A DSGE MODEL OF SHADOW BANKING IN THE US

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Abstract

In this paper, the role of shadow banking is examined in a DSGE model by allowing shadow bank lending to firms. Finding that shadow banking lending is beneficial to macroeconomic stability as it dampens the responses of the variables to shocks and affects the effectiveness of macro-prudential policy. The baseline model with the shadow-banking sector is contrasted with a counterfactual one in which shadow banking shuts off. The model is then tested and re-estimated by the method of Indirect Inference. I find that this shadow banking model fits better than the counterfactual one. The Indirect inference estimation results imply that higher estimates on the share of direct equity investment can help reduce the credit premium by providing a cheaper channel for credit leakage. Thus, the existence of the shadow banking lowers the frictions by protecting investment immune from shocks. I then extract the model's implied residuals on US unfiltered data since 1980 to replicate how the model predicts the crisis and look at the variance decomposition by running a variety of simulations bootstrapped from different sets of shocks in the sample. I find that the non-stationary productivity shock is the main driver of the US business cycle fluctuations. In addition, I also find that shadow banking can stabilize output, consumption and labour effectively and reduce welfare loss, indicating that the shadow banking model would stabilise the economy.

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Abbreviations

ABS	Asset-backed securities
ABCP	Asset-backed commercial paper
ARM	Adjustable-rate mortgage
BCBS	Basel Committee on Banking Supervision
BHC	Bank holding company
CDO	Collateralized debt obligation
CDS	Credit default swap
CLO	Collateralized loan obligation
CRA	Credit rating agency
CRE	Commercial real estate
CDS	Credit default swap
CMBS	Commercial mortgage-backed security
CMO	Collateralized mortgage obligation
EBITDA	Earnings before interest, tax, depreciation and amortization
ETF	Exchange-traded fund
FHA	Federal Housing Administration
FHLB	Federal Home Loan Bank
FHLMC	Federal Home Loan Mortgage Corporation
FDIC	Federal Deposit Insurance Corporation
FNMA	Federal National Mortgage Association
FOMC	Federal Open Market Committee
GFC	Global financial crisis
GNMA	Government National Mortgage Association
GSE	Government-sponsored enterprise
IRF	Impulse response function
LTN	Long-term note
LCR	Liquidity Coverage Ratio
LTD	Long-term debt
MTN	Medium-term note
MBS	Mortgage-backed security
MMMF	Money market mutual fund
NSFR	Net stable funding ratio
NAV	Net asset value
OTD	Originate-to-distribute model
OMO	Open market operation
PDCF	Primary dealer credit facility
RoE	Return on equity
RR	Reserve repo
SPV	Special purpose vehicle
SIV	Structured investment vehicle
SEC	Securities and Exchange Commission
TOB	Tender offer bond
TSLF	Term securities lending facility
TAF	Term Auction Facility
US	United States
VRDO	Variable rate debt obligation
ZLB	Zero lower bound

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Chapter 1 Introduction

In this thesis, my aim is to model the role of shadow banking in the US economy. Shadow banking is a system of credit creation outside the traditional banking sector and lies at the heart of the global economy. It accounts for over half of global banking assets and represents a third of the global financial system. Shadow bank is the name given to financial firms that intermediate between households and firms through financial nonbank contracts. Examples of these are peer-to-peer loans, private equity and hedge fund investments; the wide variety of these is enumerated in a later section. The US economy experienced a severe growth slowdown since the global financial crisis (GFC) in 2007 and followed by a slow recovery. Pozsar (2008) argues that the rise and fall of shadow banking plays a significant role in the US economy, and the shrinkage of shadow banks contributed to the Slow Recovery of the US economy after the Great Recession (Fève et al.,2022). My thesis uses a Dynamic Stochastic General Equilibrium model to explore the importance of a shadow banking channel in explaining the US business cycle behaviour and the necessary regulatory policies toward this sector in order to improve economic welfare.

The main contribution of my thesis is setting an equity channel for firms who are unable to borrow from commercial banks to raise capital. To do this, I allow shadow banks to operate in a sub-system affiliated to the main system constituted by normal commercial banks. According to empirical evidence, the existence of shadow banks can increase the efficiency of the whole US banking system and reduce the borrowing cost. Some existing works by Meeks et al. (2017) and Ferrante (2018) find that the shadow banking system leads to an increase in macroeconomic volatility. I show in this paper that shadow banking can stabilize the economy through an equity channel. I focus on the macroeconomic transmission channels of the shadow banking sector, bank regulation, and the associated welfare implications. Because regular banks pursue regulatory arbitrage via shadow banking who works to bypass frictions in the normal banking system, enhancing the overall efficiency of the US banking system. Highlighting this potential explanation for the US business cycle is my main contribution. The US shadow banking system collapsed in 2007, with hedge funds and broker-dealers reducing their holdings of securitized assets, whereas traditional banks' liabilities increased significantly. To capture the unique business structure of commercial banks in the US and illustrate that the shadow banking sector could affect the dynamics of the whole economy, I embed in our DSGE model an explicit shadow banking sector. My contribution is featuring a richer banking system by extending lending to a proportion of firms who use the equity mechanism to fund their operation. I allow shadow banks to operate in a sub-system affiliated to the main system constituted by normal commercial banks. To demonstrate the importance of the shadow-banking sector, I use macro data to estimate this proportion to judge the size of this channel; I find that the existence of shadow banks reduces financial friction, increases the efficiency of the whole US banking system, and so raises welfare.

I use Indirect Inference estimation and evaluation to test this DSGE model with the hypothesis that shadow banking brings more efficiency, against the US quarterly macro data from 1980 to 2018. This method of estimation is chosen over the Bayesian maximum likelihood method because it allows us to test the overall ability of the model to replicate key aspects of data behaviour. Therefore, it essentially focuses on testing the model itself rather than a particular set of parameter values that could be at fault. This estimation establishes whether this specification can explain the US business cycle behaviour. The estimates can also indicate the importance of the shadow banking sector. Using the estimates, I proceed to consider whether a strict regulation to minimise the shadow banking activities is desirable, i.e. whether it is welfare-enhancing.

I find that my hypothesis of having an efficient shadow banking sector is not rejected by the data. My DSGE model with this assumption improves its fit to the data. The test results show that the model with the shadow-banking sector fits better than the alternative without the shadow-banking sector. Shadow banking increases economic stability by providing an extra source of liquidity in the face of shocks, thus raising social welfare. With higher estimates on shadow banking shares that participate in direct equity investment, it shows that this channel is important and enables many firms to operate who otherwise would not have existed.

In the rest of the thesis, I first review the nature of shadow banking in Chapter 2 and the literature that has studied it in Chapter 3. In Chapter 4, I recap the DSGE model used to add this shadow-banking sector and then set out how it is added. The baseline model builds upon a variant specification of the Smets and Wouters (2007, SW) model with a banking sector in Bernanke et al.(1999, BGG), but I extend it to include the interaction with a shadow-banking sector and also monetary effects. I then estimate and test this model, using indirect inference in Chapter 5. The indirect inference method is a powerful testing framework in small samples and also offers low estimation bias. The discussion on the properties of shocks and analysis of how the errors drive the episode are shown in Chapter 6. Chapter 7 presents an empirical analysis. I set out the empirical results for the model and simulate the model's behaviour under repeated shocks of all kinds. Finally, in Chapter 8, we evaluate the welfare effects of allowing the shadow-banking sector. The conclusion is briefly outlined in Chapter 9.

Chapter 2 The Shadow Banking System

2.1 What is shadow banking

The shadow banking system comprises non-bank financial institutions, instruments, vehicles, and entities. It is defined in the following ways. Pozsar et al. (2010) define the shadow banking system as a web of credit intermediation that channels funding from savers to investors through a wide range of securitization and secured funding techniques. In addition, a shadow bank is also known as a non-bank financial company which creates credit but is subject to less regulatory oversight than traditional banks. Although shadow banks conduct maturity, credit, and liquidity transformation[1] like traditional banks, they cannot access explicit central bank liquidity or public service credit guarantees. Whereas for traditional banks, deposits are guaranteed by the Federal Deposit Insurance Corporation (FDIC), and liquidity backstop is supported by the Federal Reserve's discount window. However, shadow banks have no explicit access to public backstops. Their credit line and tail-risk insurance are provided by private lenders coming from commercial banks and insurance companies. Therefore, shadow banks are inherently fragile to some extent because the downturn in the financial market may expose banks to the risk of a run by investors.

In the traditional banking system, lending and borrowing occur in a single entity. Savers deposit with banks, and banks use these deposits to fund the extension of loans to borrowers. Compared to direct lending, credit intermediation provides savers with information and reduces the cost of screening and monitoring borrowers, thereby facilitating investments in a more diverse loan portfolio. Credit intermediation can be enhanced by employing third-party liquidity and credit guarantees, which are in the form of liquidity or credit put options, such as access to central bank liquidity and deposit insurance. If these guarantees are provided by the public sector, credit intermediation is said to be officially enhanced. However, shadow credit intermediation encompasses all credit intermediation activities that are implicitly enhanced, indirectly enhanced, or unenhanced by official guarantees (Pozsar et al.,2010). These activities include debt issued or guaranteed by government-sponsored enterprises (GSEs), credit lines to conduits, asset management activities such as bank-affiliated hedge funds, money market mutual funds (MMMFs), and guarantees made by monoline insurance companies.

There are two important subgroups in the shadow banking system: the government-sponsored shadow banking subsystem and the "internal" shadow banking subsystem. In the US, government-sponsored enterprises include the

[1] Maturity transformation is a way of converting short-term deposits to long-term loans, it may expose the intermediary to rollover and duration risks; liquidity transformation whereby banks use liquid liabilities to finance illiquid assets; and credit transformation which refers to the enhancement of the credit quality of debt issued by the intermediary through the use of priority of claims.

Federal Home Loan Bank (FHLB) system, established in 1932; the Government National Mortgage Association (Ginnie Mae), created in 1968; and the Federal Home Loan Mortgage Corporation (Freddie Mac), established in 1970. These agencies are considered as shadow banks because their liabilities are implicitly guaranteed. The GSEs only engage in loan processing and funding. They are prohibited from loan origination. GSEs create agency mortgage-backed securities (MBSs). The simplest agency MBSs are pass-throughs. All investors in a pool receive the same return, but the payments they obtain are a blend of interest and principal on the underlying mortgages. In addition, agency MBSs take on interest rate and prepayment risk but not the default risk of individual borrowers. This is the case if a mortgage is prepaid when interest rates are low; the investor must reinvest the funds and earn a lower than expected rate of interest. Because GSEs guarantee their mortgages for a fee so that pool investors have protection against mortgage defaults. The GSEs facilitate their funding through the capital markets by issuing short and long-term agency debt securities to money market investors and real-money investors. Overall, even though GSEs conduct maturity, credit, and liquidity transformation, they are not chartered as banks and do not have access to explicit insurance of their liabilities by the government. However, there is an implicit guarantee, for example, after the financial crisis in 2008, these entities obtained an injection of capital from the US Treasury in the form of credit lines, but these liquidity backstops were very small compared with the size of their balance sheets.

The largest banks and dealers come with origination, warehousing, securitizing, and funding of credit, which constitute the “internal” shadow banking subsystem. The development of GSEs’ activities has reflected a full-fledged shadow banking system. In recent decades, the features of banking business transformed from credit risk intensive, deposit funded, spread based to less credit risk intensive, wholesale funded process subject to run risk. This significant transformation was attributed to the intention of increasing profitability and earning a higher return on equity (RoE). To achieve this goal, credit institutions employ a range of off-balance-sheet securitization and complex asset management techniques, enabling them to conduct lending with less capital than if they had retained the loans on their balance sheets. This contributes to a higher return on equity (RoE) for bank holding companies. The “internal” shadow banking activities are conducted as follows: 1) Bank or finance company subsidiaries originate loans. 2) Loans are warehoused and assembled in off-balance-sheet conduits, which are managed by broker-dealers. Funding is provided through wholesale markets, and liquidity enhancements are provided by banks. 3) Broker-dealers create securitized products and sell them to bankruptcy-remote special purpose vehicles (SPVs). 4) Funding the safest tranches of structured credit assets in off-balance-sheet ABS intermediaries (such as structured investment vehicles) that are managed by the asset management subsidiary of the holding company and are funded through wholesale funding markets with backstops by the bank subsidiaries. The process of “internal” shadow banking activities extends the nature of lending in the US financial system to a broader scope because there are at least four entities that engage in this process. A bank is the only one that can access the Federal Reserve's discount window and FDIC deposit insurance. However, banks only explicitly involve in loan origination and act as lenders to other subsidiaries. The off-balance-sheet vehicles engage in the warehousing, securitizing and distribution and funding of structured credit securities. Moreover, securitization has increased the implicit leverage of bank holding companies (BHCs) or capital efficiency. Capital efficiency is highly contingent on the liquid wholesale funding and debt capital markets, but along with BHCs collaborate closely with shadow bank entities, the leverage of BHCs is effectively increased, exposing BHCs to credit and liquidity risk and might give rise to systemic risk.

2.2 Sizing the shadow banking system

The growth of ABCP conduits reflects the expansion of shadow banking and constitutes a significant part of the US shadow banking system. The ABCP market emerged in the mid-1980s in the US and experienced rapid growth during the 1990s and 2000s. It has grown from $2 billion in 1983 to its highest level of about $1.2 trillion in 2007(Figure 2.2) and became the largest money market instrument in relation to the shadow banking system in the US, compared with the second largest instrument, Treasury Bills, with about $940 billion outstanding. However, it began to plummet when the financial crisis occurred in August 2007. By then, there were 296 ABCP conduits, 75 percent of which were sponsored by banks (Acharya and Schnabl, 2010). The strong growth in ABCP before the crisis can be attributed to many reasons, such as the rise in mortgage warehouse conduits, a rise in short-term tranches of collateralized debt obligations (CDOs), the growth of SIVs, the emergence of 'repo' conduits, and a continued rise in funding through multiseller conduits. By mid-2007, hundreds of billions out of the $1.2 trillion US ABCP market were backed by mortgage-related assets, involving some with subprime exposure. CDOs with a maturity of more than four years would also be refinanced by commercial paper for thirty days, with liquidity facilities provided by large American banks, such as the Bank of America or Citibank. Thereby, the ABCP market becomes an important part that participates in purchasing and packaging mortgages into MBSs so as to move them off the balance sheets via these vehicles (Fligstein and Goldstein, 2010). However, the ABCP market collapsed immediately from summer 2007 onwards when investors refused to purchase these papers any longer. Banks were forced to grant liquidity by taking the underlying assets back onto their balance sheets as they fund long-term assets through the process of short-term securitization and then sell them into the money market. Investors were not insured against the breakdown of the system. Once the bank liquidity was frozen, it could trigger a run on the shadow banking system, resulting in the shrinkage of the money market in ABCPs. He, Khang and Krishnamurthy (2010) documented that during the crisis, the hedge funds and broker-dealers reduced their shares of securitized assets by about

$800 billion, but traditional banks and the government increased their shares by$550 billion and $350billion respectively, thus the reintermediation of assets from shadow banks to traditional banks raised the debt issued by the traditional banking sector and results in a higher leverage.

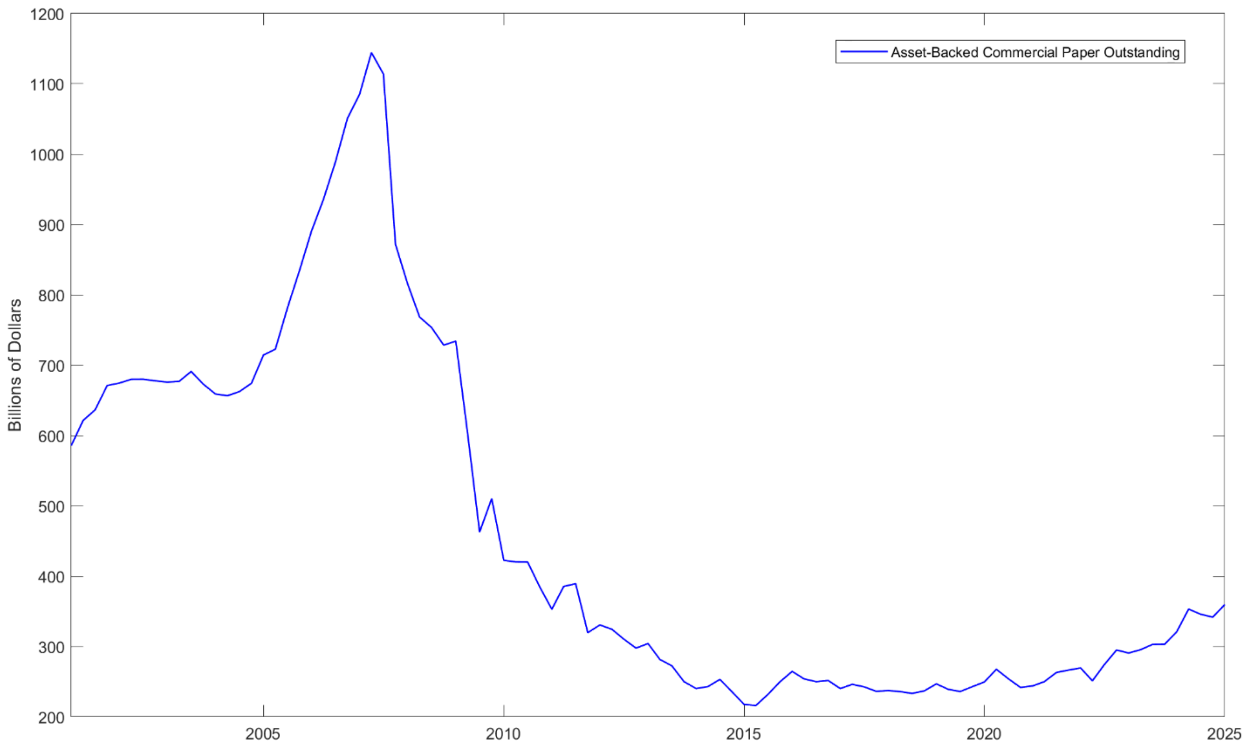


Figure 2.2: Volume of the US asset-backed commercial paper market, based on source data from the Fed.

2.3 The mechanics of securitization

Securitization is not only a useful tool for managing credit exposure but also a funding vehicle for financial institutions and non-financial corporations because banks may not have sufficient capital to satisfy the needs of business, consumers and government. In the process of securitization, loans and other assets will be repacked into new securities as collateral, which will then be sold in the securities markets. The performance of the new securities will be contingent on the performance of the collateral.

The process of securitization enables banks to remove loans from their balance sheets and frees up funds so that more loans can be made. For example, banks have used securitization to remove illiquid loans and receivables such as mortgage loans, corporate bank loans, credit card receivables and automobile loans from their balance sheets, resulting in the creation of mortgage-backed securities(MBSs), collateralized loan obligations(CLOs), collateralized debt obligations(CDOs), credit card-backed securities, and automobile-backed securities, respectively. The latter two securitized products are referred to as asset-backed securities (ABSs). These investment vehicles will be elaborated on in Section 2.5.

Banks switched their activities from the traditional buy-and-hold strategy to the new originate-to-distribute business model in the last century. Prior to securitization, banks originated loans and held them in their portfolios as an investment, which is referred to as a buy-and-hold strategy. However, under the originate-to-distribute (OTD) model, securitization, instead, banks use their expertise to originate loans and then sell them (directly or indirectly) to investors. It reduces the risks faced by the originating entity in the buy-and-hold model because illiquid loans and receivables as collateral will be sold to a special purpose vehicle (SPV). Thus, the originator does not own the collateral, and investors who hold these new securities bear the credit risk.

The development of the securitization markets can be traced back to the 1970s, the U.S. government sponsored the creation of three entities, such as Government National Mortgage Association (GNMA) or Ginnie Mae, Federal National Mortgage Association (FNMA) or Fannie Mae, and Federal Home Loan Mortgage Corporation (FHLMC) or Freddie Mac. These government agencies purchase mortgage portfolios from banks and other sponsors, package the cash flows into securities and sell these securities to investors. In this case, investors are not subject to credit risk because government agencies guarantee the mortgage payments. However, banks have used the OTD model without the help of the government agency since the 1990s, thereby investors bear the credit risk in the case of no payment guarantee. The situation got worse in the late 1990s when agencies began to accept riskier subprime loans.

SPV plays the key role in a securitization. It is established by the originating entity (the “sponsor”) and acts as a legal entity to obtain funds to purchase a pool of loans from the originator by selling new securities to investors. The SPV creates tranches by issuing senior bonds, junior (or mezzanine) bonds and equity. Tranches are created from loan portfolios so that each tranche contains different exposures to losses on the portfolio. Let me make a simplified example. For a loan portfolio with a total principal of USD 100 million sold by a bank to an SPV, the SPV obtains funds to purchase this loan portfolio by selling new issued securities to investors, who receive interest and principal payments dependent on rules for the distribution and how defaults will be treated. For three types of tranches, the senior tranche funds 70% of the loan portfolio, the mezzanine tranche funds 25% of the loan portfolio and the equity tranche funds 5% of the loan portfolio. The returns for investors are 5% for the senior tranche, 8% for the mezzanine tranche and 25% for the equity tranche under the case that investors do not bear any losses. Repayment of principal flows first to the senior tranche. When that has been paid, it then flows to the mezzanine tranche, and subsequently to the equity tranche, but only after the previous tranche has been paid. Interest payments first go to the senior tranche until they have obtained a 5% return on the outstanding principal, then flow to the mezzanine tranche to repay 5% of the return. Finally, they flow to the equity tranche. Inversely, losses can reduce these returns, with the equity tranche bearing the first 5% of losses, the mezzanine tranche bearing the next 25% of losses, and the senior tranche bearing all losses in excess of 30%.

2.4 The originate-to-distribute business model

Under the originate-to-distribute (OTD) model, the originating entity assembles a pool of similar loans and uses that pool as collateral for the new securities. In the early 1980s, certain banking activities shifted to the OTD model, primarily driven by the Basel capital adequacy requirements, competition from finance companies and broker-dealers, and innovation in securitization and credit risk transfer instruments. In addition, accounting and regulatory standards also encouraged banks to engage in the securitization process so that banks can earn more fees and upfront commissions. Under this business model, banks removed some of their capital-consuming loans from their books to optimize their use of capital and transferred credit risk to capital market investors.

The OTD model brought many benefits to the financial services industry. In terms of originators, they benefited from greater capital efficiency and enhanced funding opportunities. In addition, under the OTD model, credit risk was dispersed to investors at least in the short term, lowering the earning volatility for originators. For investors, the creation of new securities such as ABSs and other forms of investment products gives them more options to diversify their portfolios and better synchronize their risk/return profiles to meet their goals. Moreover, borrowers benefited from the lower borrowing costs due to the expansion of available credit and product options.

However, the benefits of the OTD model eroded progressively as securitization expanded to riskier loans in the years leading up to the financial crisis. The OTD model relies on liquid money and securities markets; however, banks heavily originated subprime mortgages to create opaque and less liquid structured finance CDOs. These were driven by loose monetary policy and depressed yields, with the housing boom as the backdrop. Low interest rates resulted in an abundance of credit for borrowers and a scarcity of yield for investors, prompting banks to use subprime mortgages. There are some factors that exacerbated the weakness of the OTD model. First, the OTD model posed moral hazard problems. Lenders relaxed their loan underwriting standards as they pursued short-term profits, ignoring the creditworthiness of borrowers. It indicated that compensation was tied to the amount of loans and commission rather than loan performance or suitability. Second, credit rating agencies were not transparent because some securitized products were wrongly rated higher, and the risk of subprime CDO structuring was underestimated. Third, investors lacked understanding of these complex investment instruments. They could not identify the quality of underlying assets and risks embedded in securitized products were opaque. Fourth, banks deviated from the OTD rather than follow it before the financial crisis. They acted as investors, rather than merely intermediaries transferring risk to capital market investors. Banks retained credit exposures to structured investment vehicles with high rollover risk because some levered SIVs suffered from liquidity and maturity mismatches. Therefore, relatively little credit risk was dispersed. In fact, off-balance sheet asset-backed commercial paper (ABCP) conduits and structured investment vehicles absorbed risks that should have been transferred under the OTD model[2]. Therefore, even though SIVs could bring profits during the stable economic conditions, massive leverage and risk concentration posed an amplified systemic risk[3] during the crisis.

2.5 Components of the shadow banking system

In this section, the components of the shadow banking system are discussed, notably with regard to the institutions, instruments and vehicles that make up the shadow banking system. A map provides a comprehensive overview of the shadow banking system and depicts the asset and funding flows in it.

2.5.1 Asset-backed commercial paper conduits and special investment vehicles

ABCP is commercial paper collateralized by a specific pool of financial assets. It is issued by SPVs such as ABCP conduits or SIVs. Single-seller ABCP conduits are backstops to the working capital needs of large non-bank finance companies and receive such support from a single commercial bank. Multiple-seller conduits fund the working capital needs of smaller non-bank finance companies and receive the support of multiple institutions. Similarly, SIVs can either be affiliated with a single banking institution or obtain support from multiple institutions. These entities are bankruptcy remote. Thus, the collateral backing ABCP is not subject to the potential bankruptcy of the institution that provides the backup lines of credit and liquidity. However, the ABCP is exposed to rollover risk because its maturity ranges from one to 180 days.

SIVs are specialized financial institutions that conduct shadow maturity transformation. They invest in securitized products such as ABS,MBS,CDOs,CLOs, CMOs or financial sector debt. They fund their assets by issuing ABCP, medium-term notes(MTN) or long-term notes(LTN). To obtain

[2] According to the Financial Times (July 1, 2008), 50% of AA-rated asset-backed securities were held by banks, ABCP conduits and SIVs. As much as 30% was simply parceled out by banks to each other, while 20% sat in conduits and SIVs.

[3] Systemic risk is the risk that events at one firm, or in one market, can extend to other firms or markets. In turn, this can put entire markets or economies at risk. Systemic risk played a large role in exacerbating the impact of the crisis. Basel III focuses on both firm-specific risk and systemic risk (i.e., the risk associated with the failure of a major financial institution causing other interconnected financial institutions to fail, resulting in major harm to the economy).

credit rating on their liabilities, SIVs obtain backup lines of credit from commercial banks. For example, when SIVs were first created in 1988, they helped move the financing of ABS from the balance sheet of Citigroup to an off-balance sheet SIV. They resemble commercial banks in some way, but both assets and liabilities are tradable.

ABCP has provided funding flexibility to borrowers and investment flexibility to investors since the 1980s, when ABCP was used as a way for commercial banks to fund customer trade receivables in a capital-efficient manner and at competitive rates. ABCP became a common source of warehousing for ABS collateral in the late 1990s. The off-balance sheet structure associated with lax regulatory capital requirements and leverage facilitated ABCP funding. Over time, as the market developed, ABCP conduits expanded from funding receivables and loans to long-term assets such as CDOs, ABS and corporate debt. In addition, ABCP has provided funding flexibility to borrowers, especially for corporates. The increased use of commercial paper funding sources reduces the funding costs relative to strict bank funding. However, ABCP experienced a severe investor run in July 2007 due to greater subprime mortgage exposure, weaker liquidity support, and a lower credit rating.

2.5.2 Asset-backed securities

Asset-backed securities (ABS) are collateralized claims on pools of loans, mortgages or receivables. Precisely, the underlying assets can be receivables from credit cards, auto loans, mortgages, and aircraft leases, among others. Originators typically assemble a pool of loans and use that pool as collateral for the new securities. The cash flow from ABS is structured into tranches, which receive credit ratings. The process of pooling and tranching of the ABS is referred to as securitization, which is at the heart of the shadow banking system. The securitized products will be sold to banks, shadow banks and real money investors such as mutual funds, pension funds and insurance companies.

ABSs typically perform no maturity transformation but do achieve credit and liquidity transformation. Credit transformation is achieved by diversification. For instance, the collateral of ABS might contain subprime mortgage loans, but much of the ABS's liabilities consist of AAA assets. In terms of liquidity transformation, the collateral of ABS may be illiquid, but the securitized products may be liquid; however, their liquidity is contingent upon the business cycle, as they become less liquid during economic downturns.

CDO is a special form of ABS. The collateral of CDO can be corporate bonds, ABS or pools of agency mortgage-backed securities. When the collateral of a CDO is ABS, it is referred to as an ABS CDO. When the collateral is MBS, the CDO is called a collateralized mortgage obligation (CMO). Moreover, collateralized loan obligation (CLO) is secured by syndicated loans. The underlying loans of CLOs are often risky leveraged loans that are used to restructure the funding of corporations to allow for more leverage.

2.5.3 Collateralized debt obligation

The 1988 Basel Accord induced the development of credit risk transfer instruments. In the early 1980s, the Latin American government suffered from the debt crisis triggered by loan defaults. Then in 1988, the first Basel Accord was issued, focused on the capital adequacy of financial institutions by applying minimum capital requirements to bank balance sheets and requiring more capital protection for riskier assets. As a result, it prompted banks to restructure their assets via credit risk transfer instruments such as credit default swaps (CDSs) or CDOs. To be more precise, a CDS is a financial derivative that allows investors to purchase insurance to hedge against credit losses, thereby reducing the gross risk of a loan portfolio. In addition, CDO is a complex structured finance product backed by a pool of loans and other assets. It is developed to remove the riskiest (first loss) portions of a loan portfolio.

Balance sheet CDOs were initially used to tailor the risk profile of a bank’s loan portfolios to manage capital requirements. Balance sheet CDOs enable banks to remove assets from their balance sheet, freeing up capital to take on new investments. CDOs were initially applied to corporate loans. A bank would pool corporate loans on its books (the assets of a CDO) and divide the pool’s underlying cash flows into various classes or tranches with distinct risk profiles (the liabilities of a CDO). Payouts were initially made to the least risky senior tranches, followed by mezzanine tranches, and then to the riskiest equity tranches. However, losses were absorbed in the opposite sequence. Equity tranches offered the highest yields, whereas senior tranches offered the lowest yields. The tranching of loans only skewed the distribution of risks; it did not mitigate the overall amount of risk, but banks could set aside a much smaller amount of capital than for whole loans.

Over time, CDOs have evolved to pool whole loans and corporate bonds in order to make profits from the spread between the yield offered on these assets and the payment made to various tranches, which is referred to as arbitrage CDOs. Arbitrage CDOs were initially backed by investment-grade corporate loans and bonds, which carried a relatively low risk of default. As the state of the economy improved in 2003, using investment-grade credit as collateral was discarded because corporate credit spreads narrowed and there was not enough spread income to compensate CDOs’ originators, investors and managers. Underwriters turned to an alternative collateral type such as mortgage-backed securities (MBSs) backed by subprime mortgages and other assets. This shift was primarily driven by the housing and securitization boom, which led to increased demand for loans and a subsequent collapse in underwriting standards between 2005 and early 2007. The new assets that CDOs invested in were known as ABS CDOs(or structured finance). By using a riskier class of debt, ABS CDOs could offer fat spread incomes[4]. It is worth noting that ABS CDOs are distinct from CDOs' underlying portfolios of corporate bonds in risk diversification. Traditional CDOs are backed by a well-diversified and heterogeneous pool of corporate loans and bonds across a variety of industries, which can effectively mitigate the risk of idiosyncratic events and manage systematic risk by investing in a mix of cyclical and countercyclical industries in the pool. However, the risk of ABS CDOs is driven more by macroeconomic factors, such as interest rates, house prices, and job market conditions. These risks are systematic and cannot be diversified away. They could expose investors to a higher risk profile during times of system-wide stress.

Synthetic CDOs are a modern advance in structured finance that can offer extremely high yields to investors. Unlike CDOs which invest in traditional debt products such as bonds, mortgages and loan, synthetic CDOs generate income from non-cash derivatives such as CDS, options and other contracts. Let us step back to discuss why the synthetic CDOs were created. The CDO market grew rapidly during 2005 and 2006 because its tranches offered higher yields, attracting investors such as pension funds that were struggling to match their fixed obligations with low-yielding government and corporate bonds. Broker-dealers also earned higher fee income for originating, managing CDOs and trading their tranches. The increased demand for CDOs also pushed up the demand for underlying mortgages, driving up the price of MBS and mortgage loans, which indicated that yields fell correspondingly. Some broker-dealers decided to purchase mortgage lenders outright so that they would have direct access to the loans and would avoid paying inflated market prices for them and paying fees to middlemen. In fact, it led to the deterioration of underwriting standards because lenders would offer nontraditional mortgages to risky borrowers with extremely weak credit controls. In addition, higher demand for CDOs posed another problem to CDO managers and underwriters, as there were not enough cash securities to meet the high demand. This is when synthetic CDOs were created by using CDS to mimic the performance and cash flow patterns of the MBSs. Synthetic CDOs magnified the amount of leverage and credit risks in the financial system because their underlying portfolios primarily referenced subprime mortgages.

2.5.4 Tri-party Repo

A repo is a financial transaction in which one party sells securities to another party and agrees to buy them back at a future time for a slightly higher price. Most repo contracts are short-term, less than 90 days. Repos resemble collateralized loans, but they are more beneficial to cash investors because in the event of bankruptcy, investors can sell their collateral, rather than be subject to an automatic stay. Repos are typically over-collateralized, the difference

[4] According to Moody's Economy.com estimates, 70 % of ABS CDOs' underlying portfolios were made up of subprime mortgages between 2005 and 2007.

between the value of the collateral and the sale price is called the repo haircut. In addition, the repurchase price is greater than the sale price, the difference constituting the repo rate, which is an interest rate on a collateralized loan. The tri-party repo market is very large, and around $2.8 trillion of securities were funded by tri-party repos in 2008. This size shrank to $1.6 trillion in the second half of the financial crisis. A large proportion of assets financed in the repo market is liquid and of high quality.

The participants in the tri-party repo market include securities dealers, cash investors, and clearing banks. Dealers fund their own and their clients' assets through repos. This transaction can be seen as borrowing cash using securities as collateral. The largest dealers in the tri-party repo market are primary dealers such as banks or securities broker-dealers that are authorised to trade directly with the New York Fed. They account for a large portion of borrowing. The cash investors purchase securities and sell them back later. They are more diverse than dealers, with over 4,000 individual firms active as cash investors. MMMFs, cash-rich investors such as corporate treasury functions and securities lenders are major cash investors, each accounting for about a quarter of the cash invested in that market. To diversify their risks, they tend to lend to a number of different collateral providers. The clearing bank acts as an intermediary or third party between dealers and investors. In the US, the examples of clearing banks include JPMorgan Chase and Bank of New York Mellon. They are responsible for taking custody of the securities involved in the repo, pricing the securities, ensuring that the specified margin is applied, settling the transaction on their books, and collateral allocation. The 2008 financial crisis revealed some problems associated with the tri-party repo market. For example, the tri-party repo market may give rise to systemic risk due to its high reliance on intraday credit by the clearing banks.

2.5.5 Money market mutual funds

Money market mutual funds are open-ended mutual funds that invest in highly liquid, short-term instruments, such as cash equivalent securities and debt-based securities, including Treasury bills, commercial paper (including ABCP), and repurchase agreements (repo). They are regulated by the U.S. Securities and Exchange Commission (SEC) under the Investment Company Act of 1940, but the federal government does not guarantee MMMFs with deposit insurance. By issuing redeemable units or shares to investors, MMMFs intended to offer investors high liquidity with lower risk and more attractive yields than bank deposits. The money market sector peaked at around $3.5 trillion in 2008.

MMMFs aim to maintain a stable net asset value (NAV) of $1 per share, meaning they never intend to lose money. If a fund's NAV falls below $1.00, it is referred to as "breaking the buck." An example of breaking the buck occurred in 2008, following the bankruptcy of Lehman Brothers, the Reserve Primary Fund also broke the buck. Since they held millions of the Lehman Brothers' debt obligations, they had no choice but to write off the Lehman debt. Investors redeemed their shares of money market funds in a panic, causing a decline in the NAV to $0.97 per share. Unlike traditional banks whose capital and liquidity buffers can guard against this, MMMFs are not regulated and lack government backstops. The pullout of money accelerated funding difficulties for other instruments, such as commercial paper and repo, putting pressure on broker-dealers that relied on short-term funding solutions. In this way, the run in money markets triggered the credit crunch throughout the financial system. In 2010, the SEC issued new rules to manage MMMFs better. These rules were intended to provide more stability and resilience by placing tighter restrictions on portfolio holdings and introducing provisions for imposing liquidity fees and suspending redemptions.

2.5.6 Hedge funds

Hedge funds are subject to less regulation than mutual funds and exchange-traded funds (ETFs). While mutual funds and ETFs cater to the needs of small investors, hedge funds usually accept only large investments from wealthy private individuals or institutions. Mutual funds and ETFs may be restricted in their use of leverage. A hedge fund is only restricted by the amount banks are willing to lend to it. In addition, hedge funds charge an incentive fee as well as a management fee. A typical hedge fund fee is 2 plus 20%. This means that the investors are charged 2% of the value of their investment per year, along with 20% of the profits. A hedge fund's prime broker is the bank that handles its trades and lends it money. Many hedge funds take short positions, and the prime broker will handle these for them as well. The bank may provide risk management and hedging services as well. Furthermore, the prime broker can carry out stress tests on the hedge fund's portfolio to determine how much it is willing to lend. The hedge fund can then post its securities with the bank as collateral. More importantly, hedge funds are subject to very little regulation. However, their activities may be constrained by their prime broker. During adverse economic environments, the prime broker will reduce the borrowing limit of the hedge fund and force it to close out positions.

2.6 A map of the shadow banking system

Figure 3 below depicts the components of the shadow banking system in terms of shadow banking entities, activities, vehicles and potential risks. It does not track the flow of corporate equities and securitization activity of GSEs. First, I discuss the credit institutions that assemble a pool of loans. Second, I explain how the newly created securities flow into the shadow banking system through securitization. Third, I discuss the institutions that invest in these securities. Fourth, I elaborate on how these institutions fund their investment and may give rise to investor run. The safety net is discussed in the last section. A typical shadow banking system involves asset originators such as finance companies, commercial banks and asset packagers like broker-dealers and asset managers, such as hedge funds, SIVs, pension funds and insurance companies. By employing the OTD business model, SPVs create structured credit instruments to fund their loan portfolio. The underlying cash flows and credit risks of loan pools are tranched and then distributed to investors with different risk appetites. The liquid money and securities markets are needed to ensure that the whole system operates properly.

Originators. There are three types of institutions feeding the OTD model with loans, they are finance companies, commercial banks and broker-dealers respectively. The latter two constitute bank holding companies. I use dotted lines to connect the balance sheet of originators with their corresponding lending businesses. Some examples of finance companies are Capital One, Thornburg Mortgage and New Century Financial. They originate residential mortgages, credit card loans, auto loans and student loans. Apart from the above loans, commercial banks also originate commercial mortgages and corporate loans, the latter of which includes leveraged loans, commercial and industrial loans, loans to finance companies and land development loans. Broker-dealers are typically investment banks. They underwrite leveraged loans, as well as corporate, sovereign and municipal bonds. Examples of broker-dealers include Goldman Sachs, Morgan Stanley, Lehman Brothers and Merrill Lynch. Due to fierce competition from finance companies, commercial banks have combined their business lines with broker-dealers. Such diversified financial institutions are known as banking holding companies, such as Citigroup and JPMorgan Chase. It is worth noting that the performance of the loan portfolio depends not only on the originators' underwriting standards but also on the performance of the real economy. For example, consumers' payrolls will affect their ability to repay credit card bills. Therefore, the performance of each loan type is driven by a specific set of macroeconomic variables, such as asset prices, wages, interest rates, and taxes, among others.

Securitization. The loan portfolios sold by banks or finance companies will be warehoused in asset-backed commercial paper conduits, where they await securitization. By assembling a pool of thousands of individual loans and passing their cash flows to three tranches, residential mortgages are packaged into residential mortgage-backed securities (RMBS); consumer credit receivables are packaged into asset-backed securities (ABS); and commercial mortgages are packaged into commercial mortgage-backed securities (CMBS). In addition, leveraged loans are packaged into collateralized loan obligations (CLOs), while corporate and sovereign bonds are packaged into collateralized debt obligations (CDOs). These credits are not channelled through conduits. These securitizations are all one-layer securitizations, as they have direct exposure to the underlying loans. Asset flows are mapped with solid black lines.

Risk bearers. Investors include SIVs, commercial banks, broker-dealers, hedge funds, asset managers and insurance companies. They purchase ABSs, ABS CDOs, CLOs and traditional CDOs. Apart from insurance companies and asset managers who fund their assets with long-term liabilities, the rest of the investors fund their long-term credit products with short-term funds, thereby exposing them to maturity mismatch problems.

There are some institutions formed a part of the shadow banking system because they invested in long-term assets with short-term funds, such institutions involve finance companies funding their loan portfolio through ABCP; loan warehouses (ABCP conduits) funding their inventories using ABCP; SIVs financing their investments using ABCP; broker-dealers and hedge funds funding their investments using repos. These parts of short-term funding sources are marked with yellow boxes, and they were exposed to the issue of investor run.

Funding flows. In early 2007, adjustable-rate mortgage (ARM) resets gave rise to a run on the shadow banking system. Because of the early payment defaults on loans, ABCP conduits had to exercise their options to sell defaulted loans back to the originators (dashed green line). Originators(Finance companies) had to repurchase them to protect conduits against losses. However, the shortage of cash led some originators to the brink of bankruptcy because they were unable to recycle mortgages into cash, and the securitization market froze. The US mortgage lender did not suffer due to the backup from the Federal Home Loan Bank system (FHLB). They purchased mortgages that could not be sold by banks by issuing federally guaranteed debt. The FHLB system (and indirectly the government) scooped up mortgages to the tune of $240 billion during the second half of 2007.

Moreover, the soaring delinquencies and defaults on loans also affected the value of RMBSs, ABSs and CDOs during the summer of 2007. Some hedge funds had to unwind their positions with their prime brokers, selling their assets at fire-sale prices, leading to the downgrades of ABSs and CDOs by the rating agencies. Investors lost their confidence in ABSs, CDOs and SIVs. Although money market funds dumped their ABCP assets quickly, investors refused to roll over short-term debt, cutting off the lifeline of conduits and SIVs. A run on the shadow banking system occurred.

When conduits obtained liquidity backstops from commercial banks, a massive re-intermediation of loans went back to regulated banks' balance sheets (dashed purple lines leading from conduits to commercial banks). SIVs had no backstops with banks, but to mitigate reputation risk and avoid fire sale of SIVs' AAA-rated assets at depressed prices, banks would choose to hold them on the balance sheet. This expansion in bank balance sheet led to a depressed capital ratio due to the rise in risk-weighted assets and the market-to-market losses(depressed asset prices), and banks had to pull back on discretionary lending as a consequence. In addition, the higher counterparty risk made it more difficult for interbank lending. To inject more liquidity, banks might borrow at the Fed's discount window (solid green line), but this could raise public attention that the bank is experiencing financial problems. To address this issue, the Fed introduced the Term Auction Facility (TAF). TAF disseminates funds at an auction, where banks can bid anonymously (denoted by solid black line). Another liquidity facilities introduced by the Fed were the term securities lending facility (TSLF) and the primary dealer credit facility (PDCF) (dashed black line leading from the Federal Reserve through the triparty repo system to broker-dealers). The TSLF allows primary dealers (whose lifeline is the repo market) to exchange AAA-rated RMBS, CMBS and ABS in exchange for Treasury securities. The dealers then can take the Treasurys to the Treasury repo market to raise cash. Thus it improved liquidity in the entire triparty repo system and also in the repo market that exists between hedge funds and broker-dealers (solid red and black lines between hedge funds and broker-dealers). The PDCF is a standby borrowing facility where primary dealers can obtain funds from the Fed in exchange for most major types of investment-grade securities.

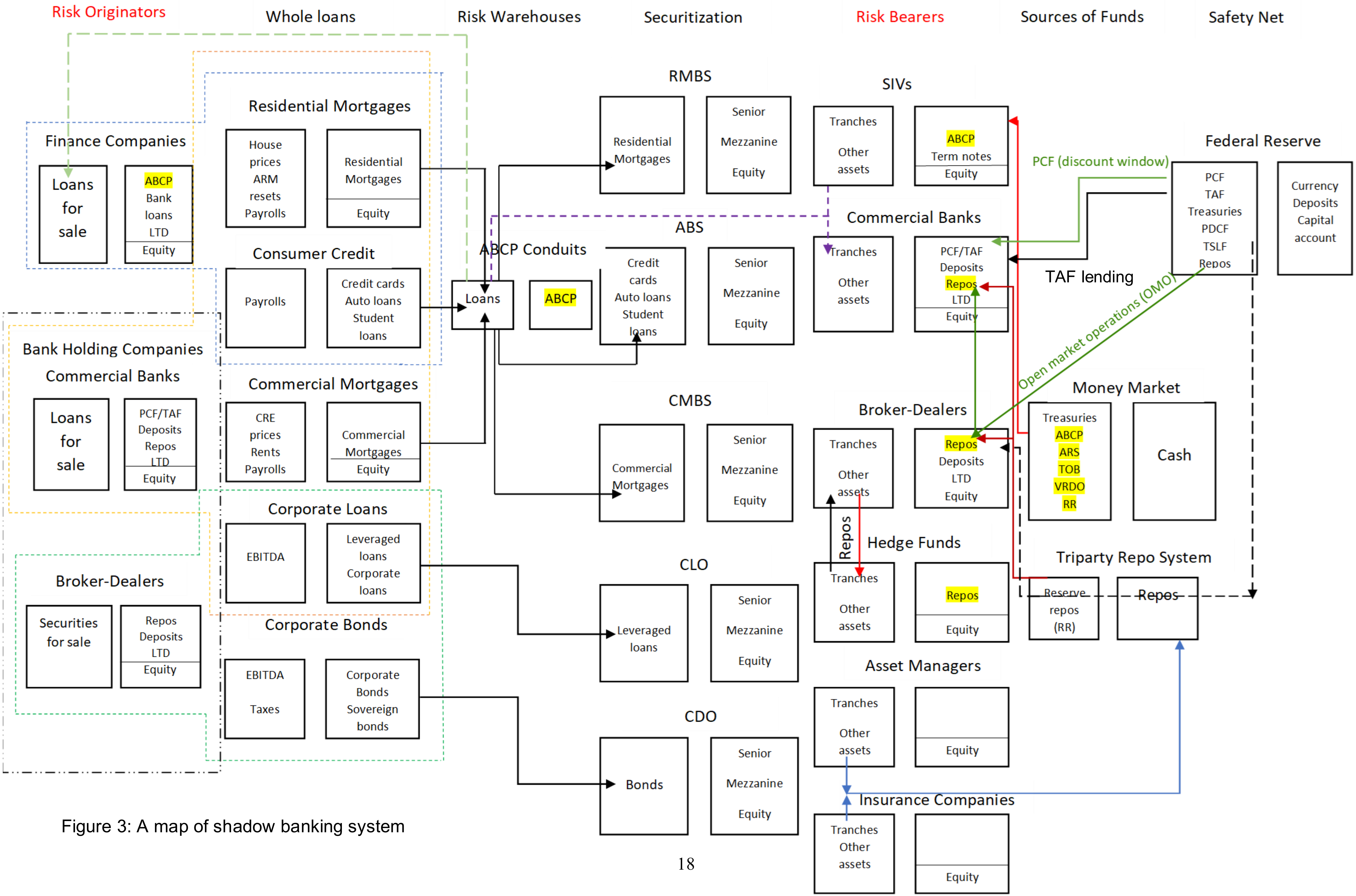


Figure 3: A map of shadow banking system

2.6 Bank regulation in the US

The Basel Committee on Banking Supervision (BCBS) is an organisation that comprises central banks and bank supervisors from 27 jurisdictions. BCBS focuses on formalizing international standards for prudential banking regulation. Although the standards set by BCBS are not legally binding, they are voluntarily incorporated into the regulatory systems of members and other jurisdictions. The 1988 Basel Accord (Basel I) established a uniform method for determining minimum capital requirements for international banks following the Latin American debt crisis. It focused on credit risk and introduced a risk-weighted approach to capital requirements, aiming to improve the stability of the financial system and maintain confidence in bank solvency. Banks were required to maintain a minimum of 8% of regulatory capital (Tier 1 and Tier 2), measured in terms of credit risk-weighted assets. Banks were required to maintain a certain amount of capital to meet their obligations. In 1996, the accord was amended to incorporate market risk[5]. This meant that total risk-weighted assets consisted of credit risk and market risk positions. This was the first time that the internal model (Value at Risk) was applied to quantify possible losses.

In 2004, the revised Basel framework (Basel II) was published, and it was further finalised in 2006. Basel II comprised three pillars. It encompassed the calculation of capital requirements on the basis of bank risks, including credit, market and operational risk[6], but the 8% minimum remained. In addition, the risk-weighting methodology was refined, and advanced measurement approaches were applied to operational risk. Moreover, the Committee turned its attention to the trading book apart from the banking book in the calculation of risk. This made Basel II more risk-sensitive and better attuned to financial innovation compared to its predecessor. However, Basel II were criticised because it allowed banks to take on too much risk with too little capital. It was considered as part of the cause of the financial crisis in 2008.

The financial crisis revealed the weakness of the banking sector, including excessive leverage, inadequate liquidity buffers, poor governance and risk management. In response to the financial crisis, the Basel Committee issued a short-term package to strengthen the Basel II capital framework in 2009, with regard to the treatment of certain complex securitisation positions, off-balance sheet vehicles and trading book exposures. In 2010, Basel III aimed to inject greater systemic resiliency in the banking system in times of economic stress through stricter capital and liquidity rules, so it announced higher global

[5] Market risks are the risks arising from a bank's exposure to movements in market variables (e.g., exchange rates, interest rates, commodity prices, and equity prices). These market variables are often referred to as risk factors. The value of a market variable is determined by trading in the financial markets.

[6] Operational risk arises from cyber-security, anti-money laundering legislation, internal fraud, external fraud and so on. It is regarded by many to be a greater challenge for banks than either market risk or credit risk.

minimum capital standards for commercial banks. Basel III raised capital quality by limiting core Tier 1 capital[7] to common equity and retained earnings, which provided loss absorption unlike other forms of hybrid debt. Basel III also imposed new ratios for short-term and long-term liquidity, such as the 30-day Liquidity Coverage Ratio (LCR) and the one-year net stable funding ratio (NSFR). In particular, the NSFR should help to counter pro-cyclicality because it is designed to ensure banks lessen their dependence on wholesale short-term funding.[8] In addition, Basel III focused on both firm-specific risk and systemic risk. From 2011, the committee focused on improving the calculation of capital requirements. The risk-based capital requirements outlined in the Basel II framework have been expanded to address risks arising from capital market activities. These risks include exposure to central counterparties, margins on non-centrally cleared derivatives, exposure to counterparty credit risks, and securitization. To reduce systemic risk and lessen procyclicality, Basel III has designed a macroprudential overlay that consists of several elements. For example, to prevent excessive bank leverage, a leverage ratio of 3% was proposed. A countercyclical capital buffer was introduced to reduce banks' losses in credit busts. The Committee completed its Basel III post-crisis reforms in 2017, issuing new standards for the calculation of capital requirements for credit risk, credit valuation adjustment risk and operational risk. The final reforms also include a revised leverage ratio, a leverage ratio buffer for global systemically important banks and an output floor, based on the revised standardised approaches, which limits the extent to which banks can use internal models to reduce risk-based capital requirements. These final reforms address shortcomings of the pre-crisis regulatory framework and provide a regulatory foundation for a resilient banking system that supports the real economy.

[7] Tier 1 capital, also called core capital and primary capital, is the sum of common stock, retained earnings, and certain reserves.

[8] When this funding evaporates during a credit crisis, it forces banks to shed assets at depressed prices to meet liquidity requirements.

Chapter 3 Literature Review

3.1 Agency problems in financial markets

Environments with costly state verification were first studied by Townsend (1979). He set up a two-agent model and then extended it to an m-agent economy. In his environment, the random return of the projects for agent 2 is private, but agent 1 can verify it at a cost. He demonstrates that stochastic verification procedures can dominate deterministic procedures, and stochastic auditing strategies are optimal in most cases.

Ashcraft and Schuermann (2008) describe seven important informational frictions that existed in the securitization of subprime mortgage credit prior to the financial crisis. These frictions mainly involve moral hazard, adverse selection and principal-agent problems. Particularly, they list seven key frictions. First, asymmetric information problems between the borrower and the originator. Borrowers can be financially unsophisticated, leading to the possibility of predatory lending because originators may charge higher fees and points to borrowers. However, the regulated commercial banks can effectively prevent predatory lending practices. This might explain why shadow bank credit is higher than commercial bank credit in some other papers. Second, frictions between the originator and the arranger. This friction arises because the originator has an information advantage over the arranger regarding the borrower's quality. Third, frictions between the arranger and third parties. The arranger has more information about the quality of the mortgage loans which creates an adverse selection problem: the arranger can securitize bad loans and keep the good ones. This friction in the securitization of subprime loans affects the relationship that the arranger has with the warehouse lender, the credit rating agency (CRA), and the asset manager. Fourth, frictions between the servicer and the mortgagor. To maintain the value of the underlying asset (the house), the mortgagor (borrower) must pay insurance and taxes on the property and generally maintain it. Fifth, frictions between the servicer and third parties. Sixth, frictions between the asset manager and investor. The investor provides the funding for the MBS purchase but is typically not financially sophisticated enough to formulate an investment strategy, conduct thorough due diligence on potential investments, and find the best price for trades. This service is provided by an asset manager (agent) who may not invest sufficient effort on behalf of the investor (principal). Seventh, frictions between the investor and the credit rating agencies. The rating agencies get the payoff from the arranger rather than from investors. It potentially leads to a conflict of interest. Because the rating agency knows more than investors, investors may not assess the efficacy of rating agency models, so they are more susceptible to both honest and dishonest errors on the agencies' part.

Verona et al. (2012) study the effect of low interest rates on the financial sector by incorporating shadow banks into a sticky-price DSGE model. However, their model does not feature securitization, and shadow banks have no direct interaction with the commercial banking system. Their model is based on the Christiano, Motto and Rostagno (2010) model, but they add a shadow banking system as a second financial sector, in addition to the standard banking model proposed by Bernanke et al. (1999). In their model, they divide the entrepreneurial sector into two groups. Safer entrepreneurs issue bonds and resort to investment banks. Riskier firms resort to retail bank financing with higher risk because they may default due to a low realization of the productivity shock. Safer entrepreneurs can obtain finance at a lower interest rate than riskier entrepreneurs. That is because, under commitment underwriting, an investment bank acts as the underwriter; they buy the entire stock of bonds from the firm and resell them to investors at a higher price, leading to a lower interest rate. Even though the bank can diversify the idiosyncratic risk by lending to a large number of entrepreneurs, the agency problem still exists between risky firms and the bank, indicating that bank hedges against credit risk by charging a premium over the risk-free rate that is borrowed from households. Their model also features normal times and excessive optimism. They then conduct the analysis based on two scenarios of an anticipated policy path and an unanticipated policy path with a varying interest rate path lasting for 6 quarters. Their simulated results suggest that the boom and bust in the U.S. during the 2000s could be attributed to the combination of three factors– a policy of too low for too long interest rates, a mood of excessive optimism and a failure of agents to anticipate the duration of the abnormally favourable macro-conditions.

However, there are some papers argue that the shadow banking system can increase macroeconomic volatility. Meeks et al. (2017) develop a DSGE model featuring securitisation and shadow banking. They examine the consequences of securitized banking for aggregate activity, credit supply and credit spreads to business cycle and financial shocks. Their model resembles a standard macroeconomic model, but they do not model complex financial instruments based on securitised assets and do not deal with issues of prudential regulation. In their model, there are two types of financial intermediaries, each facing endogenous balance sheet constraints which depend on their net worth as a standard financial accelerator. Commercial banks purchase loans from firms. They can optimally choose how much of the loans they retain on their balance sheet, and how much they sell to the shadow banking system. In their economy, shadow banks are seen as collateral manufacturers. They purchase loans originated by commercial banks and issue ABS to fund their purchase. However, commercial banks have an incentive to invest in ABS because securitized assets created by shadow banks are backed by a pool of loans. They are more tradable than opaque and idiosyncratic loans that remain on the balance sheet. For commercial banks, this can enhance the quality of collateral on their balance sheets and loosen their funding constraint. However, even though increased securitization activity expands the credit provision by broadening the amount of pledgeable assets, it makes the financial system fragile because the supply of ABS depends on the strength of shadow bank balance sheets. An adverse aggregate shock has a negative impact on both the shadow bank and commercial banks, constraining the supply of collateral for commercial banks. This shortage of collateral tightens commercial banks' financing constraints, causing them to delever, which further suppresses asset prices and amplifies volatility. They find that the ability of commercial banks to securitize loans when their net worth is impaired is beneficial in stabilizing the economy and credit supply. However, with a highly leveraged shadow banking system, the economy becomes increasingly vulnerable. In addition, they argue that following a financial shock, stabilisation policy aimed solely at securitisation markets by purchasing asset-backed securities is less attractive because the spillover effects on the rest of the financial system can weaken the effectiveness of interventions.

Similar as Meeks et al. (2017), Ferrante (2018) extend the model by adding the role for loan quality and a run on the SB-system They focus on the several factors that attribute to the instability of the shadow banking system, notably with regard to high leverage, moral hazard problem in choosing the riskiness of loans, and exposure to bank runs. In their model, shadow banks can achieve higher leverage than traditional banks because they are able to pool different loans, thereby improving the level of diversification of their idiosyncratic risk and thus have a higher endogenous leverage. It helps to expand credit, increase investment, and boost output. However, shadow banks increase the fragility of the financial system due to the aforementioned three sources. They find that there is an amplified effect similar to the financial accelerator because shadow banks increase the aggregate leverage of the banking system. In addition, the innovation of their model lies in the interaction between asset quality and leverage. The moral hazard problem exists because shadow banks have less incentive to screen projects, so they will originate riskier loans such as subprime mortgages, leading to higher leverage. When the net worth of the shadow bank declines in a recession, the quality of the project that the shadow bank intermediates will deteriorate as well, leading to a slower recovery of this financial sector due to the volatility in equity returns of financial intermediaries. Another instability arises from a run on shadow banks. Shadow banks are vulnerable to bank runs due to their high leverage, and they often issue short-term debt to finance long-term investments. However, this is not the case for traditional banks. If a run occurs, shadow banks have to sell their assets to traditional banks, leading to a decline in asset prices and further impacting investment, which in turn causes a prolonged recession and a slow recovery of the financial system.

3.2 Regulatory arbitrage and technology changes

The shadow banking system is mainly made up of levered off-balance-sheet vehicles such as SIVs. The existence of these off-balance-sheet vehicles were motivated by regulatory and tax arbitrage. Traditional banks have been constrained by regulation that restrict their leverage. It started from the 1988

Basel Accord, which required more capital protection against riskier assets, encouraged banks to shift risky activities off their balance sheet in order to escape regulation.

Buchak et al. (2018) show that shadow banks' market share in mortgage origination has grown rapidly from 2007 to 2015. Fintech lenders constitute a significant part of the growth in shadow banks. Fintech shadow banks primarily originate mortgages online. They do not face the regulatory burden as traditional banks, and their technology allows them to offer more cheaply and better products to serve riskier, less creditworthy Federal Housing Administration (FHA) borrowers. They set up a quantitative mortgage origination model that includes traditional banks, non-fintech shadow banks, and fintech shadow banks. These lenders compete for borrowers, but they differ in regulatory burden, convenience and costs of making loans. Their findings suggest that increased regulatory burdens account for 60% of shadow bank growth between 2008 and 2015, with advancement in online origination technology accounting for another 30%.

Luck and Shempp (2014) develop a simple banking model in which banks and the shadow banking sector coexist. They aim to illustrate how regulatory arbitrage induced shadow banking can contribute to the financial crisis. In their setup, commercial banks are subject to regulation and have to bear regulatory costs. The shadow banking sector competes with banks by offering maturity transformation. In addition, arbitrageurs can purchase securitized assets on a secondary market. They find that the size of the shadow banking sector has an impact on the stability of the financial system. If the size of the shadow banking sector is too large compared to the capacity of the secondary markets, it could worsen the financial system. If banks and shadow banking are intertwined, the threat of a crisis in the shadow banking sector may also impact the regulated banks due to the costly safety net.

Begenau and Landvoigt (2022) propose a tractable equilibrium model to analyze the consequence of capital requirements on regulated banks. In their model, regulated commercial bank deposits are insured and risk-free for depositors. But unregulated shadow bank deposits are in principle uninsured and risky for depositors. Therefore, commercial banks benefit from deposit insurance, which gives them a competitive advantage. Their model also quantifies two effects. The competition effect arises because traditional banks and shadow banks compete for equity capital from household investors. But the increase in the capital requirement reduces commercial banks' competitive advantage vis-à-vis shadow banks and results in a reduction in shadow banks' leverage due to their increased financing cost as they expand. The demand effect is a countervailing force to the risk that dampens the competition effect. It decreases shadow banks' debt financing costs and provides incentives to increase leverage and take on more risk. They calibrate the model and find that a higher capital requirement on commercial banks facilitates the expansion of the shadow banking sector. Although shadow banking is riskier, the increase in the risk of the shadow banking sector is economically small, and the riskiness of shadow banking can be offset by the greater stability of commercial banks, thereby reducing the fragility of the financial system.

Another important paper in the shadow banking literature is Moreira and Savov (2017). They build a dynamic microfinance model of shadow banking in which liquidity transformation in the financial sector drives the macrocycle. They then study how fragile liquidity affects asset prices and collateral values and how that interacts with macrocycles. In their model, intermediaries can issue securities. The liquidity of securities is linked to the tranche. Safe, always-liquid security is referred to as "money", fragile-liquid security is referred to as "shadow money". Shadow banking is interpreted as the process of creating shadow money. They find that shadow banking can expand liquidity provision, which drives the macrocycle when uncertainty is low. The uncertainty is modelled as a time-varying probability of a crash. The low uncertainty such as the Great Moderation period, mitigates the spread between shadow money and money, making shadow money more attractive to intermediaries, thereby expanding liquidity provision and boosting asset prices and economic growth, as producing liquid securities requires less collateral. However, it also builds up fragility as more investment is concentrated in riskier assets. With a rise in uncertainty, the shadow banking collapses because it might bring less liquidity. The liquidity contraction in turn raises discount rates and lowers asset prices, leading to a fall in investment and growth.

There are also many earlier works that integrate shadow banks into the DSGE model. These papers highlight the amplification effect associated with shadow banking. Fève et al. (2019) estimate a small-scale DSGE model of the US economy with a financial sector including traditional and shadow banks. Their model is similar to Meeks et al. (2017). Traditional banks are subject to regulation, and they finance through deposits. Shadow banks are less regulated and they finance by issuing ABS, so that traditional banks have an incentive to substitute loans with ABS in order to increase their leverage. Their model shows that shadow banks have an amplification effect and can increase efficiency because they can escape constraints arising from traditional banks. They also consider the effect of macro-prudential regulation. They find that shadow banking activity expands when traditional banks face tighter regulatory constraints. This regulatory arbitrage affects the effectiveness of policy, fails to reduce aggregate fluctuations. However, if both traditional and shadow credit are strictly regulated, it is beneficial to stabilize the economy and credit cycles.

Gebauer and Mazelis (2023) also find that tighter capital requirements on commercial banks increase shadow bank lending and have adverse financial stability effects. In their model, commercial banks and shadow banks intermediate funds between savers(households) and borrowers(entrepreneurs), but shadow banks are not subject to macroprudential policies. Commercial banks can access public support and act as risk-free deposit-takers under monopolistic competition. However, shadow banks operate under perfect competition. Investing in shadow banks is risky due to agency problems between shadow banks and investors. They follow Gertler and Karadi (2011) and assume that shadow banks can divert a share of funds and default on the remaining liabilities because they face an incentive to disappear and leave investors with losses. This default risk results in a spread between shadow bank and commercial bank deposit rates, reflecting a higher compensation that households require when making investments. However, for households, commercial bank deposits and shadow bank investments are assumed to be perfect substitutes. In addition, they set an exogenous regulatory loan-to-value ratio for borrowers when raising funds from commercial banks, but shadow bank funding is not constrained by regulation. Shadow banks' ability to raise funds is subject to the moral hazard problem discussed above. Entrepreneurs tend to borrow from commercial banks first due to the credit spread between interest rates charged for shadow bank and commercial bank loans. In their policy analysis section, they create a time-varying macroprudential tool to capture the countercyclical capital buffer that regulators can use to prevent banks from engaging in excessive leverage. They first define a moderate regulator and set capital requirements for commercial banks by raising the capital-to-asset ratio above the steady-state level of capital requirements whenever the respective four types of credit measures deviate from their steady-state value. Then they analyse the case of a prudent regulator by taking shadow banking lending into account and consider the overall credit. Their results illustrate the credit leakage towards shadow banks under tighter monetary policy which is in line with the observation of the leakage mechanism in Fève et al. (2019), but this may have adverse financial stability effects. They also find that coordinating macroprudential tightening with monetary easing can help mitigate undesired leakage towards the shadow banks. Moreover, a more prudent regulatory regime enforced on shadow banks can stabilise inflation and nominal interest rates.

Lubello and Rouabah(2024) design an NK-DSGE model calibrated to the EA economy. In their model, traditional banks and shadow banks interact through a securitization market, and they then examine how the shadow financial system affects the economy and financial stability. As in Gertler et al. (2016), commercial banks can divert a proportion of funds which leads to a limit in leverage due to the moral hazard problem. In addition, their model considers regulatory arbitrage considerations. They propose the concept of "frictional regulation" and argue that the imperfect regulatory requirements within the regulatory framework allow banks to securitize loans. This is contrary to Fève et al. (2019), who argue that the shadow banks are subject to less regulation than commercial banks and lead to credit leakages and regulatory arbitrage. They also include a heterogeneous agent model where small risky firms raise funds through commercial banks operating under moral hazard. Commercial banks sell securitized loans to shadow banks to exploit regulatory arbitrage opportunities. Large firms raise funds through shadow banks, which also hold interbank deposits with commercial banks. In addition, securitization enables commercial banks to benefit from capital redeployment opportunities, which lower bank loan monitoring and lead to reduced bank lending, investment, and output. They also assess the effectiveness of macroprudential policy in the presence of regulatory arbitrage by considering a two-instrument macroprudential policy toolkit for the traditional banking sector. It takes the form of caps on the leverage ratio and the securitization ratio. Their welfare analysis confirms that conditional on a technology shock, containing leverage and securitization is welfare-improving.

There are some papers that focus on the contribution of shadow banking to the Slow Recovery. Fève et al. (2022) study whether the shrinkage in shadow banks contributed to the Slow Recovery of the US economy after the Great Recession and how banking shocks can explain the post-crisis shifts. To capture the role of shadow banks before the financial crisis, shadow banks are set to follow an originate-to-distribute mechanism. Entrepreneurs finance their capital through traditional banks, which are subject to regulatory requirements. To raise capital, traditional banks sell a proportion of their securitized products to unregulated shadow banks, as in Meeks et al. (2017). This is contrary to the approach of Fève et al. (2019), in which shadow banks supplied funds directly to the ultimate borrowers. They include two banking shocks in their model. The first is an aggregate disturbance to the cost of loan origination which is referred to as the loan cost shock, leading to a credit spread, as in the model of financial accelerator in Bernanke et al. (1999). The second shock is the shadow banking shock, which affects the cost of screening shadow bank liabilities. A rise in this shock makes shadow bank lending more costly, driving credit supply to move toward traditional banks and impeding the efficiency of financial intermediation in the economy. Their model finds that negative realisations of shadow banking shock are the main driver of the Slow Recovery. The fall in shadow banking after the financial crisis impaired the efficiency of the US banking system.

Chapter 4 Model Setup (DSGE Model)

In this chapter, I describe the DSGE model structure in Section 4.1. I then outline some fixed, calibrated parameters that are difficult to identify from the data in Section 4.2.

4.1 A DSGE model with shadow banking

In this section, we mainly discuss the micro-foundation of the DSGE model. The model is based on the work of CEE (2005) and Smets and Wouters (2007). We also include a banking sector that amplifies the effects of monetary shocks via the financial accelerator as in Bernanke et al. (1999). More importantly, we allow for shadow bank lending to affect the equity market and consider the role of quantitative easing and bank regulation based on Le et al. (2016). For this reason, we sketch out the main building blocks.

4.1.1 General consumer behaviour

There is a continuum of infinitely lived households indexed by $j \in [0, 1]$, the j^{th} household makes decisions in each period, it chooses consumption $C_t(j)$, hours worked $L_t(j)$, deposits $D_t(j)$ to maximise the following objective function. This instantaneous utility function is non-separable in consumption and labour. According to King, Plosser and Rebelo (1988), a non-separable utility function with unrestricted intertemporal substitution elasticity is consistent with a steady-state growth path and stationary labour supply, and Basu and Kimball (1997) point out that it can be used to deal with the empirically observed excess sensitivity of consumption in regard to current income fluctuations.

$$\max_{C_t, L_t, B_t, D_t,} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left[\frac{1}{1-\sigma_c}\left(C_{t+s}(j) - \lambda C_{t+s-1}(j)\right)^{1-\sigma_c}\right] exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_{t+s}(j)^{1+\sigma_l}\right) \quad (4.1.1)$$

Where β is the discount factor, σ_c denotes the coefficient of relative risk aversion of households or the inverse of the intertemporal elasticity of substitution for constant labour. λC_{t+s-1} represents the external habit stock, which is assumed to be proportional to aggregate past consumption. In particular, the parameter $\lambda > 0$ measures the intensity of external habit formation in consumption, providing a source of real rigidity.[9] The above intertemporal utility function implies that the utility of each household depends on the difference between current consumption and the average consumption from the

[9] An alternative manner is internal habit formation in which agents recognize their own influence on the formation of the habit.

previous period and labour hours. σ_l is the inverse of the elasticity of labour with respect to the real wage.

Each household maximizes its objective function subject to the intertemporal budget constraint in real terms:

$$C_t(j) + \frac{B_t(j)}{\epsilon_t^b(1+R_t)P_t} + \frac{D_t(j)}{(1+R_t)P_t} + T_t \le \frac{B_{t-1}(j)}{P_t} + \frac{D_{t-1}(j)}{P_t} + \frac{W_t^h(j)L_t(j)}{P_t} + \frac{Div_t}{P_t} \quad (4.1.2)$$

On the left-hand side, household divides its total income between consumption of final goods C_t, purchase of government bonds B_t (or deposits to a proportion of firms that receive funding from commercial bank), deposit D_t to the other firms that raise funding through the shadow bank, and payment of lump-sum taxes T_t.

It should be noted that government bond B_t and shadow bank deposits D_t are assumed to be perfect substitutes, each offering the same riskless return R_t. High net worth households deposit their money with the bank at riskless return R_t, then it will be further borrowed to a proportion of firms through shadow banks with premium. It is also applicable to our assumption that when the central bank conducts quantitative easing, households are willing to sell bonds in exchange for M0 which will further be placed with commercial banks as deposits.

Note that the one-period bond is expressed on its face value purchased at time *t*. ϵ_t^b is an exogenous premium in the return to bonds as in Smets and Wouters (2007). This shock is assumed to follow a first-order autoregressive process with an IID-Normal error term. $\epsilon_t^b = \rho_b \epsilon_{t-1}^b + \eta_t^b$, $\eta_t^b \sim N(0, \sigma_b^2)$. R_t is the nominal interest rate. On the right-hand side, total income consists of proceeds from bonds purchased in the previous period, return on deposits, labour income and dividends distributed by labour unions.

The Lagrangian function is :

$$\max_{C_t, L_t, B_t, D_t,} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left(\left[\frac{1}{1-\sigma_c} (C_t(j) - \lambda C_{t-1}(j))^{1-\sigma_c} \right] exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_t(j)^{1+\sigma_l} \right) + \Xi_t \left[\frac{B_{t-1}(j)}{P_t} + \frac{D_{t-1}(j)}{P_t} + \frac{W_t^h(j)L_t(j)}{P_t} + \frac{Div_t}{P_t} - C_t(j) - \frac{B_t(j)}{\epsilon_t^b(1+R_t)P_t} - \frac{D_t(j)}{(1+R_t)P_t} - T_t \right] \right) \quad (4.1.3)$$

Where Ξ_t is the Lagrange multiplier associated with the budget constraint, it represents the marginal utility of consumption, which is identical across households. In equilibrium, the household makes the optimal choice for consumption, labour hours, bonds and deposits, the first order conditions with respect to C_t, L_t, B_t, D_t can be written as (dropping the *j* index):

$$(\partial C_t) \quad \left[exp\left[\frac{\sigma_c-1}{1+\sigma_l}L_t^{1+\sigma_l}\right](C_t-\lambda C_{t-1})^{-\sigma_c}\right]=\Xi_t \tag{4.1.4}$$

$$(\partial L_t) \quad \left[\frac{1}{1-\sigma_c}(C_t-\lambda C_{t-1})^{1-\sigma_c}exp\left(\frac{\sigma_c-1}{1+\sigma_l}L_t^{1+\sigma_l}\right)(\sigma_c-1)L_t^{\sigma_l}\right]=-\Xi_t\frac{W_t^h}{P_t} \tag{4.1.5}$$

$$(\partial B_t) \quad \frac{\Xi_t}{\epsilon_t^b P_t}= \mathbb{E}_t(\beta\frac{\Xi_{t+1}}{P_{t+1}}(1+R_t)) \tag{4.1.6}$$

$$(\partial D_t) \quad \frac{\Xi_t}{P_t}= \mathbb{E}_t(\beta\frac{\Xi_{t+1}}{P_{t+1}}(1+R_t)) \tag{4.1.7}$$

Households' optimal decisions on consumption and labour are standard as in Smets and Wouters (2007). Combining equations (4.1.4) and (4.1.6), we obtain the Consumption Euler equation:

$$\left[exp\left[\frac{\sigma_c-1}{1+\sigma_l}L_t^{1+\sigma_l}\right](C_t-\lambda C_{t-1})^{-\sigma_c}\right]=\mathbb{E}_t\left[\beta\frac{P_t}{P_{t+1}}\epsilon_t^b(1+R_t)exp\left[\frac{\sigma_c-1}{1+\sigma_l}L_{t+1}^{1+\sigma_l}\right](C_{t+1}-\lambda C_t)^{-\sigma_c}\right] \tag{4.1.8}$$

It is a dynamic optimality condition showing a dynamic optimality decision for consumption in the present and the future. In effect, there would be a slight risk premium to marginal rate of substitution relative to riskless bond, but in practice of dealing with dynamic stochastic general equilibrium models suffice it to say there will be a close connection between real interest rate on bonds and the marginal rate of substitution of consumption (Walsh, 2005).

4.1.2 Labour market structure and wage decisions

Households supply their homogeneous labour to an intermediate labour union, which will differentiate the labour services, then labour packers bundle differentiated labour and resell it to intermediate firms. However, we extend the model design by incorporating two sorts of labour in the household's utility function and we will have a hybrid wage setting. As in Le et al. (2011), we assume that firms produce intermediate goods have a production function that combines in a fixed proportion labour in imperfect competitive markets(unionised) with labour from competitive markets. Thus, the labour used by intermediate goods producers becomes:

$$L_t=L_{1t}+L_{2t}=\left[\int_0^1 L_{1t}(i)^{\frac{1}{1+\lambda_{w,t}}}di\right]^{1+\lambda_{w,t}}+\left[\int_0^1 L_{2t}(i)di\right] \tag{4.1.10}$$

Where $L_{1t}(i)$ represents the unionised labour, and $L_{2t}(i)$ is the competitive labour supplied by the ith household at time t. L_t stands for the activities of an intermediary labour packer. If we use ω_{NK}^w to denote the share of unionised labour in the total, then $L_{1t}=\omega_{NK}^w L_t$, and $L_{2t}=(1-\omega_{NK}^w)L_t$.

Here we provide more details on labour market structure. As in SW (2007), the labor L_{1t} from the imperfect competitive markets is a composite using the aggregator function:

$$L_{1t} = \left[\int_0^1 L_{1t}(i)^{\frac{1}{1+\lambda_{w,t}}} di\right]^{1+\lambda_{w,t}} \tag{4.1.11}$$

L_{1t} and $L_{1t}(i)$ represent the composite labour and differentiated labour services respectively. The parameter $\lambda_{w,t}$is the wage elasticity at period t of the relevant labour demand function that we derived below. We assume that elasticity varies exogenously over time, representing a shock to the wage mark-up, which leads to changes in the union's market power.$1 + \lambda_{w,t}$ determines the wage mark-up over the labour disutility. The labour packer maximizes profits in a perfectly competitive market as follows:

$$L_{1t}W_{1t} - \int_0^1 L_{1t}(i)W_{1t}(i)di \tag{4.1.12}$$

The first order condition with respect to each unionised labour yields:

$$L_{1t}(i) = \left(\frac{W_{1t}(i)}{W_{1t}}\right)^{-\frac{1+\lambda_{w,t}}{\lambda_{w,t}}} L_{1t} \tag{4.1.13}$$

Where W_{1t} is the aggregate wage rate, i.e., the price of unionised labour. $W_{1t}(i)$ is individual household wage. This labour demand function measures the amount of labour hours that the labour packer demands in response to the wage determined by the labour union. If we combine this condition with the zero profit condition, the expression for the aggregate wage is given by[10]:

$$W_{1t} = \left[\int_0^1 W_{1t}(i)^{-\frac{1}{\lambda_{w,t}}} di\right]^{-\lambda_{w,t}} \tag{4.1.14}$$

Now we turn to the wage decision. Since there are two sorts of labour participating in the household's utility function, we can obtain a hybrid wage equation:

$$W_t = \omega_{NK}^w W_{1t} + (1 - \omega_{NK}^w)W_{2t} \tag{4.1.15}$$

Notably, the labour union has a monopoly power over the supply of its differentiated labour and will determine wages subject to the labour demand function derived above. The union is also subject to rigidity, so here W_{1t} is set via the Calvo scheme. While W_{2t} is set equal to the current expected marginal

[10] Aggregate wage rate is in association with individual household wage, this will be replaced by the law of motion of the aggregate wage index

monetary disutility of work. These wages are then passed on to the labour bundler who offers each unit of labour at this weighted average wage before intermediate firms purchase these labour units for use in production.

More formally, since the labour union acts as price-setters in the labour market, for W_{1t}, the wage setting in the Calvo scheme implies that in each period, only a fraction of unions receive a random signal that is able to re-optimise the wage. The probability that they can readjust wage is constant and equal to $1 - \xi_w$, for those who did not receive wage-change signal, wage will be partially indexed to past inflation. While for those that can adjust, the problem is to choose an optimal wage that maximize the wage income, taking account of the probability that the union is stuck with that wage in the future. The optimisation problem is given as follows:

$$\underset{W_{1t}(l)}{max} E_t \sum_{s=0}^{\infty} \xi_w^s \left[\frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}}\right] [W_{1t+s}(i) - W_{t+s}^h] L_{1t+s}(i)$$

$$\text{s.t.} \quad L_{1t+s}(i) = \left(\frac{W_{1t+s}(i)}{W_{1t+s}}\right)^{-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}} L_{1t+s}$$

Where $W_{1t+s}(i) = \tilde{W}_{1t}(i)\left(\Pi_{l=1}^{s} \gamma \pi_{t+l-1}^{\iota_w} \pi_*^{1-\iota_w}\right)$for $s = 1, \ldots, \infty$. (4.1.16)

In the first equation, $\left[\frac{\Xi_{t+s} P_t}{\Xi_t P_{t+s}}\right]$ is derived from the general consumer problem related to marginal utility of consumption. This equation implies that the union chooses a optimal wage in order to maximise their respective households utility against their individual utility, subject to the labour demand equation, so that the present value of marginal return to working is a mark up over the present value of marginal cost of working, or equivalently, the difference between the utility of consumption gained from selling labour and the utility loss related to giving up leisure. The markup above the marginal disutility will be distributed to the households. ξ_w^s is the degree of wage stickiness. If $\xi_w^s = 0$, we will have an economy without rigidities, so wages are perfectly flexible, the real wage will be a constant mark-up over the marginal rate of substitution between consumption and leisure. In the second equation, $\tilde{W}_{1t}(i)$ represents the optimal wage, for those who cannot adjust wage, wage is determined by previous-period wage and infaltion, γ is deterministic growth rate, $\pi_{t+i-1}^{\iota_w} \pi_*^{1-\iota_w}$ denotes a weighted average of last period's inflation π_{t-1} and of the steady state inflation π_* . ι_w denotes the degree of wage indexation to past inflation, if $\iota_w = 1$, complete indexation to inflation in the previous period takes place. If $\iota_w = 0$, wages are indexed to the inflation objective of the central bank.

The first order condition with respect to $W_{1t}(i)$ is:

$$0 = E_t \sum_{s=0}^{\infty} \xi_w^s \frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}} [(W_{1t+s}(i) - W_{t+s}^h) \left(\frac{X_{t,s} \tilde{W}_{1t}(i)}{W_{1t+s}}\right)^{-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}-1} \left(-\frac{1+\lambda_{w,t+s}}{\lambda_{w,t+s}}\right)\left(\frac{X_{t,s}}{W_{1t+s}}\right) L_{1t+s} - X_{t,s} L_{1t+s}]$$

where $$X_{t,s} = \begin{cases} 1 \; for \; s = 0 \\ (\Pi_{l=1}^{s} \gamma \pi_{t+i-1}^{\iota_w} \pi_*^{1-\iota_w}) \text{for } s = 1, \ldots, \infty \end{cases} \quad (4.1.17)$$

Simplifying by substituting for the individual labour and multiplying by the optimal wage:

$$E_t \sum_{s=0}^{\infty} \xi_w^s \frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}} L_{1t+s}(i) \frac{1}{\lambda_{w,t+s}} \left[(1 + \lambda_{w,t+s}) W_{t+s}^h - X_{t,s} \tilde{W}_{1t}(i)\right] = 0 \quad (4.1.18)$$

The law of motion of the aggregate wage is given by[11]:

$$W_{1t} = \left[(1 - \xi_w) \tilde{W}_{1t}^{\frac{1}{\lambda_{w,t}}} + \xi_w (\gamma \pi_{t-1}^{\iota_w} \pi_*^{1-\iota_w} W_{1t-1})^{\frac{1}{\lambda_{w,t}}}\right]^{\lambda_{w,t}} \quad (4.1.19)$$

4.1.3 Final goods producers

Final goods producers act as price takers in a perfectly competitive market. They produce final goods by purchasing intermediate goods from the intermediate goods producers, then package their final output and resell it to consumers, investors and governments. Similar to hybrid wage setting, the price is also set in a hybrid form. We assume that the retail output is now made up in a fixed proportion of intermediate goods in an imperfectly competitive market, and intermediate goods are sold competitively. Retail output is therefore given by:

$$Y_t = Y_{1t} + Y_{2t} = \left[\int_0^1 (Y_{1jt})^{\frac{1}{1+\lambda_{p,t}}} dj\right]^{1+\lambda_{p,t}} + \left[\int_0^1 (Y_{2jt}) dj\right] \quad (4.1.20)$$

where the intermediate goods producers prices Y_{1t} according to the Calvo mark-up equation on marginal costs, and Y_{2t} at marginal costs. Note that $Y_{1t} =$

[11] Wage is the same across all unions, so the indices i can be dropped.

$\omega_{NK}^{p} Y_t$, ω_{NK}^{p} is the share of imperfectly competitive goods market, thus $Y_{2t} = (1-\omega_{NK}^{p})Y_t$. The retailer combines these goods as above in a bundle which it sells at a weighted average price:

$$P_t = \omega_{NK}^{p} P_{1t} + (1-\omega_{NK}^{p}) P_{2t} \tag{4.1.21}$$

Furthermore, for a proportion of intermediate goods sold in imperfect competitive market, the final goods are produced by combining a continuum of these differentiated intermediate goods $Y_{1t}(j)$, indexed by $j \in [0,1]$ in the following Dixit-Stiglitz technology:

$$Y_{1t} = \left[\int_0^1 Y_{1t}(j)^{\frac{1}{1+\lambda_{p,t}}} dj\right]^{1+\lambda_{p,t}} \tag{4.1.22}$$

The profit maximization problem of the final good firm is[12]:

$$\Pi_t = P_{1t} Y_{1t} - \int_0^1 P_{1t}(j) Y_{1t}(j) dj \tag{4.1.23}$$

Where $P_{1t}(j)$ is the price of jth intermediate goods, P_{1t} is the price of final goods. $\lambda_{p,t}$ can be considered as a measure of their market power, which provides a source of nominal stickiness in the economy. It is an exogenous process. A shock to this stochastic parameter will be interpreted as a cost-push shock to the inflation equation, as it will result in changes to the elasticity of demand and therefore time-varying markup in the goods market.

Deriving first order condition with respect to $Y_{1t}(j)$, the demand function for thejth intermediate good is given by:

$$Y_{1t}(j) = \left(\frac{P_{1t}(j)}{P_{1t}}\right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_{1t} \tag{4.1.24}$$

Combining above equation with zero-profit condition, we can obtain the relationship between final goods price and intermediate goods price.

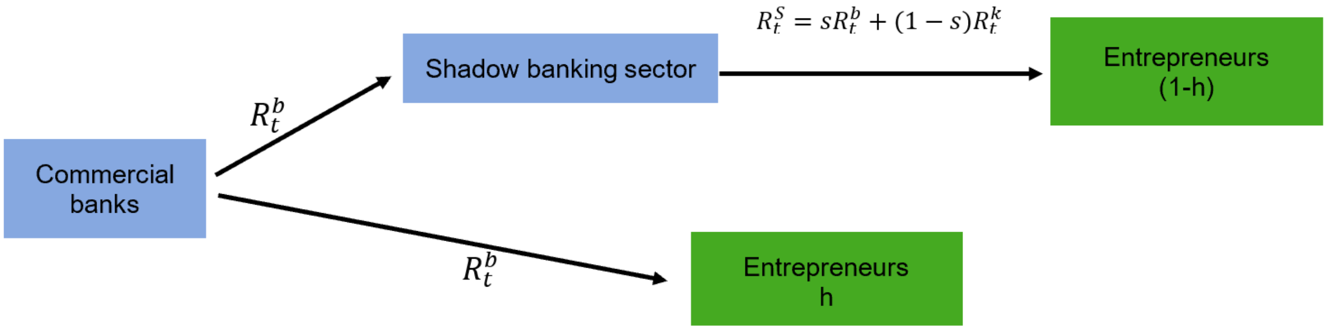
$$P_{1t} = \left(\int_0^1 P_{1t}(j)^{-\frac{1}{\lambda_{p,t}}} dj\right)^{-\lambda_{p,t}} \tag{4.1.25}$$

4.1.4 Intermediate goods producers

[12] Since there are no intertemporal effects, the final good producer's problem is actually static.

4.1.4.1 With the shadow-banking sector

We augment our DSGE model with a shadow banking sector, which can be thought of as representing the intermediation of funds between households and the set of entrepreneurs who are unable to borrow from the commercial banks. The model works as follows: we think of banks as the bank in normal mode, plus an investment partner, such as hedge funds, representing high net worth households that want to invest directly in risky capital. Thus, in our model, commercial banks are designed to lend money to shadow banks (hedge funds) who will grant loans to a $1-h$ proportion of firms through an equity channel. For this part of firms[13], suppose the hedge fund share in the investment is $1-s$, then the interest rate in the shadow-banking sector R_t^S is set as $sR_t^b + (1-s)R_t^k$, implying that for high net worth households, they want to take a stake, aiming to get an R_t^kreturn, while to firms, they have to surrender some of its R_t^k return due to the hedge funds participating in the capital. Then for the rest h part of firms, they borrow from commercial banks at the commercial lending rate R_t^b. Therefore, in my model, commercial banks can lend to both firms and shadow banks at the external financing cost a la Bernanke et al (1999), but shadow banks engage in equity lending to several firms who might not be able to get fundings at all, while passing on the commercial rate to other firms. This means that the shadow banking rate – a weighted average of commercial banks' rate and the return on capital, is lower than the commercial rate itself. Altogether, across all firms, the cost of external finance will be a weighted average of the lending rate by the commercial banks and shadow banks' lending rate $R_t^C = hR_t^b + (1-h)R_t^S$.



Cost of external finance: $R_t^C = hR_t^b + (1-h)R_t^S$

[13] Similarly to Verona et al (2013), these firms refer to the ones who are big enough to issue corporate bonds to raise funds, or we can think of small start-ups who need capital venture to take off the ground. Households provide funds via savings to both the shadow banking system/investment banks and commercial/retail banking system/retail banks. The shadow banks lend money to safer entrepreneurs through bond finance, while the commercial/retail. banks lend to riskier entrepreneurs through bank loans. This means that shadow lending is done at a lower rate than retail/commercial lending.

Figure 4.1.4: Structure of the shadow-banking sector

4.1.4.2 Production and price decision

Intermediate goods producers hire labour and purchase capital services from the capital producers to produce differentiated intermediate goods by using the following Cobb-Douglas production function with fixed costs Φ:

$$Y_t(j) = \epsilon_t^a K_t^s(j)^\alpha [\gamma^t L_t(j)]^{1-\alpha} - \gamma^t \Phi \tag{4.1.26}$$

Where $K_t^s(j)$ and $L_t(j)$ denote capital services and aggregate labour input to produce the jth intermediate good, $j \in [0,1]$. $0 < a < 1$ stands for the capital share in production. $\Phi > 0$ denotes fixed cost of production[14]. γ^t respresents the labour-augmenting deterministic growth rate in the economy, ϵ_t^a is total factor productivity, this stochastic productivity level is common across firms and follows a ARIMA(1,1,0) process:

$$ln\epsilon_t^a = \ln\epsilon_{t-1}^a + \rho_a(ln\epsilon_{t-1}^a - ln\epsilon_{t-2}^a) + \eta_t^a, \quad \eta_t^a \sim N(0, \sigma_a^2).$$

Intermediate firms choose the optimal utilization rate of capital for producing intermediate goods. The profit maximization problem is:

$$max\ R_t^k\ U_t(j)K_{t-1}(j) - P_t a(U_t(j))K_{t-1}(j) \tag{4.1.27}$$

Where $K_t^s(j) = U_t(j)K_{t-1}(j)$ denotes the amount of effective capital they use, $U_t(j)$ is the utilization rate of capital, R_t^k is marginal product of capital. The first component $R_t^k\ U_t(j)K_{t-1}(j)$ represents the income from capital production, the second term $P_t a(U_t(j))K_{t-1}(j)$ is the cost of changing capital utilization.

The first-order condition for capital utilization is:

$$\partial U_t(j): \qquad \frac{R_t^k}{P_t} = a'(U_t) \tag{4.1.28}$$

The intermediate firms' optimisation problem includes the following two parts, solving the cost minimization problem to determine the relationship between capital and labour demand; Setting the optimal price by maximizing the profit. For the first problem, the cost minimization implies:

$$\min W_t L_t(j) + R_t^k K_t^s(j)$$

$$s.t. \quad Y_t(j) = \epsilon_t^a K_t^s(j)^\alpha [\gamma^t L_t(j)]^{1-\alpha} - \gamma^t \Phi \tag{4.1.29}$$

[14] Correspond with Basu and Fernald(1994), Hall(1988), and Rotemberg and Woodford(1995), fixed cost is set to guarantee that economic profits are close to zero in steady state.

Yielding the following conditions:

$$\partial K_t:\ \Theta_t(j)\,\gamma^{t(1-\alpha)}\,\alpha\epsilon_t^a K_t^s(j)^{\alpha-1}L_t(j)^{1-\alpha} = R_t^k \tag{4.1.30}$$

$$\partial L_t:\ \Theta_t(j)\,\gamma^{t(1-\alpha)}(1-\alpha)\epsilon_t^a(\frac{K_t^S(j)}{L_t(j)})^{\alpha} = W_t \tag{4.1.31}$$

Where $\Theta_t(j)$ is the Lagrange multiplier associated with the production function and equals marginal cost MC_t

Combining equation (4.1.30) and (4.1.31) to derive the identical capital-labour ratio across firms:

$$K_t^s = \frac{\alpha W_t}{(1-\alpha)\,R_t^k}L_t \tag{4.1.32}$$

The firm's marginal cost is given by:

$$MC_t = \frac{(R_t^k)^{\alpha}W_t^{1-\alpha}}{\epsilon_t^a\alpha^{\alpha}(1-\alpha)^{(1-\alpha)}\gamma^{t(1-\alpha)}} \tag{4.1.33}$$

It implies that the marginal cost MC_t is also independent of the intermediate goods produced and is also the same for all firms due to the constant return to scale, so it is taken as given to the firm when it decides on price for simplification:

The second part of the firm's problem is the price decision which will closely mimic the wage decision via the Calvo pricing with partial indexation. The intermediate firms produce intermediate goods and set prices for their products to maximize profits. In each period, the probability that a firm receives a price signal to reset its price is constant and equal to $1 - \xi_p$, however, if they do not receive the price signal, the price of for its products is indexed to the weighted sum of last period's inflation and inflation objective from the central bank. The profit maximization implies that:

$$MaxE_t\sum_{s=0}^{\infty}\xi_p^s\left[\frac{\beta^s\Xi_{t+s}P_t}{\Xi_tP_{t+s}}\right]\left[\tilde{P}_{1t}(j)\left(\Pi_{l=1}^{s}\gamma\pi_{t+l-1}^{\iota_p}\pi_*^{1-\iota_p}\right)-MC_{t+s}\right]Y_{1t+s}(j) \tag{4.1.34}$$

$$s.t. \qquad Y_{1t+s}(j) = \left(\frac{P_{1t+s}(j)}{P_{1t+s}}\right)^{-\frac{1+\lambda_{p,t+s}}{\lambda_{p,t+s}}}Y_{1t+s}$$

Where $\tilde{P}_{1t}(j)$ is the newly set optimal price, $\frac{\beta^s\Xi_{t+s}P_t}{\Xi_tP_{t+s}}$ is the firm's nominal discount factor, this is consistent with the discount factor for households who are final owners of the firms. ι_p is the indexation parameter. This equation represents the difference between revenues from sales and costs.

Derive the first order condition with respect to $P_{1t}(j)$ and simplify the equation, we obtain:

$$E_t \sum_{s=0}^{\infty} \xi_p^s \frac{\beta^s \Xi_{t+s} P_t}{\Xi_t P_{t+s}} Y_{1t+s}(j) \frac{1}{\lambda_{p,t+s}} \left[\left(1+\lambda_{p,t+s}\right) MC_{t+s} - \Pi_{l=1}^{s} \gamma \pi_{t+l-1}^{\iota_p} \pi_*^{1-\iota_p} \tilde{P}_{1t}(j) \right] = 0 \quad (4.1.35)$$

It implies that the price set by the intermediate firm j at time t is a function of expected future marginal costs. If $\xi_p^s > 0$, the optimal price is a markup over the weighted average of marginal costs. Under the sticky prices, the mark-up becomes variable over time when the economy is hit by exogenous shocks. A positive demand shock lowers the mark-up and stimulates employment, investment and real output; If $\xi_p^s = 0$, prices are flexible, for the intermediate goods sold in perfectly competitive market, the firm sets its price at a markup over expected marginal cost $1 + \lambda_{p,t+s}$.

As firms are identical and they set the same prices, we can drop the indices. The aggregate price index for the intermediate goods sold in the imperfectly competitive market is given by:

$$P_{1t} = \left[\left(1-\xi_p\right) \tilde{P}_{1t}^{\frac{1}{\lambda_{p,t}}} + \xi_p \left(\gamma \pi_{t-1}^{\iota_p} \pi_*^{1-\iota_p} P_{1t-1} \right)^{\frac{1}{\lambda_{p,t}}} \right]^{\lambda_{p,t}} \quad (4.1.36)$$

4.1.4.3 Loan decision and the standard debt contract

As in BGG (1999), asymmetric information causes financial friction between entrepreneurs and banks. Here, I focus on the endogenous leverage constraints that arise from the agency problem between banks and firms. Specifically, we incorporate financial accelerator effects by setting up an endogenous financial contract and financial intermediaries. Intermediate firms (entrepreneurs) play a critical role in the economy. The acquisition of capital they purchase is financed by their net worth, pledged as loans from the bank, which converts household savings into lending. Particularly, their net worth matters as the objective of financial accelerator via the firms' balance sheet channel is to show how fluctuations in borrower's net worth can act to amplify and propagate the exogeneous shock from the credit market to the real economy, thus firms' net worth is associated with their financial position which determines their cost of external finance. A firm with a higher level of net worth can obtain more financing at a lower monitoring cost, as the agency problem is mitigated, resulting in a lower external finance premium; thus, firms can invest more.

Furthermore, to endogenously motivate the existence of an external finance premium, we turn to the optimal financial contract problem under the assumption of ‘costly state verification’. As Townsend (1979) showed, this assumption explains why external finance may be more expensive than internal finance without imposing arbitrary restrictions on the contract structure. We then proceed in three steps. We first derive the bank’s zero profit condition, then we turn to the firm’s expected return maximization problem and finally solve the firm's partial equilibrium problem of optimal contract to generate the relationship between the firm’s demand for capital and net worth and embed this into the model.

Zero profit condition on the bank

As in the BGG paper, the intermediate goods producer is subject to an idiosyncratic disturbance ω to its return, lenders must pay a fixed auditing cost if they wish to observe an individual borrower's realized return on capital, but the borrower observes the return for free. Thus, the optimal contractual arrangement is designed to minimize the expected agency costs.

For a firm who has to finance the difference between its expenditures on capital goods and net worth, the amount of money they borrow is given by:

$$B_{t+1} = q_t K_{t+1} - NW_{t+1} \tag{4.1.37}$$

The threshold value of the idiosyncratic shock $\overline{\omega}$ is defined by:

$$\overline{\omega}(1 + R^b_{t+1}) q_t K_{t+1} = Z_{t+1} B_{t+1} \tag{4.1.38}$$

Where R^b is the required return on capital for a firm. If the value of idiosyncratic shock is above the threshold level $\overline{\omega}$, $i.e.\ \omega \geq \overline{\omega}$, this firm is able to repay the loan at the contractual rate Z_{t+1} and keeps the surplus which is equal to $\omega(1 + R^b_{t+1}) q_t K_{t+1} - Z_{t+1} B_{t+1}$, where $Z_{t+1} B_{t+1}$ is the value of funds they promised to pay the lender. However, if $\omega < \overline{\omega}$, the entrepreneur would declare default, in this situation the bank pays the auditing cost and keeps what it finds. While a defaulting firm receives nothing. Particularly, the auditing cost is essentially the cost of bankruptcy[15], it is assumed to equal a proportion μ of the realized gross payoff to the firm's capital, thus the net receipts of the bank are $(1 - \mu)\omega(1 + R^b_{t+1}) q_t K_{t+1}$.

[15] Including for example auditing, accounting, and legal costs, as well as losses associated with asset liquidation and interruption of business.

As bank is perfectly competitive, under the zero-profit condition, the optimal financial contract takes a state-contingent form must satisfy:

$$[1 - F(\overline{\omega})]Z_{t+1}B_{t+1} + (1-\mu)\int_0^{\overline{\omega}} \omega(1 + R_{t+1}^b)q_t K_{t+1} dF(\omega) = (1 + R_{t+1})B_{t+1} \quad (4.1.39)$$

Where $F(\overline{\omega})$ denotes the probability of default, it is the cumulative distribution function of ω. The values of $\overline{\omega}$ and Z_{t+1} under the optimal contract for the bank are determined by the requirement that an expected return on the bank's lending is equal to the bank's opportunity cost of obtaining funds from households at the risk-free rate R_{t+1}. The riskless rate is the relevant opportunity cost because under the assumption, firms are risk-neutral and households are risk-averse. Under the financial contract, firms have to absorb any aggregate risk. In equilibrium, the bank holds a perfectly safe portfolio, which perfectly diversifies the idiosyncratic risk involved in lending, implying that households earn the riskless rate on their saving. Therefore, to ensure that loan risk is perfectly diversifiable, the optimal loan contract must satisfy the above equation.

Combining equations (4.1.37) and (4.1.38) with equation (4.1.39) to eliminate Z_{t+1}, we can derive the bank's expected return as a function of the cutoff value of the firm's idiosyncratic productivity shock $\overline{\omega}$:

$$\{[1 - F(\overline{\omega})]\overline{\omega} + (1-\mu)\int_0^{\overline{\omega}} \omega dF(\omega)\}\,[(1 + R_{t+1}^b)q_t K_{t+1}] = (1 + R_{t+1})(q_t K_{t+1} - NW_{t+1}) \quad (4.1.40)$$

Similar to BGG (1999), we are restricting attention to non-rationing equilibria, i.e., equilibria in which the equilibrium value of $\overline{\omega}$ always lies below the maximum feasible value. Since the expected payoff function is concave in this case, the lender's expected return is always increasing in $\overline{\omega}$. The above equation implies a set of restrictions, one for each realization of R^b. Specifically, $\overline{\omega}$ is contingent on the realized aggregate state and there exists a value of $\overline{\omega}$ for each aggregate state that satisfies the above equation. Under aggregate risk, $\overline{\omega}$ will depend on the ex-post realization of return on capital R^b. According to the assumption, firms are risk-neutral and households are risk-averse, the project firm is investing in exhibits constant returns to scale in production. That implies that the risk-neutral firm cares only about the mean return on his wealth. The firm is willing to bear all the aggregate risk because his value function can be shown to be linear in wealth as proved in Bernanke and Gertler (1989, 1990). Thereby, he is willing to guarantee the bank a return that is free of any systematic risk. It indicates that conditional on the ex-post realization of return on capital R^b, the firm offers a state-contingent non-default payment to ensure that the lender receives a return equal in expected value to the riskless rate. Overall, non-default loan rate Z_{t+1} is countercyclically. A lower realization of R^b indicates a higher default probability; lenders must be compensated with a higher non-default payment and loan rate, and the premium on external funds rises.

Firm's expected return maximization problem

Then we turn to the firm's general problem of determining its demand for capital. The firm's expected return on capital is given by:

$$E\{\int_{\overline{\omega}}^{\infty}\omega(1+R_{t+1}^{b})q_tK_{t+1}dF(\omega)-[1-F(\overline{\omega})]\overline{\omega}(1+R_{t+1}^{b})q_tK_{t+1}\} \quad (4.1.41)$$

Combining equation (4.1.40) with equation (4.1.41) to simplify the firm's objective to maximization of:

$$E\{(1-\mu\int_{0}^{\overline{\omega}}\omega dF(\omega))U_{t+1}^{b}\}\ E\{(1+R_{t+1}^{b})\}q_tK_{t+1}-(1+R_{t+1})(q_tK_{t+1}-NW_{t+1})$$
(4.1.42)

Where we define $U_{t+1}^{b}\equiv\frac{1+R_{t+1}^{b}}{E\{1+R_{t+1}^{b}\}}$ is the ratio of the realized return to capital to the expected return.

Now we can express optimal contracting problems as the firm's maximization of expected return (4.1.42)subject to zero profit condition on bank (4.1.40). We define the external financing premium as

$s_t\equiv \mathrm{E}\left\{\frac{1+R_{t+1}^{b}}{1+R_{t+1}}\right\}$, with $s_t\geq 1$, we derive the first order conditions of the optimal contract to yield the relation for optimal capital purchases:

$$E\{1+R_{t+1}^{b}\}=s\left(\frac{NW_{t+1}}{q_tK_{t+1}}\right)(1+R_{t+1}) \quad (4.1.43)$$

Where $s'(.)<0$ is a decreasing function of the share of a firm's net worth to capital investment.

Log-linearizing yields:

$$E_t\hat{r}_{t+1}^{b}-\hat{r}_t=\hat{pm}_t=\chi(\hat{q}q_t+\hat{k}_{t+1}-\hat{nw}_{t+1})+\epsilon_t^{pm} \quad (4.1.44)$$

This equilibrium condition implies that the external finance premium pm_twhich is measured by the wedge between the cost of external finance and the cost of internal finance, or the difference between the expected return on capital and riskless return, depends positively on the leverage ratio which is defined by $Lev_t=q_tK_{t+1}/NW_{t+1}$. Where $\chi>0$ is the parameter that measures the degree of financial friction. ϵ_t^{pm} is premium shock. For a firm with a lower leverage ratio, the expected default probability reduces. Thus, the firm can expand its investment and take on more debt. Nevertheless, it is constrained from raising the size of the firm indefinitely by the fact that expected default costs also rise as the ratio of borrowing to net worth increases.

4.1.4.4 Firms net worth and capital arbitrage condition

We assume that the probability that each firm can survive to the next period is constant and equal to θ, the net worth of each firm is kept below the demand for capital by a fixed death rate of these firms $(1-\theta)$. Having the survival probability be constant facilitates aggregation.

The aggregate firm's net worth is given by:

$$NW_{t+1} = \epsilon_t^{nw}\theta V_t \tag{4.1.45}$$

Where V_t is the firm's equity or wealth accumulated by entrepreneurs from operating firms. ϵ_t^{nw} represents the shock to equity.

Firm's equity is given by the gross return on capital less expected return (repayment of borrowings):

$$V_t = (1+R_t^b)q_{t-1}K_t - E_{t-1}[(1+R_t^b)(q_{t-1}K_t - NW_{t-1})] \tag{4.1.46}$$

Combining Equations (4.1.45) and (4.1.46), yields the net worth as follows:

$$NW_{t+1} = \epsilon_t^{nw}\theta V_t = \epsilon_t^{nw}\theta\left[(1+R_t^b)q_{t-1}K_t - E_{t-1}[(1+R_t^b)(q_{t-1}K_t - NW_{t-1})]\right] \tag{4.1.47}$$

A firm that drops out of the market will consume the residual equity. So entrepreneurial consumption is given by:

$$C_t^e = (1-\theta)V_t \tag{4.1.48}$$

As in BGG(1999), the firms purchase capital from capital producers at price q_t for production, at period $t+1$, they receive the marginal product of capital $R_{t+1}^k$and sell the undepreciated fraction $1-\delta$ of its capital back to the capital producers also at price q_t. The capital arbitrage condition across all the firms is given by:

$$\mathbb{E}_t[R_{t+1}^C] = \mathbb{E}_t\left[\frac{R_{t+1}^k + (1-\delta)q_{t+1}}{q_t}\right] \tag{4.1.49}$$

where $E_t R_{t+1}^C$ is the expected marginal rate of return on capital and δ is the depreciation rate. This equation implies that the expected gross return to holding a unit of capital (cost of external finance) from period t, to $t+1$ is equal to marginal product of capital plus capital gain.

4.1.5 Capital producers

Competitive capital producers purchase investment I_t from final goods producers and undepreciated capital $(1-\delta)K_{t-1}$ at period $t-1$ from intermediate goods producers, combining them to produce new capital and resold to intermediate firms at price q_t. However, the transformation of investment goods is subject to quadratic adjustment costs.

The representative capital producer's profit maximization problem is given by:

$$\max_{I_t} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \lambda_t [q_t K_t - q_t(1-\delta)K_{t-1} - I_t] \quad (4.1.50)$$

subject to the capital accumulation equation:

$$K_t = (1-\delta)K_{t-1} + \epsilon_t^i \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t \quad (4.1.51)$$

Where δ is the depreciation rate, I_t denotes gross investment. Changes in investment are in association with additional costs, $S(\cdot)$ is the adjustment cost function, with $S(1)=0$, $S'(1)=0$, and $S''(1)>0$ (i.e. the adjustment cost function for investment is positive and its first derivative equals zero in steady state). As in Kiyotaki and Moore (1997), we incorporate adjustment cost to allow for a variable capital price because the variability of asset price contributes to volatility in entrepreneurial net worth. ϵ_t^i is investment shock and follows an exogenous process:

$$ln\epsilon_t^i = \rho_i ln\epsilon_{t-1}^i + \eta_t^i, \quad \eta_t^i \sim N(0, \sigma_i)$$

First order condition with respect to I_t to derive the investment demand equation:

$$1 = q_t \epsilon_t^i \left(1 - S\left(\frac{i_t}{i_{t-1}}\right) - S'\left(\frac{i_t}{i_{t-1}}\right)\frac{i_t}{i_{t-1}}\right) - \beta E_t \left\{\frac{\lambda_{t+1}}{\lambda_t}\left[q_{t+1}\varepsilon_{t+1}^i S'\left(\frac{i_{t+1}}{i_t}\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right]\right\} \quad (4.1.52)$$

4.1.6 Quantitative easing and bank regulation

We start by allowing the effects of quantitative easing. The Fed has implemented four rounds of quantitative easing programs from the 2008 financial crisis through the 2022 COVID period, seeking to provide more monetary stimulus. The first round of QE1 was announced in late 2008, involving \$1.25 trillion in purchases of mortgage-backed securities. As an unconventional policy, the central bank turns to quantitative easing when the short-term interest rates reach the zero lower bound.

As in Le et al. (2016), collateral is incorporated into the model. In the BGG paper, firms put up no collateral, all the net worth is invested in capital purchase, once they go bankrupt, they will obtain less value as second-hand sales. The requirement for some amount of collateral offers firms a greater incentive to avoid bankruptcy. Thus, based on these conditions, we augment the BGG paper with the assumption that banks require firms to provide a fraction c of their net worth as collateral. And the recovery of this collateral costs a proportion δ of its original value. Particularly, we use cash $M0$ as the cheapest collateral, since if firms hold some cash on their balance sheet, once they declare default, the lender can seize the collateral and recoup their loss directly without auditing cost, thus eliminating the cost of liquidation δ. With a fall in the cost of liquidating collateral, it lowers the credit premium for a given leverage, then firms are able to increase leverage and so raise their expected returns.

We then link the central bank's quantitative easing program with $M0$ collateral. The central bank issues $M0$ in exchange for the government bonds held by households, who would place extra $M0$ on deposit. The bank then lends it to firms, and we assume that firms wish to hold as much cash as possible for collateral use, as the minimum counterpart to the credit advanced. Thus $M0$ exists in firms' balance sheet where it will be pledged to the bank to prevent bankruptcy. Since a large part of collateral is held as $M0$, when the δ falls, the bank credit premium falls. Therefore, the effect of $M0$ is to reduce the credit premium via lowering the cost of liquidating collateral, which will further raise the firms' investment. The credit premium equation is now given by:

$$E_t\hat{r}^b_{t+1} - \hat{r}_t = \hat{pm}_t = \chi(\hat{qq}_t + \hat{k}_{t+1} - \hat{nw}_{t+1}) - \theta\hat{m}^0_t + \epsilon^{pm}_t \qquad (4.1.53)$$

where $\chi > 0$, is the elasticity of premium to $M0$. Conditional on leverage ratio, the injection of $M0$ into the premium equation, increasing bank's willingness to provide funds via zero profit condition. Thus with a lower bankruptcy threshold and lower required rate of return on firm, credit premium will reduce.

Turning to bank regulation, the widely used macroprudential policy tools involve collateral constraints, capital requirements for banks and affordability constraints on mortgage borrowers which aim to help stabilise debt, avoid excessive lending and reduce the risks posed by the financial market on the real economy. We model the regulation by adding an additional credit friction ς_{1t} to the credit premium equation as the impact of this is to raise the cost of lending to firms. We can consider it as a buffer of $M0$ or negative $M0$, to prevent excessive lending. Banks need to hold sufficient regulatory liquidity, so they cannot convert this part of the deposit into collateral. Hence, the credit premium equation becomes:

$$E_t \hat{r}^b_{t+1} - \hat{r}_t = \hat{pm}_t = \chi(\hat{qq}_t + \hat{k}_{t+1} - \hat{nw}_{t+1}) - \theta \hat{m}^0_t + \varsigma_t + \epsilon^{pm}_t \quad (4.1.54)$$

For $\varsigma_t > 0$, a tightening macroprudential policy is applied, raising the credit friction, reducing the credit supply. For $\varsigma_t < 0$, a loosening macroprudential policy is carried out, more liquidity will be injected into the financial market and it is analogous to the quantitative easing operation.

4.1.7 Monetary and government policy

For the normal regime before the crisis($r_t > 0.0625\%$ quarterly), the central bank conducts conventional monetary policy according to the Taylor rule as in SW (2007), so the interest rate is adjusted in response to developments in inflation and output.

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1-\rho)\left(\rho_\pi \hat{\pi}_t + \rho_y \hat{y}_t\right) + \rho_{\Delta y}\left(\hat{y}_t - \hat{y}_{t-1}\right) + \epsilon^r_t \quad (4.1.55)$$

$$\hat{m}^0_t - \hat{m}^0_{t-1} = \psi_1(\hat{m}^2_t - \hat{m}^2_{t-1}) + \epsilon^{m0}_t \quad (4.1.56)$$

$$\hat{m}^2_t = (1 + v - c - \mu)\hat{k}_t + \mu \hat{m}^0_t - v\hat{nw}_t \quad (4.1.57)$$

Where ρ denotes the degree of interest rate smoothing; ρ_π, ρ_y and $\rho_{\Delta y}$ are the Taylor rule's responses to inflation, output and change in output respectively. ψ_1 represents the elasticity of M0 to M2. v, μ, c are the ratios of net worth, M0 and collateral to money. The supply of M0 is set to accommodate the broad money supply M2 and M2 is determined by bank's balance sheets quantities in which M2 is defined as credit+M0.

In the crisis regime($r_t < 0.0625\%$ quarterly), the nominal interest rate fixed at the ZLB, the central bank resorts to unconventional monetary policy, making M0 the primary tool to target the credit market, aiming to reduce the premium for given leverage and boost the supply of credit. Then the supply of M0 is set contingent on the credit spread. The wider the credit spread, the greater the effort it requires to stabilise the premium via M0 injection. This feedback rule allows the monetary authority to alleviate the strains in the credit market before it brings credit provision back to normal.

$$\hat{m}^0_t - \hat{m}^0_{t-1} = \psi_2(\hat{pm}_t - \hat{pm}^*_t) + \epsilon^{m0}_t \quad (4.1.58)$$

where ψ_2 represents the elasticity of M0 with respect to premium.

Fiscal policy is similar as in SW (2007), its behaviour is taken as exogenous by households and firms. The government spending is subject to the stochastic disturbance ϵ_t^g:

$$\frac{G_t}{Y\gamma^t} = \epsilon_t^g \tag{4.1.59}$$

Resource constraints:

The resource constraint states that aggregate output Y_t depends on consumption, investment, exogenous government spending ϵ_t^g and entrepreneurs' consumption:

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{I}{Y}\hat{i}_t + (R_*^k k_y \frac{1-\psi}{\psi})\hat{rk}_t + \hat{c}_y^e \hat{c}_t^e + \epsilon_t^g \tag{4.1.60}$$

4.2 Calibrated fixed parameters

The model is calibrated using values consistent with those presented in earlier related papers, including Kimball (1995), Bernanke et al. (1999), Smets and Wouters (2007), Christiano et al. (2010), and Le et al. (2016). The value of these parameters can be summarised into two groups. The first group chooses the parameters based on previous estimated New Keynesian literature, and the second group lists the steady state ratios, which are difficult to identify from the data. Table 4.2 gives a full listing.

In the first group, we set the quarterly discount factor to 0.99, so the steady-state quarterly risk-free rate can be pinned down at 0.01. The depreciation rate for capital is set at the usual value of 0.025. The gross growth rate is calculated based on the net growth rate in percentage terms and equals 1.004. We set the survival rate of entrepreneurs at 0.97 quarterly, which corresponds with the value in Bernanke et al. (1999). Kimball aggregator curvature in the goods and labour market is set at 10 as in Smets and Wouters (2007).

In terms of the steady-state ratios listed in the second group, all these values are consistently selected in accordance with the model structure and data properties. From the log-linearised market clearing condition, we use the steady-state ratios as computed in Smets and Wouters (2007) to in line with studies of the US, so we take the steady-state share of the consumption in total output $\frac{C}{Y}$ to be 0.689, Investment to output ratio is set at 0.131. The entrepreneurial consumption to output ratio $\frac{C^e}{Y}$ is equal to 0.01 as indicated by Bernanke et al. (1999), since it takes up a relatively small and fixed fraction of aggregate net worth. We also follow the leverage ratio as in Bernanke et al. (1999), so that the ratio of capital to net worth is set at 2. The quarterly steady state values of shadow rate, total cost of capital and commercial lending rate are set based on average values of 2.30, 2.164 and 2.111 respectively, and the quarterly steady state return rate of capital is around 0.04.

Symbol	Description	Value
Fixed parameters		
β	Quarterly discount factor	0.99
δ	Depreciation rate	0.025
γ	Gross growth rate	1.004
θ	Survival rate of entrepreneurs	0.97
ε_p	Kimball aggregator curvature in the goods market	10
ε_w	Kimball aggregator curvature in the labour market	10
Steady state values		
$\frac{C}{Y}$	Consumption to output ratio	0.689
$\frac{C^e}{Y}$	Entrepreneurial consumption to output ratio	0.01
$\frac{I}{Y}$	Investment to output ratio	0.131
$\frac{K}{N}$	Capital to net worth ratio	2
R_*^s	Shadow rate	2.30
R_*^c	Total cost of capital	2.164
R_*^b	Commercial lending rate	2.111
R_*^k	Return rate of capital	0.038

Table 4.2: Parameters and steady-state ratios held fixed in the model

Chapter 5

Methodology: Indirect Inference Testing and Estimation Procedure

In this chapter, I discuss a classical statistical inferential method for evaluating and estimating our DSGE model. In Section 5.1, I introduce the concept of the Indirect Inference Wald testing procedure. In Section 5.2, I present the approach of using a VAR as the auxiliary model.

5.1 The method of Indirect Inference

Indirect inference provides a simulation-based method for testing a calibrated or estimated model. It is able to maintain the fundamental idea of comparing the moments generated by simulated data with the moments generated by actual data in the early real business cycle model. This method was developed by Minford et al. (2009) and then refined by Le et al. (2011), who evaluated the method using Monte Carlo experiments. The hallmark of the indirect inference is to posit an auxiliary model which is independent of the theoretical model. By evaluating the descriptors of the data by estimated parameters of the auxiliary model or IRFs and moments, we are able to evaluate the model's capacity in fitting the data for the sample period.

There are numerous papers that shed light on the use of Indirect inference in the estimation of structural models. See Smith (1993), Gregory and Smith (1991, 1993), Gourieroux et al. (1993), Gourieroux and Monfort (1997) and Canova (2011).In indirect estimation, we can choose the optimal parameters of the structure model once the estimates of the auxiliary model derived from simulated data are close to those derived from the actual data. The optimal sets of parameters for the structural model are those with minimal distance between a given function of the two sets of estimated coefficients of the auxiliary model. There are certain choices for this function, such as actual coefficients, the scores or the impulse response functions. However, when evaluating the model, the parameters of the structural model are taken as given, so we aim to compare the performance of the auxiliary model estimated on simulated data derived from the structural model with the performance of the auxiliary model when estimated from the actual data. Particularly, we treat the evaluated structural model as a true model of the economy as the null hypothesis, and we want to see whether the estimates of the auxiliary model obtained from the actual data sample lie within that model-based distribution derived from the simulated data, for a given rejection region. If the structural model is correct, then the predictions about the impulse responses, moments and time series properties of the data should match those based on the actual data.

We use a VAR as an auxiliary model because the solution of a log-linearised DSGE model can be approximately represented by a restricted VARMA model, and this can be further represented by a VAR. The reader is referred to Canova

(2011), Dave and De Jong (2007), Del Negro and Schorfheide (2004, 2006) and Del Negro et al. (2007) together with the comments by Christiano (2007), Gallant (2007), Sims (2007), Faust (2007) and Kilian (2007) for further discussion on the use of VAR to represent the solution of DSGE model. The model evaluation criterion is the Wald test, it is calculated via the difference between the vector of relevant VAR coefficients from simulated and actual data. If the model is correct, then the simulated data generated from the model will not be far away from the actual data. There are some other methods to estimate the DSGE model such as maximum likelihood and generalized method of moments or Bayesian. The reason why we use Indirect inference rather than the widely used approach of Bayesian is that for the latter, the Bayesian method is based on the assumption that the prior distributions and model structure are correct, but due to the uncertainty about priors, we may obtain biased results.

We carry out the whole procedure via modern computer resources. In practice, we first estimate the structural errors of the economic model conditional on the observed data and parameters. Particularly, the structural errors are not assumed to be normally distributed, and the number of those independent structural errors should be less than or equal to the number of endogenous variables. For equations without expectational terms, we back out structural errors directly from the equation and data, however, for equations with expectations, we follow McCallum (1976) and Wickens (1982), to estimate the expectations by employing lagged endogenous data as instrumental variables and we use VAR process to produce fitted values one-period ahead for the expectation. The structural errors are further regressed on their past values to generate identically independently distributed (i.i.d.) innovation of shocks. Then we bootstrap these shocks by drawing randomly with replacement from the set of innovations and add back those pseudo-random shocks into the model to generate the simulated data. Particularly, these shocks are bootstrapped 1000 times by time vector, aiming to preserve any simultaneity between them. Then these simulated data and actual data are input into the auxiliary model respectively to estimate their VAR coefficients. We test the model by comparing the VAR coefficients estimated on the actual data with the distribution of VAR coefficient estimates derived from multiple independent sets of the simulated data. Here, the Wald statistic is calculated based on the difference between a_T , the estimates of the VAR coefficients derived from actual data, and $\overline{a_s(\theta_0)}$, the mean of their distribution based on the simulated data, the formula is given by:

$$WS = (a_T - \overline{a_s(\theta_0)})'W(\theta_0)(a_T - \overline{a_s(\theta_0)})\ )$$

where $W(\theta_0)$ is the inverse of the variance-covariance matrix of the distribution of simulated estimates a_S. and θ_0 is the vector of parameters of the model on the null hypothesis that it is true.

To measure the closeness between the model and the data, the Wald percentile shows where in the Wald statistics bootstrap distribution the Wald statistic based on the data lies, this provides us with a practical indicator of how far the

Wald from the data lies in the tail of the distribution. For the model to fit the data at the 95% confidence level , we want the critical Wald statistic for the actual data to be less than the 95th percentile of the Wald distribution from the simulated data. Alternatively, this can be shown as Mahalanobis distance based on the same joint distribution which is the square root of the Wald value. Since the Wald is a chi-squared, the square root is asymptotically a normal variable, so the Wald percentile can be converted into a t-statistic by adjusting the mean and the size, or equivalent Wald p-value. If the resulting t-statistic is less than the threshold value of 1.645 at the 95% point of the distribution, we conclude that we do not reject the null hypothesis that the model is correct. The normalised t-statistics take the form of:

$$T = 1.645 * \left(\frac{\sqrt{2W^{\alpha}} - \sqrt{2k-1}}{\sqrt{2W^{95}} - \sqrt{2k-1}} \right)$$

where k is the number of parameters in a_T , WS^{α} is the Wald statistic on the actual data and WS^{95} is the Wald statistic for the 95th percentile of the simulated data. This is scaled by 1.645 so that when WS^{α} = WS^{95} the statistic come close to the 95th percentile of the standard normal distribution.

5.2 Using a VAR as the auxiliary model

Our model uses unfiltered data and contains non-stationary productivity shock, the reduced form of our model can be written as a VARMA model or approximately a VAR where non-stationary forcing variables enter as conditioning variables to achieve cointegration, so that the errors in the VAR are stationary after picking up the stochastic trends in the endogenous vector. After log-linearization, a DSGE model can be written as follows:

$$A(L)y_t = BE_t y_{t+1} + C(L)x_t + D(L)e_t$$

where y_t are $p \times 1$ vector of endogenous variables, $E_t y_{t+1}$are $r \times 1$ vector of expected future endogenous variables, x_t are $q \times 1$ vector of non-stationary exogenous variables and we assume are driven by:

$$\Delta x_t = a(L)\Delta x_{t-1} + d + c(L)\epsilon_t$$

Exogenous variables may consist of both observable and unobservable variables, such as a technology shock. The disturbances e_t and ϵ_t are both iid variables with zero means. L denotes the lag operator such as $z_{t-s} = L^s z_t$ and all polynomials in the lag operator have roots outside the unit circle. $y_t$is also non-stationary due to its linear dependency on x_t. The general solution of y_t is:

$$y_t = G(L)y_{t-1} + H(L)x_t + f + M(L)e_t + N(L)\epsilon_t$$

Where f is a vector of constants. As y_t and $x_t$are non-stationary, the solution has the p cointegration relations

$$y_t = [I - G(1)]^{-1}[H(1)x_t + f]$$
$$= \Pi x_t + g$$

In the long run, the endogenous variables are a function of the level of the unit root variables, which are in turn functions of all past shocks.

$$\overline{y}_t = \Pi \overline{x}_t + g$$
$$\overline{x}_t = [1 - a(1)]^{-1}[dt + c(1)\xi_t]$$
$$\xi_t = \sum_{i=0}^{t-1} \epsilon_{t-s}$$

The long-run behaviour of x_t is comprised of a deterministic trend $\overline{x}_t^D = [1 - a(1)]^{-1}dt$ and a stochastic trend $\overline{x}_t^S = [1 - a(1)]^{-1}c(1)\xi_t$, so the solution could be written as $\overline{x}_t = \overline{x}_t^D + \overline{x}_t^S$, it consists of this trend plus a VARMA in deviations from it.

An alternative formulation is as a cointegrated VECM with a mixed moving average error term ω_t

$$\Delta y_t = -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_t + f + M(L)e_t + N(L)\epsilon_t$$
$$= -[I - G(1)](y_{t-1} - \Pi x_{t-1}) + P(L)\Delta y_{t-1} + Q(L)\Delta x_t + f + \omega_t$$
$$\omega_t = M(L)e_t + N(L)\epsilon_t$$

which can be approximated as VARX

$$\Delta y_t = K(y_{t-1} - \Pi x_{t-1}) + R(L)\Delta y_{t-1} + S(L)\Delta x_t + g + \varsigma_t \quad (5.2.1)$$

where ς_t is an iid zero-mean process, or equivalently. Since $\overline{y}_{t-1} = \Pi \overline{x}_{t-1} + g$, the VECM can also be written as

$$\Delta y_t = K[(y_{t-1} - \overline{y}_{t-1}) - \Pi(x_{t-1} - \overline{x}_{t-1})] + R(L)\Delta y_{t-1} + S(L)\Delta x_t + h + \varsigma_t$$

Rewriting equation 5.2.1 as a levels VARX (1) we get

$$y_t = [I - K]y_{t-1} + \gamma \bar{x}_{t-1} + gt + v_t$$

where $\bar{x}_{t-1}$is the stochastic trend in productivity, gt are the deterministic trends, and v_t are the VECM innovations. This VARX (1) approximation to the reduced form of the model is the unrestricted auxiliary model used to assess the closeness of model-simulated samples to the observed data.

Following Le et al. (2011), the Wald statistic based on the full set of variables is referred to as the Full Wald test. It provides an approach to check the model’s specification in a wide sense. However, the power of the full Wald test increases as more endogenous variables are added and the lag order is increased, leading to uniform rejections. Thus, here we consider the other test of the Directed Wald statistic, which concentrates on more limited features of the structural model. Particularly, we select certain key macro variables into the VAR for testing, say output, interest rate and inflation, because we want to know how well these three variables are reproduced from the model, so that we create a Wald statistic based on the VAR equation for these three variables alone. It can also be used to measure how well the structural model captures the effects of a particular set of shocks by checking the joint distribution of the IRFs for these shocks. Even under misspecification in the model, the Directed Wald test provides information about whether the model is well-specified enough to deal with specific aspects of economic behaviour.

The VARX (1) serves as the auxiliary model takes the matrix form as follows:

$$\begin{bmatrix} y_t \\ \pi_t \\ r_t \end{bmatrix} = B \begin{bmatrix} y_{t-1} \\ \pi_{t-1} \\ r_{t-1} \end{bmatrix} + C \begin{bmatrix} T \\ \epsilon_t^a \end{bmatrix} + \begin{bmatrix} \varepsilon_t^y \\ \varepsilon_t^\pi \\ \varepsilon_t^r \end{bmatrix}$$

where

$$B = \begin{bmatrix} \theta_{yy} & \theta_{y\pi} & \theta_{yr} \\ \theta_{\pi y} & \theta_{\pi\pi} & \theta_{\pi r} \\ \theta_{ry} & \theta_{r\pi} & \theta_{rr} \end{bmatrix}$$

On the LHS, they are endogenous variables. On the RHS, we incorporate lagged endogenous variables in the first part. B stands for the coefficient matrix, which contains 9 parameters. T in the second part of RHS denotes deterministic time trend, ϵ_t^adenotes non-stationary productivity shock. The last part of RHS contains the error terms of the dependent variables. To calculate the Wald value, we focus on the coefficients on the lagged endogenous ones (matrix B). Hence, the parameter vector a consists of 9 coefficients in matrix B, plus the variances of three error processes:

$$\beta = \left[\theta_{yy}\ \theta_{y\pi}\ \theta_{yr}\ \theta_{\pi y}\ \theta_{\pi\pi}\ \theta_{\pi r}\ \theta_{ry}\ \theta_{r\pi}\ \theta_{rr}\ var(\varepsilon_t^y)\ var(\varepsilon_t^\pi)\ var(\varepsilon_t^r)\right]'$$

where the first 9 parameters characterize the dynamics of the data, and the last 3 capture the size of variations. The model will pass the test only if it jointly matches 12 coefficients. However, if I try to include an extra variable, this results in a 4×4 coefficient matrix plus 4 variance terms, i.e. 20 coefficients to match. The test could be too powerful and potentially reject a true model. If I reduce the variables to two, this results in a 2×2 coefficient matrix plus two variance terms, so 6 coefficients to match in total, which may lead to a reduction in testing power.

Chapter 6 Data

In this chapter, I begin with data dynamics in Section 6.1. Then, I characterize the shocks that explain macroeconomic dynamics in the US economy over the sample period in Section 6.2 and further analyse how the errors drive the episode in Section 6.3.

6.1 Macroeconomic data for the US

We employ quarterly eighteen macroeconomic series over 1980-2018. Data is not filtered, so it may be non-stationary and consist of random movements, which can contribute to economic fluctuations. Some studies use filtered data, such as the popular Hodrick-Prescott (HP) filter, which alters the lag dynamic structure, generating non-existent cycles. It may distort the dynamic properties of the model and also transform the forward-looking properties of the model due to the two-sidedness of the filter. These defects will affect the estimates of the model and bias the model's fit. Therefore, I prefer to use the original data.

Figure 6.1 shows the main series employed in our model. Grey shaded bars stand for the financial crisis in 2008. During the Great Inflation period in the early 1980s, inflation soared to its highest level. The chairman of the Federal Reserve Board, Paul Volcker, announced that fight against high inflation with higher interest rates and greater control of reserve growth and broad money supply growth. It might seem counterintuitive because this tightening monetary policy disrupted economic activity, manufactured a recession to bring prices back down, as high interest rates put pressure on industries reliant on borrowing, such as manufacturing and construction, leading to a high unemployment rate. During this time, business investment slowed, and productivity faltered due to the credit control. After some oscillation, inflation returned to target by November 1982, long-run interest rates began to decline, and the economy stabilized. Then, after the volatility of the Great Inflation, the US economy was relatively stable over the period of the mid-1980s to 2007, and reduced inflation and price stability laid the foundation for the Great Moderation. In 1989, the surge in inflation forced the Fed to raise the interest rate which restricted the credit into the economy and the savings and loan crisis and the oil price shock, worsened the already weak economy, causing the US economy to enter recession in early 1990, resulting in the rise in the unemployment rate. Since 1992, the GDP has grown slowly, with the economy in recovery. During this period, although the US economy was hit by many large shocks, such as the stock market crash of 1987, the Asian financial crisis in 1997, the changes in the structure of the economy like deregulation and effective monetary policy contributed to the flexibility of the economy and allowed the economy to adjust more smoothly to various shocks. The 2008 financial crisis began with falling house prices and rising mortgage defaults, then it was hit by the subprime mortgage crisis, and the bankruptcy of Lehman Brothers caused a global banking panic. The GDP fell sharply in 2008, and the unemployment rate rose more than doubled. To stimulate the economy, the Federal Open Market Committee (FOMC) lowered its target for the federal funds rate, setting the interest rate at a rock-bottom level of near-zero. They also initiated a series of large-scale asset purchase programs to inject liquidity into the market. During 2009, the economic weakness persisted. Output grew moderately, and the unemployment rate remained at historically elevated levels. The Fed maintained an exceptionally low level for the federal funds rate target and carried out quantitative easing to accelerate the economic recovery.

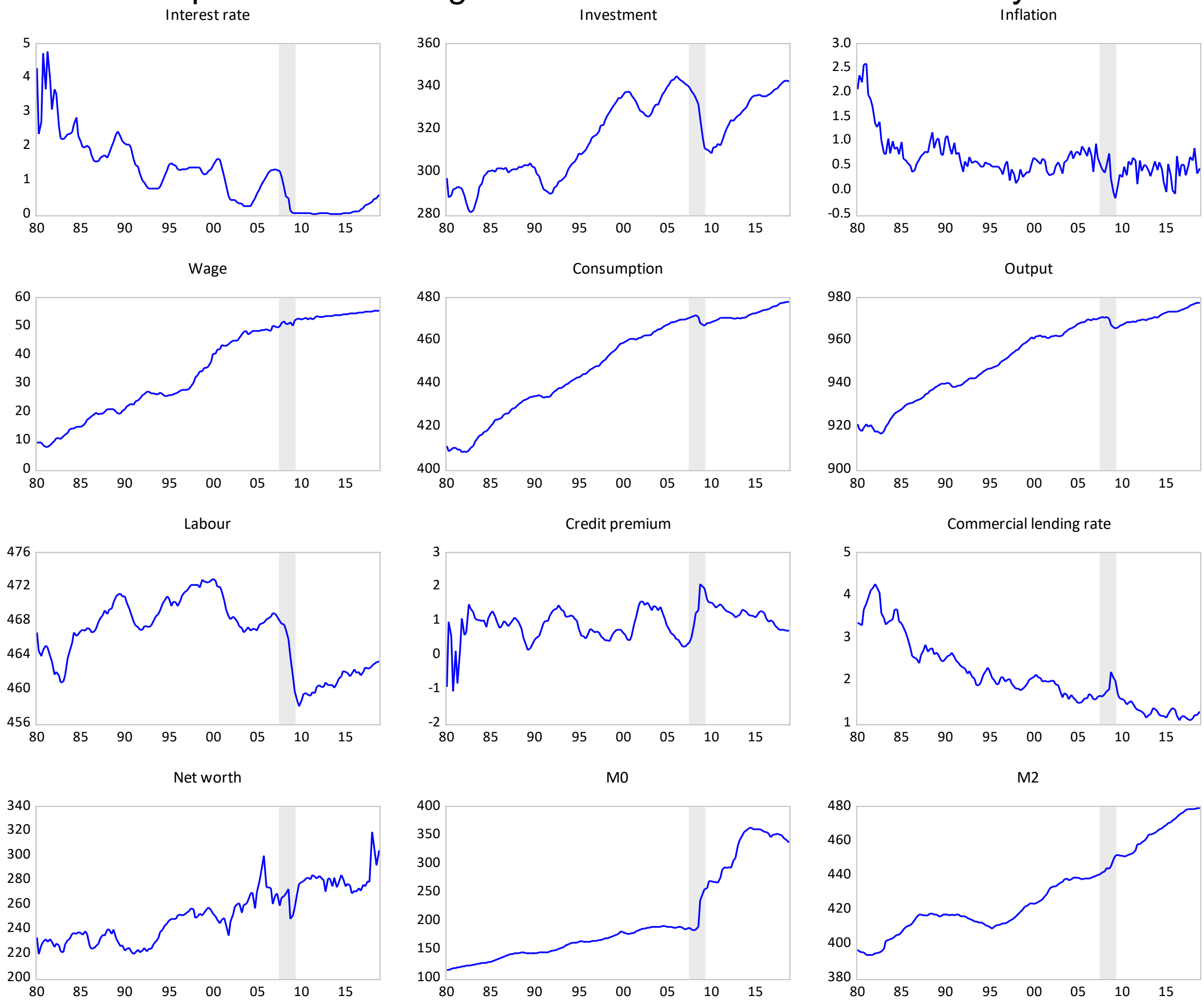


Figure 6.1: Data series (1980Q1 - 2018Q4)

6.2 Properties of shocks

Indirect Inference estimation is carried out in Chapter 5. Since the results show that the model with the shadow-banking sector is not rejected by the data, I then apply it to the recent crisis episode in the US. There are 12 structural shocks included in our DSGE model, which provide the source of volatility. I first extract model shocks from the unfiltered data, shocks are i.i.d. and follow an AR process. I then allow the error data to determine the AR parameters. Table 6.2.1 lists these shocks with results of their degrees of persistence and standard deviations. Although the AR coefficients do not closely approach the unit root, many of them show high persistence, such as price mark-up shock, labour supply shock and risk premium shock. Model implied shock histories are plotted in Figure 6.2.2.

Symbols & Descriptions		AR coefficients		Standard deviations
ϵ_t^g	Government spending shock	ρ_g	0.8338	0.4306
ϵ_t^g	Response of exogenous spending to productivity development	ρ_{ga}	0.2190	0.4306
ϵ_t^b	Preference shock	ρ_b	0.2089	0.2303
ϵ_t^i	Investment specific shock	ρ_i	0.5810	0.7242
ϵ_t^r	Taylor rule shock	ρ_r	0.5512	0.4803
ϵ_t^a	Productivity shock	ρ_a	0.2043	0.4562
ϵ_t^p	Price mark-up shock	ρ_p	0.9717	0.2409
ϵ_t^w	NK wage mark-up shock	ρ_w	0.9356	0.6422
ϵ_t^{ws}	Labour supply shock	ρ_{ws}	0.9747	2.6147
ϵ_t^{pm}	Risk premium shock	ρ_{pm}	0.9685	0.3644
ϵ_t^n	Net worth shock	ρ_n	0.3456	7.2207
$\epsilon_t^{m_0}$	Quantitative easing shock	ρ_{m_0}	0.3465	4.5735

Table 6.2.1: Statistical properties of shocks (1980Q4 - 2018Q3)

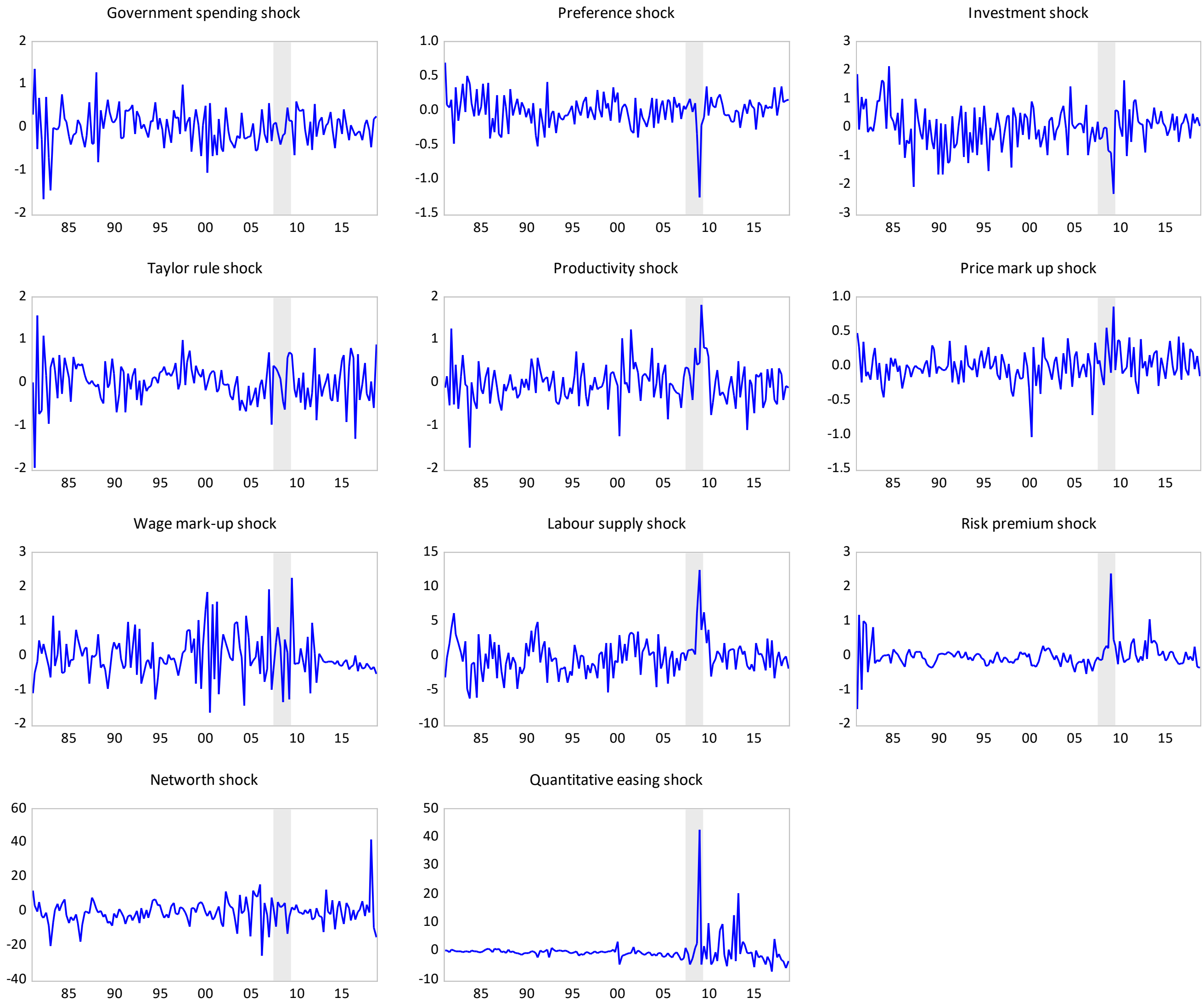


Figure 6.2.2: Model implied shock histories (1981Q1- 2018Q4)

6.3 Properties of errors

Beginning with plotting the behaviour of the main model errors in the sample period, the residuals are calculated as the total cumulated innovations over time. It can be seen from Figure 6.3.1 that there were two periods during which the US economy entered into recession and then bottomed out, the 'Great Inflation period' and the 'Financial Crisis period' separately. I focus on four key errors: productivity, labour supply, the external finance premium, and quantitative easing. These four are treated as the main drivers of the economic fluctuation during crises periods as they behave in a particularly persistent way. The productivity grows steadily during the recovery period but stalls and falls during great inflation and the financial crisis. There is a huge increase in quantitative easing error due to the operation of the zero bound. The labour supply error is derived from the competitive sector wage equation, which is the product of the upward real wage push or the decline in the labour force during these two recessions. As the rise in oil and commodity prices reduced the real wages, it might cause a reduction in labour supply through intertemporal substitution.

Finally, the error in the external finance premium equation also shows a huge persistent upward trend over these two periods, which might be a result of the savings and loan crisis in the first recession and then the panic of bank runs due to the collapse of Lehman and the sub-prime mortgage crisis in the great recession.

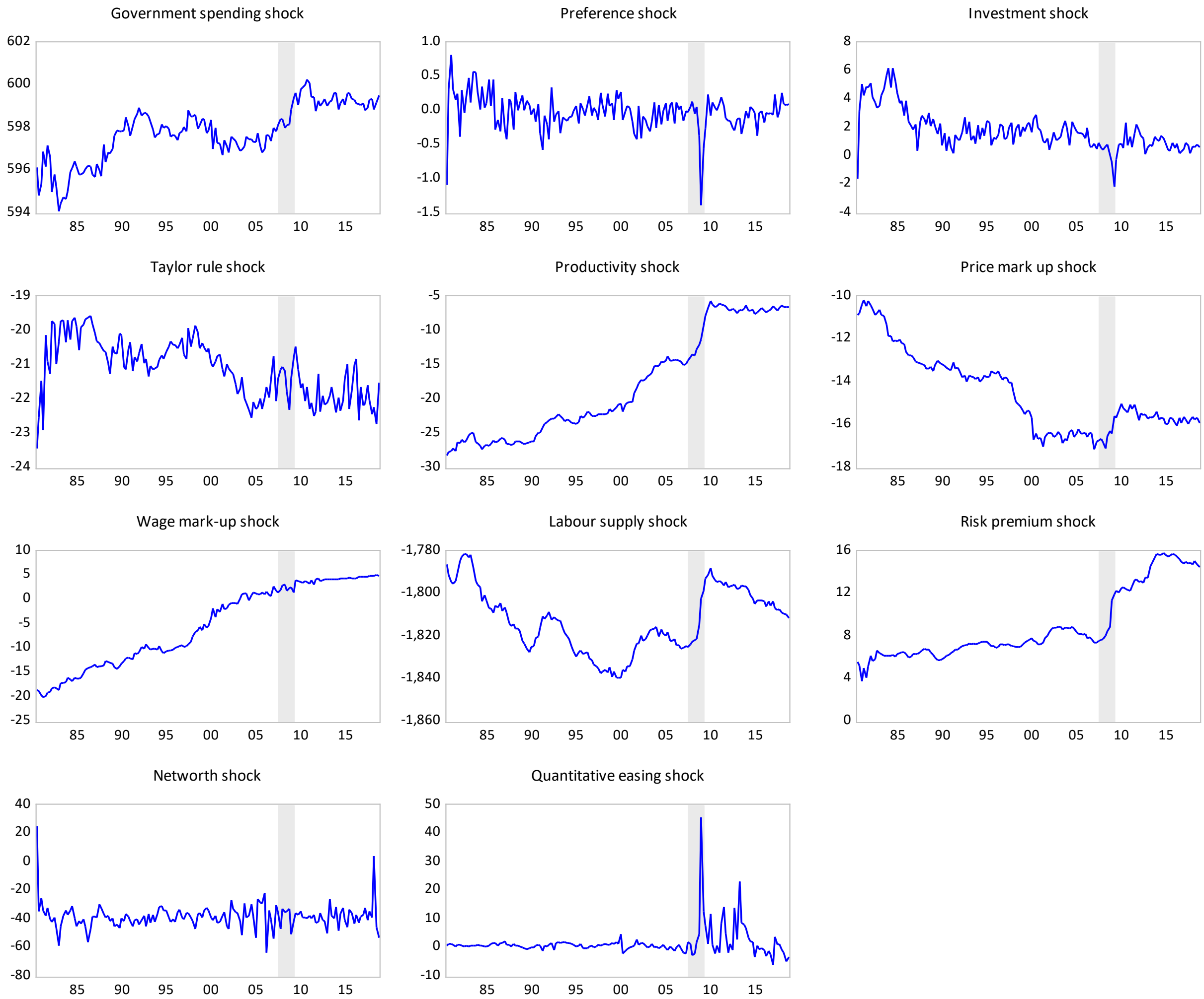


Figure 6.3.1: Model implied residual histories (1980Q3 - 2018Q4)

I then go on to test the stationarity of these time series. Here we use three stationarity tests, namely Augmented Dickey-Fuller (ADF, 1979), Phillips–Perron (PP,1988) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS,1992) tests. Particularly, both the ADF and PP tests for the null hypothesis of a unit root process, while the KPSS tests for the null hypothesis of stationarity. The results are reported in Table 6.3.2. We find that for wage mark-up, labour supply shock and risk premium shock, although the ADF and PP tests are consistent with unit roots, the KPSS test offers contradictory results. Besides, most of the shocks are treated as either stationary or trend-stationary, apart from the productivity shock, which apparently has a unit root, and it is specified in first differences. In sum, the TFP shock is the only I (1) process; in our assumption, it is treated as ARIMA (1,1,0), while the rest of the shocks are assumed to be AR (1).

	Augmented Dickey-Fuller t-stats				Phillips-Perron t-stats				KPSS LM-stats			
	Level(c)	Level(c,t)	Difference(c)	Conclusion	Level(c)	Level(c,t)	Difference(c)	Conclusion	Level(c)	Level(c,t)	Difference(c)	Conclusion
Government spending shock	-2.216	-3.360*	-16.646***	TS (10%)	-2.012	-3.963**	-17.858***	TS (5%)	1.054+++	0.129	0.064	TS(1%)
Preference shock	-3.601***	-4.408***	-17.190***	S(1%)	-5.400***	-7.358***	-25.337***	S(1%)	0.788+++	0.145+	0.104	TS(1%)
Investment shock	-3.066**	-4.505***	-18.025***	S(5%)	-5.593***	-8.342***	-20.484***	S(1%)	0.921+++	0.133+	0.114	TS(1%)
Taylor rule shock	-1.072	-8.403***	-16.406***	TS(1%)	-3.134**	-8.739***	-21.972***	S(5%)	1.280+++	0.068	0.174	TS(1%)
Productivity shock	-0.240	-1.742	-12.198***	I(1%)	-0.271	-1.951	-12.229***	I(1%)	1.429+++	0.240+++	0.102	I(1%)
Price mark-up shock	-4.218***	-3.517**	-12.921***	S(1%)	-3.711***	-3.549**	-17.521***	S(1%)	0.686++	0.260+++	0.217	S(1%)
NK wage mark-up shock	-1.212	-1.151	-16.595***	I(1%)	-1.150	-1.574	-17.153***	I(1%)	1.476+++	0.191++	0.205	TS(1%)
Labour supply shock Risk premium shock	-2.143	-2.110	-5.054***	I(1%)	-2.116	-1.933	-8.471***	I(1%)	0.363+	0.302+++	0.181	S(5%)
Net worth shock	-0.882	-1.616	-11.974***	I(1%)	-0.356	-1.862	-12.130***	I(1%)	1.224+++	0.190++	0.201	TS(1%)
Quantitative easing shock	-14.447***	-14.480***	-9.238***	S(1%)	-15.804***	-17.298***	-72.644***	S(1%)	0.072	0.074	0.247	S(1%)
	-8.411***	-8.478***	-10.860***	S(1%)	-8.547***	-8.602***	-53.465***	S(1%)	0.241	0.081	0.134	S(1%)
Critical values(1%)	-3.474	-4.020	-3.474		-3.474	-4.020	-3.474		0.739	0.216	0.739	
Critical values(5%)	-2.880	-3.440	-2.880		-2.880	-3.440	-2.880		0.463	0.146	0.463	
Critical values(10%)	-2.577	-3.144	-2.577		-2.577	-3.144	-2.577		0.347	0.119	0.347	

Table 6.3.2: Statistical properties of shocks (1980Q4 - 2018Q3). Note: Tests in levels are conducted with model "level (c)" with a constant, and "level (c,t)" with both constant and linear trend. Tests in first difference are conducted using model "difference (c)" with a constant only. For ADF and PP tests, asterisks denotes rejection of unit root null at 10 %(*) 5% (**)and 1%(***)significant levels respectively. The KPSS test evaluates the null of stationarity. Plus signs indicate rejection of the stationarity null for KPSS test at 10% (+), 5% (++) and 1% (+++) significance levels.

Chapter 7

Empirical Results by Indirect Inference

The DSDE model is first tested for the starting calibration. Then I re-estimate the model through the Indirect Inference estimation procedure. Both results are reported together in Section 7.1. In Section 7.2, I present the empirical results for the model and contrast the baseline model with the shadow-banking sector to a counterfactual one in which shadow banking is absent in Section 7.3. Section 7.4 depicts the historical variance decomposition.

7.1 Indirect Inference estimation and test result

The model is estimated by Indirect Inference to search for the best fit set of coefficients for the 1980 - 2018 period. The search is adjusted to around 30% on either side of the starting set of coefficients. The estimated model is also tested against the three main macroeconomic variables, output, inflation and the interest rate separately. I want to see whether the model can match the time series properties of the data jointly. In addition, I estimate the coefficients of the model with and without the shadow-banking sector to compare which model fits the data better. The estimated results are presented in Table 7.1. Note that estimation[1] shows the estimated coefficients of the model with the shadow-banking sector, and estimation[2] represents the estimated coefficients of the model without the shadow-banking sector. Specifically, for the model with the shadow-banking sector, the Wald t-statistic of 0.329 is conditional on estimated parameters being less than the threshold of 1.645, implying that the model fits the data well within the sample period. In addition, our P-value shows that the model with the shadow-banking sector fits better than the model without the shadow-banking sector.

The estimated set of coefficients is different from the calibrated coefficients, for which we used Le et al. (2016) estimated parameters of the non-shadow banking model. Many of them have moved some way below their starting values. For Taylor rule parameters, we can see that the Interest rate smoothing rate has decreased by 82%, the Taylor rule response to inflation is higher and has increased by 12%, indicating that monetary policy is estimated to be more responsive to the fluctuation of inflation. The Taylor rule response to output is constant, but the response to the change in output has decreased by 19%. For nominal friction parameters, the degree of wage inflation is higher than that of price inflation, indicating higher persistence; particularly, the former has decreased by 20% while the latter has increased by 11%. The low estimate of the coefficient on proportion of sticky prices in hybrid price setting, at 0.021, indicates a lower percentage of New Keynesian price has been estimated. In real friction parameters, external habit formation in consumption has decreased by 11%. Both the elasticity of investment adjustment cost and capital utilisation cost have decreased slightly, but the share of fixed costs in production has increased by 20%. The rest part is financial friction and monetary response parameters. The response of the spread to the leverage ratio has decreased by 69%, implying that the premium is less sensitive to the change in leverage. An increased impact of M0 on premium via quantitative easing implies higher sensitivity. For a non-crisis regime, the response of M0 to M2 has decreased by 5% and for a crisis regime, the response of M0 to the risk premium is almost the same. Other parameters, such as the coefficient of relative risk aversion, have been reduced by 16%, and the elasticity of labour supply with respect to the real wage has increased by 12%. For the estimated parameters from shadow banking equations, the proportion of entrepreneurs who rely on shadow bank lending has increased by 6%, and the hedge fund shares that participate with the entrepreneurs as equity partners have increased by 2%.

Symbol	Description	Calibration	Estimation[1]	Estimation[2]
Taylor rule parameters				
ρ	Interest rate smoothing	0.737	0.135	0.117
ρ_π	Taylor rule response to inflation	2.375	2.649	2.666
ρ_y	Taylor rule response to output	0.025	0.025	0.025
$\rho_{\Delta y}$	Taylor rule response to change in output	0.021	0.017	0.015
Nominal friction parameters				
ξ_p	Degree of Calvo price stickiness	0.973	0.169	0.146
ξ_w	Degree of Calvo wage stickiness	0.617	0.683	0.688
ι_P	Degree of indexation to past inflation	0.168	0.187	0.189
ι_w	Degree of indexation to past wages	0.354	0.284	0.246
ω^p	Proportion of sticky prices in hybrid price setting	0.090	0.021	0.018
ω_w	Proportion of sticky wages in hybrid wage setting	0.442	0.432	0.435
Real friction parameters				
λ	Degree of external habit formation in consumption	0.714	0.636	0.552
φ	Elasticity of investment adjustment cost	6.814	6.624	6.668
ψ	Elasticity of capital utilisation cost to capital inputs	0.104	0.102	0.089

ϕ	Share of fixed costs in production	1.761	2.113	2.127
Financial friction and monetary response parameters				
χ	Elasticity of risk premium to leverage ratio	0.032	0.010	0.009
θ	Risk premium response to M0 via quantitative easing	0.055	0.061	0.053
ψ_1	Elasticity of M0 to M2 (no crisis regime)	0.043	0.041	0.036
ψ_2	M0 responses to risk premium (crisis regime)	0.065	0.064	0.064
Other parameters				
σ_c	Coefficient of relative risk aversion	1.670	1.399	1.408
σ_l	Elasticity of labour supply with respect to the real wage	2.683	2.997	3.017
α	Share of capital in production	0.178	0.169	0.170
1-h	Proportion of entrepreneurs who rely on shadow bank lending	0.277	0.293	_
1-s	Hedge fund shares that participate with the entrepreneurs as equity partners	0.676	0.690	_
Wald (Y, π, R)		37.86	14.23	15.925
Transformed t-statistic (Y, π, R)		2.265	0.329	0.552
P-value		0.012	0.214	0.186

Table 7.1: Calibration and estimates of structural parameters (1980Q1 - 2018Q4)

7.2 Impulse response analysis

In this section, the impulse response functions (IRFs) are derived to analyse the impact of shocks on the economic outcomes. IRFs represent the response of the solved endogenous variables to a one-off shock. In the experiments, I take into account four types of aggregate shocks: the fiscal policy shock, the Taylor rule shock, the macro-prudential shock, and the quantitative easing shock.

7.2.1 Responses to government spending shock

Beginning with a fiscal policy shock. Figure 7.2.1 displays the effect of an expansionary fiscal shock in the standard non-crisis context (blue solid line) where the government spending shock is operating. In this case, we can see that the rise in government spending pushes up the output and inflation, driving the nominal interest rate rises via the response of the Taylor rule. This is the standard fiscal multiplier, causing crowding-out via a higher nominal interest rate. The rise in the nominal interest rate discourages consumption. In the labour market, real wage rises with higher output, and labour hours increase. The credit premium goes up with rising commercial lending rate, reflecting the decline in net worth. M0 increases to accommodate the expansionary fiscal policy. In addition, investment rises with the rising price of capital via the investment Euler equation; the interest rate in the shadow-banking sector rises due to the rise in capital utilisation and commercial lending rate.

In the crisis regime (red dashed line), the effects on some variables are slightly different from those in the non-crisis regime. When the nominal interest rate is fixed at the zero lower bound, consumption rises with the rise in output, and the lower interest rate also reduces the credit premium and drives up the net worth with a decreased commercial lending rate. In the labour market, the labour hours rise is higher when compared with the normal regime as the output and real wage response more.

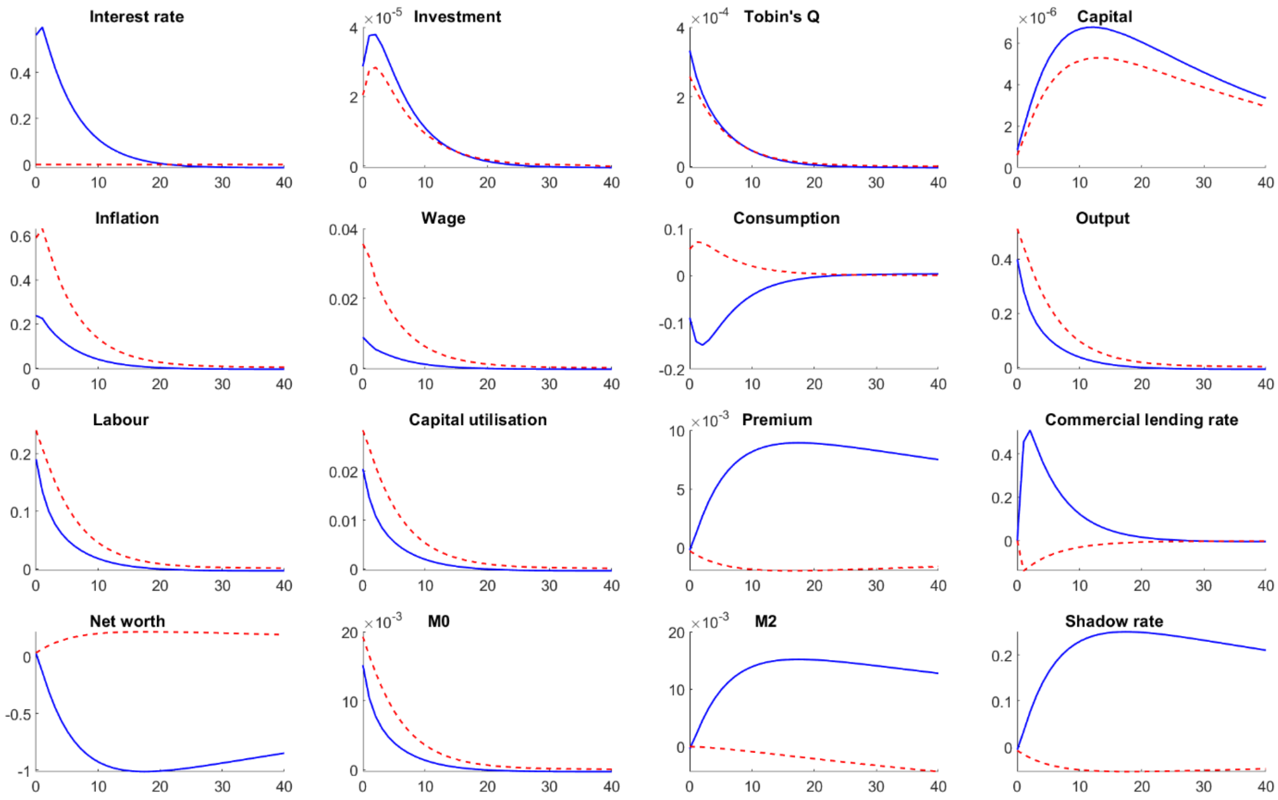


Figure 7.2.1: IRFs for a government spending shock to the non-crisis (solid blue) and crisis model (red dashed)

7.2.2 Responses to Taylor rule shock

The next experiment considered is the Taylor rule shock. Figure 7.2.2 depicts the responses of the main variables to a rise in the nominal interest rate, which is in line with stylized facts from most New Keynesian literature on monetary policy shock. Under the normal regime, the raised real interest rate discourages both consumption and investment, reducing demand for capital, and the price of capital falls. The decline in asset price also lowers the entrepreneurs' net worth, driving up the credit premium, which in turn further reduces the investment. The output falls due to a fall in investment and consumption, forcing down real wage and labour hours. The money supply, M0, falls in accordance with this contractionary monetary policy.

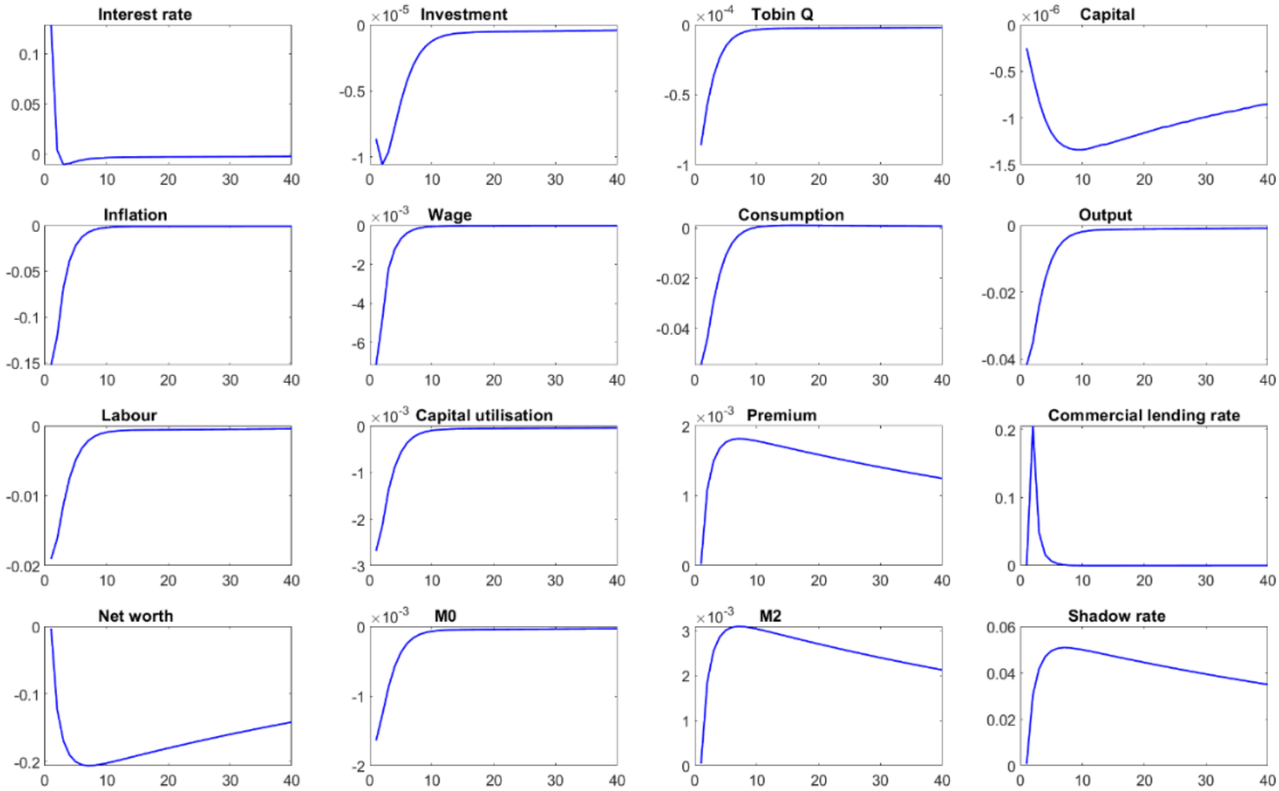


Figure 7.2.2: IRFs for a monetary policy shock to the non-crisis model

7.2.3 Responses to M0 shock

Figure 7.2.3 shows the effect of an exogenous shock to the supply of high-powered money M0. Under the normal regime, the increased M0 drives down the credit premium by raising asset price and stimulates an investment boom. With rising investment, the output rises. In the labour market, the labour supply increases with higher real wage. This in turn generates inflation and nominal interest rates rise via the Taylor rule, reducing consumption due to the higher cost of consumption. Moreover, the fall in credit premium pushes up the net worth with higher asset price.

The responses under the crisis regime are considerably more accentuated. The M0 expansion also reduces the credit spread and commercial lending rate. There are more substantial expansions in labour, real wage, consumption, investment, output and inflation as those variables are boosted even more compared with the normal scenario. In addition to this, consumption rises in response to the rise in M0.

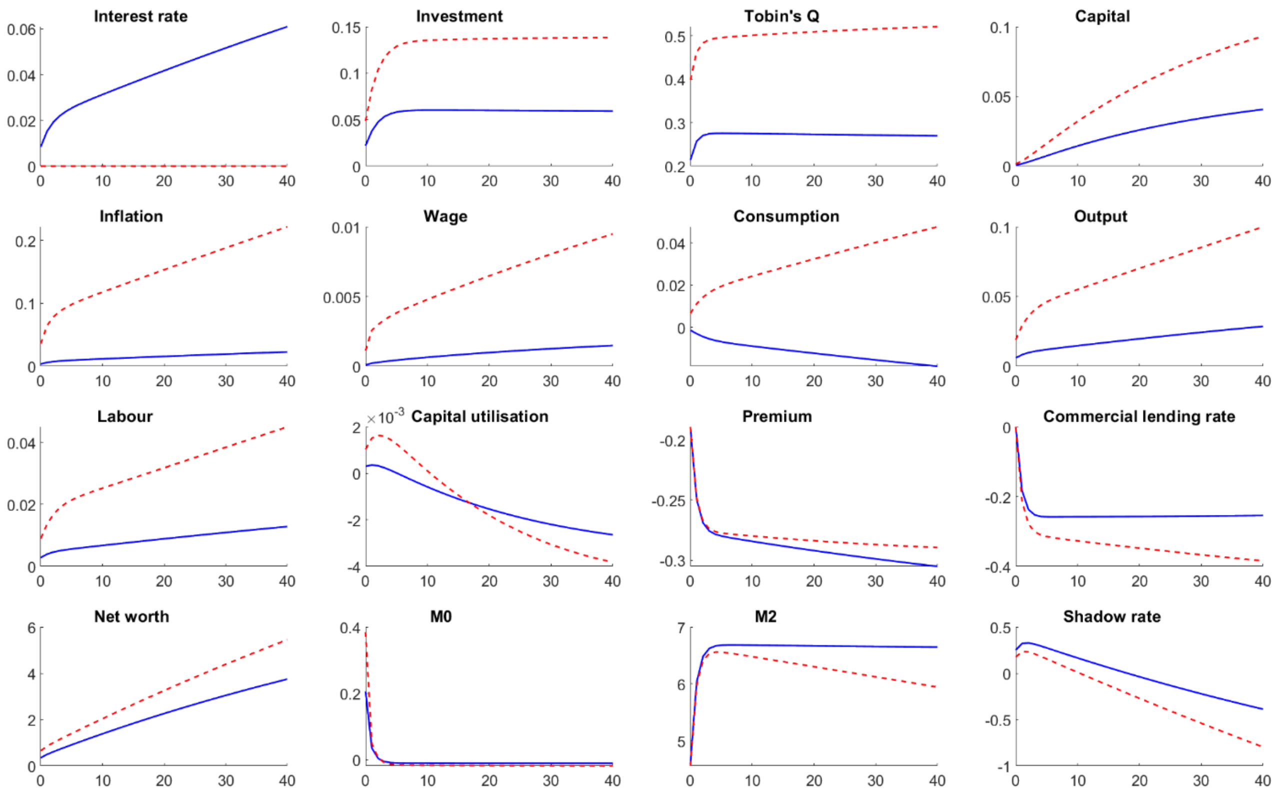


Figure 7.2.3: IRFs for a M0 shock to the non-crisis (blue solid) and crisis model (red dashed)

7.2.4 Responses to a regulatory shock

Figure 7.2.4 shows the effect of a regulatory shock, as the macro-prudential regulation is modelled by adding a regulatory instrument directly into the credit premium equation, so the rise in the credit premium is the consequence of the implementation of a tightening macroprudential policy by the central bank to avoid excessive lending. A higher credit premium under a non-crisis regime leads to a fall in net worth due to a higher commercial lending rate. It further drives down the asset price, reducing the demand for capital and investment. This has negative effects on output, real wage and labour hours. The depressed economic activity puts downward pressure on inflation and reduces the nominal interest rate.

Under the crisis regime, when the nominal interest rate is near zero, it does not completely offset the impact of regulatory tightening. The permanent interest rate peg leads to a rise in the real interest rate, reducing consumption. M0 gradually rises after three quarters to stabilize the credit market at the zero lower bound. In particular, the response emanating from the equity market is dampened, as the decrease in investment, capital price and capital is lower. However, the effects on real variables are greater.

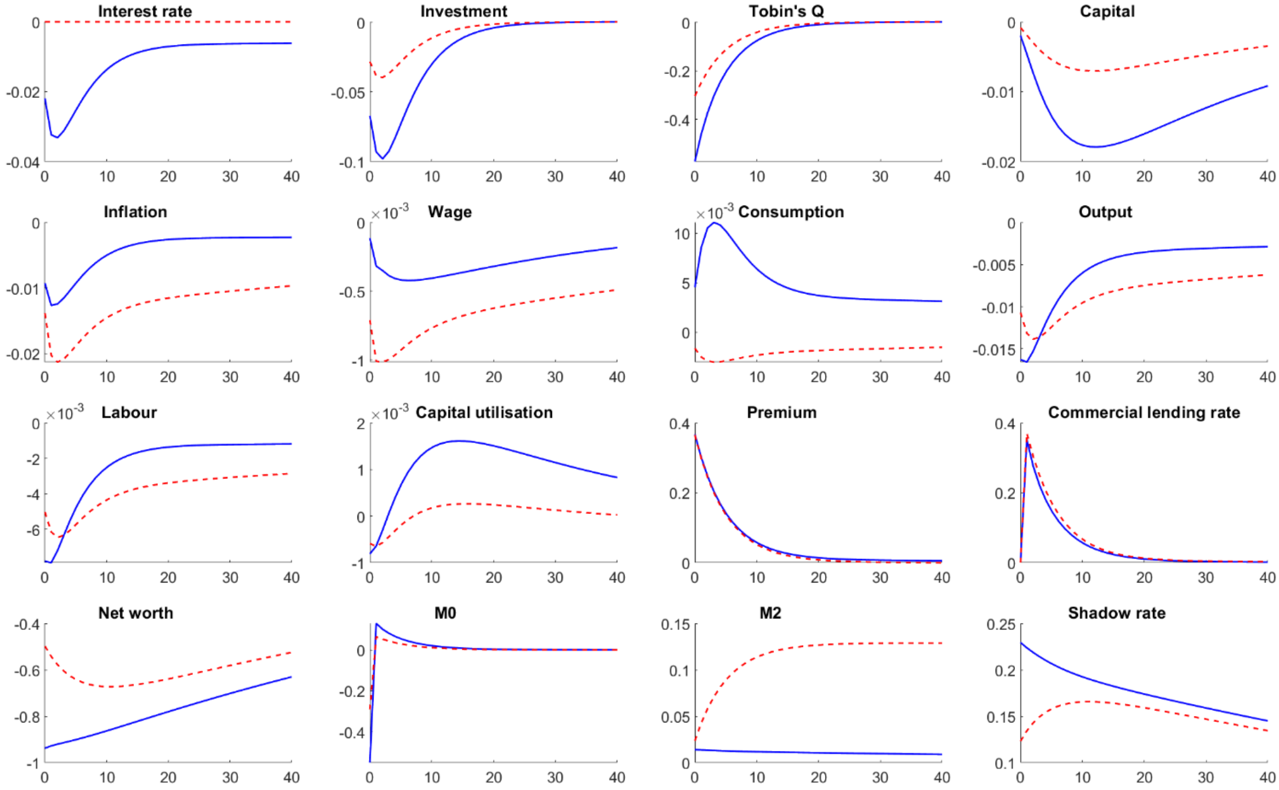


Figure 7.2.4: IRFs for a macro-prudential shock to the non-crisis (blue solid) and crisis model (red dashed)

7.3 Variance decomposition

Table 7.3.1 summarises the variance decomposition of the key variables and the shocks under the assumption that they are independent as in Meenagh et al. (2010). In the bootstrap simulation, the shocks are drawn by time vectors to allow for any correlations between them. According to Meenagh et al. (2010), there is no basis on which to allocate variances between correlated shocks in the absence of a model for the shocks themselves. Thus, we see our variance decomposition as an allocation for that percent of the shock variation that is not explained by other shocks.

The objective is to see how far the different shocks explain the variation over various horizons. The decomposition suggests that in the short run, productivity shock plays a significant role in driving the cyclical fluctuation in interest rates and inflation, explaining over 90% of the variance at three different short horizons, this is because the output gap is highest then before later converging.

Whereas the output effects of productivity converge as length increases and it dominates in the long run.

In more detail, in the long run, the nominal interest rate's variance is contributed primarily by the productivity shock (69.27%) and by the preference shock (12.67%), both of which account for 81.94% of the total variation. Inflation is mainly dominated by the investment shock (around 60%) and by the productivity shock (10.54%), with 10.39% coming from the risk premium shock. Output is primarily explained by productivity shock (54.28%), with 8.61% of its variance due to labour supply shock. Investment's behaviour is predominantly explained by the productivity shock (16%) and investment shock (14.92%). Overall, productivity shock as an exogenous permanent shock is one of the main drivers of the fluctuation in the US economy in the long run.

Table 7.3.1: Variance Decomposition

Variable	Government spending shock	Investment shock	Labour supply shock	Net worth shock	Preference shock	Price markup shock	Quantitative easing shock	Taylor rule shock	Premium shock	Wage markup shock	Productivity shock
2 Year											
Interest rate	1.59	0.15	0.90	0.12	0.93	0.00	0.38	0.10	0.01	0.19	95.62
Investment	0.00	0.52	8.72	0.00	0.00	0.00	90.72	0.00	0.01	0.00	0.03
Inflation	1.54	0.15	1.08	0.11	1.12	0.00	0.41	0.29	0.01	0.23	95.07
Output	1.65	0.19	45.75	0.10	0.06	0.00	25.16	0.03	0.01	0.03	27.01
5 Year											
Interest rate	0.63	0.11	0.37	0.10	0.36	0.00	0.46	0.04	0.00	0.07	97.86
Investment	0.00	0.11	5.95	0.00	0.00	0.00	93.91	0.00	0.00	0.00	0.02
Inflation	0.62	0.11	0.43	0.10	0.44	0.00	0.41	0.11	0.00	0.09	97.69
Output	0.65	0.08	36.76	0.07	0.03	0.00	30.99	0.01	0.00	0.01	31.39
10 year											
Interest rate	0.32	0.07	0.19	0.09	0.18	0.00	0.33	0.02	0.00	0.04	98.75
Investment	0.00	0.06	4.94	0.00	0.00	0.00	94.98	0.00	0.00	0.00	0.02
Inflation	0.32	0.07	0.22	0.09	0.22	0.00	0.29	0.06	0.00	0.05	98.68
Output	0.41	0.05	29.09	0.07	0.02	0.00	26.79	0.01	0.00	0.01	43.56
Long Run											
Interest rate	2.78	1.71	5.49	1.08	12.67	1.16	1.12	1.63	1.78	1.31	69.27
Investment	7.66	14.92	8.57	7.04	8.90	8.00	7.60	7.48	6.42	7.41	16.00
Inflation	1.73	59.33	1.54	2.70	6.62	1.59	1.48	2.56	10.39	1.52	10.54
Output	4.49	4.78	8.61	3.97	4.20	3.95	3.89	3.94	3.93	3.97	54.28

7.4 Historical variance decomposition

I am also interested in quantifying how much a given structural shock explains the historically observed fluctuations in the VAR variables. To do this, historical variance decomposition is depicted to show the cumulative effect of a given structural shock on each variable at every given point in time. Taylor rule shock and M0 shock arise from monetary policy, the credit premium shock comes from financial markets, and all other shocks are considered to be the normal contributions of the business cycle. Figure 7.4.1 displays the historical variance decomposition of shocks to the output. In the early 1980s, output was dominated by monetary policy shocks, financial shocks and general business cycle shocks. The productivity shock had a lower impact. The downturn was first triggered by a monetary policy shock and then exacerbated by a large financial shock in the US. During the Great Inflation period, the Fed carried out a tight monetary policy in an effort to fight mounting inflation. Due to the credit-control program, the financial sector suffered a period of distress as high inflation and interest rates wiped out savings and loan (S&L) industry's net worth. The contribution of productivity shock to output volatility was higher during the Great Moderation. These shocks might be associated with the changes in the structure of the US economy or the growing organisational inefficiency. In 2008, the main sources were large swings in financial shock, other shocks and monetary policy shock. The financial markets have experienced significant turbulence since the bankruptcy of Lehman Brothers, so driving forces from the financial market contributed to a part of the economic downturn.

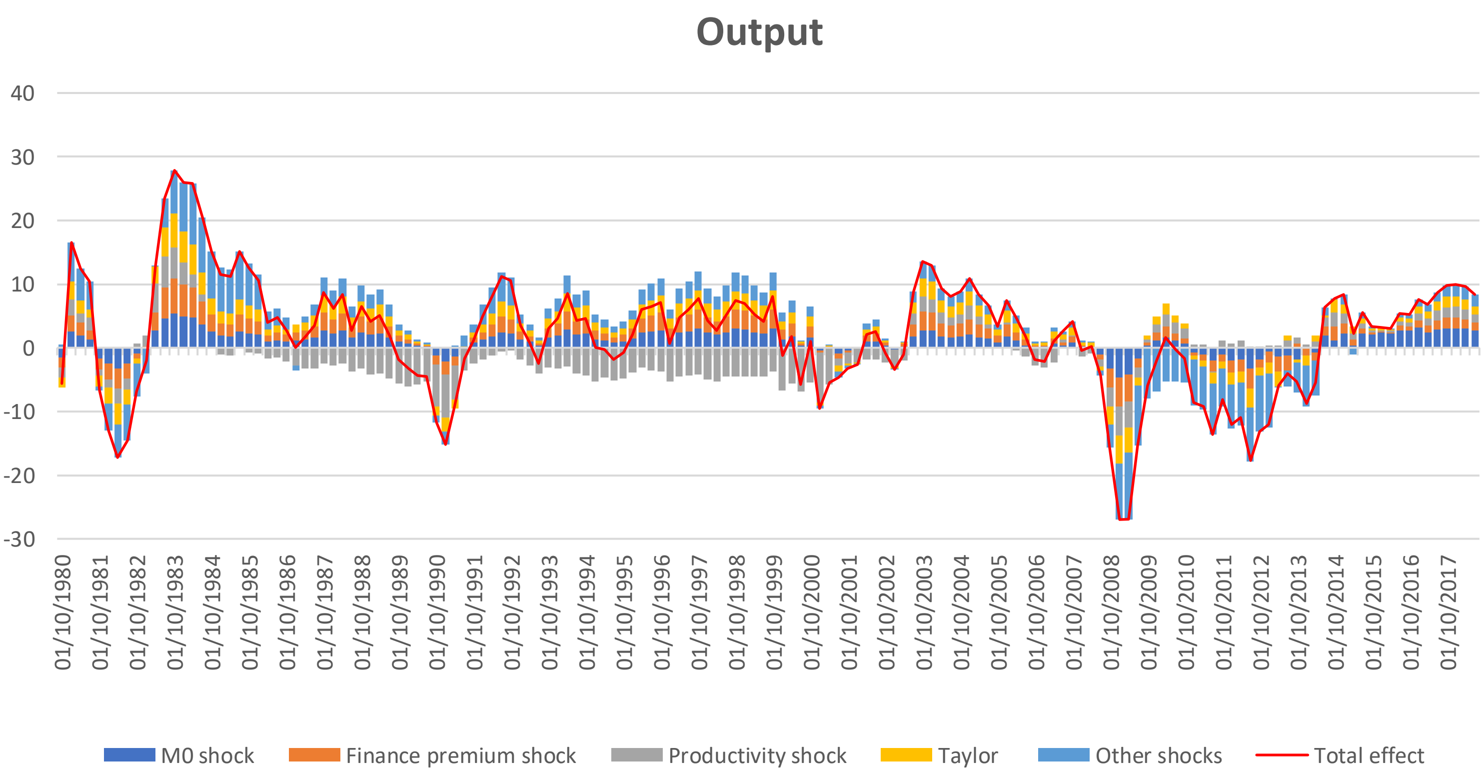


Figure 7.4.1: Historical decomposition of output

With respect to the interest rate in Figure 7.4.2, in 1980, general business cycle and monetary policy shocks can account for a large proportion of interest rate volatility, they lead interest rate with a positive movement in the interest rate. During the Great Moderation period, the swings of interest rate tended to be stable until the financial crisis around 2008, plunging associated with the fall in home prices. Therefore, the interest rate was dominated by the Taylor rule and M0 shocks, with smaller contributions from productivity and the general business cycle. In response to a recession, the FOMC accelerated its interest rate cuts, taking the rate to near zero. They also carried out quantitative easing to stimulate the economy and contributed to a positive effect on the movement since the end of 2008.

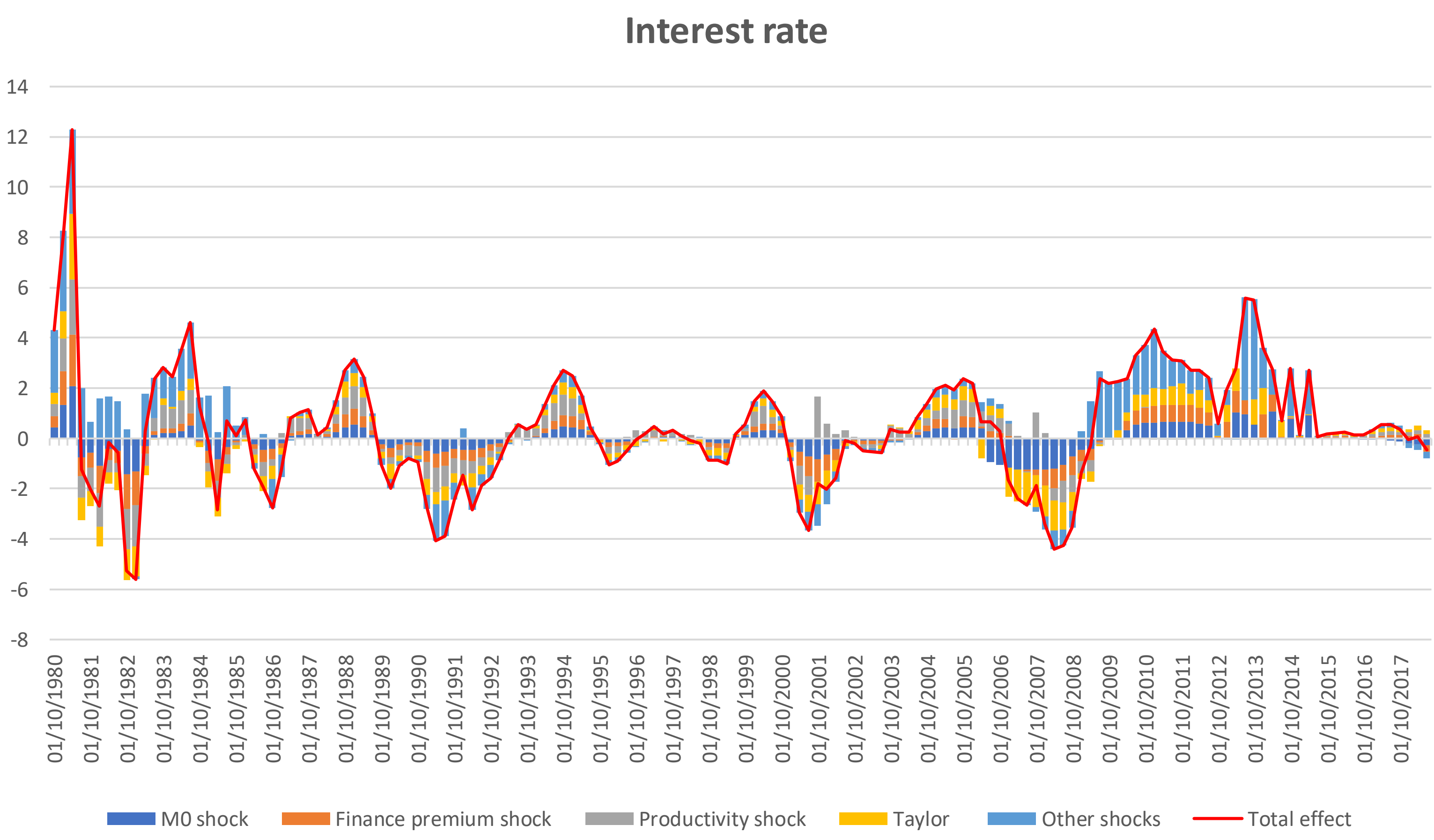


Figure 7.4.2: Historical decomposition of interest rate

7.5 Model simulated behaviour

In order to investigate the causes of the crisis based on our sample period, Figure 8 presents some examples of the simulated nominal interest rate and output versus the actual data in two scenarios. As in Le et al. (2016), the crisis can be interpreted as a steep drop in output growth lasting for at least three years, and the financial crisis as a crisis occurs when there is also a binding zero lower bound. Our data cover the period 1980 to 2018. First the shocks are bootstrapped, and some simulated data is depicted that corresponds with financial crisis features. We define these as 'crisis-inclusive shock scenarios', then we pick some other samples that exclude the financial shocks, and we call these 'standard shock scenarios'.

According to our randomly selected samples of bootstrap simulation, in the standard shock scenarios, crises are regular results in this period, so the shocks from the financial crisis period are not necessary conditions for large economic recessions. In addition, the behaviour of these variables is similar, but crises become more frequent in the crisis-inclusive shock scenarios. Under the zero lower bound, the fall in output is larger, indicating that shocks from financial friction amplify the crisis and even prolong the recession.

Figure 8: Crises with financial crisis(crisis-inclusive shock scenarios)

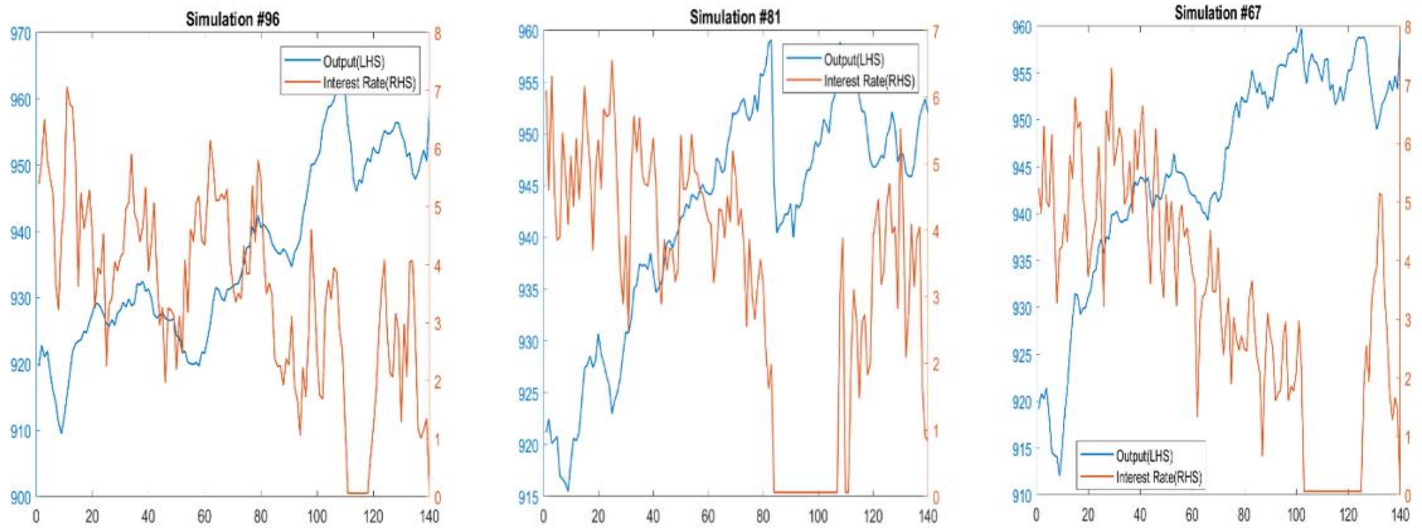
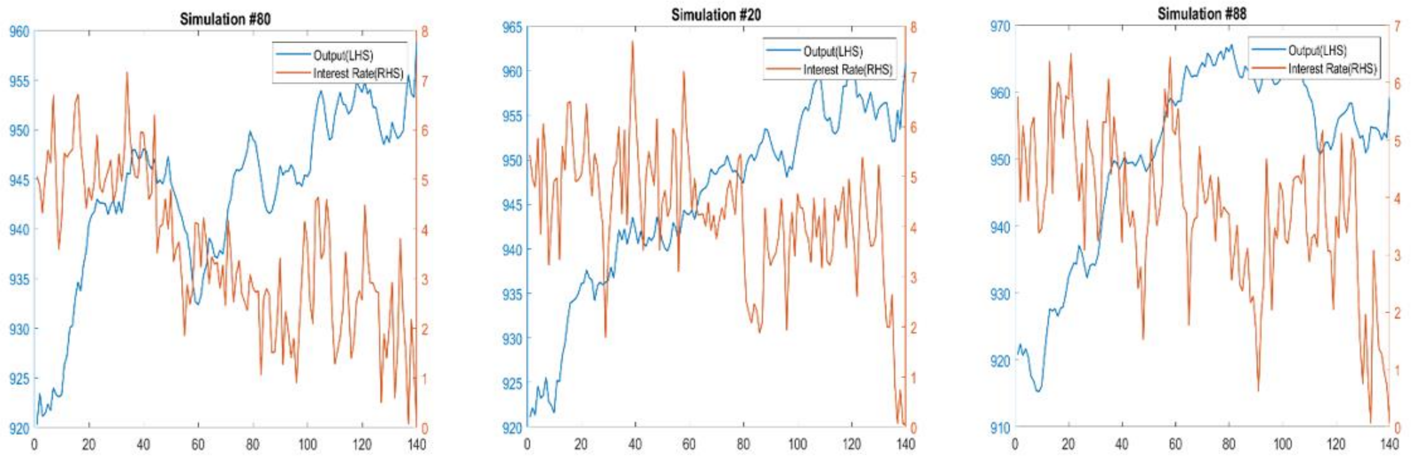


Figure 9: Crises without financial crisis(Standard shock scenarios)



Chapter 8

Policy Analysis

8.1 Comparison analysis

To demonstrate the implication of shadow banking on the US economy and explore whether it has an impact on the effectiveness of the operation of policies. The baseline model with the shadow-banking sector is contrasted to a counterfactual one in which shadow banking is absent in Section 8.1, then I compare the welfare loss, including or excluding shadow banking in the model in Section 8.2, to demonstrate whether shadow banking can stabilize the US economy.

8.1.1 Responses to a regulatory shock

Since the financial crisis in 2008, regulatory reform efforts have aimed to strengthen the stability of the shadow banking system, as financial regulation can raise the credit premium and reduce the vulnerability of the economy to financial shocks. However, a regulatory constraint on commercial banks might induce credit leakage towards unregulated financial institutions and result in financial fragility if no regulation banning shadow banks. Hence, to understand the influence of shadow banking on the US economy, I compare the dynamics triggered by a positive regulatory shock to see whether the operation of regulatory policy is ineffective under the shadow banking model with no regulation restriction.

Figure 8.1.1 compares the effect of the regulatory policy shock on the model with and without the shadow-banking sector. The solid blue lines show the results from the baseline model with the shadow-banking sector included. In contrast, the dashed orange lines show impulse responses from the baseline model with shadow banking shut off. Evidently, they almost respond in the same direction. Higher credit premium forces down net worth due to higher cost of borrowing, resulting in a decrease in asset price and investment. Although in both cases, investment responds negatively, the degree varies. The reaction to investment in the baseline model with shadow banking is less sensitive than that in the model without shadow banking. Under the regulation, the lending by commercial banks to firms is binding, so that in the counterfactual economy without shadow banking, investment is constrained by the limit on leverage as in the standard banking BGG model. However, the unregulated shadow banking is not affected, because the estimated share of hedge funds that participate with the set of entrepreneurs as equity partners reaches 0.69 high level. It implies that 0.69 share of direct equity investment is largely unconstrained, thus it is more like a model without banking as it essentially provides a cheaper channel for credit to flow from saving households to investing households, supplementing banks which charge more to offset the monitoring costs of possible default, resulting in less effect on asset price, as a result in the baseline model investment reacts very little. It incentivises the regular banks to divert funding to the shadow sector, creating a substitution in lending away to a proportion of firms who are unable to get funding from commercial banks. The decreased price of capital with weakened impact on investment forces down the capital, so the movement of capital is also dampened in the baseline model. This further dampened the effects on other real variables such as output, labour hours and real wage. In addition, since the off-balance shadow banking sector can create more liquidity in the financial market, amplifying the currency multiplier, it results in a rise in broad money supply M2. In summary, the responses of our baseline model with shadow banking are analogous to the model without shadow banking, apart from that the former one reacts weaker. That is because the impact of financial frictions are dampened in the baseline model compared with BGG model without shadow banking that financial frictions work strongly so it has more effects on real variables.

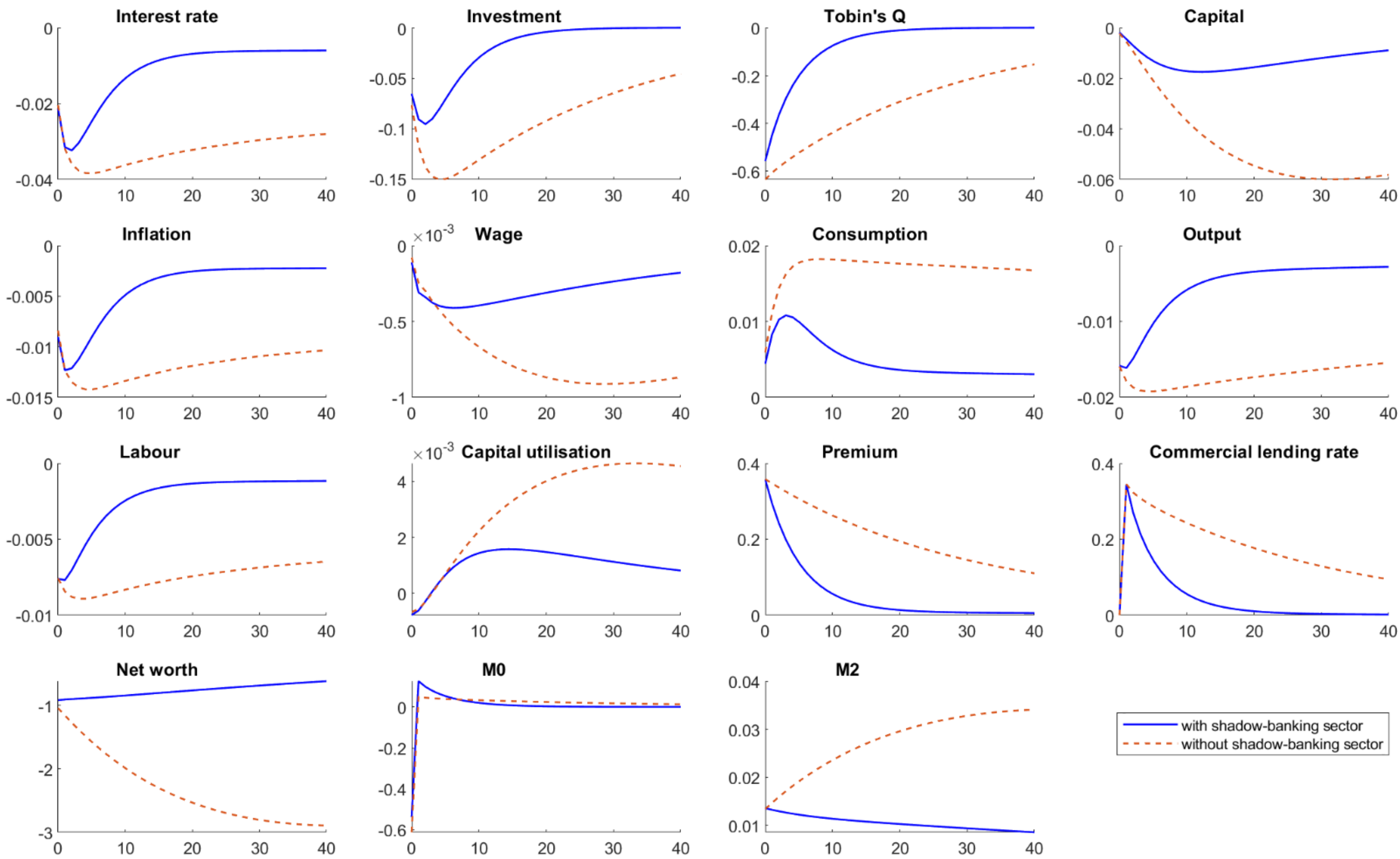


Figure 8.1.1: IRFs for regulatory shock to the model with the shadow-banking sector (blue solid) and the model without the shadow-banking sector (orange dashed)

8.1.2 Responses to Taylor rule shock

Figure 8.1.2 illustrates the effect on main variables in response to the Taylor rule shock; the comparison reveals that the results are conventional, and our baseline model corresponds with the model without shadow banking, as most of the variables show an analogous reaction, unless the reactions in the credit market are slightly different. Notably, the responses of investment, stock of capital and capital price are weaker in the baseline model with the shadow-banking sector included. Since a rise in the nominal interest rate raises the credit premium, it provides another way of shadow banking credit to firms. It has a lower impact on the investment in the baseline model and impedes the movement of capital, resulting in a weakened decline in net worth. In addition, the shadow banking credit via the off-balance sheet of commercial banks provides more liquidity in the market, but the response of the broad money supply is less sensitive because more credit poses a more systemic risk, weakening the central bank's ability to control the broad money supply. Overall, the effects of financial frictions are impeded mainly due to the share of direct equity investment being largely unconstrained by the limit on leverage in our baseline model. This effect applies to Tabin's Q, the asset price reacts little and further lowers the effect on investment. Hence, the impact of the shadow banking is to protect the equity market from the shock but has less impact on the real economy.

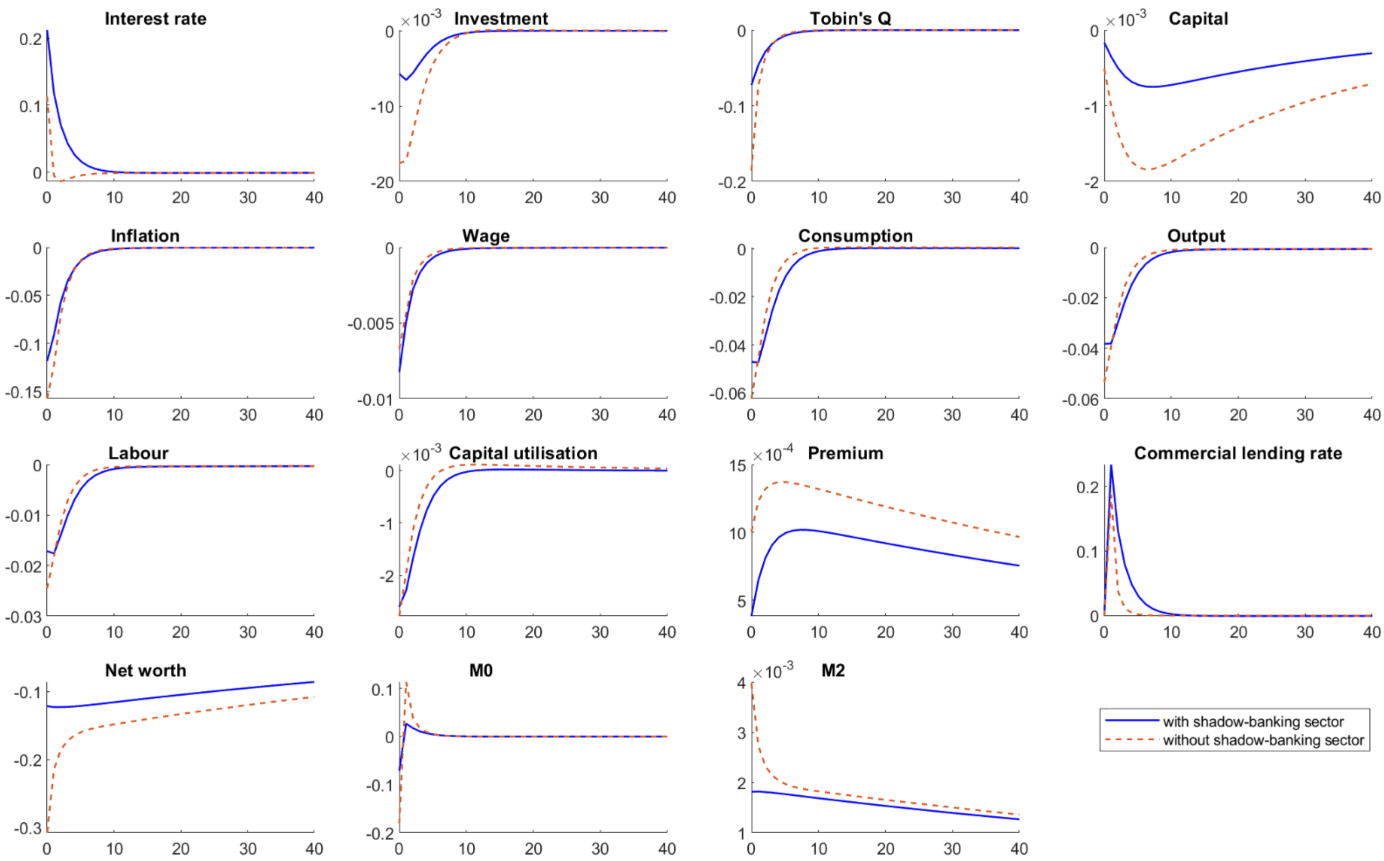


Figure 8.1.2: IRFs for Taylor rule shock to the model with the shadow-banking sector (blue solid) and the model without the shadow-banking sector (orange dashed)

8.1.3 Impulse responses to productivity shock

Figure 8.1.3 displays the impulse responses of key macroeconomic variables to a positive permanent productivity shock. Through comparing the dynamics of the economy triggered by non-stationary productivity shock in the baseline model and in the counterfactual model when shadow banking is turned off, we demonstrate that shadow banking can also weaken and propagate productivity shock as the effects on most variables are weaker in our baseline model with the shadow-banking sector included than in counterfactual model without shadow banking. With higher productivity, the capital utilisation rises, which raises firms' profits. The rise in firm's asset price spurs an investment boom, which raises the stock of capital and increases the net worth so that firms can take on more debt. With higher net worth, the credit premium is reduced, associated with a lower commercial lending rate. In the labour market, the rise in productivity drives up the workers' real wage, and hours worked are reduced due to the improvement in technological progress, then output and consumption rise. In particular, output rises by about 80 basis points at its peak in the baseline model compared with that without the shadow banking economy, which rises by about 100 basis points. Overall, we conclude that our shadow banking model can better stabilize the economy, as a positive productivity shock has a smaller effect on the shadow banking economy.

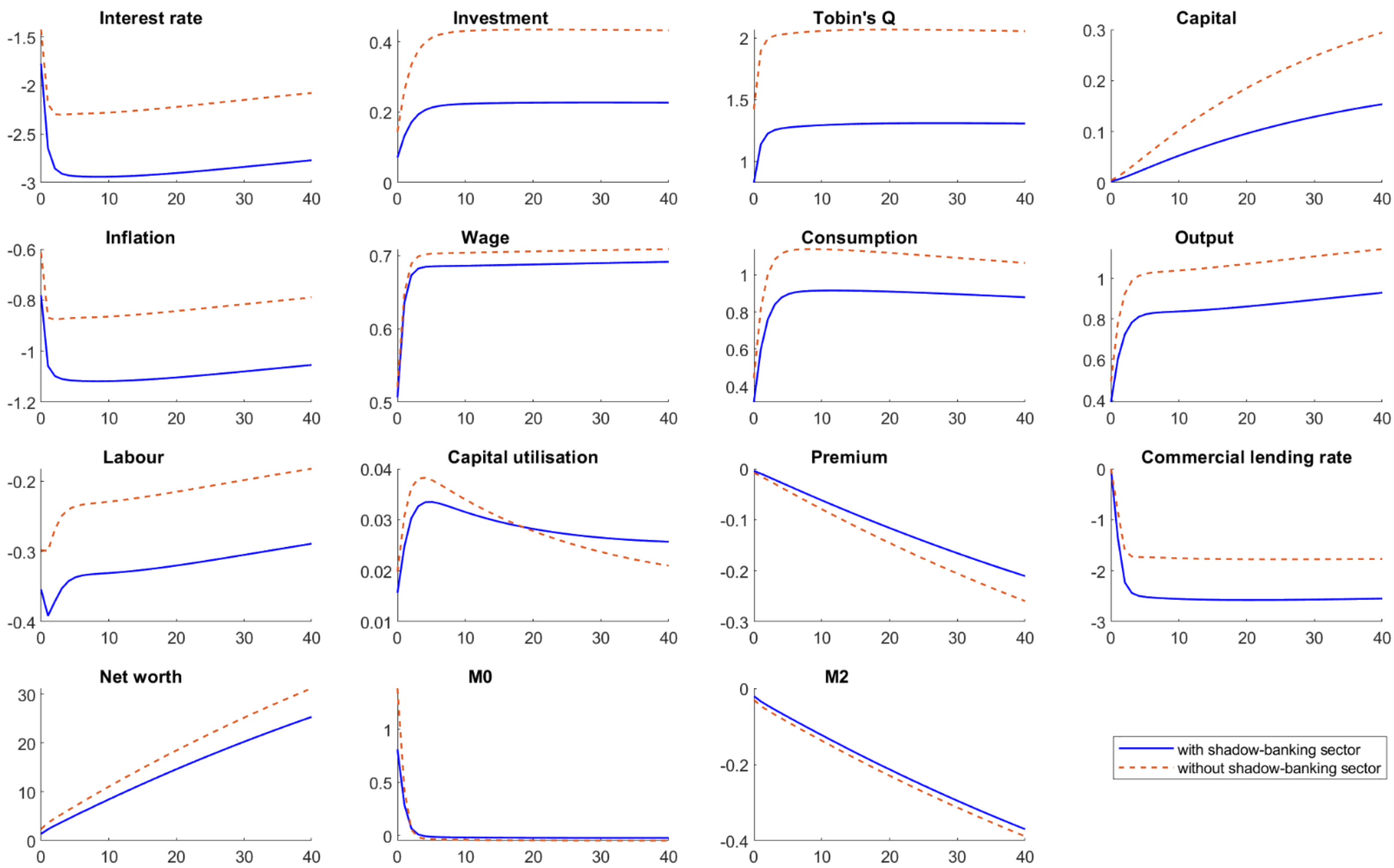


Figure 8.1.3: IRFs for productivity shock to the model with the shadow-banking sector (blue solid) and the model without the shadow-banking sector (orange dashed)

8.1.4 Responses to money supply shock (M0)

In Figure 8.1.4, an expansionary money supply shock aims to reduce the credit premium by increasing asset price, and reducing the commercial lending rate, facilitating an investment boom. This stimulates more output, pushing up real wage and hours worked. This in turn generates inflation after around 5 quarters and leads to the rise in nominal interest rate via the Taylor rule, thus further reducing the consumption. In addition, the money supply shock generates a hump-shaped response of output, but the response of output is impeded in the baseline model. Hence, the persistence of the response is less pronounced in the first 20 quarters in our baseline model when shadow banking is allowed to operate, and these effects also apply to other real variables, dampening the movements of investment, real wage and capital.

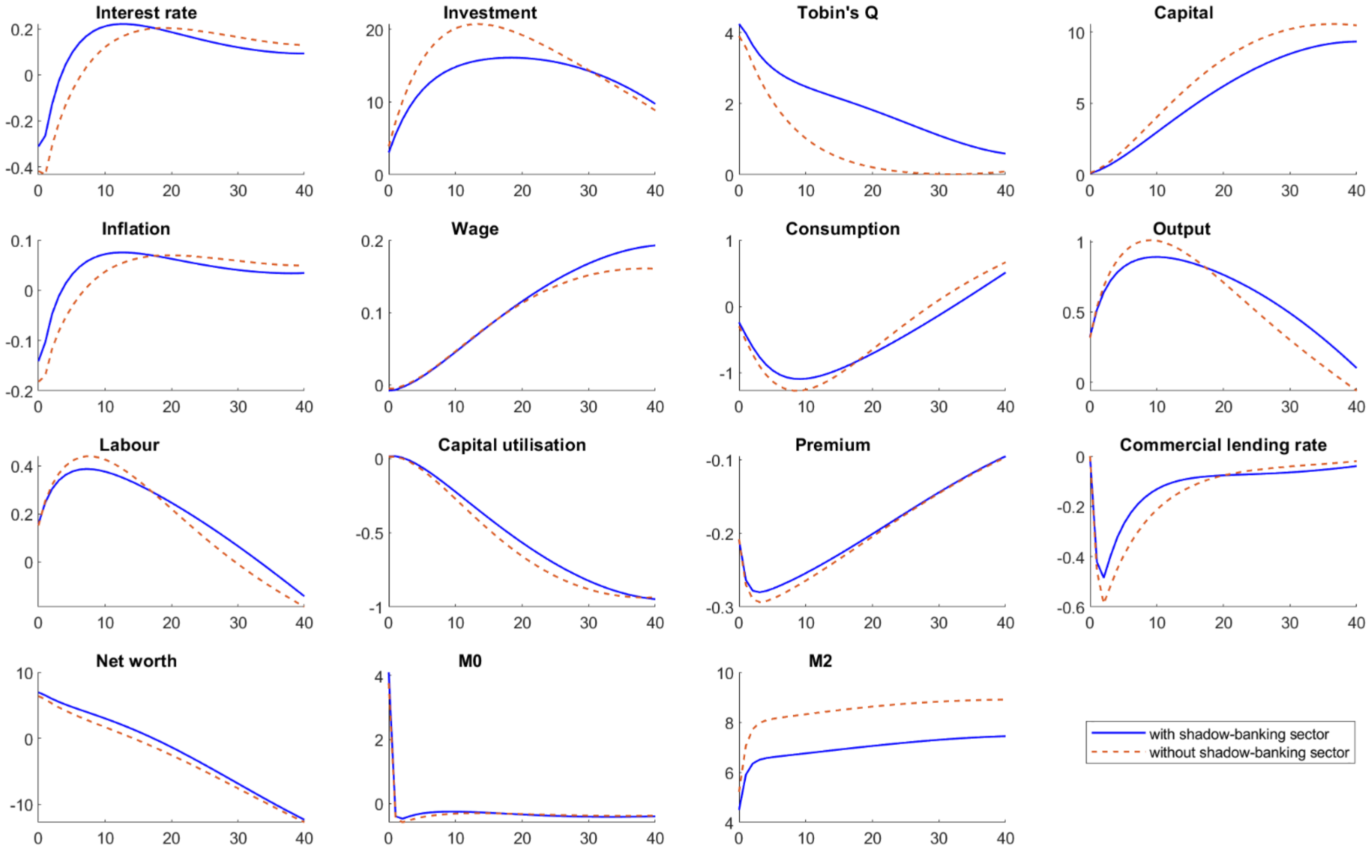


Figure 8.1.4: IRFs for money supply shock(M0) to the model with the shadow-banking sector (blue solid) and the model without the shadow-banking sector (orange dashed)

8.2 Welfare analysis

In this section, I use an estimated model with the shadow-banking sector and welfare analysis to investigate whether regulations should target and reduce shadow banking activities. I calculate the welfare cost for this model and then assuming a strict regulations which could seize the shadow banking sector completely, the welfare cost is calculated for this version too.

The welfare cost is calculated using the ad hoc central bank's preference function, a weighted average of inflation variability and output variability as below.

$$L = \lambda(y_t - y_*)^2 + (1-\lambda)(\pi_t - \pi_*)^2 \qquad (8.2.1)$$

where y_* represents natural output level, π_* represents inflation target level. The weight λ reflects the preferences of policymakers whose aim is either to stabilise output or to stabilise inflation. For simplicity, we assume $\lambda = 0.5$. Thus, policymakers are indifferent between stabilising output and stabilising inflation. The loss equation is analogous to the following equation, which I use as a reference to calculate welfare loss:

$$L = \frac{1}{2}(\sigma_y^2 + \sigma_\pi^2) \qquad (8.2.2)$$

where σ_y^2 represents the variance of output, σ_π^2 denotes the variance of inflation. Bootstrapping the simulated data 1000 times yields the following results in Table 8.2.

Welfare loss analysis		
Variance of fluctuations	Model with the shadow-banking sector	Model without the shadow-banking sector
σ_y^2	12.32	13.76
σ_π^2	23.33	16.32
Welfare cost(1)*	17.83	15.04
σ_c^2	17.31	20.25
σ_h^2	4.20	4.80
Welfare cost(2)*	10.76	12.53
Consumption gain(%)		13.09%

Table 8.2 : Welfare costs analysis
*Equal weights for each variance, the last row measures the percentage of consumption gain in terms of the change from the no shadow banking model to the shadow banking model.

I report the welfare loss results for two scenarios: the model with the shadow-banking sector and the model without the shadow-banking sector[16]. The welfare loss(1)* is measured by a weighted average of the variance of output and inflation, while welfare loss(2)* is measured by a weighted average of the variance of consumption and labour. In practice, after the bootstrapping simulation, I use the HP filter to detrend the simulated data in order to reduce the estimated persistence of the driving processes; then, I extract cycles and

[16] I impose no shadow banking restriction(set 1-s=0) on the model with the shadow-banking sector and investigate the difference in implied welfare.

compute the variance of these cycles. Alternatively, we can calculate the household's consumption gain or loss concerning the trade-off between the model with the shadow-banking sector and the model without the shadow-banking sector. To do this, based on the household utility function in equation (4.1.1), we can convert average utility into consumption gain once we get the consumption percent from the simulations.

The comparisons of the variance of output, inflation, consumption, labour and consumption gain provide a welfare ranking of different models as above. The results in welfare cost(1)* show that the model without the shadow-banking sector generates smaller welfare loss, but the variance of output is lower in our baseline model. However, the results of welfare cost(2)*indicate that the welfare costs of fluctuations in consumption and labour hours are all smaller in the model with the shadow-banking sector. If we calculate in terms of the household's consumption gain of moving from the no shadow banking model to the shadow banking model, the consumption gain increases by 13.09%, indicating that households will be willing to give up 13.09% of consumption to have shadow banking. Overall, I conclude that shadow banking is beneficial to macroeconomic stability. Therefore, regulations should not aim to reduce its activities in the US.

Chapter 9 Conclusion

In this study, I developed a DSGE model by incorporating a shadow banking sector. The main objective is to study the impact of shadow banking on the US economy. I argue that the shadow banking model would help stabilize the economy, as it dampens the responses of the variables to shocks and affects the effectiveness of regulatory policy by providing a cheaper channel for credit leakage, supplementing banks, which charge more to offset the monitoring costs of possible default.

I first take account of the role of money and bank credit. I think that money not only can set the interest rate on short-term government bonds but also plays an important role in providing cheap collateral and can affect monetary policy. By introducing the zero lower bound constraint and unconventional monetary policy, I find that, when the interest rate is suspended at the zero lower bound, through changing the supply of M0 via open market operations, the central bank improves the effectiveness of unconventional monetary policy in affecting the credit premium on banking lending to firms. While in the non-ZLB situation, this effect comes along with the Taylor rule, the central bank stabilizes the economy by adjusting the nominal interest rate in normal times. I also add a macroprudential policy instrument into the credit premium equation, which is taken as part of the premium shock and also alters the premium and commercial lending rate. In order to combine a shadow-banking sector with traditional commercial banks, I assume that commercial banks can divert a fraction of their loans acquired from the deposit market to the shadow banking sector, such as hedge funds, representing high net worth households that want to invest directly in risky capital. I also assume that a proportion of firms resort to the shadow banking sector. Thus, they have to surrender some of their return due to hedge funds participating in their capital.

Then to analyse the behaviour of shadow banking in explaining the US economic volatility, I looked at the variance decomposition. My results show that productivity shock was the main driver of the US economy over our sample period rather than financial shocks. Based on this conclusion, to explore whether shadow banking has an influence on the effectiveness of the operation of policies, it is necessary to contrast our baseline model with the shadow-banking sector to a counterfactual one in which shadow banking is shut off, to demonstrate further whether the shadow banking plays a major role in explaining the business cylce of the US economy. The impulse response functions depict the impact of shocks on the economic outcomes. I find that the existence of shadow banking in the US without any regulatory restrictions would dampen the effectiveness of policies by providing a cheaper channel for credit leakage.

In summary, my main finding can be explained as follows. First, the P-values of the estimated results imply that the model with the shadow-banking sector(1-

s=0.69) fits better than the one without shadow banking(1-s=0). In addition, since our estimated coefficient on shadow banking is very high, it implies that 0.69 share of direct equity investment is largely unconstrained in our shadow banking model compared with the standard banking BGG model, where investment is constrained by the limit on leverage. Thus, the existence of shadow banking essentially provides a cheaper channel for credit to flow from saving households to investing households, supplementing banks, which charge more to offset the monitoring costs of possible default, and it is more like a model without banking.

Second, we find that shadow banking dampens the responses of the variables to shocks; in so doing, it also reduces the effectiveness of macro-prudential policy, since banks can offload some of their assets to the shadow-banking sector and escape from regulation. However, shadow banking also lowers credit friction, so it increases economic stability.

Third, from the welfare analysis, my results show that when shadow banking is allowed, the welfare cost of fluctuations in output, consumption and labour hours are all lower apart from inflation, and average household utility is higher, by an equivalent permanent consumption gain of 13%. This result is the main policy contribution of this study.

However, there are some limitations in this study. The macroprudential instrument introduced in our model is set as an exogenous component of the credit premium, so we cannot distinguish the regulation and the premium shocks. In addition, more choice of macroprudential instruments such as counter-cyclical capital buffers, reserve requirements, caps on loan-to-value and liquidity coverage ratio might be taken into account in future research so as to elaborate the modelling of shadow banking regulation. In addition, I have not modelled securitization or the interaction between commercial banks and shadow banking. These things could be pursued in future research.

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Model list:

Consumption Euler equation:

$$\hat{c}_t = \left(\frac{\frac{\lambda}{\gamma}}{1+\frac{\lambda}{\gamma}}\right)\hat{c}_{t-1} + \left(\frac{1}{1+\frac{\lambda}{\gamma}}\right)E_t\hat{c}_{t+1} + \left[\frac{(\sigma_c - 1)\frac{W_*^h h_*}{C_*}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right]\left(\hat{h}_t - E_t\hat{h}_{t+1}\right) - \left[\frac{1-\frac{\lambda}{\gamma}}{\left(1+\frac{\lambda}{\gamma}\right)\sigma_c}\right]\left(\hat{r}_t - E_t\hat{\pi}_{t+1} + \epsilon_t^b\right)$$

Investment Euler equation:

$$\hat{i}_t = \frac{1}{1+\beta\gamma^{1-\sigma_c}}\hat{i}_{t-1} + \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}}E_t\hat{i}_{t+1} + \frac{1}{(1+\beta\gamma^{(1-\sigma_c)})\gamma^2\varphi}\hat{qq}_t + \epsilon_t^{inv}$$

Capital accumulation equation

$$\hat{k}_t = \left(\frac{1-\delta}{\gamma}\right)\hat{k}_{t-1} + \left(1-\frac{1-\delta}{\gamma}\right)\hat{i}_t + \left(1-\frac{1-\delta}{\gamma}\right)\left(1+\beta\gamma^{(1-\sigma_c)}\right)\gamma^2\varphi\epsilon_t^{inv}$$

Aggregate production function:

$$\hat{y}_t = \phi[\alpha\hat{k}_{t-1} + \alpha\left(\frac{1-\psi}{\psi}\right)\hat{rk}_t + (1-\alpha)\hat{h}_t + \epsilon_t^{\alpha}]$$

Labour demand:

$$\hat{h}_t = -\hat{w}_t + \left(1+\frac{1-\psi}{\psi}\right)\hat{rk}_t + \hat{k}_{t-1}$$

Capital arbitrage condition:

$$\hat{qq}_t = \left(\frac{1-\delta}{1-\delta+R_*^k}\right)E_t\hat{qq}_{t+1} + \left(\frac{R_*^k}{1-\delta+R_*^k}\right)E_t\hat{rk}_{t+1} - E_t r_{t+1}^c$$

Where r_{t+1}^c is the total cost of capital.

External financing premium:

$$s_t = E_t\hat{r}_{t+1}^b - \hat{r}_t = \hat{pm}_t = \chi(\hat{qq}_t + \hat{k}_t - \hat{nw}_t) - \psi\hat{m}_t + \varsigma_t + \varepsilon_t^{pm}$$

Net worth:

$$\hat{nw}_t = \frac{K}{NW}\left(\hat{r}_t^b - E_{t-1}\hat{r}_t^b\right) + E_{t-1}\hat{r}_t^b + \theta\hat{nw}_{t-1} + \epsilon_t^{nw}$$

Entrepreneurial consumption:

$$\hat{c}_t^e = \hat{nw}_t$$

Wage setting equation:

$$\hat{w}_t = \omega_w \left[\frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}} E_t \hat{w}_{t+1} + \frac{1}{1+\beta\gamma^{(1-\sigma_c)}} \hat{w}_{t-1} + \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}} E_t \hat{\pi}_{t+1} \right.$$

$$- \frac{1+\beta\gamma^{(1-\sigma_c)}\iota_w}{1+\beta\gamma^{(1-\sigma_c)}} \hat{\pi}_t + \frac{\iota_w}{1+\beta\gamma^{(1-\sigma_c)}} \hat{\pi}_{t-1}$$

$$- \frac{1}{1+\beta\gamma^{(1-\sigma_c)}} \left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_w\right)(1-\xi_w)}{\left(1+\varepsilon_w(\varphi_w-1)\right)\xi_w} \right) \left(\hat{w}_t - \sigma_l \hat{h}_t \right.$$

$$\left. \left. - \left(\frac{1}{1-\frac{\lambda}{\gamma}} \right) \left(\hat{c}_t - \frac{\lambda}{\gamma} \hat{c}_{t-1} \right) \right) + \epsilon_t^w \right]$$

$$+(1-\omega_w) \left[\sigma_l \hat{l}_t + \left(\frac{1}{1-\frac{\lambda}{\gamma}} \right) \left(\hat{c}_t - \frac{\lambda}{\gamma} \hat{c}_{t-1} \right) - (\pi_t - E_{t-1}\pi_t) + \varepsilon_t^{ws} \right]$$

Final price setting equation:

$$\hat{rk}_t = \omega^p \left[\frac{\frac{\iota_P}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} \hat{\pi}_{t-1} + \frac{\beta\gamma^{(1-\sigma_c)}}{1+\beta\gamma^{(1-\sigma_c)}\iota_p} E_t \hat{\pi}_{t+1} - \hat{\pi}_t + \epsilon_t^p}{-\alpha \left(\frac{1}{1+\beta\gamma^{(1-\sigma_c)}\iota_P} \right) \left(\frac{\left(1-\beta\gamma^{(1-\sigma_c)}\xi_p\right)\left(1-\xi_p\right)}{\xi_p\left(\left(\varphi_p-1\right)\varepsilon_p+1\right)} \right)} + \frac{\alpha-1}{\alpha} \hat{w}_t - \frac{\epsilon_t^\alpha}{\alpha} \right]$$

$$+ (1-\omega^p) \left[\frac{(\alpha-1)\hat{w}_t + \epsilon_t^\alpha}{\alpha} \right]$$

Shadow rate:

$$\hat{r}_t^s = \frac{sR_*^b}{R_*^s} \hat{r}_t^b + \frac{(1-s)R_*^k}{R_*^s} \hat{r}_t^k$$

Where R_*^b and R_*^k are steady state value of external finance cost and return on capital for firm.

Total cost of capital:

$$\hat{r}_t^c = \frac{hR_*^b}{R_*^c} \hat{r}_t^b + \frac{(1-h)R_*^s}{R_*^c} \hat{r}_t^s$$

R_*^b and R_*^s are steady state value of external finance cost and shadow rate.

Monetary policy:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1-\rho) \left(\rho_\pi \hat{\pi}_t + \rho_y \hat{y}_t \right) + \rho_{\Delta y} \left(\hat{y}_t - \hat{y}_{t-1} \right) + \varepsilon_t^m$$

M0:
$$\hat{m}_t^0 - \hat{m}_{t-1}^0 = \psi_1(\hat{m}_t^2 - \hat{m}_{t-1}^2) + \varepsilon_t^{m0} \text{ for } r_t > 0.0625\%$$

$$\hat{m}_t^0 - \hat{m}_{t-1}^0 = \psi_2(\hat{pm}_t - \hat{pm}_t^*) + \varepsilon_t^{m0} \text{ for } r_t \leq 0.0625\%$$

M2:
$$\hat{m}_t^2 = (1 + v - \mu)\hat{k}_t + \mu\hat{m}_t^0 - vn\hat{w}_t$$

Market clearing condition in goods market:
$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{I}{Y}\hat{i}_t + R_*^k k_y \frac{1-\psi}{\psi}\hat{rk}_t + \frac{C^e}{Y}\hat{c}_t^e + \epsilon_t^g$$

Exogenous processes:

Productivity shock:
$$\epsilon_t^g = \rho_g \epsilon_{t-1}^g + \eta_t^g + \rho_{ga}\eta_t^a, \quad \eta^g \sim N(0, \sigma_g^2) \;\; \eta_t^a \sim N(0, \sigma_a^2)$$

Preference shock :

$$\epsilon_t^b = \rho_b \epsilon_{t-1}^b + \eta_t^b, \quad \eta_t^b \sim N(0, \sigma_b^2)$$

Investment-specific shock:

$$\epsilon_t^i = \rho_i \epsilon_{t-1}^i + \eta_t^i, \quad \eta_t^i \sim N(0, \sigma_i^2)$$

Monetary policy shock :

$$\epsilon_t^r = \rho_r \epsilon_{t-1}^r + \eta_t^r, \quad \eta_t^r \sim N(0, \sigma_r^2)$$

The TFP shock :

$$\epsilon_t^a = \epsilon_{t-1}^a + \rho_a(\epsilon_{t-1}^a - \epsilon_{t-2}^a) + \eta_t^a, \quad \eta_t^a \sim N(0, \sigma_a^2)$$

Price mark-up shock:

$$\epsilon_t^p = \rho_p \epsilon_{t-1}^p + \eta_t^p, \quad \eta_t^p \sim N(0, \sigma_p^2)$$

Wage mark-up shock :

$$\epsilon_t^w = \rho_w \epsilon_{t-1}^w + \eta_t^w, \quad \eta_t^w \sim N(0, \sigma_w^2)$$

Labour supply shock:

$$\epsilon_t^{ws} = \rho_{ws}\epsilon_{t-1}^{ws} + \eta_t^{ws}, \quad \eta_t^{ws} \sim N(0, \sigma_{ws}^2)$$

Risk premium shock:

$$\epsilon_t^{pm} = \rho_{pm}\epsilon_{t-1}^{pm} + \eta_t^{pm}, \quad \eta_t^{pm} \sim N(0, \sigma_{pm}^2)$$

Net worth shock:

$$\epsilon_t^{n} = \rho_{n}\epsilon_{t-1}^{n} + \eta_t^{n}, \quad \eta_t^{n} \sim N(0, \sigma_{n}^2)$$

M_0 supply shock:

$$\epsilon_t^{m_0} = \rho_{m_0}\epsilon_{t-1}^{m_0} + \eta_t^{m_0}, \quad \eta_t^{m_0} \sim N(0, \sigma_{m_0}^2)$$

Symbol	Variable	Definition and description	Source
R	Nominal interest rate	Quarterly effective federal funds rate	Federal Reserve Economic Data
I	Investment	$\frac{\text{Gross fixed capital formation}}{GDP\ deflator * Population\ level}$	Federal Reserve Economic Data
q	Price of capital	Derived from capital arbitrage equation	Calculation
K	Capital stock	Derived from capital accumulation equation	Calculation
π	Inflation	$\frac{CPI_t - CPI_{t-1}}{CPI_{t-1}} * 100$	Federal Reserve Economic Data
W	Wage	$\frac{\text{Real Hourly Compensation for All Employed Persons}}{GDP\ deflator}$	Federal Reserve Economic Data
C	Consumption	$\frac{\text{Personal Consumption Expenditures}}{GDP\ deflator * Population\ level}$	Federal Reserve Economic Data
Y	Output	$\frac{\text{Real Gross Domestic Product}}{Population\ level}$	Federal Reserve Economic Data
L	Labour	$\frac{\text{Average weekly hours worked for all employed persons} * \text{Employment level}}{\text{Population level}}$	Federal Reserve Economic Data
R^k	Marginal product of capital	Derived from labour demand equation	Federal Reserve Economic Data
pm	Credit premium	R^b- *R*	Calculation
R^b	Commercial lending rate	Baa Corporate Bond Yield	Moody's
R^C	Total cost of capital	Derived from a weighted average of commercial lending rate and interest rate in the shadow-banking sector	Calculation
R^S	Interest rate in the shadow-banking sector	Derived from a weighted average of commercial lending rate and return on capital	Calculation
NW	Net worth	$\frac{Internal\ Funds}{GDP\ deflator * Population\ level}$	Federal Reserve Economic Data
M0	Monetary base	$\frac{Monetary\ Base}{GDP\ deflator * Population\ level}$	Federal Reserve Economic Data
M2	Broad supply of money	$\frac{\text{M2}}{GDP\ deflator * Population\ level}$	Federal Reserve Economic Data

TableA1.1:Data construction and sources