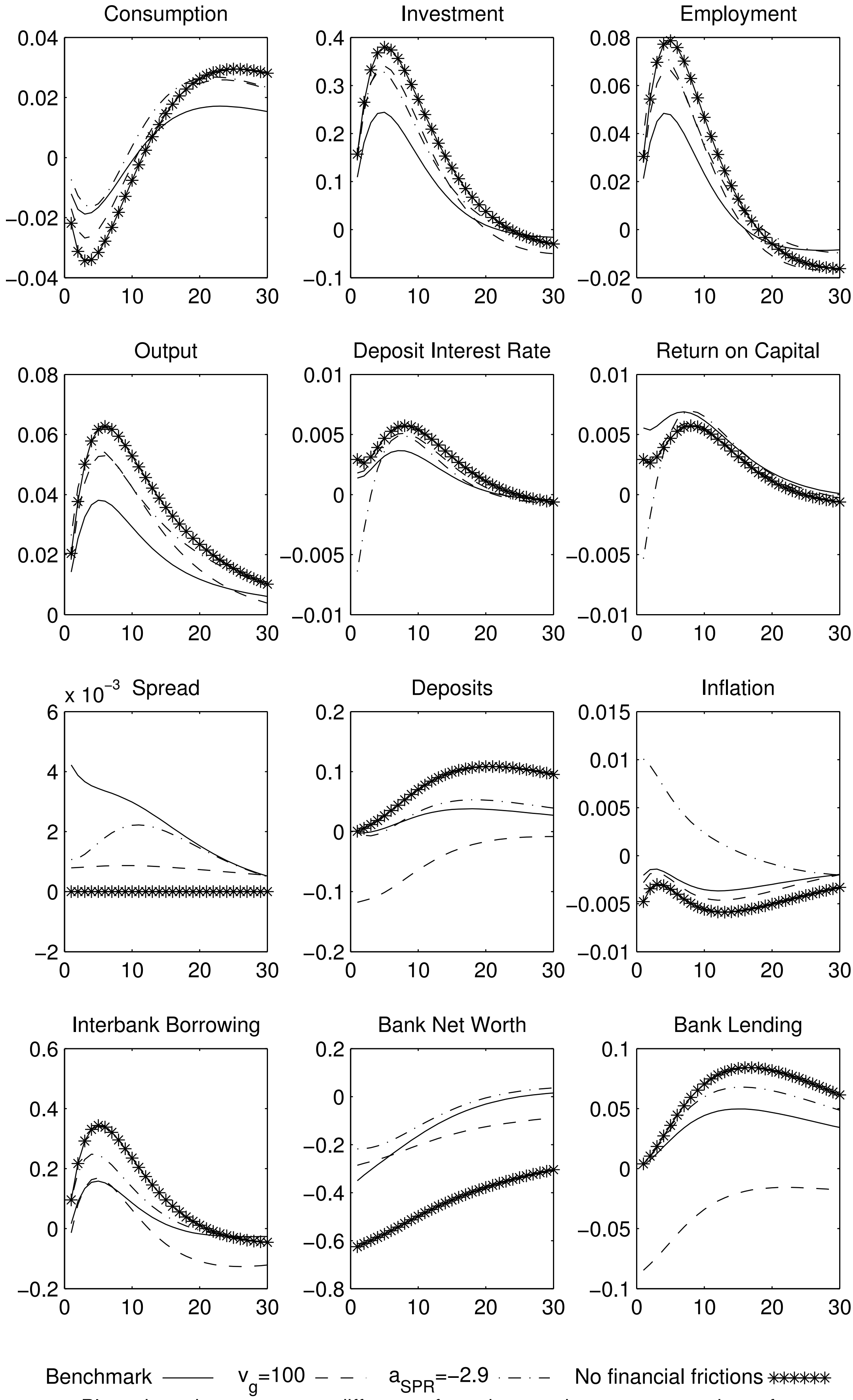
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 4.3: Preference Shock IRFs



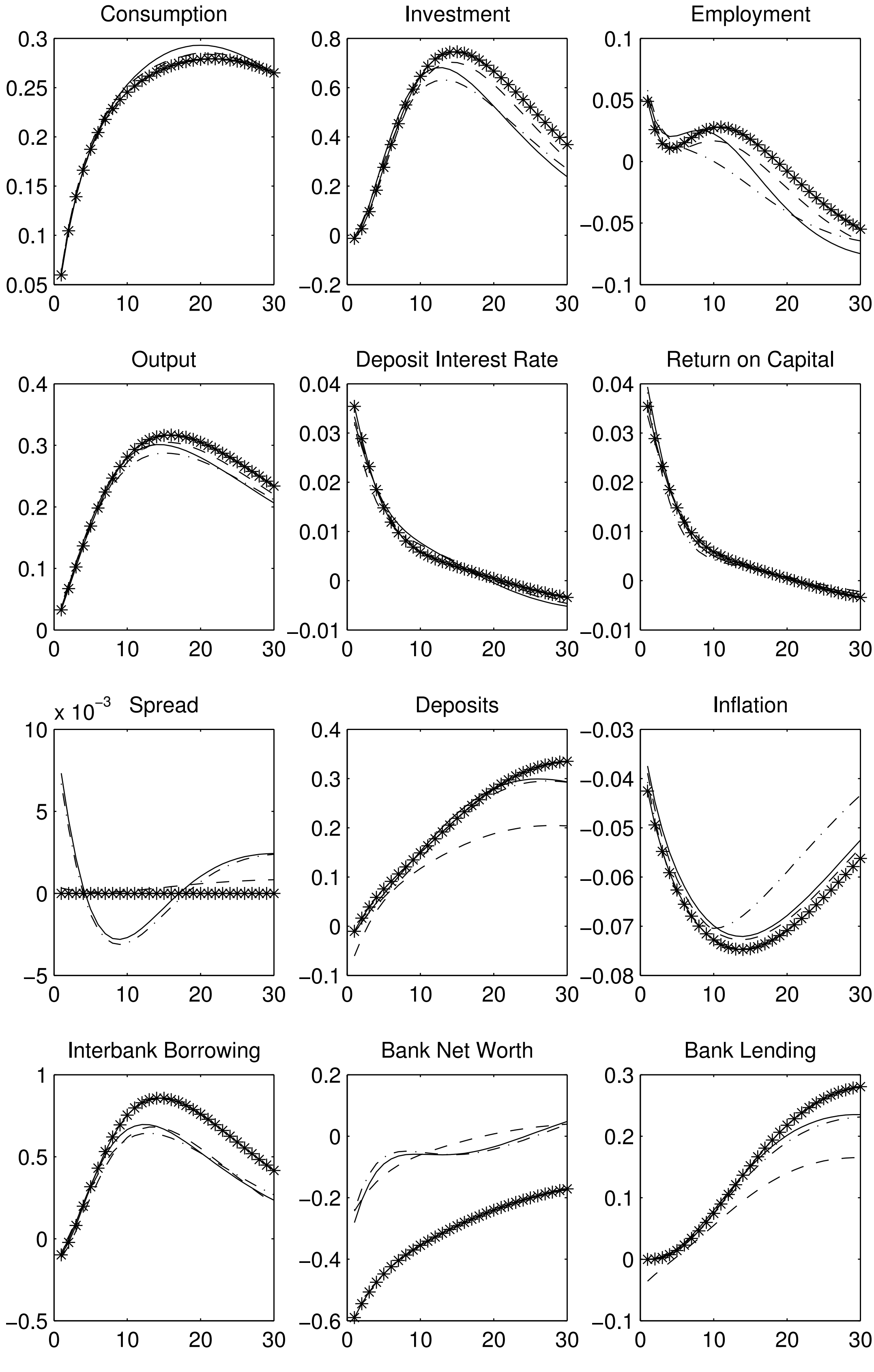
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 4.4: Investment Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

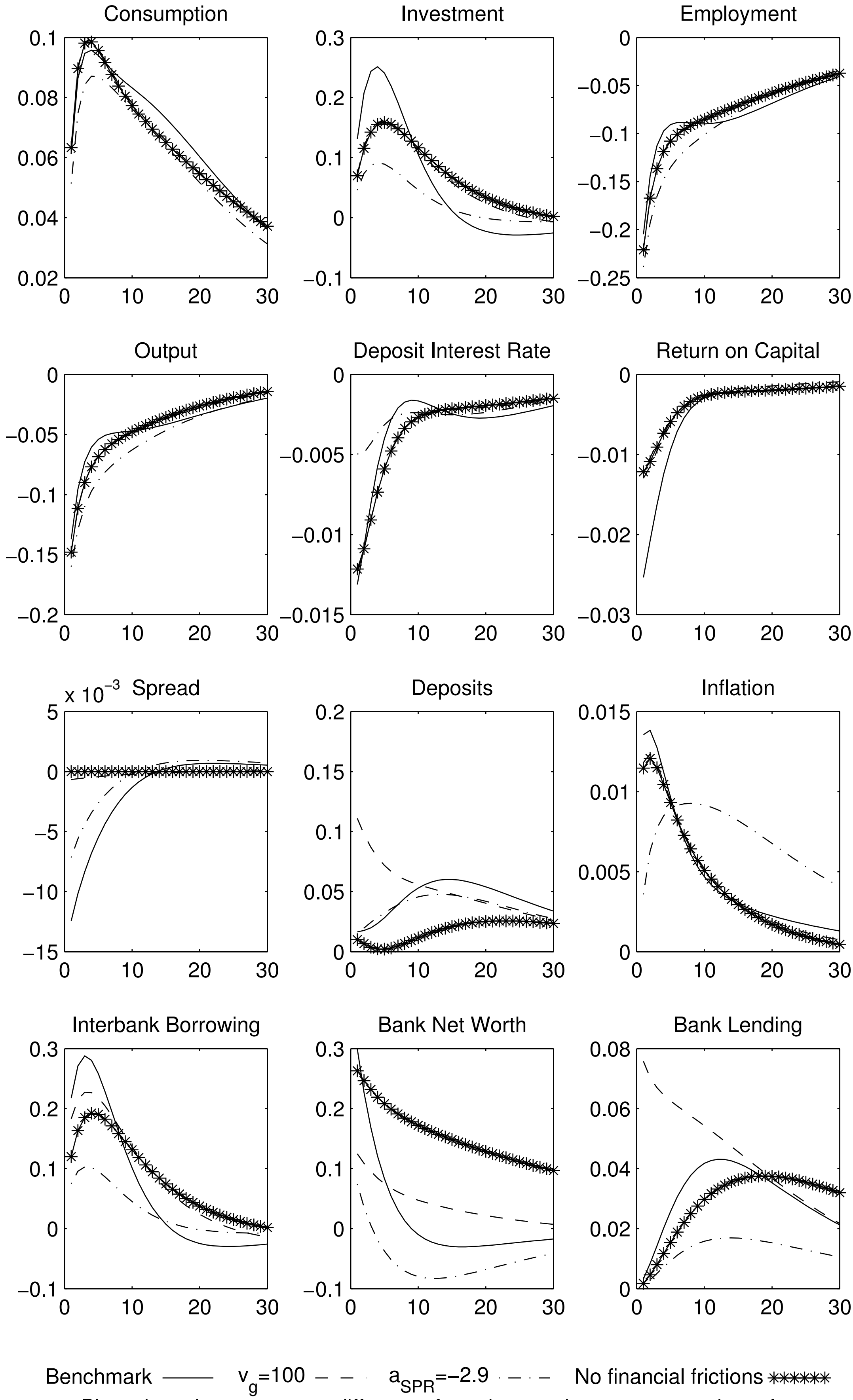
Figure 4.5: News Shock IRFs



Benchmark —— v_g=100 – – a_{SPR}=−2.9 ·–·– No financial frictions ∗∗∗∗∗

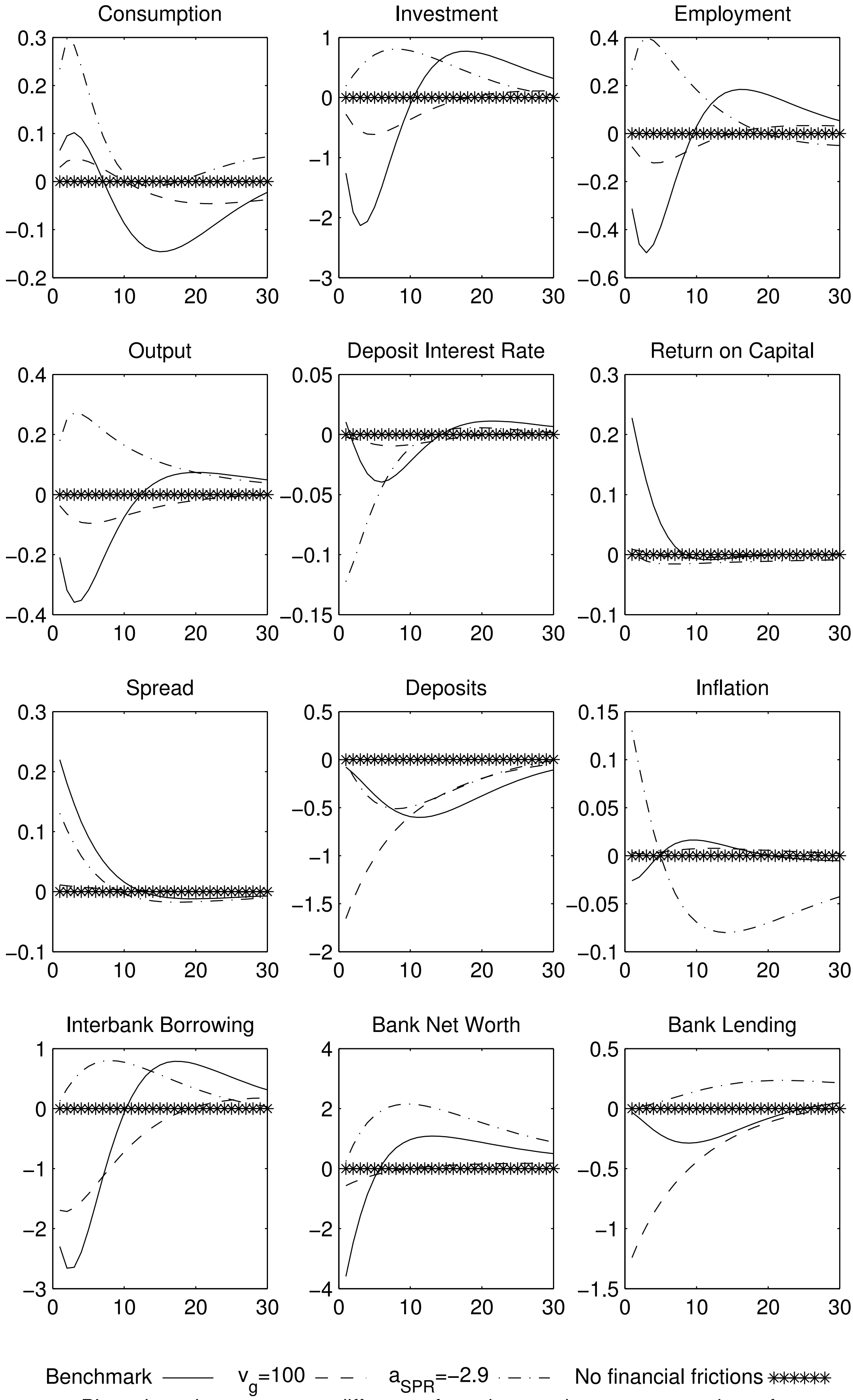
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 4.6: Government Spending Shock IRFs



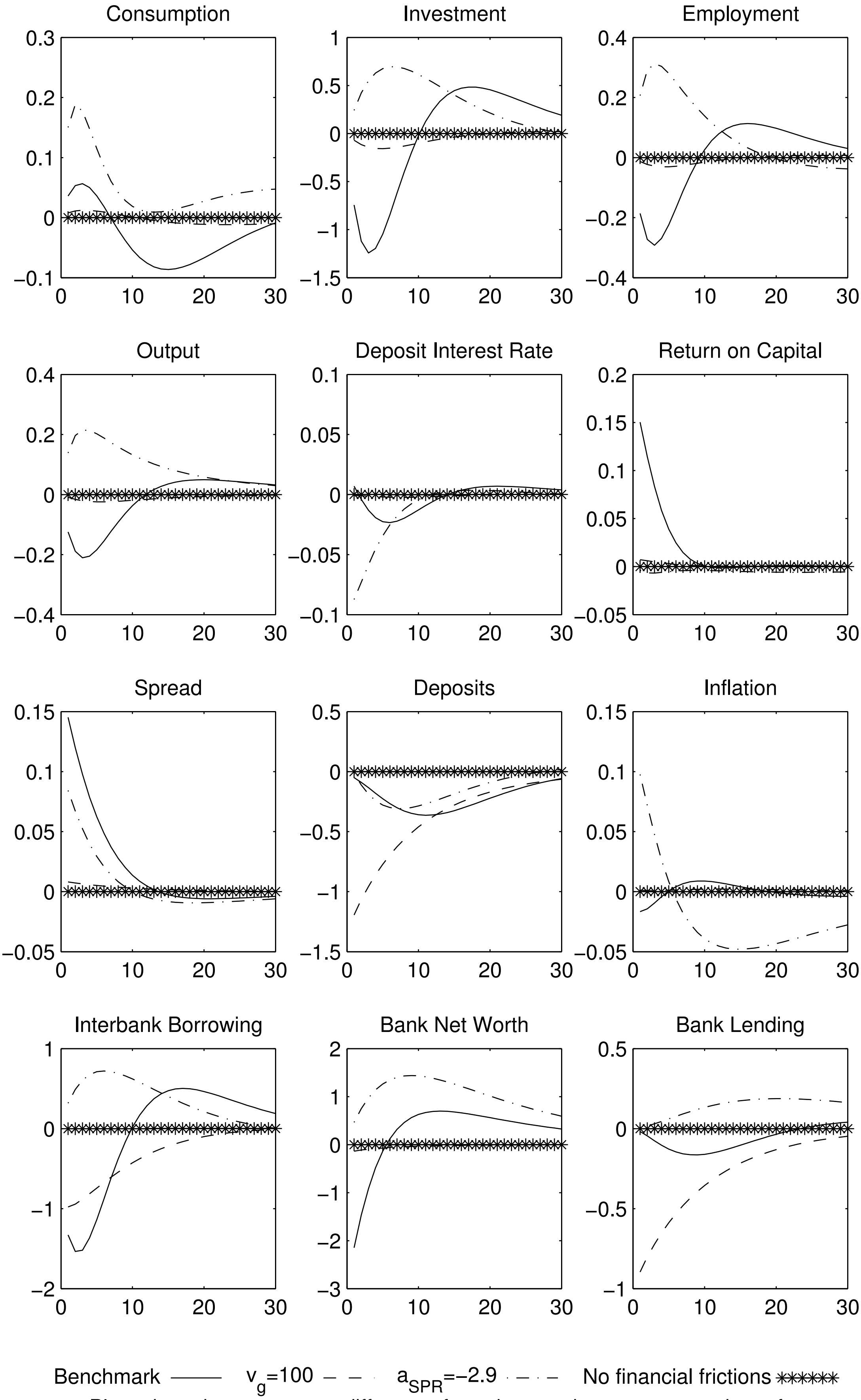
Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 4.7: Interbank Friction Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Figure 4.8: Fraction of Divertable Funds Shock IRFs



Plots show the percentage difference from the steady state, except those for the deposit interest rate, the return on capital, the spread and inflation, which show the percentage point difference from the steady state.

Table4.1: Standard Deviation for Critical Variables and Welfare under Different Monetary Policies

Policy (a_π, a_{SPR}, v_g)	σ_Y	σ_π	σ_{SPR}	welfare
(1.0 0.00 0)	0.1598	0.1455	0.0321	−6.0937
(1.0 −3.00 0)	0.1447	0.1330	0.0133	−5.4032
(1.0 −5.00 0)	0.1591	0.1315	0.0106	−5.3314
(1.0 0.00 50)	0.1213	0.1379	0.0070	−5.6974
(1.0 −3.00 50)	0.1447	0.1021	0.0042	−4.0918
(1.0 −5.00 50)	0.1600	0.0891	0.0034	−3.6388
(1.0 0.00 100)	0.1231	0.1379	0.0052	−5.6947
(1.0 −3.00 100)	0.1445	0.1000	0.0034	−4.0110
(1.0 −5.00 100)	0.1581	0.0859	0.0028	−3.5336
(2.0 0.00 0)	0.2468	0.0326	0.0160	−2.4139
(2.0 −3.00 0)	0.2365	0.0341	0.0084	−2.4322
(2.0 −5.00 0)	0.2339	0.0368	0.0068	−2.4688
(2.0 0.00 50)	0.2479	0.0329	0.0023	−2.4150
(2.0 −3.00 50)	0.2440	0.0322	0.0020	−2.4059
(2.0 −5.00 50)	0.2421	0.0318	0.0018	−2.4016
(2.0 0.00 100)	0.2486	0.0330	0.0014	−2.4153
(2.0 −3.00 100)	0.2464	0.0324	0.0013	−2.4077
(2.0 −5.00 100)	0.2451	0.0320	0.0013	−2.4036
(3.0 0.00 0)	0.2532	0.0175	0.0157	−2.2761
(3.0 −3.00 0)	0.2462	0.0202	0.0096	−2.2944
(3.0 −5.00 0)	0.2447	0.0229	0.0079	−2.3171
(3.0 0.00 50)	0.2554	0.0176	0.0023	−2.2747
(3.0 −3.00 50)	0.2530	0.0174	0.0021	−2.2730
(3.0 −5.00 50)	0.2516	0.0175	0.0020	−2.2732
(3.0 0.00 100)	0.2561	0.0176	0.0015	−2.2741
(3.0 −3.00 100)	0.2548	0.0174	0.0014	−2.2724
(3.0 −5.00 100)	0.2540	0.0174	0.0013	−2.2719

Table4.2: Welfare Optimisation and the Corresponding Optimal v_g

in Cases with Different ω and θ Values

ω \ θ	0.30	0.35	0.40
0.00	38.00 −4.6353	26.00 −4.6474	17.00 −4.6580
	200.00 −5.00 −2.1984	200.00 −4.00 −2.2094	200.00 −4.00 −2.2110
0.50	44.00 −4.6527	31.00 −4.6648	22.00 −4.6756
	200.00 −2.00 −2.2106	200.00 −2.00 −2.2128	200.00 −2.00 −2.2149
1.00	50.00 −4.6718	36.00 −4.6837	27.00 −4.6942
	20.00 200.00 −2.2150	24.00 200.00 −2.2165	27.00 200.00 −2.2180

Top Half of Each Cell: Optimisation over v_g
(1st number: optimal v_g; 2nd number: optimal welfare)
Bottom Half of Each Cell: Optimisation over a_π and v_g
(1st number: optimal a_π; 2nd number: optimal v_g; 3rd number: optimal welfare)

Table4.3: Welfare Optimisation and the Corresponding Optimal V_g

in Cases with Different a_π and a_Y Values

a_π \ a_Y	0.0	0.5	1.0
1.0	−1.00 −2.8424	78.00 −9.2124	77.00 −11.2360
2.0	200.00 −2.2380	0.00 −3.9275	12.00 −6.1848
3.0	200.00 −2.2251	−1.00 −2.8212	−1.00 −4.0434

1st Number of Each Cell: Optimal v_g

2nd Number of Each Cell: Optimal Welfare

Table4.4: Welfare Optimisation and the Corresponding Optimal v_g

in Cases with Different Doubled Shocks

Doubled Shock	v_g	welfare	a_π	v_g	welfare
TFP	26.60	−4.8050	109.00	−1.00	−2.2157
Capital Quality	27.10	−4.7090	111.00	−1.00	−2.2142
Interbank Shock	27.30	−4.6819	87.00	−1.00	−2.2177
Financial Friction (θ)	28.60	−4.6861	128.00	−1.00	−2.2158
Preference	27.10	−4.6820	90.00	−1.00	−2.2165
Investment	27.10	−4.6812	93.00	−1.00	−2.2165
News Shock	26.80	−11.8990	81.00	−1.00	−2.2005
Government Spending	27.10	−4.6813	93.00	−1.00	−2.2165

Chapter 5
Conclusion

If we go back to the summer of 2007, when the crisis first started, the global economy suffered from a severe shock in financial markets, which in turn affected all goods markets. It has been widely agreed that the crisis was started by the unexpected increase in delinquencies in the U.S. subprime mortgage market, which sequentially caused an enormous shock to investor's confidence in credit markets all over the world. Much recent research has focused on the modelling of the crisis, either looking backwards or forwards. Backward looking research has concentrated on the prior weakness of the financial markets and has investigated the underlying reasons for the sudden shock. On the other hand, forward looking research has focused on the follow-up chain reactions and damage to the economy and therefore investigates the fiscal and monetary responses of governments and central banks. Economic research is motivated to avoid the future crises and to stabilise the economy if crises do occur.

As is widely known, the current crisis started with the sudden jump in U.S. subprime mortgage delinquencies. However, Bernanke (2009) argues that this is not the only reason for the sudden and fast collapse of the credit market, though it was an important trigger event. As argued in Elliott and Baily (2009), it was not just a bubble in the housing market. Before the rise of delinquencies in U.S. subprime mortgage market, financial markets in most countries were already quite fragile. Ex ante of the shock, general credit standards in financial markets had been decreased gradually; average compensation for risky securities was falling; market reliance had been shifting to more complicated credit instruments; and furthermore, credit rating agencies broke down.

From historical experience, a full blown financial crisis can impact a great deal in both human and economic terms. The corresponding chain reactions create a large amplification from the shock, and therefore, damage the economy even further. Brunnermeier and Sannikov (2010) illustrated the severe follow-up reactions with a qualitative model. Other papers which analyse this 'endogenous risk' and amplification loop are Bernanke, Gertler and Gilchrist (1999) and Kiyotaki and Moore (1997).

The primary function of the interbank market is to transfer liquidity among banks. As stated in Allen and Gale (2000), the financial distress of a single financial institution may affect other financial institutions through contagion via the interbank market and may eventually have impacts on the rest of the financial system and the state of the total economy. Right after the crisis, in early September 2007, the rate at which British banks lend to each other – known as the London Interbank Offered Rate (LIBOR) – rose to its highest level in almost nine years. The three-month loan rate hit 6.7975%, above the Bank of England's emergency lending rate of 6.75%, suggesting that banks were reluctant to lend money in the interbank market. Facing this difficulty in borrowing in the interbank market, the Northern Rock Bank experienced serious funding problems in 2007. Similar problems also occurred in two large US mortgage banks - the Countrywide and the IndyMac. After this shock each party had to hold further funds to protect itself against possible risks and this further reduced the liquidity in the market. This 'gridlock' in the interbank lending market reduced the funds available to financial intermediaries and this was a major cause of the slowdown in the real economy during the crisis.

Monetary authorities faced high demand to ease the serious liquidity drought in financial markets. Both conventional and unconventional monetary policies were adopted during the crisis in 2007. The conventional monetary policies concerned the traditional tools of adjusting liquidity conditions, for example the short term policy interest rate as set by the Taylor rule. Unconventional monetary policies related to other forms of monetary policy, which are particularly used when the policy interest rate are at or near the zero lower bound. Examples of unconventional monetary policies include credit easing, quantitative easing and signalling. In credit easing, central banks purchase private sector assets in order to improve liquidity and improve access to credit. During the credit crisis, the US Federal Reserve adopted several quantitative easing policies. The Bank of Canada made a "conditional commitment" to keep the interest rates at the lower bound until the end of the second quarter of 2010 (which is an example of the policy signalling).

In this thesis, I focus on a particular area of concern during the crisis. Starting with Chapter 2, I focus on a model of an imperfect interbank market under eight different types of shocks. There are two major financial frictions considered in the model: an interbank market friction and a general friction in the banks' ability to raise funds from retail depositors. I consider shocks that arise from the interbank market and the deposit market and compare these financial shocks with other supply and demand shocks to the model. Chapter 3 builds on the baseline model in Chapter 2 but adds price stickiness. Chapter 3 focuses on conventional monetary policies in the form of a modified Taylor rule. I extend the Taylor rule to make the nominal interest rate respond to inflation, output and the spread between deposit and lending interest rates. The model is then analysed with different policies and a welfare analysis is presented. Chapter 4 extends the analysis further to consider unconventional monetary policies in the form of direct lending by the central bank to private borrowers. Again a welfare analysis is presented.

From the analysis in this thesis, several results have been derived. Firstly, the financial frictions lead to a general amplification for the effects of the shocks. This amplification mechanism is small under the demand shocks comparing to the supply shocks of the model. The small interbank market shock has limited effect to the economy. However with a very large interbank market shock, the real economy would suffer from a severe recession following this shock. The deposit market shock has more obvious effect than the small interbank market shock.

Secondly, the conventional monetary policy rule with the modified Taylor rule function in Chapter 3 improves the response of the economy to the shocks. The response of the economy can be further improved by adopting the "welfare-optimised" value of a_{SPR} in the Taylor rule. The amplification effects of the financial frictions can be diminished. However, including the spread in the Taylor rule does not eliminate all the negative impacts from the financial frictions. The response of both interbank borrowing and loans to firms still has some amplification effects on the economy after shocks.

Lastly, the direct lending unconventional monetary policy appears to dampen the amplification mechanism caused by financial frictions However, this improvement in the economy is not so good as adopting the welfare-optimised a_{SPR} policy when only the response to the credit spread is optimised. The financial frictions' amplification mechanism is more dampened in the case with the welfare-optimised a_{SPR} in Taylor rule. However the difference between these two types of policies is not big. The unconventional policy rule does not stabilise output in the "aggressive" inflation-targeting regimes. In an aggressive inflation-targeting regime, the direct lending rule makes output respond more to the shocks. However, with conventional monetary policies, stabilisation can be achieved by adopting an aggressive inflation-targeting regime. It can also be achieved by adopting a higher response to the spread in accommodative inflation-targeting cases.

In the case where only the response to the spread is optimised (either a_{SPR} or v_g), the optimal conventional policy yields higher optimised welfare than the optimal unconventional monetary policy. However this result is reversed when the response of conventional policy to inflation (the parameter a_π) is also optimised. In this case the unconventional policy yields higher welfare than conventional policy.

Further research can be interesting to focus on a wider combination of conventional and unconventional monetary policies. There might by further elements that can be added in the Taylor rule or other unconventional policies. It would also be interesting the expand further to consider the cost of adopting monetary policies in the economy.

Appendix A
Dynare code

The following Dynare model code encompasses all the version of the model used in the thesis. This code includes the special cases: the RBC version of the model (i.e. no sticky prices or financial frictions), the benchmark case (which is the version of the model without sticky prices used in Chapter 2), the version of the model with sticky prices used in Chapter 3 and the most general version of the model with sticky prices and unconventional monetary policy used in Chapter 4.

```
var K;
var TFP PSI W THETA TAY TAU MIU NEWS G;
var C Z I L Y U R WG RK RK11 RK12 RK21 RK22 SP1 SP2 SP;
var DVA1 DVA2 B1 B2 D N1 N2 Q1 Q2 RT1 RT2 SPR;
var V VB VS X1 LAMBDA1 LAMBDABA OMEGA1 OMEGA2 V1 V2 EBV1 EBV2;
var SX1 SX2 PK P MC INT PI;
var YF F WEL1 WEL;
var SG1 SG2 PHIG;
var lv;
varexo ep1 ep2 ep3 ep4 ep5 ep6 ep7 ep8 ep9;
parameters s beta alpha gamma phi DA DB DW DT DTA DTAU DM DN DG delta;
parameters sigma xi theta pi1 pi2 w chi rho api ay asp fi rhx gb vg phib sb;
parameters flgs flgd rbc rh1 rh2 rh3 rh4 rh5 rh6 rh7 rh8 rh9;
s = 1.5;
beta = 0.99;
```

```
alpha = 0.33;

gamma = 0.5;

phi = 0.333;

delta = 0.025;

sigma = 0.972;

pi1 = 0.25;

pi2 = 0.75;

chi = 5.584;

w = 0.75;

xi = 0.002;

theta = 0.383;

DA = 0.95;

DB = 0.4;

DW = 0.9;

DT = 0.9;

DTA = 0.15;

DTAU = 0.838;

DM = 0.91;

DN = 0.9;

DG = 0.943;

rho = 0.0;

fi = 10.0;

sb = 1;

api = 1.5;
```

```
ay = 0.5/4;

rhx = 0.8;

asp = 0.0;

gb = 0.2;

vg = 0.0;

phib = 0.1;

flgs = 0;

flgd = 0;

rbc = 2;

rh1 = 1;

rh2 = 1;

rh3 = 1;

rh4 = 1;

rh5 = 1;

rh6 = 1;

rh7 = 1;

rh8 = 1;

rh9 = 1;

model;

exp(K) = ( (1-delta)*exp(K(-1)) + exp(I(-1)) )*exp(PSI);

TFP = DA*TFP(-1) + rh1*ep1 + (DA-DN)*NEWS(-1);

PSI = DB*PSI(-1) + rh2*ep2;

W - w = DW*( W(-1) - w ) + rh3*ep3;

THETA - log(theta) = DT*( THETA(-1) - log(theta) ) + rh4*ep4;
```

```
TAY = DTA*TAY(-1) + rh5*ep5;

TAU = DTAU*TAU(-1) + rh6*ep6;

MIU = DM*MIU(-1) + rh7*ep7;

NEWS = DN*NEWS(-1) + rh8*ep8;

G - STEADY_STATE(G) = DG*(G(-1)-STEADY_STATE(G)) + rh9*ep9;

exp(U)*exp(WG) = chi*exp(TAU)*exp(L)^phi;

exp(U) = (exp(TAU))/

    ( exp(C) - gamma*exp(C(-1)) ) -

    beta*gamma*(exp(TAU(+1)))/( exp(C(+1)) - gamma*exp(C) );

beta*exp(U(+1))*exp(R) = exp(U);

exp(Y) = exp(TFP)*(exp(K)^alpha)*(exp(L)^(1-alpha));

exp(Z) = exp(TFP)*alpha*(exp(K)^(alpha-1))*(exp(L)^(1-alpha))*exp(MC);

exp(WG) = exp(TFP)*(1-alpha)*(exp(K)^alpha)*(exp(L)^(-alpha))*exp(MC);

exp(YF) = exp(I)*( 1 + (s/2)*( exp(I)/exp(I(-1)) - 1 )^2 ) + exp(C) + exp(G);

exp(Q1) = 1 + (s/2)*( exp(MIU)*exp(I)/exp(I(-1)) - 1 )^2 +

    ( exp(I)/exp(I(-1)) )*s*( exp(MIU)*exp(I)/exp(I(-1)) - 1 ) -

    beta*( exp(U(+1))/exp(U) )*( exp(I(+1))/exp(I) )*

    ( exp(I(+1))/exp(I) )*s*( exp(MIU(+1))*exp(I(+1))/exp(I) - 1 );

exp(RT1) = ( exp(Z) + (1-delta)*exp(Q1) )*exp(PSI);

exp(RT2) = ( exp(Z) + (1-delta)*exp(Q2) )*exp(PSI);

exp(RK) = pi1*( pi1*exp(RK11) + pi2*exp(RK12) ) +

    pi2*( pi1*exp(RK21) + pi2*exp(RK22) );

exp(RK11) = exp(RT1(+1))/exp(Q1);

exp(RK12) = exp(RT2(+1))/exp(Q1);
```

```
exp(RK21) = exp(RT1(+1))/exp(Q2);

exp(RK22) = exp(RT2(+1))/exp(Q2);

exp(D) + exp(N1) + exp(N2) = exp(SP1)*exp(Q1) + exp(SP2)*exp(Q2);

exp(SP1) + exp(SG1) = pi1*(1-delta)*exp(K) + exp(I);

exp(SP2) + exp(SG2) = pi2*(1-delta)*exp(K);

exp(SP) = exp(SP1) + exp(SP2);

exp(SG1) = PHIG*( exp(SP1) + exp(SG1) );

exp(SG2) = PHIG*( exp(SP2) + exp(SG2) );

PHIG - phib = vg*( SPR - STEADY_STATE(SPR) );

exp(N1) = pi1*(sigma+xi)*exp(RT1)*exp(SP(-1)) -

        pi1*sigma*exp(R(-1))*exp(D(-1));

exp(N2) = pi2*(sigma+xi)*exp(RT2)*exp(SP(-1)) -

        pi2*sigma*exp(R(-1))*exp(D(-1));

(1-flgd)*EBV1 + flgd*( SPR - STEADY_STATE(SPR) ) = 0;

exp(V1) = exp(VS)*exp(SP1) - exp(VB)*B1 - pi1*exp(V)*exp(D);

exp(V2) = exp(VS)*exp(SP2) - exp(VB)*B2 - pi2*exp(V)*exp(D);

EBV1 = exp(V1) - exp(DVA1)*exp(THETA);

EBV2 = exp(V2) - exp(DVA2)*exp(THETA);

exp(DVA1) = exp(SP1)*exp(Q1) - W*B1;

exp(DVA2) = exp(SP2)*exp(Q2) - W*B2;

pi1*exp(D) + exp(N1) + B1 = exp(SP1)*exp(Q1);

pi2*exp(D) + exp(N2) + B2 = exp(SP2)*exp(Q2);

SPR = exp(RK) - exp(R);

exp(V) = beta*exp(R)*(exp(U(+1))/exp(U))*
```

```
    ( pi1*exp(OMEGA1(+1)) + pi2*exp(OMEGA2(+1)) );
( 1 + LAMBDABA )*( exp(VB) - exp(V) ) = exp(THETA)*W*LAMBDABA;
exp(VS) = beta*(exp(U(+1))/exp(U))*
    ( pi1*exp(OMEGA1(+1))*exp(RT1(+1)) +
    pi2*exp(OMEGA2(+1))*exp(RT2(+1)) );
X1 = (exp(VS)/exp(Q1)) - exp(VB);
0 = (exp(VS)/exp(Q2)) - exp(VB);
LAMBDA1*( exp(THETA)*(1-W) - X1 ) = X1;
LAMBDABA = pi1*LAMBDA1;
exp(OMEGA1) = 1 - sigma + sigma*( exp(VB) +
    LAMBDA1*( exp(VB) - exp(THETA)*W ) );
exp(OMEGA2) = 1 - sigma + sigma*( exp(VB) );
exp(SX1) = exp(U)*exp(YF) + beta*rho*exp(SX1(+1))*exp((fi-1)*PI(+1));
exp(SX2) = exp(U)*exp(YF)*exp(MC) +
    beta*rho*exp(SX2(+1))*exp(fi*PI(+1));
exp(PK)*exp(SX1) = (fi/(fi-1))*exp(SX2)/sb;
1 = rho*(exp(PI)^(fi-1)) + (1-rho)*(exp(PK)^(1-fi));
exp(Y) = exp(YF)*exp(F);
exp(F) - rho*exp(fi*PI)*exp(F(-1)) = (1-rho)*exp(-fi*PK);
INT - STEADY_STATE(INT) =
    rhx*( INT(-1) - STEADY_STATE(INT) ) +
    (1-rhx)*api*PI(+1) + (1-rhx)*ay*( Y - STEADY_STATE(Y) ) +
    (1-rhx)*asp*( SPR - STEADY_STATE(SPR) ) + TAY;
exp(INT) = exp(R)*exp(PI(+1));
```

```
WEL1 = log( exp(C) - gamma*exp(C(-1)) ) - (chi/(1+phi))*(exp(L)^(1+phi));

WEL = (1-beta)*WEL1 + beta*WEL(+1);

lv = (exp(SP1)*exp(Q1)+exp(SP2)*exp(Q2))/(exp(N1)+exp(N2));

P = 0;

end;

shocks;

var ep1 = 0.01^2;

var ep2 = 0.02^2;

var ep3 = 0.25^2;

var ep4 = 0.05^2;

var ep5 = 0.0024^2;

var ep6 = 0.00407^2;

var ep7 = 0.00113^2;

var ep8 = 0.02;

var ep9 = 0.00335^2;

end;
```

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