Essays on Money and Financial Frictions in Finance and Macroeconomics



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Abstract

This thesis consists of four essays in the area of macro-finance and international finance in financial economics. The common thread linking the four essays is the interaction between money and endogenous default, as well as the scope for policy to improve social welfare. Chapter 1 introduces the novelty of inside money and banking to a New Keynesian model, with the policy focus on the real and nominal behaviours of the macro-economy. The model shows at the zero lower bound on deposit rates (ZLBD), further policy rate reductions reduce spreads, and thereby reduce bank profitability, deposit creation, and output. Moreover, at the ZLBD, Phillips curves are flatter because credit rationing is both contractionary and inflationary. Finally, alternative policy rules are proposed to alleviate the economic strain at the ZLBD. Chapter 2 develops a two-country general equilibrium model to examine the benefits of the bankruptcy code of a capital markets union - in the absence of a fiscal union - as an alternative mechanism to improve the financial stability and welfare of a currency union. I show when domestic credit risks are present, a lenient union-wide bankruptcy code that allows for default in the cross-border capital markets union removes the pecuniary externality of banking insolvency; therefore, it leads to a Pareto improvement within the currency union. The model provides the welfare and financial stability implications of bankruptcy within a capital markets union in the Eurozone. Chapter 3 develops a dynamic stochastic general equilibrium (DSGE) model featuring deposit issuance via bank credit and endogenous default to study the complex interactions between the real and nominal sectors of the economy, with policy implications provided. Chapter 4 builds a dynamic model with endogenous default and banks' costly monitoring to assess the Basel III liquidity tool Net Stable Funding Ratio and its effect on bank credit quality and monetary policy transmission.

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Introduction

This thesis incorporates inside money issuance against bank credit and endogenous default in macro-finance and international finance models. It is motivated by one of the key lessons of the Global Financial Crisis that price stability does not guarantee financial stability. Price stability is a core aspect of a central bank's mandate because it ensures fiat money's store of value. Nevertheless, as revealed by the Global Financial Crisis, price stability did not prevent the build-up of excessive credit and money-like claims through the financial system, which led to financial fragility via default. Credit and money-like claims affect asset prices and financial stability, and the relationship between them is elegantly elucidated in Keynes (1931) and Minsky's Financial Instability Hypothesis (1977). Both papers argued that the provision of fiat money is through banks' credit extension and that it is a fundamental step to understanding the structural relationship between price stability and financial stability. Meanwhile, comprehensive empirical evidence has been provided on the role of banking credit in business cycles and financial distress (see e.g., Schularick and Taylor 2012). Therefore, the central themes linking the four chapters are money issuance against bank credit and endogenous default.

Chapter 1 revisits a canonical New Keynesian model, and the innovation of this chapter is to embed inside money issuance against bank credit in the New Keynesian framework so that both the financing channel of deposit creation and the nominal rigidity channel due to sticky prices of the monetary policy transmission can be assessed simultaneously. Chapter 2 provides the welfare and financial stability implications of bankruptcy within a capital markets union in the Eurozone. Since the Eurozone Debt Crisis of 2010-12, a critical debate on the sustainability of a currency union has centred around the role of a fiscal union in adjusting for country heterogeneity. However, a fully-fledged fiscal union may not be politically feasible (see Sargent 2012). Therefore, this chapter assumes the

absence of a fiscal union in a currency union and shows that bankruptcy code adjustment can be a close substitute for a fiscal union. I show that when domestic credit risks are present, a lenient union-wide bankruptcy code that allows for default in the cross-border capital markets union removes the pecuniary externality of banking insolvency, so it leads to a Pareto improvement in a currency union. Such bankruptcy code adjustment can be shown to compensate for the lost benefits of credible nominal exchange rates. Chapter 3 incorporates bank credit and default in an infinite horizon model to address the following questions: when do monetary and financial policy goals conflict with each other? When is monetary policy a complement to or a substitute for macroprudential policy? What is the role of money-financed fiscal expansion and its impact on allocations, prices, and financial stability? Using a DSGE model featuring deposit issuance against an offsetting bank credit and endogenous default, Chapter 3 shows that both the official rate and the financial wedge, namely, the spread between and loan and deposit rates, are the key variables for the analysis of the interaction between price stability and financial fragility. It establishes, first, both the monetary policy and the financial wedge exert real effects even though prices are fully flexible; second, that contractionary monetary policy is typically unable to lean effectively against the wind during financial deregulation; third, that money-financed fiscal expansion is effective in raising output and inflation, accompanied with lower credit risks. Chapter 4 is a further application of inside money and endogenous default in a dynamic stochastic general equilibrium (DSGE). The Basel Committee proposed the Net Stable Funding Ratio (NSFR) to curb the excessive maturity mismatch of the banking sector. However, very little study has been done to understand the real and financial effects of the NSFR on bank credit quality, investment, and the pass-through of monetary policy. In light of this issue, Chapter 4 develops a nominal dynamic general equilibrium featuring banks' maturity mismatch and the moral hazard due to costly monitoring. I calibrate the model with the recent US macroeconomic and financial data and provide a quantitative assessment of the NSFR on banks' credit quality and the pass-through of monetary policy.

Literature Review

This thesis builds on the insight mainly from two strands of literature: 1) the monetary theory in general equilibrium with incomplete markets and 2) strategic default. The creation of fiat money via bank credit was extensively written about by the early generation of economists when the banking sector just started booming. Classic papers that provided insight into this mechanism include but are not limited to Macleod (1866), Wicksell (1906), Hann (1920), Hawtrey (1923), Keynes (1931), Schumpeter (1954), Tobin (1963), and Minsky (1977). Then the monetary theory in general equilibrium with incomplete markets provides the early formalisation of the mechanism. In this group of literature, it is assumed that money must be used to carry out all transactions modelled as cash-in-advance constraints, in a similar vein to Grandmont and Younes (1972, 1973) and Lucas and Stokey (1987). In this literature, money never enters any utility functions. As in Shubik and Tsomocos (1992), Dubey and Geanakoplos (1992, 2003b, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), Goodhart et al. (2006, 2013), inside money refers to money issued when borrowing agents apply for loans from the banks, and it enters the economy against an offsetting obligation that guarantees its departure. Some quantity of money, called outside money, is present as agents' initial monetary endowment that is used to pay for loan interest. Outside money is any monetary endowment free and clear of any debt obligations, and it helps to achieve price level determinacy. As in Tsomocos (2003), commercial banks can thus be viewed as creators of "money" a la Tobin (1963).

After the Global Financial Crisis, there has been a revival of inside money modelling. Recent advances include and are not limited to Bigio and Weill (2016), Brunnermeier and Sannikov (2016) , Faure and Gersbach (2017), Donaldson et al. (2018), Kumhof and Wang (2018), Bianchi and Bigio (2018), Piazzesi and Schneider (2018), McMahon et al. (2018), Kiyotaki and Moore (2018a), and Wang (2019).

The second key group of literature is on strategic default à la Shubik and Wilson (1977) and Dubey et al. (2005). Default is introduced as a choice via a non-pecuniary default penalty. The total cost of default increases with the size of default and this follows a similar treatment as in Dubey et al (2005) and Adam and Grill (2017). In equilibrium, the borrower compares the marginal cost of default and marginal benefit of default, and may repay fully or partially, or default completely at a given state, depending on the states of nature.

There are also other ways of modelling default punishment. For example, one widely used approach is to collateralise the borrowing and model secured lending (see Simsek 2013, Fostel and Geanakoplos 2015, and Yan 2017). In this approach, default is discontinuous. The borrower defaults and the lender seizes the collateral whenever the value of the collateral falls below the value of debt obligation. And this generates a financial accelerator via fire-sale dynamics. Collateralising debt is a sensible approach to model default in the context of housing and automobiles loans; nevertheless, its logic does not extend to the vast amount of unsecured lending. One could argue that debt obligations collateralised with financial assets such as treasury bills would be secured lending. However, because financial assets such as treasury bills are not durable goods per se but are claims on goods or physical capital, they themselves are not secured from a macroeconomic perspective. In the particular case of treasury bills, one might also argue that government debt is "backed" by tax, but tax collected by the government is in terms of money which itself is an IOU, not goods or physical capital. In this sense, the fact that government bonds may seem backed by tax does not render government borrowing secured either. Thus, we argue collateralising financial securities is not secured lending at its heart. In any case, this thesis solely focuses on unsecured lending.

In the context of unsecured lending, another conventional approach of modelling default punishment is to assume a certain period of market or credit exclusion when the borrower defaults. As Huang and Winton (2016) show, credit exclusion in equilibrium creates soft collateral in the form of the borrower's reputation. The cost of default in this scenario is in fact isomorphic to a reputation damage, as in the non-pecuniary default penalty in Dubey et al. (2005). In reality, the punishment for default takes a myriad of forms well beyond market/credit exclusion or pecuniary aspects. It could range from the harshness of the terms of debt restructuring and the cost of internal devaluation and austerity tax at a sovereign level, to the immediate liquidation of assets and garnish of future income at an individual or firm level. Technically speaking, at the core the specific form of default punishment does

not matter in a general equilibrium, as long as it affects the marginal rate of substitution of goods. Therefore, I argue that the approach of modelling default punishment taken in this thesis is comprehensive enough and that it also has the advantage of analytic convenience, as the repayment of debt becomes a continuous decision variable.

Chapter 1

Banks, Money, and the Zero Lower Bound on Deposit Rates

[1]

We study a New Keynesian model where banks create deposits through loans, with the policy focus on the real and nominal behaviours of the macro-economy in the post-crisis low interest rate environment. In the model, non-banks face deposits-in-advance constraints, and deposits are issued against an offsetting bank credit to facilitate all transactions. Both individual and aggregate purchasing power can increase beyond prior income through deposit creation. We show that first, monetary policy affects the aggregate supply by passing through to the financing cost through the bank financing and deposit creation channel, and that monetary policy affects the aggregate demand by altering the real interest rate due to nominal rigidities. Second, at the ZLB on deposit rates (ZLBD), further policy rate reductions reduce spreads, and thereby reduce bank profitability, deposit creation, and output. Third, at the ZLBD, Phillips curves are flatter because credit rationing is both contractionary and inflationary. Finally, we discuss alternative policy rules to alleviate the economic strain at the ZLBD.

[1]This chapter derives from my joint work with Michael Kumhof at the Bank of England. We thank Charles Goodhart, Kyle Hood, Udara Peiris, Dimitrios Tsomocos, and seminar participants at the 2018 Oxford Saïd Macro-Finance Workshop on Money Creation, the 2019 Royal Economic Society conference, Centre for Macroeconomics, the 2019 CEPR MMCN conference, the 50th Anniversary Conference of the Money, Macro & Finance Research Group (MMF), EEA-ESEM 2019, and the 19th Annual Conference of Society for the Advancement of Economic Theory (SAET) for helpful comments and suggestions.

1. Introduction

Since the Global Financial Crisis, there has been a renewed and increasing interest in understanding the role of bank financing and deposit creation in the transmission of monetary policy. Comprehensive empirical evidence has been provided on the role of bank credit in aggregate fluctuations and financial distress (Schularick and Taylor 2012). In practice, the understanding of this bank financing channel has helped public policy with various crisis management. For example, in combating the Covid-19 pandemic, to take the heat off struggling businesses, the UK government unveiled a package of £330 bn in loans, totaling around 15% of the UK GDP, through the banking system with the help of the Bank of England. Meanwhile in academia, a burgeoning emergence of theoretical literature is catching up to reintroduce inside money to banking in the macroeconomic context, in which inside money refers to deposits issued against an offsetting bank credit. Recent advances include but are not limited to Jakab and Kumhof (2015), Brunnermeier and Sannikov (2016), Piazzesi and Schneider (2018), and Bianchi and Bigio (2018).[2] In particular, Jakab and Kumhof (2019) show that aggregate banking sector balance sheets exhibit substantial and rapid quarter-on-quarter changes and that it is much more in line with the data of four major advanced economies than the case without the deposits creation channel. Empirically, Drechsler et al. (2017) find that there is a significant spread between the Fed funds rate and the household deposit rate and that the deposit channel accounts for a major transmission of monetary policy.

In our view, these applaudable works could well complement the New Keynesian models in providing a more comprehensive understanding of the monetary policy transmission both qualitatively and quantitatively, as well as shedding light upon the determinacy region of the Taylor rule. Therefore, our paper incorporates deposits or inside money creation via bank credit in an otherwise canonical New Keynesian model, without assuming deposits in the utility function, so that both the bank financing channel and the conventional sticky price channel of the monetary policy transmission can be studied simultaneously. And notably, the policy focus of our model is the post-crisis low interest rate environment. As suggested empirically by Heider et al. (2019), Lucas et al. (2019), and Goodhart and Kabiri (2019) and shown theoretically by Brunnermeier and Koby (2018), lowering monetary policy further

[2] There is also an important literature from leading legal scholars that explains the nature of banks as creators of deposit money. See e.g. Desan (2014), Ricks (2018) and Hockett and Omarova (2016), but of course from a legal rather than an economic perspective.

at the interest rate lower bound can bring detrimental real effects. However, very few studies address the nominal effects and the associated puzzles of monetary policy at the interest rate lower bound together with its real effects, and it also remains to be ascertained what alternative monetary policy rules are available to alleviate the economic strain at the ultra-low interest rate environment.

In light of these questions, our model interacts deposits creation via bank credit with the sticky price setting of monopolistic firms, and we establish the following results. First, monetary policy affects both the aggregate supply and the aggregate demand of the economy. Monetary policy affects aggregate supply via the bank financing and deposit creation channel. Monetary policy affects aggregate demand via changing the real interest rate due to nominal rigidity. Second, we show the willingness of banks to issue deposits against loan extension depends on the spread between loan and deposit interest rates, and that the zero lower bound on deposit rates (ZLBD)[3] has sizeable effects on deposit creation and output. Third, at the ZLBD, reductions of the monetary policy rate are contractionary and the Phillips curve is flatter than away from the ZLBD. The brief intuition is that at the ZLBD, reductions of the monetary policy rate squeeze banks' net interest margin which constrains the banks from extending credit and issuing deposits, and this financing friction acts as a cost-push shock to the firms' price-setting behavior. Finally, we propose two inflationary policies that can render monetary policy expansionary at the ZLBD.

In a nutshell, our model setup is of infinite horizons and features four major players: firms, households, the banking sector, and the government. Households accumulate capital and can work. The firms have the technology to produce perishable consumption goods. To use capital and labor from the households, the firms borrow bank loans to get deposits which are used to purchase capital and labor from the households - this is when inside money enters the economy. After the firms produce perishable output, the households use the deposits - acquired by providing labor and capital - to purchase output for consumption. The firms then use revenues in the form of deposits to settle the loans - this is when inside money exits the economy.

[3]As empirically shown in Heider et al. (2019), banks generally do not push deposit rates to the negative territory. In the interest rate lower bound, the policy rate can fall to below zero but not as much as desired due to the ZLB on deposit rates. Thus, our paper takes the ZLB on deposit rates as the key friction to assess policy and macroeconomic dynamics at the ultra-low interest rate environment.

Apart from sticky price-setting by monopolistic firms as in standard New Keynesian models, the other major component of our model is deposit creation against bank credit, as it is in monetary operations in reality.[4] To formalize this mechanism, we model a deposits-in-advance constraint in a similar vein to Shapley and Shubik (1977) and Lucas and Stokey (1987), and deposits are issued upon bank credit to facilitate all transactions. The deposits in our model are sometimes referred to as inside money in literature, which, together with outside money and interest rate rules, helps establish equilibrium existence and nominal determinacy in general equilibrium with incomplete markets (see Shubik and Tsomocos 1992; Dubey and Geanakoplos 2003, 2006). What propels the acceptance of deposits as means of transaction is the central bank acting as the lender of the last resort to provide reserves as the legal tender. In our model, at any point in time to meet deposits withdrawals, the commercial banks can sell their nominal assets to the central bank to obtain reserves on demand, at the cost of the policy rate, which rules out arbitrage on the central bank. Furthermore, in extending bank loans and creating deposits, the commercial banks incur a cost of making loans, reflecting the underlying agency frictions of financial intermediation much emphasized in the macro-finance literature (see e.g., Bernanke et al. 1999; Lorenzoni 2008; Gertler and Karadi 2011).

First, we derive the analytic result that the policy rate passes through to the loan rate and that the spread between the policy rate and the deposit rate compensates for the cost of financial intermediation. This is in line with the empirical evidence provided by Ippolito et al. (2017) and Drechsler et al. (2017). Drechsler et al. (2017) document the wide spread between the Fed funds rate and the household deposit rate, and Ippolito et al. (2017) show that the floating rates of bank loans are tied to monetary policy rates. Both pieces of evidence are reflected in our analytic result. We demonstrate that on the one hand, monetary policy affects aggregate supply because it passes through to the financing cost of the production factors such as labor and capital. On the other hand, monetary policy affects aggregate demand because it alters the real interest rate of the household's Euler equation due to sticky prices. Both of these forces contribute to the non-neutrality of money.

[4]The clearest explanations of deposit creation via bank loans come from two papers by the Bank of England (McLeay et al. (2014a,b). Other central banks and policy institutions have also produced meaningful works on this mechanism, including the Bank for International Settlements (Borio and Disyatat 2011), the Bundesbank (Bundesbank 2017), Reserve Bank of Australia (Doherty et al. 2018), the International Monetary Fund (Benes et al. 2014a,b), Central Bank of Ireland (Lozej et al. 2017; Lozej and Rannenberg 2017), Lithuanian Central Bank (Ramanauskas and Karmelavicius 2018), Norges Bank (Kravik and Paulsen 2017), and People's Bank of China (Sun and He 2018), to name a few.

Then we use the model to focus on policy implications in the post-crisis low interest rate environment. Our concern is not per se with the level and therefore the zero lower bound on the policy rate (ZLB), but rather with the effect of changes in the policy rate on banks' lending and deposit rates and therefore on their net interest margin, which in turn affects their incentives to lend. Net interest margins are not directly affected by the ZLB but rather by the ZLBD, and there is generally further scope to lower the policy rate once the ZLBD has been reached. The fact that the ZLBD, especially on retail deposits, has indeed been an effective constraint in several low-interest economies is documented in Bech and Malkhozov (2016) and Heider et al. (2017)14, and the empirical literature has shown that this has had negative consequences for bank profitability and lending. Section 2.3 contains additional references.

To illustrate this concern, our theoretical model compares the behavior of the ZLBD-constrained economy to that of an otherwise identical unconstrained economy. In the unconstrained economy deposit interest rates adjust to achieve the spread that banks require in order to cover the cost of making loans, so that loans respond highly elastically to changes in credit demand. At the ZLBD deposit interest rates can no longer adjust, and any change in the policy rate, which leads to a one-for-one change in banks' lending rates, leads to a change in spreads that changes banks' ability to cover the cost of making loans, and therefore to a change in the creation of loans and deposits. We solve for the equilibrium of the ZLBD-constrained economy by borrowing insight from the *Drèze Equilibirum* (Drèze 1975) that demand is constrained when prices are upward rigid. At the ZLBD, banks' credit spread is upward rigid,[5] so the loan supply curve becomes a credit rationing constraint for the borrowing firms' demand.

Thus, in this ZLBD-constrained environment, rather counterintuitively, higher policy rates are expansionary and lower policy rates are contractionary. Specifically, because banks' profit margins depend on nominal credit spreads, a permanent increase in the nominal policy rate that does not depart from the fundamental level of the real interest rate, in other words a higher level of steady state inflation, implies a permanent expansion in credit, deposits and output, and vice versa. Similarly, policies that give rise to a temporary increase (decrease) in policy rates are expansionary (contractionary). The economy therefore behaves in a highly monetarily non-neutral way, both in the short term and the long term. Albeit the argument

[5]This is because the banks as the supplier of credit would want the credit spread to increase, but the ZLBD keeps the credit spread from increasing.

that higher inflation can help to get an economy out of a deep recession is not new, our innovation lies at the transmission mechanism from inflation to credit spreads to deposit creation to economic exchange to real activity.

Furthermore, in the ZLBD-constrained environment the drivers of inflation include not only traditional marginal cost terms but also the multiplier of a credit rationing constraint. Based on our empirical estimates, the supply of credit is highly responsive to credit spreads, and this means that disinflationary demand and supply shocks, if accompanied by a drop in the policy rate, are characterized not only by a drop in traditional marginal cost terms but also by tighter credit rationing. The latter has an inflationary rather than a deflationary effect, because credit rationing induces producers to charge higher prices, given that higher sales revenue allows them to relax their credit rationing constraint. This offsetting effect implies that the inflation response to shocks near the ZLBD is much more subdued than away from the ZLBD, while the output response is significantly amplified. In other words, the Phillips curve is much flatter near the ZLBD. We also emphasize another key feature of our model, the endogenous strong comovement between consumption and investment at the ZLBD. The reason is that at the ZLBD the overall quantity of deposits is constrained, with scarce deposits being required for the purchase of both consumption and investment.

Note that the price level can be nevertheless determinate because of sticky price inflation following Ireland (2001), and in our numerical analysis we provide the determinacy region of the Taylor rule in this bank financing environment. Calvo (2012, 2016) argues that government fiat money derives its liquidity and positive purchasing power from the existence of sticky prices, which provide an output backing to money. He terms this the price theory of money, and traces its origin back to Keynes' General Theory.

The rest of the paper is organized as follows. Section 2 reviews the related theoretical and empirical literatures. Section 3 presents empirical evidence on the semi-elasticity of credit supply with respect to credit spreads. Section 4 develops our theoretical model. Section 5 studies illustrative simulations based on this model. Section 6 concludes.

2. Literature Review

In this section we review five strands of literature that are related to our paper. Section 2.1 reviews the recent theoretical macro literature on deposits creation against bank credit. Section 2.2 reviews the early literature on inside money in general equilibrium with incomplete markets. Section 2.3 reviews the literature on the distinction between aggregate income and aggregate purchasing power. Section 2.4 reviews the literature on contractionary reductions in nominal policy interest rates in low-interest economies. Section 2.5 reviews the literature on the flattening of the Phillips curve.

2.1. Macroeconomic Models with Deposits Creation against Bank Credit

Our paper is broadly part of the large literature of DSGE models with financial frictions (see e.g., Kiyotaki and Moore 1997; Iacoviello 2005; de Fiore et al. 2011; Gertler and Kiyotaki 2011; Jermann and Quadrini 2012; Christiano et al. 2014). However, our novelty is the emphasis on banks' liability in providing liquidity service and the associated impact on monetary policy transmission. In this sense, our paper connects most closely with the recent academic endeavor to model deposits creation[6] against bank loans in the macroecononomic context (see e.g., Goodfriend and McCallum 2007, Faure and Gersbach 2017, and Clancy and Merola 2017).

In Goodfriend and McCallum (2007), loans create deposits that enter a deposits-in-advance constraint on consumption. Their work differs from ours in several dimensions. First, banks interact with a representative household rather than intermediating payments between households, firms and government. Second, all transactions other than consumption are carried out using physical resources, so that for their overall expenditure households still face a budget constraint rather than a deposits-in-advance constraint. This makes it harder to discuss the difference between income and purchasing power that is at the heart of some key results in our paper. Third, while deposits themselves do not represent physical resources, a role for physical resources is reintroduced into the model because loans are produced using a Cobb-Douglas production function in capital (as collateral, together with bonds) and labor, which gives impulse responses a strong real flavor, akin to a manufacturing firm, that is absent in our model. Faure and Gersbach (2017), in a 2-period model, show that in the absence of uncertainty financing models imply identical allocations to loanable funds models. This is

[6] In this paper, we use *deposits* and *inside money* interchangeably.

related to the result in Jakab and Kumhof (2015, 2019) that the deterministic steady states of the two model classes are identical. Finally, Clancy and Merola (2017) study macroprudential policies in small open economies in a variant of the financing model of Benes et al. (2014a,b).

In another part of the recent literature banks' deposits creation via loans plays a role; however, it does so alongside other mechanisms. The 3-period model of Donaldson et al. (2018) is based on a combination of the financing and loanable funds mechanisms for balance sheet growth. As in financing models, banks issue book money ("fake receipts") through risky lending. But as in loanable funds models, banks also need to function as warehouses that issue commodity money ("commodities receipts"), because warehoused commodities are required as collateral. The paper has at its heart an excellent explanation of the ability of banks to create money through lending. In Piazzesi and Schneider (2018), bank deposits are created through non-banks' physical saving and the purchase of Lucas trees by banks from non-banks. Non-banks can also obtain liquidity through intraday loans, which are close relatives of the fake receipts of Donaldson et al. (2018).

Furthermore, in the three-period two-state model of Bigio and Weill (2016) banks buy high-risk illiquid assets from producers in exchange for issuing low-risk liquid deposits, thereby allowing producers to hire additional workers who will not accept to be paid in high-risk assets. At the final stage however bankers settle their deposit contracts using the physical returns on their assets, so that banks are still intermediaries of physical resources, and workers still buy the output of producers by paying in physical resources. This dimension of the model could however be removed by allowing for a mechanism similar to that in financing models, whereby workers spend their deposits to buy output from producers, and producers use these deposits to repurchase the illiquid assets. To our knowledge, the only other paper that incorporates deposits creation via bank loans in a New Keynesian framework with nominal rigidities is Piazzesi et al. (2019). However, their focus is short rate disconnect, so deposits appear in the utility function that generates a convenience yield, whereas in our model deposits only appear in the flow of funds constraints, because our focus is the transaction role and store of value of deposits and the associated impact on monetary policy transmission.

2.2. Inside Money in General Equilibrium with Incomplete Markets

Our paper also further connects with the early literature on money. The so-called "loans creating deposits" has been a known fact for over a century. It was much emphasized in older economics literature when the banking sector had just started booming. Many authors such as Macleod (1866), Wicksell (1906), Hahn (1920), Hawtrey (1919), Schumpeter (1934, 1954), Keynes (1931), and Tobin et al. (1963) have all produced insightful work on this mechanism. These papers all make the explicit point that money is a financing outcome of bank credit.

The early formalization of money as the financing outcome of bank credit to our knowledge can be found in the monetary theory in the general equilibrium with incomplete markets. In this literature, there is an assumed requirement that money must be used to carry out transactions formalized through cash-in-advance constraints similar to Grandmont and Younes (1972, 1973). Inside money enters the economy against an offsetting obligation that guarantees its departure, and it is issued when borrowing agents apply for loans from the banks. As in Tsomocos (2003), commercial banks can be viewed as creators of "money " à la Tobin et al. (1963). Some quantity of money, called outside money, is present as agents' initial monetary endowment that is used to pay for loan interest. The banking sector therefore can be either an intermediary of existing money or a creator of new inside money, as in Shubik and Tsomocos (1992), Dubey and Geanakoplos (1992, 2003b, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), Goodhart et al. (2006, 2013) and Wang (2019). Equilibrium existence and nominal determinacy are established. Particularly, price level determinacy requires positive nominal interest rates that occur either via positive amounts of outside money as in Dubey and Geanakoplos (2006) or via endogenous default in equilibrium (Lin et al. 2016).

The deposits in our model are essentially inside money. However, in our model we do not take a stand on outside money, which is not needed for us to obtain nominal determinacy. In a similar spirit to the price theory à la Calvo, sticky prices, together with the interest rate rule, establish determinacy in our setup, and we provide the specific determinacy region of the Taylor rule in our modeling environment.

2.3. Income, Credit and Purchasing Power

Deposits creation via bank credit illustrates the financing role of banks. An insight emerges from such financing models that aggregate purchasing power equals prior income plus net new credit, because in this case the debt-financed increase in the purchasing power of borrowers is not offset by a fall in the purchasing power of other agents. The reason is that the new purchasing power is created in ledgers rather than physically, through an equal increase in the assets and the liabilities of the banking sector. In turn, this new purchasing power, by mobilizing resources that would otherwise have remained idle, triggers increases in the economy's post-loan income, while expost spending must of course equal ex-post income. What is needed in this from third parties is not a deposit of physical resources but the acceptance of the new purchasing power in payment for physical resources. This emphasis on the distinction between income and purchasing power can be traced back to some of the leading economists of the past, including Schumpeter (1934), Keynes (1939) and Kaldor (1989). This tradition continues in the Post-Keynesian literature, which emphasizes the ability of commercial banks to create "endogenous money" that adds to agents' purchasing power, and the importance of this mechanism for monetary and financial stability, see e.g. Minsky (1977), Moore (1979), Lavoie (2014) and Keen (2014, 2015). Keen argues that endogenous money plays a crucial role in Minsky's development of the Financial Instability Hypothesis.[7]

2.4. Contractionary Reductions in Nominal Policy Rates

One of the key conclusions of our paper is that at the ZLBD a further reduction in the nominal policy rate reduces output. The reason is that it reduces bank lending rates and thereby credit spreads, which in turn reduces loan extension and deposit creation, in an environment where real activity depends on deposits-based economic exchange.

In the theoretical literature, the paper by Brunnermeier and Koby (2018) makes a related point. It argues that a drop in the policy rate, on the one hand, increases the net return on high-interest legacy assets while on the other hand, reducing the net interest margin on new loans. Below a "reversal interest rate", which does not need to be located at zero, the latter effect starts to dominate, so that accommodative monetary policy becomes contrac-

[7] Bhattacharya et al. (2015) formalize some of Minsky's intuition, by modeling endogenous default and endogenous demand for credit and money.

tionary. The reversal interest rate is determined by the pattern of interest semi-elasticities of loan and deposit demands and the quantities of legacy assets and pre-endowed banking equity on the balance sheet. Our model is simpler and has a different transmission mechanism, the rationing of deposit creation and loan extension when deposit interest rates are at their exogenous lower bound. Also, Brunnermeier and Koby (2018) focus exclusively on the banking sector and take the rest of the economy, including loan and deposit demands, as given, while our model is concerned with the general equilibrium interaction between the banking sector and the real economy. Eggertsson et al. (2017) empirically document a collapse in pass-through from policy rates to other rates, especially to deposit rates, once the policy rate turns negative, and provide a New Keynesian model where negative policy rates either have a neutral or a contractionary effect on aggregate demand. The contractionary effect occurs under the additional assumption that an intermediation cost function depends negatively on bank profits. Under this assumption, because paying negative interest rates on reserves reduces bank profits, it increases intermediation costs and thereby lending rates, and the latter reduces aggregate demand. The main difference between this paper and ours is that in Eggertsson et al. (2017) deposits are accumulated through physical saving and do not play a role in economic exchange. The transmission mechanism from lower policy rates to the real economy is, therefore, different.

The empirical literature documents the effects of long periods at the ZLBD on banks' profits, equity, and lending in many countries around the world. Landier et al. (2013) focus on the US case and show that an increase in the Fed funds rate near the ZLBD induces banks to increase their quarterly earnings and that this is, in turn, associated with stronger bank lending. This is consistent with our theoretical predictions. Heider et al. (2017) study the euro area and show that when the central bank reduces the policy rate to zero or below, banks are reluctant to pass on negative rates to depositors, leading to a reduction of profits and lending, particularly among low-risk banks, and to "search for yield" among high risk banks. By contrast, when monetary policy rates are significantly positive this mechanism is of no importance. The latter is consistent with our unconstrained model. Basten and Mariathasan (2018) study Switzerland and show that negative interest rates have eroded bank equity. Gerstenberger and Schnabl (2017) focus on Japan and show that low interest rates have compressed banks' interest margins. Claessens et al. (2018), in a sample of 3385 banks from 47 countries from 2005 to 2013, demonstrate that drops in policy rates adversely

affect banks' net interest margins and profitability. Borio et al. (2015), in a sample of 109 large international banks headquartered in 14 advanced economies from 1995 to 2012, find similar results, and moreover find that this effect is stronger when the interest rate level is lower. Ampudia and Van den Heuvel (2018) show that the decrease in policy rates at the onset of the crisis boosted banks' stock prices, but that the effects reversed during the recent period with low and even negative policy rates.

On the policy front, in 2016 the Bank of England voiced concerns very similar to the ones in this paper, namely that absent additional policy measures further reductions in policy rates might not be fully transmitted to the real economy, with perverse effects on lending, because of an erosion in banks' intermediation margins near the ZLBD (Bank of England (2016a,b)). The rate cut decision at that time was therefore complemented by the introduction of the Term Funding Scheme (TFS), which provided low-interest funding and additional incentives to banks.

2.5. Flattening of the Phillips Curve

After the Global Financial Crisis of 2008, output in many countries remained far below the prerecession trend, unemployment remained high and inflation did not fall by as much as anticipated. In other words, there was a post-crisis flattening of the Phillips curve. Figure 1 shows the US data. A large literature has studied the reasons, but it has not yet converged on a consensus.

One popular explanation points to the better anchoring of inflation expectations due to central bank gains in credibility. Blanchard et al. (2015) and Blanchard (2016) provide empirical evidence suggesting that the flattening of the Phillips curve started in the 1980's, and that the slope did not decline further after the crisis. The main reason for the flattening of the curve, they argue, is a better anchoring of inflation expectations. This argument is challenged by Kiley (2015), who argues that the anchoring of inflation expectations is insufficient to account for all the inflation inactivity after the crisis. Similarly, Ball and Mazumder (2011) show that the anchoring of inflation expectations can account for the decline of the slope, but only on the strong assumption that expectations stay anchored at 2.5 % for several years when actual inflation was less than 1%.

Another explanation attributes the phenomenon to (typically real) shocks. Leduc and Wilson (2017) use cross-city data in the US to show that there was a decline in the slope of the Phillips curve after the crisis. They argue that this was caused by shocks and that the flattening should be short-lived, with the slope returning to normal once the economy recovers. Laseen and Sanjani (2016) also argue that changes in shocks are a more salient feature of US data than changes in coefficients. Specifically, they argue that exogenous cost-push shocks stopped inflation from falling so that the claim that the Phillips curve has flattened would be incorrect.

A related set of explanations emphasizes longer-term structural changes. Gordon (2013) argues that there has been an increase in the natural rate of unemployment, and that the Phillips curve is alive and well. Christiano et al. (2015), using a DSGE model, attribute the decline in inflation relative to pre-1996 norms to a decline in the growth rate of technology, not to a flat Phillips curve. Another possibility, studied by De Loecker and Eeckhout (2017) and De Loecker et al. (2016), is that competition has declined in the markets for goods and services, leading to a drop in supply and an increase in price markups. Coibion et al. (2018) and Coibion and Gorodnichenko (2015) call for a reconsideration of the formation of inflation expectations to account for the missing disinflation. Some papers also suggest that the reduced form of the Phillips curve would look flat even when the structural form produces a steeper slope. This has been explored by Ball and Mazumder (2011) and by Del Negro et al. (2015).

The only paper that, to our knowledge, relates the flattening of the Phillips curve to financial frictions is Gilchrist et al. (2017), who show that financially constrained firms increased prices in 2008 while their unconstrained counterparts cut prices. Based on a theoretical model, they argue that firms which face a higher external finance premium find it optimal to raise prices even if this implies a sacrifice of future market share, because an improvement in revenue reduces the need for external financing. This rationale for price increases is similar to ours while the nature of the financial friction is different. In our model bank credit rationing near the ZLBD leads to reduced deposit creation, while in Gilchrist et al. (2017), financial market credit rationing leads to higher external finance premia. Also, the argument of Gilchrist et al. (2017) focuses on the episode of the crisis itself, which was characterized by high credit spreads, whereas our argument is mainly concerned with the post-crisis ZLBD period, which was characterized by much lower spreads.

3. Estimation of the Spread Semi-Elasticity of Credit Supply

In this section we provide an estimate of the semi-elasticity of credit supply with respect to the credit spread, a key input into our model calibration and simulation. We collect quarterly US data for the sample period 1997Q1 - 2017Q1 from the Federal Reserve Bank of St. Louis, Call Reports, Datastream, and the Fed Loan Survey. Table 1 lists the data. The dependent variable is the log of real balances of commercial and industrial (C&I) loans from the US Flow of Funds. The corresponding spread is the spread on C&I loans net of smoothed charge-offs. This is a FISIM interest rate spread calculated using the methodology of Kyle Hood (2013).[8] The advantage of using a FISIM spread is that it approximates the average interest rate spread on the entirety of C&I loans. To control for endogeneity, we use standard 2SLS and instrument the spread using three candidate instrumental variables (IV) that are correlated with the demand for C&I loans, namely the purchasing manager index (PMI), nonfinancial business investment ($INVE$) and the percentage of banks reporting stronger loan demand in the Fed loan survey ($DEMAND$). The latter turns out to be the best IV according to standard criteria, with a four-quarter lag giving the best fit. We introduce three controls that capture shifts of the supply of C&I loans that are independent of the spread, the one-quarter lags of the growth rate of real GDP (Δgdp), of banks' liquid to total assets ratio ($liquidity$), and of the percentage of banks reporting tightening lending standards to large and medium firms ($supply$).

Table 2 reports estimation results for the instrument $DEMAND_{t-4}$.[9] The interpretation of the coefficient on the credit spread is that a 1 percentage point increase in the spread is associated with, *ceteris paribus*, a 10 percent increase in the level of loans. This will be treated as the baseline value of the short-term semi-elasticity for our model simulations. This is not a surprisingly large value, given that a 1 percentage point change in the spread is very large compared to historically observed average spreads. Additional considerations apply for the semi-elasticity over the longer run, because banks can over time adapt their business models in order to keep lending despite lower spreads, for example by increasing non-interest income. For the purpose of simulating permanent shocks, we therefore assume that the baseline long-term semi-elasticity equals 5 instead of 10.

[8] FISIM stands for Financial Intermediation Services Indirectly Measured in the System of National Accounts. It is an estimate of the value of the services provided by financial intermediaries, measured by multiplying loans and deposits by FISIM loan and FISIM deposit rate margins, both relative to a common reference rate. We are grateful to Kyle Hood for his support in performing the FISIM calculations.

[9] Estimation results for the other instruments are available upon request, and produce estimation results for the elasticity that are as large or larger than the one reported in Table 2.

The actual evolution of US spreads around the period of the 2008 Global Financial Crisis is shown in Figure 2. We observe that immediately after the crisis all interest rates dropped along with the Fed Funds rate. But the drop in the lending rate was far faster, and followed the Fed Funds rate much more closely. In our model it will follow the Fed Funds rate one for one. The deposit rate on the other hand adjusted much more slowly and was bounded below by zero rather than becoming negative. The consequence of the much faster drop in the lending rate along with the Fed Funds rate was a significant compression in spreads in the two years following the crisis. Spreads did recover later on, due to a combination of deposit rates gradually closing the remaining gap to the ZLBD and lending rates starting to exhibit a larger spread relative to the Fed Funds rate. The latter is not part of our model, and accounting for it would make the ZLBD less binding over the longer run. However, it is a clear feature of the data that this process takes time, so that the assumption of a fixed credit spread relative to the policy rate seems appropriate for the analysis of transitory shocks. Furthermore, even by 2016 spreads remained low relative to historical averages, so that some part of the compression in spreads may remain until the economy exits from the ZLBD.

4. The Model

4.1. Overview

The model economy consists of four sets of agents, banks, firms, households and government. One period represents one quarter. Upper/lower case symbols represent nominal/real variables. For simplicity we assume that the trend real growth rate and the steady state inflation rate equal zero.

The economy is intertemporally linked through households' holdings of government bonds and physical capital. However, the issuance and retirement of deposit money by banks remains purely intratemporal, with new deposits issued by banks at the beginning of each period, and the same deposits being retired, or destroyed, at the end of that period. Figure 3 summarizes the timeline, and Figure 4 shows the intra-period flows of deposit payments between agents. Each period begins with the realization of aggregate shocks. Immediately after this banks make loans to firms that create deposits for firms, with nominal interest rates i_t^ℓ and i_t^d, and with both loans and deposits assumed to be non-defaultable. Banks subsequently provide a payment system that the four sets of agents must use to make payments to each other by way

of deposit transfers. Note that at any point in time, banks face random deposit withdrawals. To meet such liquidity demand, banks can sell nominal loans to the central bank to obtain reserves at the cost of the policy rate i_t.

Firms, once their deposits have been created, face a deposits-in-advance constraint whereby they need to use deposits to make payments ahead of producing commodities. They make payments for wages, rental costs and dividends[10] to households and for net interest to banks, where it is assumed that banks immediately pass those payments through to households as lump-sum dividends.[11] Households, after receiving deposits from firms, are subject to a deposits-in-advance constraint whereby they need to use deposits to make payments ahead of consuming commodities. They make payments for private consumption, private investment and investment adjustment costs to firms. They also need to make payments (labour income taxes, purchases of net new government bonds) to government by way of deposits, and government, once it has received these deposits, needs to use them to make payments to firms (government consumption) and households (interest on government debt).[12] Once households and government have paid firms for their newly produced commodities, all circulating deposits have returned to firms and firms repay their loans in full.

We note that for agents that do not have access to credit but only to the payment system (households and government in our model), their principal deposits-in-advance constraints are formally equivalent to budget constraints, which state, in terms of physical resources, that expenditure has to be less than or equal to prior income.[13] In practice it is the availability of purchasing power (deposits) that matters for expenditure, and furthermore in modern economies all sectors have some access to credit, and are therefore subject to deposits-in-advance constraints that are not *prima facie* equivalent to budget constraints, as is the case for firms in our model. This explains why we refer even to the constraints of households and government as deposits-in-advance constraints. Of course the problems of these sectors could be generalized, but this would come at the cost of a less transparent model.

[10] It could alternatively be assumed that dividends can only be paid out after production has taken place. However, it can be shown that this does not materially change the results, while the exposition under our assumption is considerably simplified.

[11] These dividends represent a conversion of bank equity (earned through the interest rate spread) into bank deposits that are then transferred to households.

[12] In reality government treasuries receive and make payments into and from reserve accounts at the central bank, upon clearing of the underlying payment instrument. We abstract from this without loss of generality.

[13] Recall that for agents with access to credit, expenditure is less than or equal to prior income plus net new credit.

4.2. Banks

There is a continuum of banks of measure 1, with an individual bank indexed by j. For the ease of exposition, we only index j when necessary. When variables are not indexed, they refer to the banking sector. Bank loans L_t that charge an interest rate i_t^{ℓ} create deposit money D_t that pays an interest rate i_t^d, subject to an increasing and convex marginal cost of creating deposits through loans $C(L_t)$.[14] This cost of making loans is the proxy for any cost of financial intermediation. It encompasses the underlying agency frictions of financial intermediation much emphasized in the macro-finance literature (see e.g., Bernanke et al. 1999; Lorenzoni 2008; Gertler and Karadi 2009). For tractability and the ease of data estimation of the spread semi-elasticity of credit supply, we do not seek to further take a stance on the specific forms of the underlying agency frictions.

The banking sector makes profits by charging the spread between the loan rate and the deposit rate, and it would also incur a cost when obtaining reserves from the central bank. The profit maximization problem of the banking sector is

$$\begin{aligned} \underset{\{L_t, D_t, \Delta L_t, S_t\}}{Max} \Pi_t^b = i_t^l \int_0^1 (L_t - \Delta L_t(j)) dj \\ - i_t^d \int_0^1 (D_t - \Delta D_t(j)) dj \\ + i_t^l \Delta L_t - i_t S_t - C(L_t). \end{aligned} \tag{1.1}$$

Note that for each individual bank j, it faces an idiosyncratic and random deposit withdrawal of $\Delta D_t(j)$. To meet such liquidity demand, via the open market operation each bank sells nominal asset $\Delta L_t(j)$ to the central bank to obtain reserves $S_t(j)$ at the cost of the policy rate, and each bank ensures the reserves it has obtained $S_t(j)$ is sufficient to meet the deposit withdrawal. Therefore, the bank's balance sheet should shrink if households withdraw deposits; hence, eq(1.1) subtracts $\Delta L_t(j)$ on the asset side and $\Delta D_t(j)$ on the liability side. Eventually, the currency in circulation flows back to the banking sector to extinguish the loans for $i_t^l \Delta L_t$, and the banking sector repays the central bank $i_t S_t$ to redeem the nominal assets via the open market operation. Each bank is assumed to share the cost of obtaining reserves evenly.

[14] For another use of an exogenous intermediation cost function see Eggertsson et al. (2017).

Given the market clearing for reserves $\Delta L_t = S_t$, substitute it into eq(1.1) and take the first-order condition for S_t, it follows that

$$i_t^l = i_t. \tag{1.2}$$

The above result suggests that in our model monetary policy passes through to the loan rate. This result is in line with the theoretical results in Peiris and Polemarchakis (2017) and Brunnermeier and Koby (2019), and it is also supported by empirical evidence(see Drechsler et al. 2017; Ippolito et al. 2018) that floating loan rates are tied to the policy rate and that there is a substantial spread between policy rate and deposit rate.

The cost of making loans is expressed in (1.3)[15]

$$C(L_t) = \frac{\kappa}{1+\frac{1}{\xi}} P_t \bar{a} (\frac{L_t}{P_t \bar{a}})^{1+\frac{1}{\xi}}. \tag{1.3}$$

Here $\bar{a}$ is calibrated to equal the steady state real size of banks' balance sheet, and ξ determines the spread semi-elasticity of credit supply. For simplicity we assume that $C(L_t)$ represents a lump-sum transfer to households rather than a resource cost. Because banks also transfer their profits to households, total lump-sum receipts of households from bank j equal $\left(i_t^\ell - i_t^d\right) D_t = \left(i_t - i_t^d\right) L_t$.

Substitute the banking sector's balance sheet equation $L_t = D_t$ into eq(1.1) and take the first-order condition for L_t, it follows that

$$d_t = \ell_t = \bar{a} (\frac{i_t - i_t^d}{\kappa})^{\xi}. \tag{1.4}$$

The equality $d_t = \ell_t$ states that in our economy money equals loans, or credit. Furthermore, we have $i_t^d = 1$ at the ZLBD. Condition (1.4) shows that in the unconstrained economy credit supply responds highly elastically to credit demand, as i_t^d can adjust and is determined

[15]For another use of an exogenous intermediation cost function see Eggertsson et al. (2017). For the purpose of studying the effects of monetary policy this formulation has the advantage of keeping the model's transmission mechanism simple and transparent. In future work on macroprudential policy, which unlike monetary policy may itself affect the shape of the cost function, we will aim to replace this with a more comprehensive model of bank optimization.

in equilibrium so that the bank can accommodate credit demand, and that in the ZLBD-constrained economy credit supply responds highly inelastically to credit demand, as credit must adjust so that the bank can continue to make zero profits at the margin, given that i_t is exogenous to the bank and i_t^d cannot adjust. The parameter ξ plays a critical role for the quantity of credit at the ZLBD, while it mainly determines the evolution of deposit interest rates away from the ZLBD. The equation (1.4) can be used to compute the spread semi-elasticity of credit supply with respect to the credit spread, $d\ln\left(\ell_t/\bar{\ell}\right)/d\hat{\imath}_t$, where $\hat{\imath}_t = \left(i_t - i_t^d\right) * 400$, as a function of ξ. Following the empirical results of Section 3 we set this elasticity equal to 10, meaning that credit supply increases by 10 percent for a 1 percentage point increase in the spread.

An important question concerns the recipient of the interest paid on deposits. We observe that money circulates inside each period, so that any deposit is held by multiple agents before it is destroyed at the end of the period. The assignment of the recipient of deposit interest is therefore necessarily arbitrary. For simplicity and ease of interpretation, we assume that all deposit interest is received by firms. This ensures that the spread between loan and deposit rates enters in a single location in the model, namely in the Phillips curve. It represents the opportunity cost of having banks create money for firms, with the benefit being the relaxation of firms' deposits-in-advance constraint. Firms pay this spread to rent the exclusive ability of banks to create a generally accepted medium of exchange.

4.3. Firms

There is a continuum of firms of measure 1, with an individual firm indexed by j. Each firm produces output $y_t(j)$ at price $P_t(j)$, subject to monopolistic competition and stickiness in price inflation. Aggregate output y_t is a Dixit-Stiglitz aggregate over varieties $y_t(j)$, with elasticity of substitution θ, and the corresponding aggregate price level and inflation rate are P_t and π_t. Real inflation adjustment costs are given by

$$G_{P,t}(j) = \frac{\phi_p}{2} y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2 , \tag{1.5}$$

where ϕ_p calibrates the degree of inflation stickiness. Each firm hires labour $h_t(j)$ and capital $K_t(j)$ at competitive nominal/real prices W_t/w_t and R_t^k/r_t^k. Aggregate labour h_t and capital K_t are integrals over $h_t(j)$ and $K_t(j)$, respectively. The firm obtains loans to satisfy a

deposits-in-advance constraint, and pays a gross nominal interest rate of i_t^ℓ on the loans while earning a gross nominal interest rate of i_t^d on the corresponding deposits. Using the equality $D_t(j) = L_t(j)$, the nominal profit of firm j is therefore given by

$$\Pi_t^F(j) = P_t(j)y_t(j) - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t^\ell - i_t^d) - P_t G_{P,t}(j) \; . \tag{1.6}$$

The deposits-in-advance constraint of firm j states that it needs to use its deposits to pay net interest to its bank, wages to its workers, rental costs to its providers of capital and dividends to its shareholders, all ahead of production. We therefore have

$$L_t(j) \geqslant L_t(j)(i_t^\ell - i_t^d) + W_t h_t(j) + R_t^k K_t(j) + \Pi_t^F(j) \; . \tag{1.7}$$

The left-hand side of this constraint represents the total liquidity generated for the firm by the bank. The right-hand side represents the payments made with these deposits. We adopt the notation $D_t^{hb}(j) = L_t(j)(i_t^\ell - i_t^d)$ (deposits to cover net interest payments, which are received by banks from firms and then by households from banks), $D_t^{hf}(j) = W_t h_t(j) + R_t^k K_t(j)$ (deposits to cover wage and user cost payments, which are received by households from firms) and $D_t^{hm}(j) = \Pi_t^F(j)$ (deposits to cover firm payouts of monopolistic profits, which are received by households from firms). Inflation adjustment costs $P_t G_{P,t}(j)$ are paid by firms to each other, and therefore do not change the bank deposits of the aggregate firm sector. The deposits-in-advance constraint must be binding in equilibrium, because the opportunity cost to firms of having banks create idle deposit balances for them, the spread $i_t^\ell - i_t^d$, must be positive in equilibrium by (1.4), (1.2) and the Inada conditions on consumption utility - recall that no production, and therefore no consumption, could take place in the complete absence of monetary exchange. For the remainder of this paper we will inquire for each agent whether prior income or net new credit finances spending. The key observation for the case of firms is that before starting production firms' prior income equals zero, and it is *only* the extension of new credit that allows the production cycle to start.

Combining (1.6) and (1.7), we obtain the final form of the deposits-in-advance constraint:

$$L_t(j) \geqslant P_t(j)y_t(j) - P_t G_{P,t}(j) \; . \tag{1.8}$$

The firm's technology is standard, with the supply of output $y_t^s(j)$ given by

$$y_t^s(j) = S_t^a h_t(j)^{1-\alpha} K_t(j)^{\alpha} \,, \tag{1.9}$$

where α calibrates the capital share in output and S_t^a is a first-order autoregressive process for total factor productivity. Standard optimization with imperfectly substitutable output varieties yields the demand for output $y_t^d(j)$,

$$y_t^d(j) = \left(P_t(j)\right)^{-\theta} \left(P_t\right)^{\theta} y_t \,,$$

where in equilibrium $y_t^d(j) = y_t^s(j)$. The optimization problem of firms is

$$\underset{\{P_t(j),h_t(j),K_t(j),L_t(j)\}_{t=0}^{\infty}}{Max} E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t^h \Big[\left(P_t(j)\right)^{1-\theta} \left(P_t\right)^{\theta} y_t - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t^{\ell} - i_t^d) \tag{1.10}$$

$$- \frac{\phi_P}{2} P_t y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2 - MC_t \left(\left(P_t(j)\right)^{-\theta} \left(P_t\right)^{\theta} y_t - S_t^a h_t(j)^{1-\alpha} K_t(j)^{\alpha} \right)$$

$$+ \eta_t^f \left(L_t(j) - \left(P_t(j)\right)^{1-\theta} \left(P_t\right)^{\theta} y_t + \frac{\phi_P}{2} P_t y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2 \right)$$

$$- \eta_t^b \left(L_t(j) - P_t \bar{a} \left(\frac{i_t^{\ell} - i_t^d}{\kappa} \right)^{\xi} \right) \Big] \quad ,$$

where $i_t^d = 1$ at the ZLBD, β is the household intertemporal discount factor, and Λ_t^h is the multiplier of the household's nominal budget constraint. The corresponding multiplier of the real budget constraint is λ_t^h. The firm maximizes the present discounted value of its profits subject to three constraints. First, goods supply must equal goods demand, with a multiplier on this constraint of MC_t, which denotes nominal marginal cost. Second, the deposits-in-advance constraint (1.8) must hold, with a multiplier of η_t^f.

Noteworthy is that at the ZLBD banks' participation constraint (1.4), or credit rationing constraint, must hold, with a multiplier of $\eta_t^b \geq 0$, where changes in η_t^b depend on relative changes in credit supply and credit demand. In the unconstrained economy the interest rate i_t^d is free to vary to achieve the spread that is necessary for the bank to elastically accommodate credit demand. Therefore, there is no quantity rationing of credit and $\eta_t^b = 0$. This approach of solving the equilibrium at and away from the ZLBD borrowings insight from the *Drèze Equilibirum* (Drèze 1975) that demand is constrained when prices are upward rigid. At the

ZLBD, banks' credit spread is upward rigid. This is because the banks as the supplier of credit would want the credit spread to increase, but the ZLBD keeps the credit spread from increasing. Thus, the loan supply curve eq(1.4) becomes a credit rationing constraint for the borrowing firms' demand, and banks' participation constraint (1.4), therefore, shows up in the firms' problem. This also follows the convention in the macro-finance literature that models financial frictions as financial intermediaries' participation constraint or incentive compatibility constraint that distorts the firms' or the households' maximization problem (see e.g., Carlstrom and Fuerst 1997; Bernanke et al. 1999). And away from the ZLBD, the deposit rate emerges in equilibrium and clears the market so that eq(1.4) holds but is non-binding.

The firm's optimality conditions for capital and labour are standard, and we do not show them here to conserve space. But the Phillips curve is now affected by credit rationing

$$\frac{\mu mc_t}{(1-\eta_t^f)} - 1 = \phi_p(\mu-1)\left(\frac{\pi_t}{\pi_{t-1}}-1\right)\frac{\pi_t}{\pi_{t-1}} - \beta E_t \frac{\lambda_{t+1}^h}{\lambda_t^h}\frac{y_{t+1}}{y_t}\frac{(1-\eta_{t+1}^f)}{(1-\eta_t^f)}\phi_p(\mu-1)\left(\frac{\pi_{t+1}}{\pi_t}-1\right)\frac{\pi_{t+1}}{\pi_t}\,, \tag{1.11}$$

where mc_t is real marginal cost and $\mu = \theta/(\theta-1)$. The optimality condition for loans is

$$i_t^\ell - i_t^d = \eta_t^f - \eta_t^b\,. \tag{1.12}$$

In the unconstrained economy this simplifies to $1-\eta_t^f = 1-i_t^\ell + i_t^d$, so that the Phillips curve is directly affected only by the credit spread. In the ZLBD-constrained economy we have $1-\eta_t^f = 2-i_t^\ell-\eta_t^b$, in other words the multiplier on the credit rationing constraint directly enters the Phillips curve, with higher η_t^b putting upward pressure on prices. We calibrate our ZLBD-constrained model economy such that steady state interest rates are far from the point where the economy would escape the ZLBD, and we assume that the standard errors of shocks are small enough so that the possibility of transitioning between ZLBD-constrained and unconstrained economies can be ignored. This allows us to focus our analysis on the two polar extremes, which illustrate all the key economic insights.

4.4. Households

There is a continuum of households of measure 1, with an individual household indexed by j. Utility depends on consumption $c_t(j)$ and hours worked $h_t(j)$, and is subject to consumption demand shocks S_t^c that follow a first-order autoregressive process. The intertemporal elasticity of substitution is ϵ, external habit persistence is v, the weight on labour disutility is χ, and the labour supply elasticity equals 1. Households maximize lifetime utility, where consumption utility satisfies the Inada conditions, by choosing paths for $c_t(j)$, $h_t(j)$, physical investment $I_t(j)$, physical capital $k_t(j)$ and holdings of government bonds $B_t(j)$,

$$\underset{\{c_t(j),h_t(j),I_t(j),k_t(j),B_t(j)\}_{t=0}^{\infty}}{Max} E_0 \sum_{t=0}^{\infty} \beta^t [S_t^c (1-v)^{\frac{1}{\epsilon}} \frac{(c_t(j) - v c_{t-1})^{1-\frac{1}{\epsilon}}}{1-\frac{1}{\epsilon}} - \frac{\chi}{2} h_t(j)^2] \quad , \tag{1.13}$$

subject to a sequence of deposits-in-advance constraints. Household spending is financed entirely through prior income received in the form of bank deposits, which in this case includes factor incomes $W_t h_t(j)$ and $R_t^k k_{t-1}(j)$ and lump-sum dividend incomes $D_t^{hm}(j)$ and $D_t^{hb}(j)$. Households' first deposits-in-advance constraint is that the above-mentioned incomes must be sufficient to cover gross payments to the government, including purchases of net new government debt and labor income taxes:

$$W_t h_t(j) + R_t^k k_{t-1}(j) + D_t^{hm}(j) + D_t^{hb}(j) \geq B_t(j) - B_{t-1}(j) + W_t h_t(j) \tau_{L,t} \; . \tag{1.14}$$

In our simulations this constraint is never binding. For future reference, we denote the net aggregate deposits collected by the government from households by $D_t^{gh} = B_t - B_{t-1} + W_t h_t \tau_{L,t}$. Next, households receive net interest $i_t - 1$ on government bonds held between periods t and $t+1$. This interest is received in period t, with only the principal settled in period $t+1$. This treatment of interest is equivalent to the treatment of private loan (and deposit) interest. The difference is that loans are always repaid in full before being renewed while government debt is not. Households's second deposits-in-advance constraint is that their factor and dividend incomes minus payments to the government net of interest received must be sufficient to cover payments for commodities purchases to firms, which include consumption $P_t c_t(j)$, investment $P_t I_t(j)$ and investment adjustment costs $P_t G_{I,t}(j)$, where real investment adjustment costs equal

$$G_{I,t}(j) = \frac{\phi_I}{2} I_t \left(\frac{I_t(j)}{I_{t-1}(j)} - 1 \right)^2 \; , \tag{1.15}$$

and where ϕ_I calibrates the degree of investment inertia. We therefore have

$$W_t h_t(j) + R_t^k k_{t-1}(j) + D_t^{hm}(j) + D_t^{hb}(j) - (B_t(j) - B_{t-1}(j) - W_t h_t(j)\tau_{L,t} - B_t(j)(i_t - 1)) \geq \tag{1.16}$$

$$P_t c_t(j) + P_t I_t(j) + P_t G_{I,t}(j) \ .$$

This deposits-in-advance constraint must be binding in equilibrium because the opportunity cost to households of investing in idle and (for households) zero interest deposit balances, the net interest rate on government bonds $i_t - 1$, must be positive in equilibrium because, as discussed above, $i_t^\ell - i_t^d$ must be positive in equilibrium. Finally, the accumulation equation for physical capital is given by the law of motion

$$k_t(j) = (1 - \delta)\, k_{t-1}(j) + I_t(j) \ , \tag{1.17}$$

where δ is the depreciation rate of capital. Given the binding deposits-in-advance constraint, the household problem is standard for New Keynesian models. All optimality conditions are therefore also standard, and we do not show them to conserve space.

4.5. Government

The government's deposits-in-advance constraint is given by

$$D_t^{gh} \geq B_t\,(i_t - 1) + P_t g_t \ . \tag{1.18}$$

Government spending is financed entirely through prior income received in the form of bank deposits, which in this case includes household income transferred to government in payment of taxes and in exchange for new government bonds. The deposits-in-advance constraint must be binding in equilibrium because the cost to government of borrowing to acquire idle and (for government) zero interest deposit balances, the net interest rate $i_t - 1$, must be positive in equilibrium because $i_t^\ell - i_t^d$ must be positive in equilibrium. The labour tax rate is determined by the fiscal rule

$$\tau_{L,t} - \bar{\tau}_L = f_b \left(\frac{b_t}{4y_t} - \frac{\bar{b}}{4\bar{y}} \right) \ , \tag{1.19}$$

where f_b is the feedback coefficient on the debt-to-GDP ratio. The monetary policy rule is given by

$$i_t = ((2-\beta)\,\pi_t)\left(\frac{\pi_t}{\bar{\pi}}\right)^{m_\pi}\left(\frac{\ell_t}{\bar{\ell}}\right)^{m_\ell}\ , \tag{1.20}$$

where m_π is the inflation gap feedback coefficient and m_ℓ is the loans gap feedback coefficient. The target real interest rate $2-\beta$ is consistent with the economy's steady state real interest rate, and the target for gross inflation is $\bar{\pi}$. The Taylor principle corresponds to $m_\pi > 0$.

4.6. Market Clearing and GDP

The goods market clearing condition is

$$y_t = c_t + I_t + g_t + G_{p,t} + G_{I,t}\ . \tag{1.21}$$

The market clearing condition for physical capital is

$$K_t = k_{t-1}\ . \tag{1.22}$$

And finally, GDP is defined as

$$gdp_t = c_t + I_t + g_t\ . \tag{1.23}$$

4.7. Calibration

Table 3 presents the details of our model calibration. It distinguishes between calibrated parameter values in a ZLBD-constrained (fourth column) and an unconstrained (fifth column) economy. The discount factor β is set to fix the steady state real policy interest rate to 3% per annum in both models. The nominal and real rates are equal in steady state because the central bank's net inflation target is set to 0% per annum. Keeping the steady state policy rate equal across models has the advantage of implying similar steady state real variables as we move from unconstrained to ZLBD-constrained economies.[16] Instead of differences in the steady state policy rate, distinctions between unconstrained and ZLBD-constrained economies are therefore assumed to be due to differences in steady state deposit interest rates that are in turn due to differences in the cost of supplying credit. To implement this we specify three models that differ by the value taken by the deposit rate, an unconstrained

[16] Otherwise there would for example be very large differences in steady state capital stocks.

model with a rate of 1% per annum, a hypothetical unconstrained model with a -1% rate, and a ZLBD-constrained model with a 0% rate. The first and second models are used to calibrate the respective parameters of the credit supply cost function (1.3), $\bar{a}$, κ and ξ. The three parameters from the second (hypothetical) model are then applied to the third, ZLBD-constrained, model. The idea is that a "fundamental" credit supply cost function can be identified from the unconstrained model under the counterfactual (in the model) assumption that deposit rates can become negative, and that the ZLBD does not affect this function but instead forces the economy's steady state, and especially banks' lending volume, to adjust to the constraint, given the credit supply cost function of the hypothetical unconstrained economy. In both unconstrained economies the elasticity parameters ξ are set to fix the steady state spread semi-elasticity of credit supply at 10 in the baseline, and at 5 and 1 in two alternatives. The parameters κ are set to fix the steady state real deposit rates at 1% and -1% per annum, respectively, while the steady state levels of loans $\bar{a}$ are determined by loan demand at that interest rate.

The remainder of the calibration applies equally to both models. For preferences, we remain close to much of the macro literature by setting households' intertemporal elasticity of substitution to $\epsilon = 0.5$ and the habit persistence parameter to $v = 0.75$. The weight χ on hours in the utility function is set to normalize steady state labour supply to 1. For technologies, the production function parameter α is set to fix the steady state ratio of labour income to GDP at 60%, and the depreciation rate δ is set to fix the investment-to-GDP ratio at 20%. Both are in line with recent US data. We calibrate the steady state government spending to GDP ratio at 18%, and the steady state level of the labour income tax rate is set to be consistent with a steady state government debt to GDP ratio of 100%. Again, both are close to recent US data. The calibration of the investment adjustment cost parameter $\phi_I = 2.5$ follows Christiano et al. (2005). The steady state gross markup, in line with much of the New Keynesian literature, is set to $\mu = 1.1$, and the degree of inflation stickiness to $\phi_p = 200$. Together these values imply a contract duration of 5 quarters in an equivalent Calvo (1983) model with indexation to past inflation. In the fiscal policy rule the debt feedback coefficient is set to $f_b = 0.1$. In the monetary policy rule the baseline inflation gap and loans gap feedback coefficients are fixed at $m_\pi = 3.0$ and $m_\ell = 0$. We will perform sensitivity analysis for these coefficients. The persistence of first-order autoregressive shocks in our illustrative simulations is $\rho_c = 0.7$ for consumption demand shocks (habit persistence imparts additional

persistence to this shock) and $\rho_a = 0.95$ for technology shocks. With the foregoing calibration our ZLBD-constrained model economy is located well within the ZLBD-constrained region in steady state, and it remains in that region even after shocks that have sizeable real and financial effects. This justifies our reliance on simulations that ignore the small probability of transitioning to the unconstrained economy (and vice versa).

5. Model Simulations

In this section we discuss impulse responses that first illustrate the behavior of the ZLBD-constrained economy as a function of the spread semi-elasticity of credit supply, and that then compare the behavior of the ZLBD-constrained economy to that of the unconstrained economy. In each case the black solid, dark blue dashed and red dotted lines show simulations for the ZLBD-constrained economy with spread semi-elasticities of 10/5/1, while the green dashed and dotted lines show simulations for the unconstrained economy with spread semi-elasticities of 10/5. We consider it important to conduct sensitivity analysis with respect to the spread semi-elasticity because, while our own estimate of around 10 is statistically significant and robust to the use of alternative instruments, at this point this is the model parameter for which there is the least guidance from other literature.

The first subsection illustrates the behavior of the ZLBD-constrained economy under standard demand and supply shocks when the monetary authority follows an interest rate rule that satisfies the Taylor principle $m_\pi > 0$. It is well known that away from the ZLBD such rules stabilize inflation and output. We show that at the ZLBD the same type of rule is contractionary under shocks that reduce the rate of inflation, such as negative shocks to consumption demand and positive shocks to technology. We also show that at the ZLBD the Phillips curve is flatter than in the equivalent unconstrained economy.

The second subsection illustrates the behavior of the ZLBD-constrained economy when the monetary authority modifies its policy rule to deal with this problem. The key insight is that at the ZLBD a policy of deliberately increasing inflation and therefore the nominal policy rate increases spreads, lending and output, and this can help the economy to not only deal with negative shocks but also to reach a permanently higher level of economic activity. We therefore first study, for the consumption demand shock analyzed in the first subsection, an endogenous response to a loans gap in addition to the inflation gap, and we then consider an exogenous and permanent increase in the policy rule's inflation target.

5.1. Reductions in the Policy Rate Are Contractionary at the ZLBD

This subsection studies two shocks that have a disinflationary effect. Under our maintained assumption about the monetary policy rule, this triggers a reduction in the nominal policy rate and therefore in credit spreads. We show that this response reduces output in a ZLBD-constrained economy unless the spread semi-elasticity of credit supply is extremely low. The reason is that even for moderately low semi-elasticities the effect of lower nominal policy rates on spreads and the quantity of credit dominates the effect of lower real interest rates on aggregate demand through intertemporal substitution.

Consumption Demand Shock

The top half of Figure 5 shows the simulated effects of a shock to consumption preferences S_t^c whereby consumption in the ZLBD-constrained economy drops by around 1.4% on impact. The shock leads to a reduction in the demand for capital and labour that triggers a reduction in wages and user costs and therefore, *ceteris paribus*, in inflation. However, the overall impact on inflation also depends on the credit rationing constraint, which in turn depends on the relative effect of the shock on the demand and supply of credit. By the deposits-in-advance constraint the drop in aggregate demand reduces the demand for credit. But by the monetary policy rule the reduction in inflation leads to a drop in the policy rate that reduces the credit spread and thereby the supply of credit. When credit supply is even moderately elastic (i.e. even for an elasticity as low as 1) with respect to the credit spread, the decrease in the supply of credit is larger, thereby reducing output beyond the direct effect of the shock, and increasing the credit rationing multiplier and thus, *ceteris paribus*, marginal cost and inflation. The more elastic is credit, the larger is the decrease in output and the smaller the decrease in inflation.

For the baseline simulation with a spread semi-elasticity of 10, investment comoves with consumption because the shortage of deposit money constrains purchases of both. As credit supply becomes less elastic, the reduction in credit supply decreases but so does the reduction in credit demand. The latter occurs because the credit rationing component of marginal cost increases less strongly so that the inflation rate drops by more, which in turn leads to a stronger drop in the real policy rate and thus a *ceteris paribus* stimulus to aggregate demand and thereby to the demand for credit. Quantitatively, with successive drops in the elasticity of credit supply, reductions in credit supply decrease by more than reductions in credit demand. However, it can be shown that the spread semi-elasticity of credit supply needs to become

even smaller than in Figure 5, specifically that it needs to drop below 0.5, for the credit rationing multiplier to drop on impact. However, before this happens the reduction in credit supply becomes sufficiently small to cause investment to rise instead of falling (see the red dotted line). In other words, the positive comovement between consumption and investment depends on the spread semi-elasticity of credit supply being sufficiently high, but with values even well below our baseline estimate leading to very strong comovement.

The bottom half of Figure 5 shows the same shock as the top half. It compares the ZLBD-constrained and unconstrained economies, in each case with a spread semi-elasticity of 10. Because the shock to consumption preferences is identical, the consumption responses of the two economies are similar, but otherwise the results are strikingly different.

For the unconstrained economy the effect of the credit rationing component $1/\left(1 - i_t + i_t^d\right)$ on marginal cost is negligible and does not offset the drop in wages and user costs. As a result, the drop in inflation is much larger despite a much smaller drop in wages and user costs, and leads to a larger drop in the nominal and real policy rate. Because this is accompanied by a similar drop in the deposit rate, the effect on the credit spread is smaller than in the ZLBD-constrained economy, and only reflects the lower marginal cost of lending after the drop in consumption demand and therefore in credit demand. The absence of credit rationing leaves banks free to supply the quantity of credit demanded by firms, while lower real policy rates stimulate aggregate demand and thereby the demand for credit. Both limit the contractionary output effects of the shock, with a smaller drop in consumption than in the ZLBD-constrained economy, and a strong increase rather than a decrease in investment. This model does therefore not generate comovement between consumption and investment under shocks to aggregate demand.

For the ZLBD-constrained economy, credit rationing that follows a contractionary demand shock implies a larger output contraction accompanied by a more subdued inflation response. In other words, the Phillips curve of the ZLBD-constrained economy is flatter than that of the unconstrained economy.

Technology Shock

The top half of Figure 6 shows the simulated effects of a persistent shock to technology S_t^a whereby total factor productivity increases by 1.0% on impact. In the ZLBD-constrained economy this otherwise expansionary shock leads to a drop in output of almost 0.6% after 6

quarters. The reason is that an expansionary technology shock reduces inflation and therefore, due to the monetary policy rule, the policy rate, the credit spread and deposits. Credit rationing therefore leads to a drop in output and a dampened effect on inflation. With less elastic credit supply we observe less credit rationing, more stable output and a larger drop in inflation. For high and moderate spread semi-elasticities of credit supply consumption and investment again comove.

The bottom half of Figure 5 shows that in the unconstrained economy the favorable technology shock is indeed expansionary. The dominant effect on inflation is the drop in wages and user costs, with a negligible contribution of the credit component $1/\left(1 - i_t + i_t^d\right)$ on marginal cost. While this leads to a significant reduction in the nominal policy rate, the deposit rate drops by even more, thereby allowing the credit spread to rise and giving banks an incentive to supply the additional credit and money that is needed by an economy that attempts to realize the potential of improved technology.

As for the Phillips curve, given the increase in potential output following the technology shock, and given rigidities in the adjustment of the components of aggregate demand, the output gap drops together with inflation. However, in the ZLBD-constrained economy the drop in the output gap is much larger while the drop in inflation is much smaller. In other words, the Phillips curve is flatter.

5.2. Inflationary Policies Are Expansionary at the ZLBD

This subsection studies two policies that have an inflationary effect, and that therefore trigger an increase in the nominal policy rate, the credit spread, deposits and output. In the ZLBD-constrained economy temporary inflationary policies have a much greater expansionary effect than in an unconstrained economy because they reduce the severity of credit rationing. And permanent inflationary policies, which have no real effect in an unconstrained economy, have a very strong and permanent effect on output.

Monetary Policy Rule with a Loans Gap

The simulations in Figures 5 and 6 emphasize that at the ZLBD systematic reductions in the nominal policy rate in response to disinflationary shocks are contractionary. This raises two questions: First, would a weaker systematic response to inflation mitigate the contractionary effects of disinflationary shocks? And second, could a systematic response to

other gap variables stabilize output more effectively? Figure 7 shows that the answer to the first question is no while the answer to the second question is yes.

The top half of Figure 7 studies the same contractionary shock to consumption demand as in Figure 5, in the ZLBD-constrained economy and with a spread semi-elasticity of credit supply of 10. It varies the inflation gap feedback coefficient m_π from 3 to 1.5 to 0.1. This figure shows that with a weaker inflation response the inflation rate drops by more following the shock while the policy rate exhibits virtually no change. The main change is therefore a slightly smaller drop in the real policy rate, while there is virtually no change in the credit spread and credit. The smaller decline in the real policy rate in turn implies a larger initial decline in investment and output. This does not support a policy of responding less strongly to inflation.

The bottom half of Figure 7 again studies the same shock, but in this case it varies the loans gap feedback coefficient m_ℓ from 0 to 2 to 8. With a positive loans gap coefficient m_ℓ, when banks reduce credit due to insufficient credit spreads, this *ceteris paribus* triggers a systematic (rules-based) monetary easing, thereby generating an inflationary response. Therefore, the policy rate, and consequently credit spreads and deposits, increase relative to the case of $m_\ell = 0$. This significantly reduces credit rationing while permitting a larger drop in the real policy rate due to higher inflation. The combination of higher credit and lower real interest rates implies a shallower contraction, specifically a smaller drop in consumption and an increase rather than a drop in investment. At the ZLBD a monetary policy response to the loans gap therefore becomes a useful countercyclical tool.

Figure 8 studies the determinacy properties of the monetary policy rule (1.20) as a function of the feedback coefficients m_π and m_ℓ. We begin with the bottom plot for the unconstrained economy, which shows that the Taylor principle $m_\pi > 0$ holds at $m_\ell = 0$, but that a slightly weaker inflation response becomes possible as m_ℓ grows. The reason is that an interest rate response to the loans gap can substitute for a response to inflation, because an increase in loans, by (1.4), implies an increase in the credit spread and therefore in the credit rationing component of marginal cost $1/\left(1 - i_t + i_t^d\right)$. But this effect is weak given the small role played by the credit rationing component when deposit rates can adjust. For the same reason, with a strong inflation feedback at $m_\pi = 3$ any loans gap feedback is compatible with determinacy.

For the ZLBD-constrained economy in the top half of Figure 9, the loans gap becomes much more important, with $m_\ell \geq 0$ required except at extremely high inflation gap coefficients.

More importantly, as long as $m_\ell \geq 0$ the inflation gap coefficient can become negative, with only a very weak requirement on the overall response to inflation of $1 + m_\pi > 0$. In other words, an interest rate response to the loans gap can substitute for a response to inflation, because the credit rationing component of marginal cost plays a much bigger role in the determination of inflation.

Permanent Increase in the Inflation Target

Because a ZLBD-constrained economy operates permanently below capacity because of credit rationing, additional credit can increase the economy's output. This suggests that a permanent increase in the policy rate, in order to permanently increase banks' lending margins, would be beneficial. This is the subject of our final simulation in Figure 9, which studies the effects of an unanticipated and permanent 0.25 percentage point increase in the nominal policy rate for a given equilibrium real interest rate, through an unanticipated and permanent increase in the inflation target in the monetary policy rule.[17] The figure shows the effects under credit spread semi-elasticities of 5 and 1. As we argued above, for permanent policy changes one should take into account that the longer-run semi-elasticity would likely not be as high as the short-run semi-elasticity, because in the long run banks can at least partly adapt their business models to different credit spreads.

As shown in the top half of Figure 9, the effect in the ZLBD-constrained economy is to immediately stimulate an increase in inflation. This leads to permanent increases in the nominal policy rate and the credit spread, and therefore supports a permanent increase in deposits that depends on the spread semi-elasticity, with the increase reaching more than 4% on impact and 1.5% in the long run for the case of a semi-elasticity of 5, and under 0.5% for a semi-elasticity of 1. This in turn permits a similar permanent increase in output.

As shown in the bottom half of Figure 9, the effect of this policy in the unconstrained economy is very small. The real policy rate drops by 45 basis points on impact, but this drop is extremely short-lived, while the credit spread remains unchanged due to adjustments in the deposit rate. As a result there is a very short-lived boost to output of less than 0.05%, with no permanent change.

[17] A transitory expansionary shock to the monetary policy rule would have transitory expansionary effects.

6. Conclusions

We have studied a New Keynesian DSGE model where banks create deposits through loans, subject to increasing marginal costs of lending. Banks provide a payment system that must be used by all spenders to make payments to each other. This monetary exchange never settles into permanent saver-borrower relationships, instead deposits created at the beginning of each period are extinguished at the end of the period, when the original deposit has circulated back to the original borrower-cum-depositor. Banks are essential for economic activity because deposit payments are a prerequisite for all real economic activity, and because additional deposit creation increases non-banks' aggregate purchasing power beyond their prior income. In other words, non-banks face deposits-in-advance constraints, whereby their expenditure has to equal their prior income plus net new deposit creation, and where additional deposits can mobilize additional resources and thereby create additional income.

This implies that any friction that prevents banks from elastically supplying deposits can have important real economic consequences. The friction that we study in this paper is the zero lower bound on deposit interest rates (ZLBD), in an economy where lending interest rates move towards zero with the policy rate and therefore compress credit spreads. We estimate a sizeable semi-elasticity of credit supply with respect to the credit spread from US data. We then calibrate our model with this semi-elasticity, and also with much more moderate semi-elasticities, and find that, once deposit rates have reached the ZLBD, any further drop in the policy rate significantly reduces deposit creation and thereby ultimately output.

Therefore, when interest rate setting at the ZLBD follows a conventional monetary policy reaction function that responds to disinflationary shocks by lowering the policy rate, this has negative effects on output. The policy response can take this into account by counter-cyclically responding to a loans gap in addition to an inflation gap, or it can move in the direction of escaping from the ZLBD by permanently increasing the inflation target in order to permanently stimulate deposit creation and output.

We also find that at the ZLBD Phillips curves are flatter when monetary policy continues to respond to inflation in the pre-ZLBD fashion by following a Taylor-type rule. The reason is that, following disinflationary shocks, lower factor cost inflation leads to a reduction in policy rates that now, unlike in the pre-ZLBD economy, leads to credit rationing that both has an offsetting inflationary effect and a sizeable negative effect on output. As a result, the drop in the output gap is much larger while the drop in inflation is much smaller.

Finally, credit rationing at the ZLBD implies a strong positive comovement between consumption and investment, because both are constrained by the availability of sufficient purchasing power.

The model used in this paper has been kept simple to focus on the main mechanisms at work. A key conclusion is that frictions that impede the banking system's creation of deposit money can have large and permanent effects on the real economy. The only friction we have studied is the ZLBD, but there are many other candidates, including the many new regulations that have been imposed on banks in the wake of the Global Financial Crisis of 2008. We want to use our framework to study these next, after embedding a more detailed model of bank optimization in our model.

Table 1.1: Data Description

Name	**Explanation**	**Nature of the variable**
$Lnrealciloan$	Natural log of the real balance of commercial and industrial loans (USD mil)	Dependent variable
$cispreadnet$	Commercial and industrial credit spread, net of charge-offs (%)	Endogenous variable
PMI	Purchasing Manager Index	Candidate IV
$INVE$	Nonfinancial business investment	Candidate IV
$DEMAND$	Percentage of banks reporting stronger loan demand to large and medium firms	Candidate IV
$liquidity$	(Securities+cash+repo)/Total Assets of banks	Control
$supply$	Percentage of banks reporting tightening loan standards to large and medium firms"	Control
Δgdp	Real GDP growth rates	Control

(quarterly data, 1997Q1 to 2017Q1)

Table 1.2: Estimation Results (2SLS)

First-Stage Regression

$cispreadnet_t$	**Coefficient**	**t**	**P>|t|**	**95% Confidence Interval**
Δgdp^*_{t-1}	0.402	3.13	0	(0.146, 0.659)
$liquidity^*_{t-1}$	-0.219	-9.01	0	(-0.267,-0.170)
$supply_{t-1}$	-0.003	-0.82	0.42	(-0.0120,0.004)
$DEMAND^*_{t-4}$	0.022	8.06	0	(0.017,0.028)
$cons*$	9.166	10.51	0	(7.43,10.905)

Second-Stage Regression

$Lnrealciloan_t$	**Coefficient**	**t**	**P>|t|**	**95% Confidence Interval**
$cispreadnet^*_t$	0.108	4.94	0	(0.064, 0.152)
Δgdp^*_{t-1}	-0.075	-3.1	0	(-0.123, -0..026)
$liquidity^*_{t-1}$	0.056	8.76	0	(0.043, 0.069)
$supply^*_{t-1}$	0.003	5.03	0	(0.002, 0.004)
$cons*$	0.448	1.77	0.8	(-0.056, 0.951)

Summary Statistics

Number of Observations:	75
Adjusted R^2:	0.703
Root MSE:	0.612

Table 1.3: Model Calibration

Description	**Calibration**	**Parameter**	**ZLBD-Constrained**	**Unconstrained**
	Target		**Value**	**Value**
Real Policy Interest Rate (p.a.)	3%	β	0.9925	0.9925
Real Deposit Interest Rate (p.a.)	0% / 1%	κ	0.0100	0.0050
Credit Spread Semi-Elasticity	10	ξ	0.3988	0.1988
Intertemporal El. of Substitution		ϵ	0.5	0.5
Consumption Habit		v	0.75	0.75
Labor Supply Elasticity			1.0	1.0
Labor Supply	1	χ	0.3123	0.2669
Labor Income Share	60%	α	0.3242	0.3367
Investment/GDP	20%	δ	0.0171	0.0144
Government Spending/GDP	18%	$\bar{g}$	0.5849	0.6845
Government Debt/GDP	100%	$\bar{\tau}_L$	0.3498	0.3498
Investment Adjustment Cost		ϕ_I	2.5	2.5
Steady State Price Mark-up	10%	μ	1.1	1.1
Inflation Adjustment Cost		ϕ_p	200	200
Fiscal Debt Gap Feedback		f_b	0.1	0.1
Policy Rate Inflation Feedback		m_π	3.0	3.0
Policy Rate Loans Feedback		m_ℓ	0	0
Shock Persistence: S_t^c		ρ_c	0.70	0.70
Shock Persistence: S_t^a		ρ_a	0.95	0.95
Shock Persistence: $\bar{a}$		ρ_ℓ	0.90	0.90
Shock Persistence: S_t^{int}		ρ_{int}	0.90	0.90

Figure 1.1: US Inflation Rate and Unemployment Rate during Recessions (IMF WEO 2013)

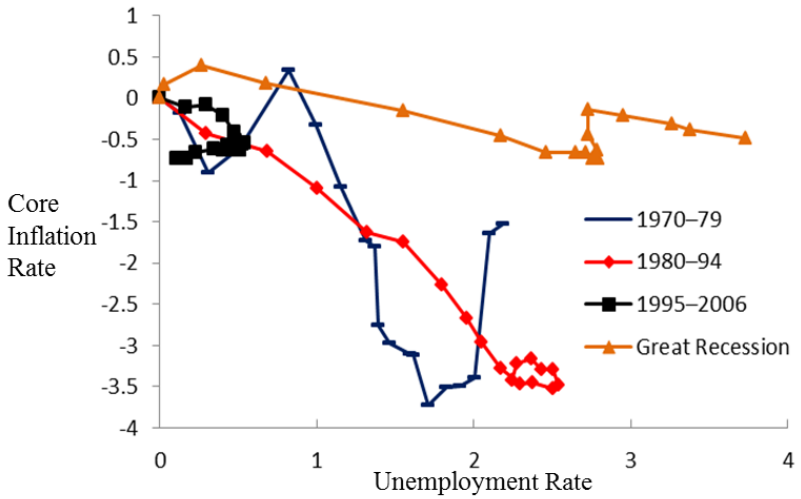


Figure 1.2: US Commercial and Industrial Loan Spreads

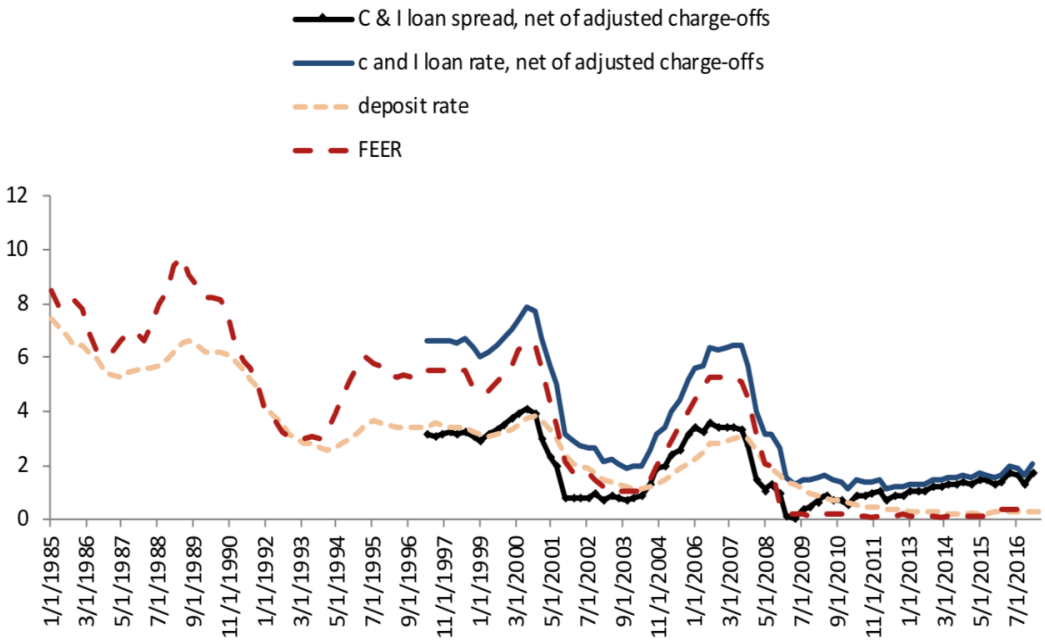


Figure 1.3: Timeline of Intra-Period Cash Flows

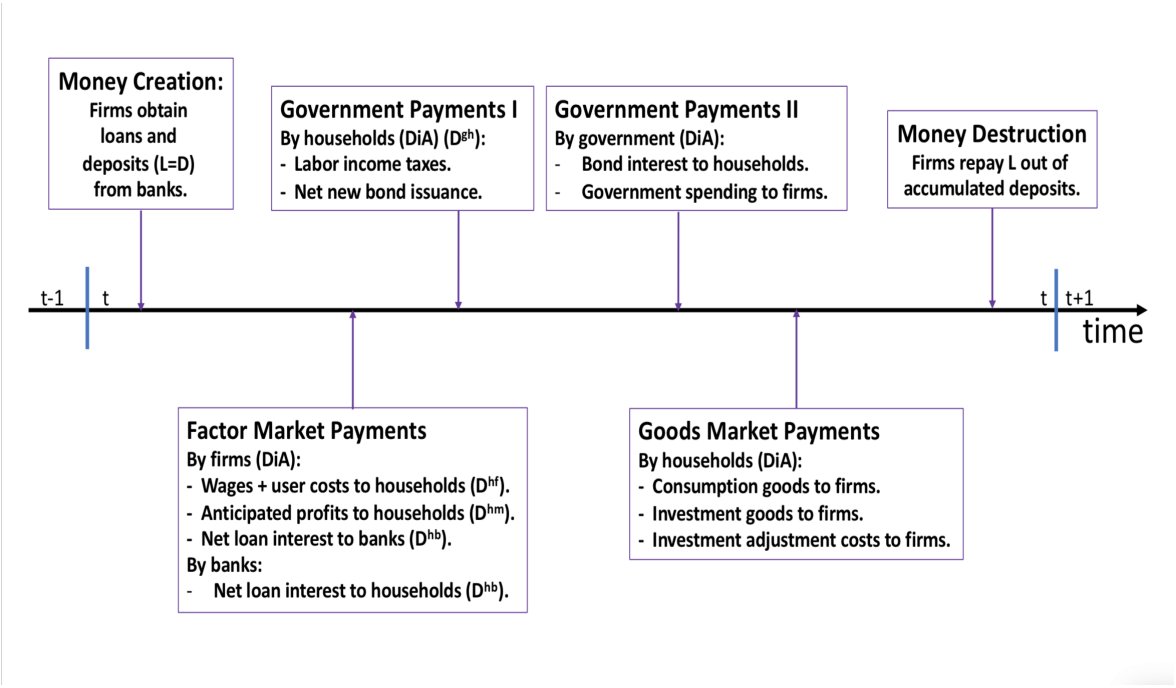


Figure 1.4: The Payment Cycle

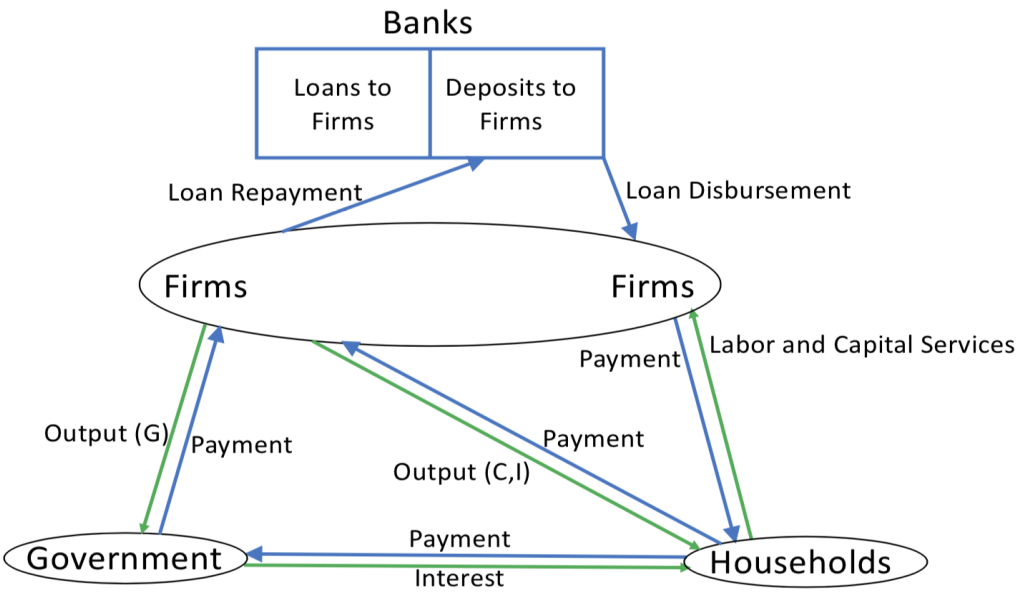
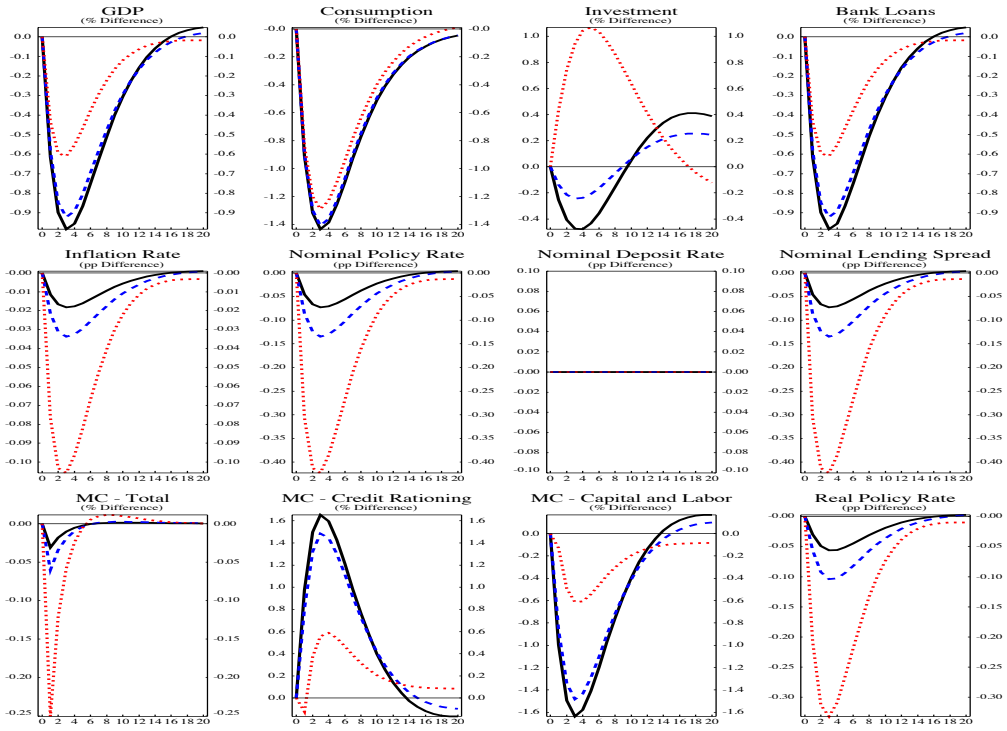
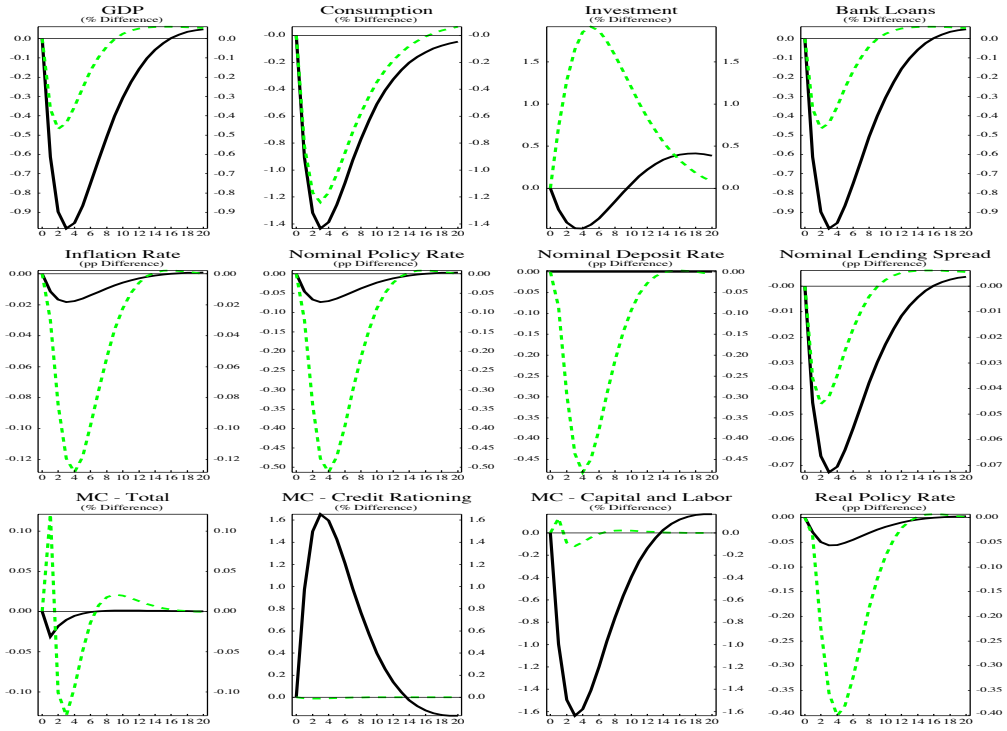


Figure 1.5: Consumption Demand Shock

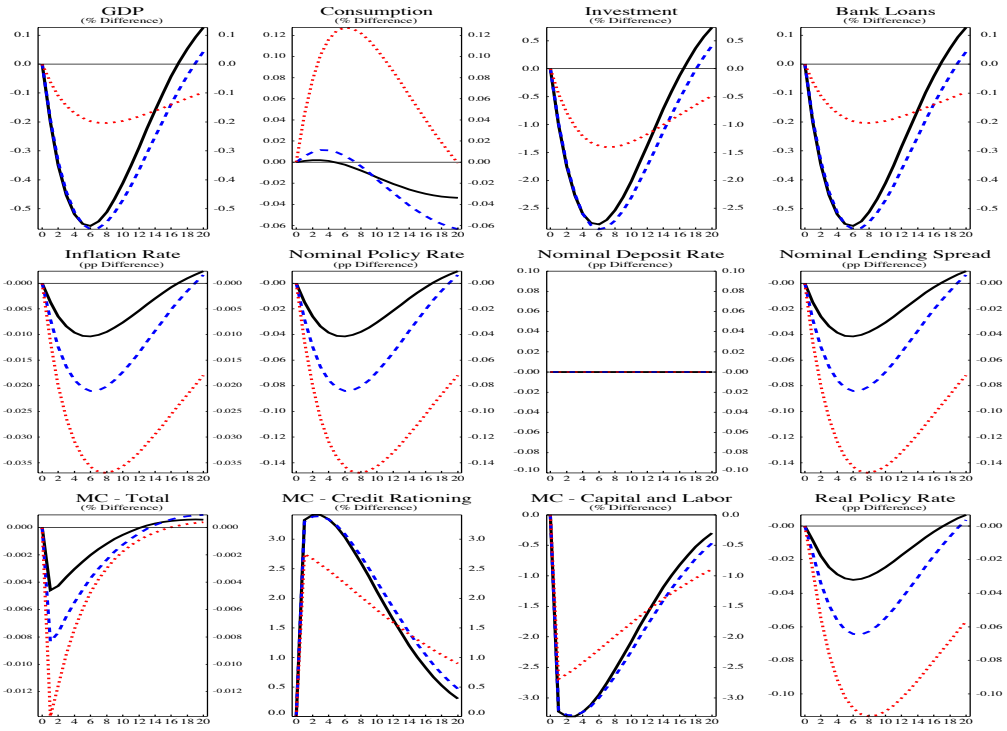


ZLBD-Constrained Economy (spread semi–elasticities: solid = 10 / dashed = 5 / dotted = 1)

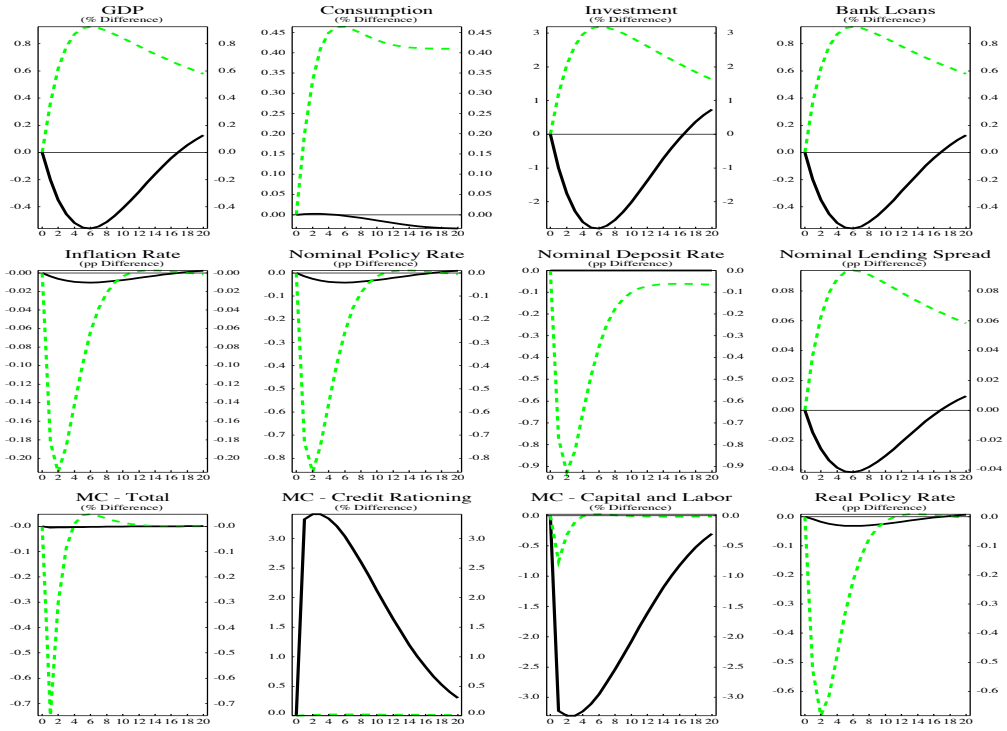


ZLB-Constrained (solid) versus Unconstrained (dashed) Economy (spread semi–elasticity = 10)

Figure 1.6: Technology Shock

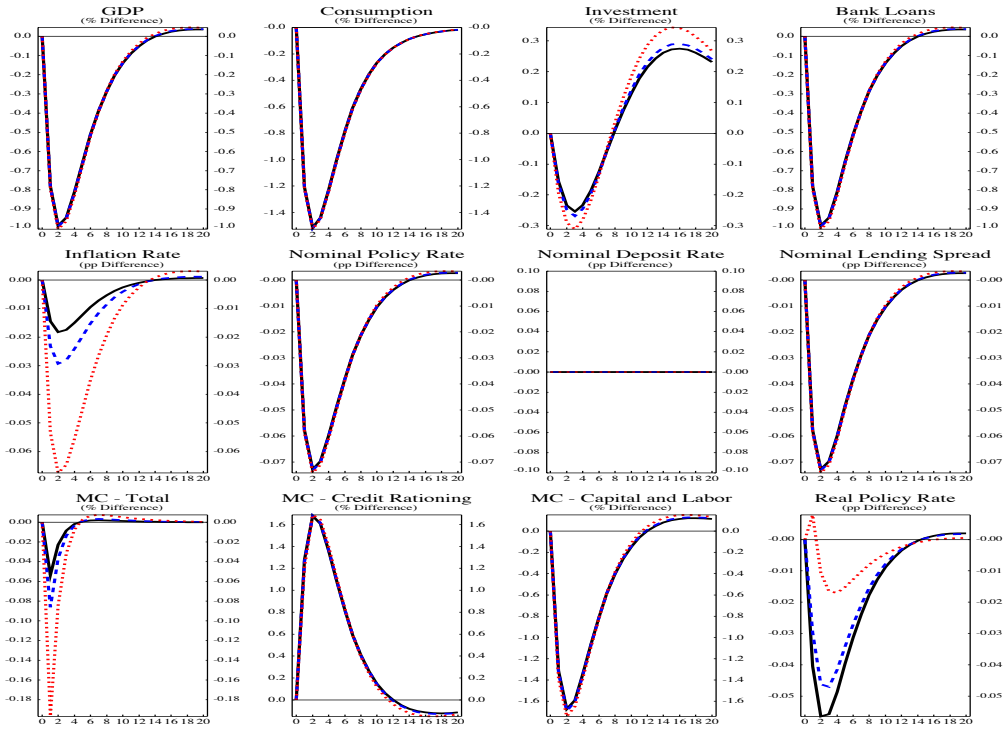


ZLBD-Constrained Economy (spread semi–elasticities: solid = 10 / dashed = 5 / dotted = 1)

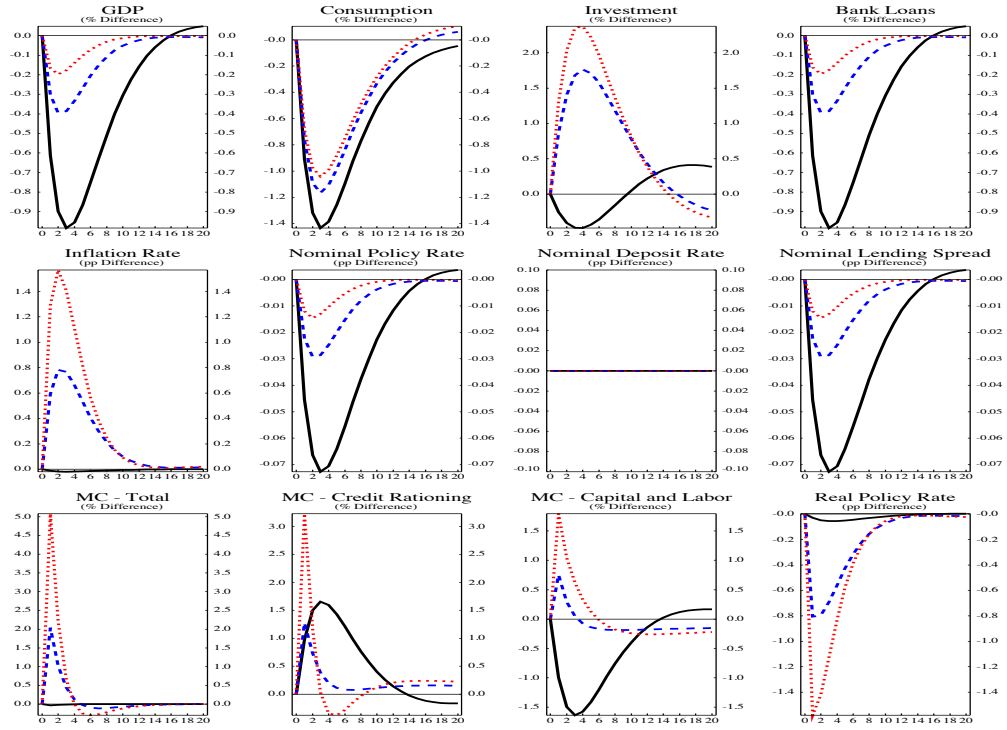


ZLBD-Constrained (solid) versus Unconstrained (dashed) Economy (spread semi–elasticity = 10)

Figure 1.7: Consumption Demand Shock with a Loans Gap Rule

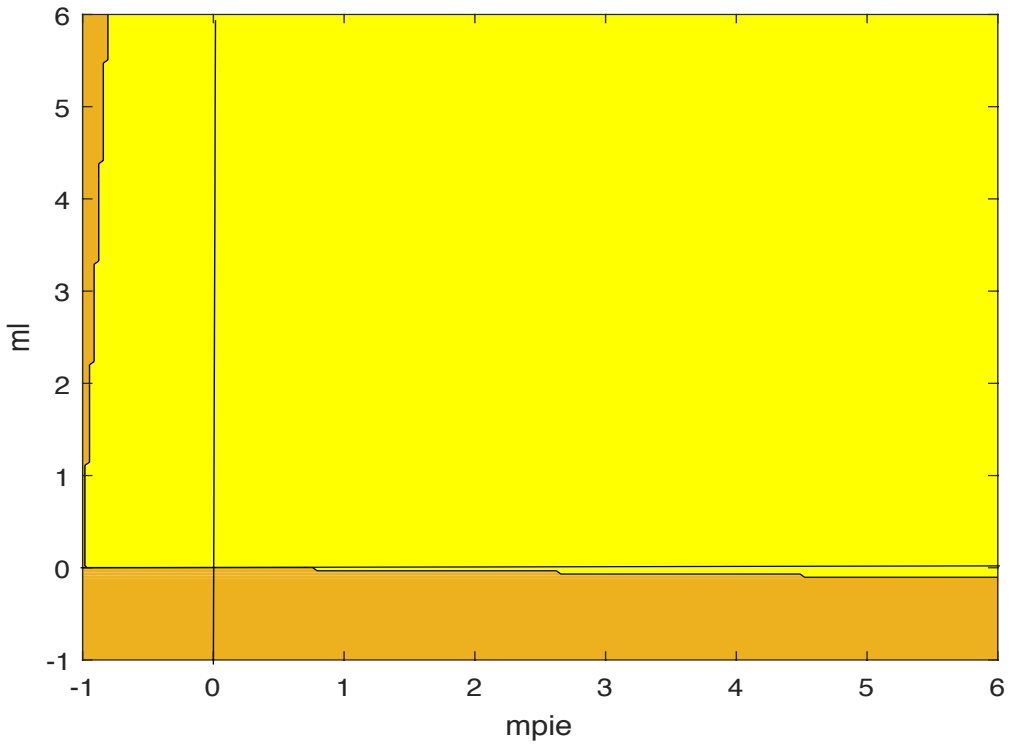


ZLBD-Constrained Economy - Weaker Inflation Response: m_π: solid = 3 / dashed = 1.5 / dotted = 0.1

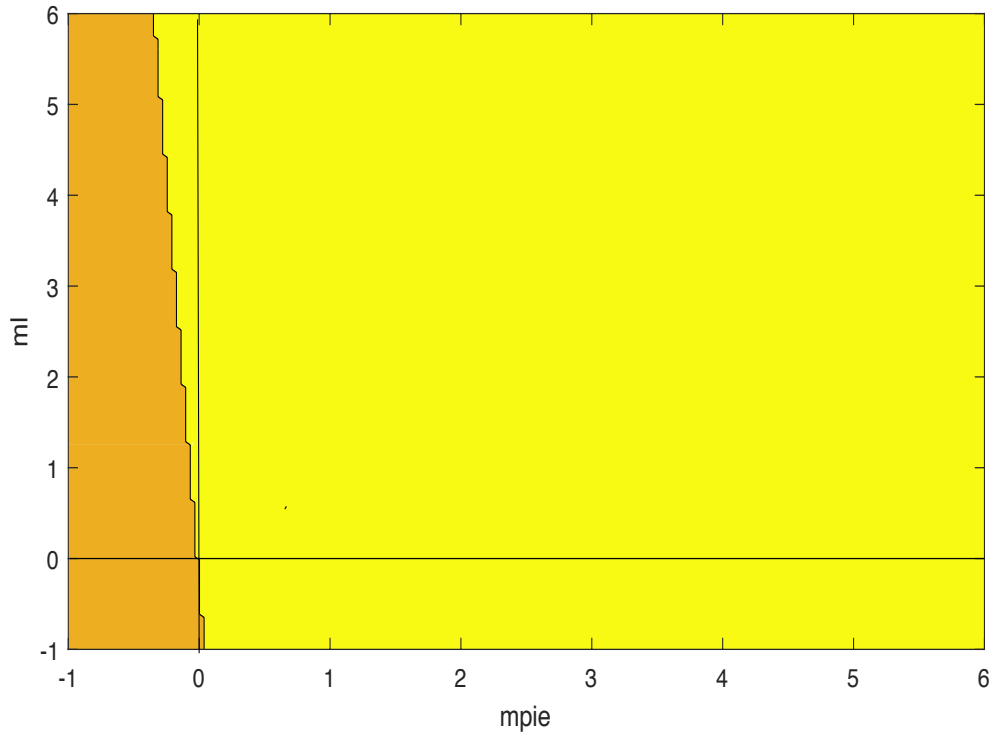


ZLBD-Constrained Economy - Stronger Credit Response: m_ℓ: solid = 0 / dashed = 2 / dotted = 8

Figure 1.8: Determinacy Regions for ZLB-Constrained and Unconstrained Economies

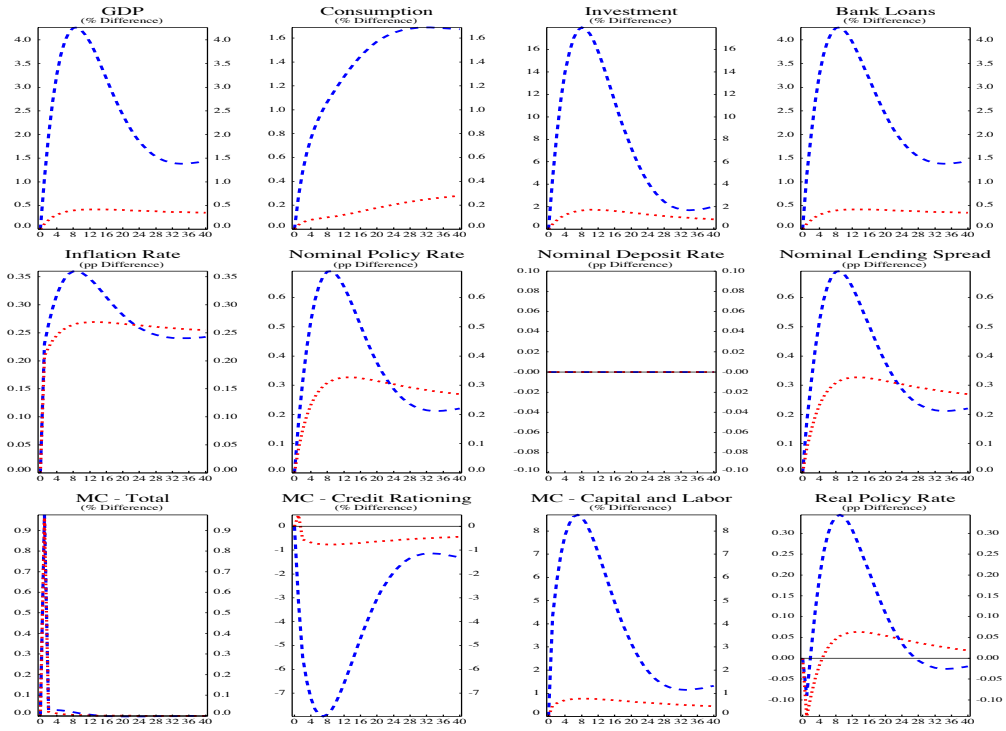


ZLBD-Constrained Economy - Spread Semi–Elasticity = 10 (yellow = BK-stable)

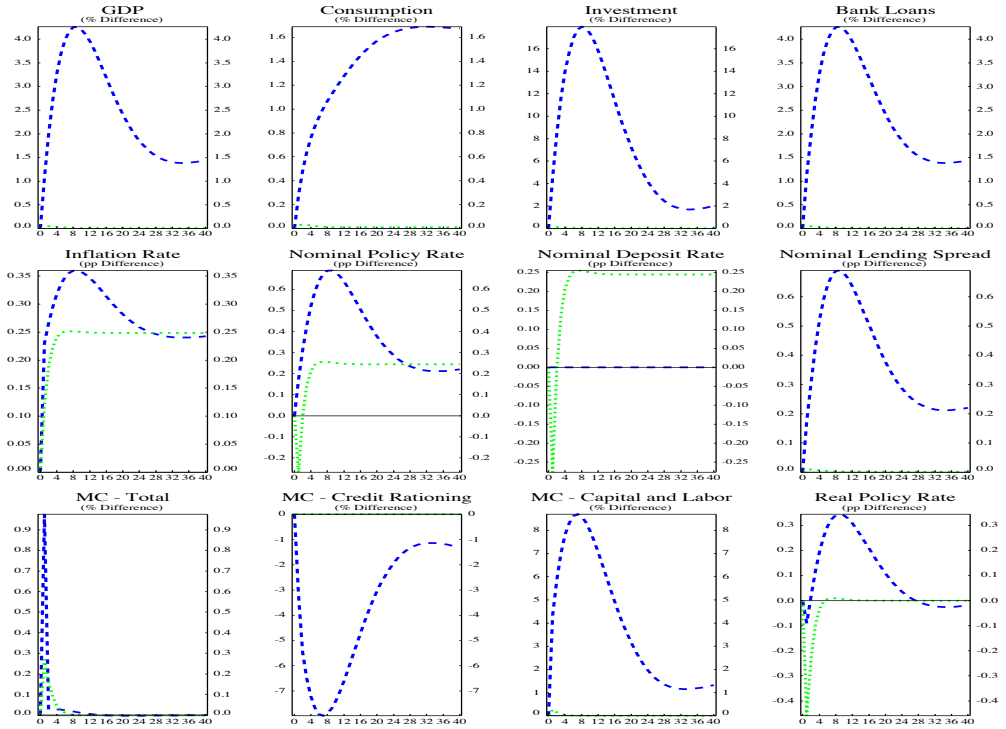


Unconstrained Economy - Spread Semi–Elasticity = 10 (yellow = BK-stable)

Figure 1.9: Permanent Inflation Target Shock



ZLBD-Constrained Economy (spread semi–elasticities: dashed = 5 / dotted = 1)



ZLBD-Constrained (dashed) versus Unconstrained (dotted) Economy (spread semi–elasticity = 5)

Chapter 2

When Do Currency Unions Benefit From Default?

[1]

Since the Eurozone Crisis of 2010-12, a critical debate on the viability of a currency union has focused on the role of a fiscal union in adjusting for country heterogeneity. However, a fully-fledged fiscal union may not be politically feasible. This paper develops a two-country general equilibrium model to examine the benefits of the bankruptcy code of a capital markets union - in the absence of a fiscal union - as an alternative mechanism to improve the financial stability and welfare of a currency union. When domestic credit risks are present, I show that a lenient union-wide bankruptcy code that allows for default in the cross-border capital markets union removes the pecuniary externality of banking insolvency, so it leads to a Pareto improvement within the currency union. Moreover, the absence of floating nominal exchange rates removes a mechanism to neutralise domestic credit risks; I show that softening the union-wide bankruptcy code can recoup the lost benefits of floating nominal exchange rates. The model provides the financial stability and welfare implications of bankruptcy within a capital markets union in the Eurozone.

[1]I am grateful to Dimitrios Tsomocos for his guidance and unwavering support, to Herakles Polemarchakis for his valuable suggestions and most generous help, and to Oren Sussman and Joel Shapiro for their insightful feedback and input for this chapter. I wish to thank Klaus Adam, Saleem Bahaj, Laurent Calvet, Martin Ellison, Charles Goodhart, Denis Gromb, Samuel Hanson, Jiri Knesl, Kebin Ma, Frederic Malherbe, Alan Morrison, Anna Pavlova, Udara Peiris, Ilaria Piatti, Martin Schmalz, Tatjana Schulze, Sergio Vicente, Ji Yan, and seminar participants at the London FIT (Financial Intermediation Theory) Workshop, Oxford Inter-departmental doctoral students Macro-Finance Research Workshop, the Saïd Business School FAME seminar, and HEC Paris Ph.D. Finance Workshop for their helpful comments. I would also like to express appreciation for the help from John Cochrane, Thomas Noe, Theofanis Papamichalis, Alexandros Vardoulakis, and Ming Yang, as well as the generous financial support from Clarendon Scholarship, Peter Thompson Scholarship, Saïd Foundation Scholarship, and Exeter College research grant.

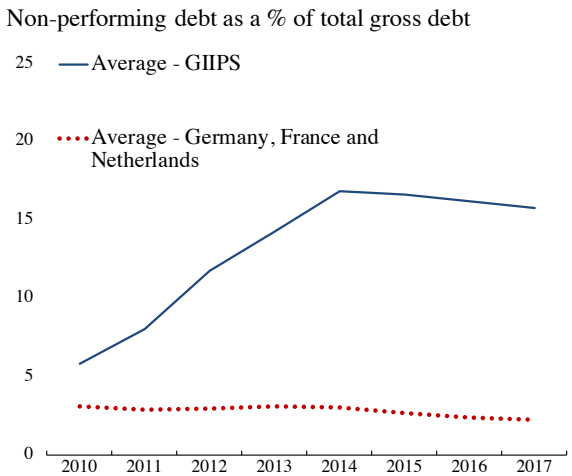
1. Introduction

The establishment of a currency union in Europe has long begged the question of what constitutes a fiscal union that is capable of making cross-country transfers within the currency union (see Friedman 1997; Goodhart 1997, 1998). One argument is that a single union-wide monetary authority may prove inadequate because countries in the Eurozone exhibit economic and financial heterogeneity; thus, a fiscal union is needed to adjust for this heterogeneity and improve financial stability. Without such fiscal integration, Friedman (1997) raised concerns that the adoption of the euro could create divergence among member countries and, in turn, lead to political disunity.

The Eurozone Crisis may appear to validate these concerns, as following the crisis, the core and the peripheral Eurozone have exhibited diverging financial stability risks and economic fundamentals, as illustrated by the non-performing loan rates and unemployment rates in Figure 2.1. Thus, 20 years since the creation of the euro, a critical debate following the Eurozone Crisis has therefore centred on the ability of a fiscal union to improve the viability of sharing a single currency. Meaningful work on fiscal unions has been timely produced (see Farhi and Werning 2017; Kehoe and Pastorino 2017). However, pragmatically, a fully-fledged fiscal union may not be politically feasible (see a detailed discussion in the Nobel Lecture by Sargent 2012). The question then arises: when such a fiscal union is absent, what else can be done to improve the welfare and financial stability of currency unions?

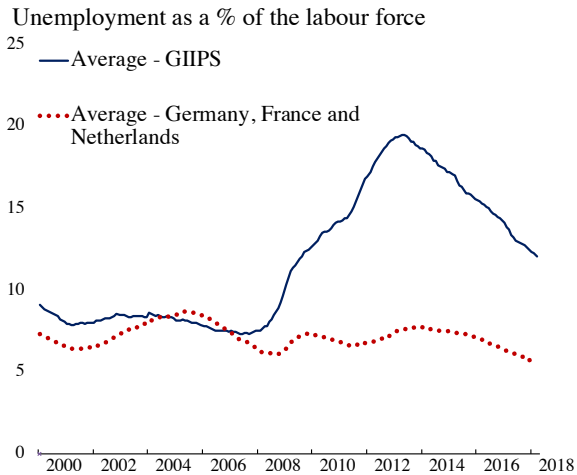
Figure 2.1: Country heterogeneity in the Eurozone

(a) Non-performing loans



Source: Statistical Data Warehouse, ECB and OECD Economic Surveys: Euro Area 2018. Average of first three quarters. GIIPS: Greece, Ireland, Italy, Portugal and Spain.

(b) Unemployment rate



Source: Eurostat database and OECD Economic Surveys: Euro Area 2018, calculated as unweighted average. GIIPS: Greece, Ireland, Italy, Portugal and Spain.

The goal of this paper, therefore, is to design the bankruptcy code of a capital markets union as an alternative mechanism to improve the financial stability and social welfare of a currency union, in the absence of a fiscal union.[2] This question is relevant as it sheds light on an ongoing debate on the capital markets union as a close substitute for a fiscal union to improve the viability of the Eurozone (see Martinez et al. 2019). Furthermore, the perspective on cross-border bankruptcy is also timely. In 2016, the European Commission proposed a legal directive of a lenient cross-border insolvency law or bankruptcy code in Europe as a vital foundation of the capital markets union. However, there has been little economic study that analyses the welfare implication of such bankruptcy code adjustment and its relevance to the financial stability of the Eurozone.[3]

For this purpose, I develop a three-period nominal general equilibrium model of a two-country and two-good endowment economy with uncertainty. My innovation is to relate the cross-border insolvency reform or the bankruptcy code adjustment to the functioning of the capital markets union in improving the financial stability of a currency union. This model has the unique features of a single currency, banking, and bankruptcy codes. I show that in the presence of moral hazards when the union-wide bankruptcy code[4] is sufficiently lenient to allow for some degree of state-dependent default in the cross-border capital markets, it removes the currency union-specific pecuniary externality of banking insolvency. Therefore, a Pareto improvement is obtained despite the social cost of default. As such, bankruptcy code leniency of a capital markets union can be a close substitute for a fiscal union. The reason is that the endogenous default on cross-border financial securities that ensues from softening the union-wide bankruptcy code generates a liquidity transfer from the country in the good state to the country in the bad state. This liquidity transfer via default adjusts for country heterogeneity and, in turn, shields the domestic banking sector from insolvency. However, if the union-wide bankruptcy code is punitive, I show that member countries will suffer from internal devaluation due to the currency union-specific pecuniary externality of banking insolvency.

Moreover, to respond to the loss of floating nominal exchange rates in a currency union,

[2] In this paper, a banking union is one manifestation of a fiscal union. The model takes the view that a banking union needs fiscal coordination, and that it is essentially a common fiscal entity making transfers across banks in different countries within the currency union.

[3] Section 6.3.2 provides a brief history and the institutional details of recent cross-border insolvency reforms in Europe.

[4] I use the terms "union-wide bankruptcy code" and "cross-border bankruptcy code" interchangeably in this paper. This bankruptcy code serves as a proxy for the cross-border insolvency law.

I also consider the case of *credible*[5] national currencies and the role of nominal exchange rates. I show that under relatively general conditions, competitive floating exchange rates can indeed neutralise credit risks across states and alleviate domestic banking stress. In a currency union, however, softening the union-wide bankruptcy code may function to recoup the lost benefits of flexible nominal exchange rates. The crucial point is when countries join a currency union without a fiscal union, and the nominal exchange rate mechanism is removed to neutralise credit risks, then the bankruptcy code needs to adjust.

To formalise this theory, I model the issuance of the single currency via banks in a two-country and two-good endowment economy. As the focus is on monetary unions, the model is nominal. Within the currency union, in each country, there are a continuum of households and a domestic commercial banking sector. Each country's households are risk-averse and are endowed with one type of consumption good in the first two periods. The endowment in the second period is state-contingent. Households borrow commercial loans from their domestic commercial banking sector to get money for all transactions. Households trade goods as they consume both home goods and foreign goods. They also trade *nominal* financial securities via the capital markets union for risk sharing. These modelling components are akin to those featured in Geanakoplos and Tsomocos (2002) and Peiris and Tsomocos (2015). More importantly, in my model, a union-wide central bank exists to issue the single currency as the only stipulated means of exchange via interbank lending to the commercial bank sectors in the two countries.

This model features a particular type of nominal rigidity. The nominal rigidity here stems from the transaction means of money and the single currency denomination of nominal prices, asset payoffs, and the face value of loans. This modelling choice allows me to focus on the unique feature of sharing a single currency exclusively and to isolate its impact on welfare. The two main frictions in the model are the endogenous domestic credit risks of commercial bank loans and their interaction with sharing a single common currency.

The backbone of the model is the role of the bank's balance sheets in creating and circulating the single currency against credit. This feature builds on the theory of inside money and outside money à la Shapley and Shubik (1977) and Dubey and Geanakoplos (1992, 2003b,

[5] "Credible" in this context means the sovereign does not intervene in the foreign exchange markets via quantitative measures and that exchange rate targeting is not in the national central bank's mandate.

2006). *Inside money* is defined as money endogenously issued against an offsetting bank credit, and *outside money* refers to the initial monetary endowment that is free and clear of any debt obligation.[6] In my model, inside money is issued in the common currency the moment households apply for loans from their respective domestic commercial banking sectors. The domestic commercial banking sectors ultimately obtain the common currency from the union-wide central bank via the interbank loan contract.

For simplicity, the only role of the banking sector that I consider here is liquidity creation against credit (see Diamond and Rajan 2001 and Hart and Zingales 2014). In my model, bank liquidity creation helps to establish the price-level determinacy and inflation determinacy, and therefore, the nominal exchange rate determination in the subsequent model extension in which I consider national currencies. Consequently, this model can generate real effects from nominal and financial forces. In equilibrium, domestic commercial bank sectors end up splitting the seigniorage with the union-wide central bank. As argued by Reis (2013), such a seigniorage split is a distinct feature of the central bank balance sheet of a currency union. Additionally, the domestic commercial banks can obtain central bank reserves in the common currency via interbank borrowing. Therefore, these commercial banks can meet the liquidity demands of domestic households at any point during the timeline subject to interest rates, even though the assets of these banks have a long-term and inter-period maturity.

As credit risks and banking fragility were at the forefront of the Eurozone Crisis (Figure 2.1a), the second key ingredient of the model is non-bank borrowers' moral hazard and endogenous credit risks that give rise to non-performing loans. Upon loan repayment, households may default but will suffer a default cost. Subject to the default cost, households may choose to default fully, partially, or repay fully, depending on the states of nature. As in Shubik and Wilson (1977), Zame (1993), and Dubey et al. (2005), I model the default cost as a non-pecuniary penalty cost. The stance of bankruptcy code is modelled as the harshness of the penalty per unit of default. With moral hazard present, I show that the currency union removes foreign exchange markets, which leads to an increase of credit risk volatilities across states, causing the pecuniary externality of banking insolvency and welfare loss. The essence of my model, therefore, is to explore the efficacy of softening the union-wide bankruptcy code of the capital markets union to "undo" this friction.

[6] These distinctions can be traced at least as far as back to Gurley and Shaw (1960).

With these two key features, I design three regimes in a currency union which I call hereafter Regimes A (internal devaluation), B (fiscal union), and C (bankruptcy leniency), as well as a national currency regime which I call Regime D. I design these regimes mainly by varying the relative stance between the domestic bankruptcy code for bank lending and the union-wide bankruptcy code of the cross-border capital markets union. For each regime, I show analytically and numerically the implication of regime characteristics for allocation efficiency within the state, risk sharing, inflation, and asset prices.

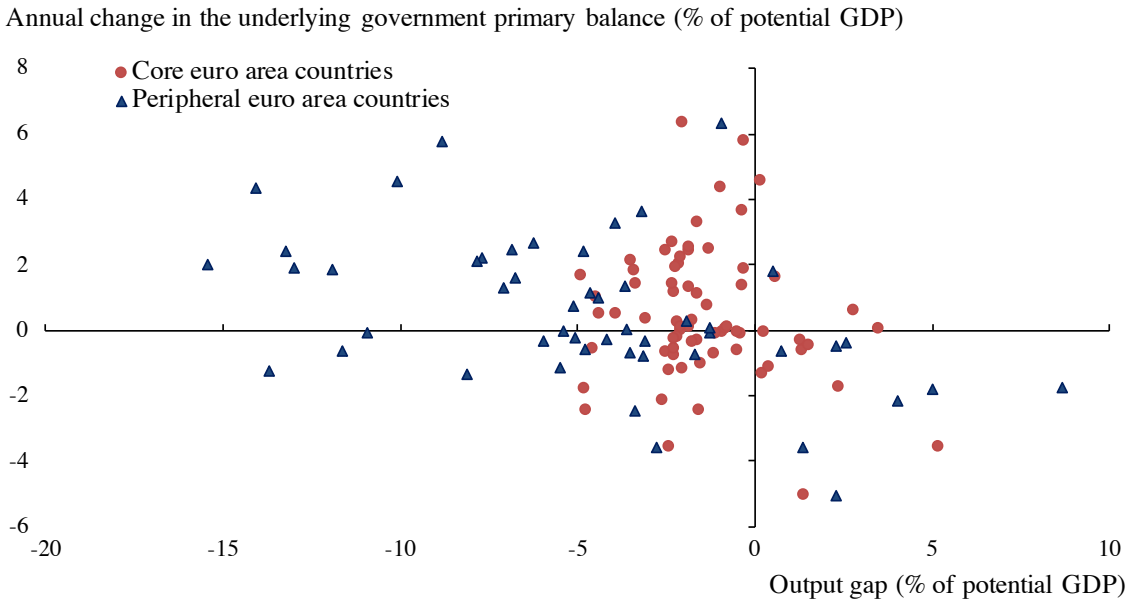
Let us start by considering **Regime A** as the baseline. It is a currency union that rules out a fiscal union and sets a punitive union-wide bankruptcy code of the capital markets union. It resembles the status quo of the Eurozone that it lacks a fully-fledged fiscal or banking union and meanwhile the stance for cross-border default is tough. I show that non-performing loans arise endogenously in the bad state and that the domestic commercial bank sector fails and has to be costly bailed out using the national bailout tax. Regime A proves to be among the least desirable in all regimes because the bailout cost causes a pecuniary externality - both the bailout cost and the domestic credit risk premium distort risk sharing and asset allocations. Since the bailout cost is due to national taxation that would be levied in the bad state when the non-performing loan rate is high, such national fiscal action resembles the actual fiscal austerity measures adopted in the Eurozone after crises. Indeed, as Figure 2.2 shows, during bad times in the peripheral countries, national governments' primary balance actually rose, suggesting fiscal austerity after crises. Prices in this regime would turn out suppressed due to higher transaction costs. Therefore, Regime A is also referred to as the *internal devaluation* regime throughout the paper.

Since the main research question is about the benefits of softening the union-wide bankruptcy code as an alternative to a fiscal union for the viability of a currency union, it is nevertheless of interest to study the equilibrium with a fiscal union for welfare comparisons. **Regime B**, therefore, is modelled as a currency union featuring cross-country transfers via a fiscal union. It would resemble a hypothetical Eurozone with a fully-fledged fiscal union. Regime B's closest existing real-world equivalences are the US and China.[7] When the fiscal union makes cross-country transfers, I show that these transfers can ensure that the domestic banking

[7]In the US, different states use the same US dollar as the only stipulated means of exchange, and in China, different provinces share the same Chinese RMB. Both countries, if seen as currency union blocks in their own right, have their federal government or central government as the "fiscal union" to make cross-state or cross-province fiscal transfers (see the discussion about the US case in Sargent 2012).

sectors survive. Consequently, fiscal union removes the pecuniary externality of banking insolvency, and welfare improves.

Figure 2.2: Fiscal austerity



Source: OECD (2018), OECD Economic Outlook: Statistics and Projections (database), annual data 2008-2017.

When a fiscal union is absent, however, **Regime C** is considered. In this regime, the union-wide bankruptcy code of the capital markets union is set more leniently than the domestic bankruptcy code.[8] As a result, domestic households may default on the cross-border financial securities in the bad state. The option to default in the cross-border capital market provides extra liquidity, acting like "cross-country transfers" from the rich to the poor to alleviate the stress of the otherwise failing banks. Consequently, there is no bailout cost or pecuniary externality of banking insolvency, and via the associated price effects, welfare improves in a Pareto sense. Thus, the internal devaluation effect via the bailout cost dissipates entirely, and the transaction costs in both countries decrease.

Nevertheless, a caveat of bankruptcy leniency remains: there exists a lower bound for the union-wide bankruptcy code. If it is set too leniently, then for all states of nature, no households in the currency union would ever repay cross-border borrowing, and the capital markets union would collapse. This scenario is inferior even to the internal devaluation regime

[8] In practice, the default cost for unsecured lending takes a myriad of forms such as market/credit exclusion, sanctions, immediate liquidation, or harshness of the terms of debt restructuring. Take market/credit exclusion as an example: an ultra-tough bankruptcy code could mean when borrowers default, they are excluded from credit markets forever. A somewhat lenient bankruptcy code could mean upon default, per unit of default, defaulters are excluded from credit markets only for a certain period.

because such an ultra-lenient union-wide bankruptcy code impedes cross-border risk sharing.

To corroborate the role of Regime C (bankruptcy leniency) in improving the viability of currency unions, the model needs to explain why cross-border default via bankruptcy code adjustment is *particularly* vital for currency unions. To understand this question, it is essential to know what benefits a currency union has given up and whether cross-border default can serve to recoup these benefits. Therefore, I extend the model to consider currency union dissolution and national currencies, a question largely unaddressed in the existing literature.

Regime D is such an extension. It considers national currencies and competitive floating exchange rates. I prove that under very general conditions, competitive floating exchanges indeed adjust for and neutralise domestic credit risks. Accordingly, banks survive, and welfare improves. However, if a currency union is the *a priori* arrangement of member countries, in a parameterisation of the model, I show that Regime C (bankruptcy leniency) obviates such needs for floating exchange rates to neutralise domestic credit risks. Necessarily, removing nominal exchange rates implies rigidities in country-level inflation. Since countries cannot rely on inflation as a form of "soft" default, the capital markets union should allow for actual default and acknowledge the underlying credit risks. Encouraging some degree of cross-border default by softening the union-wide bankruptcy code, therefore, provides compensation for the lost benefits of nominal exchange rates.

The rest of the paper is structured as follows: Section 2 reviews the related literature. Section 3 presents the currency union model, various regime equilibrium analyses, and the analytical results. Section 4 conducts welfare and numerical analysis and provides the impetus for policy considerations. Section 5 investigates the national currency case. Section 6 discusses the results, policy implications, and two layers of institutional details (one on the Eurozone TARGET2 system and the other on the cross-border insolvency reforms in practice). Section 7 is a conclusion.

2. Related Literature

A burgeoning emergence of academic endeavour has started tackling this issue of currency union viability.[9] Broadly, there are three types of proposals, albeit not orthogonal to one

[9] See Brunnermeier and Reis (2015) for an excellent summary of recent theories.

another and non-exhaustive: 1) fiscal unions (e.g., Farhi and Werning 2017; Kehoe and Pastorino 2017), 2) banking unions (e.g.,Martinez et al. 2019), and 3) union-wide safe assets (e.g., Brunnermeier et al. 2016). The welfare improvement hinges on whether these proposals can reduce transaction costs and improve risk sharing; however, pragmatically, the proposals above may encounter political resistance from nation-states within the currency union. Therefore, the political-economic consideration of these three proposals is likely to spark off further exciting research (see Foarta 2018). My work contributes to existing work by considering an alternative financial regime, i.e., capital markets union (see Martinez et al. 2019). The key step forward is that I consider the economics of bankruptcy within the capital markets union in the presence of credit risks, which are omitted in Martinez et al. (2019). Such a financial regime is plausible because the forces work through the invisible hand of the markets, which might encounter less political resistance in terms of implementation.

This paper is also related to the rich body of literature on optimal currency areas that starts with Mundell (1961); McKinnon (1963); Kenen (1969). Subsequently, the new open economy macro literature (salient examples include Obstfeld and Rogoff 2000; Gali and Monacelli 2005) builds micro-foundations and is applied to provide concrete welfare analysis on the monetary and fiscal issues in currency unions (see Gali and Monacelli 2008; Ferrero 2009; Aguiar et al. 2015; Farhi and Werning 2017; Kehoe and Pastorino 2017; Adam and Grill 2017). My work complements this body of literature by introducing the finance elements and explicitly modelling the endogenous determination of the value of currencies. Moreover, I incorporate credit risks and moral hazards, which were at the forefront of the Eurozone debt crisis. Rather than assuming a continuum of atomistic countries, I take the two-country international finance approach, which is a suitable laboratory to analyse the north-and-south dynamics in the Eurozone.

In terms of the broader message, my paper shares a similar kindred spirit to Adam and Grill (2017) and Goodhart et al. (2018) that cross-border default can conditionally benefit currency unions. However, these two papers do not explain why cross-border default is particularly vital to sustaining a currency union. For example, the friction in Adam and Grill (2017) is the non-state contingent bond, which is not necessarily a friction that is specific to currency unions. It is known in the general equilibrium theory with incomplete markets that strategic default can improve risk sharing by increasing the asset span (see Zame 1993; Dubey et al. 2005). Thus, the welfare improvement result found in Adam and Grill (2017) is expected and

should hold qualitatively, even assuming away currency unions. Different from Goodhart et al. (2018) and Adam and Grill (2017), my work explicitly models the arrangement of sharing the common currency. Meanwhile, my model makes available state-contingent nominal financial securities in order to show that cross-border default is needed for risk sharing due to being bound by the common currency in the presence of domestic credit risks. Therefore, using this model, one can conduct the counterfactual experiment on currency union dissolution and compare and contrast a currency union with the case of national currencies and competitive flexible exchange rates.

To model a currency union with banking fragility (e.g. the Eurozone Crisis), the model should explicitly include the currency, banks, liquidity, and credit. Therefore, I choose an international finance modelling framework based on the seminal papers by Geanakoplos and Tsomocos (2002); Tsomocos (2008); Peiris and Tsomocos (2015). Geanakoplos and Tsomocos (2002) model a general equilibrium to unify international trade and finance. Their model is rich enough to include multiple goods, multiple countries, multiple consumers in each country, multiple periods, multiple credit markets, and multiple currencies. The authors prove the existence of the equilibrium. Because of the role of money and the heterogeneity of markets and agents, the authors prove that fiscal and monetary policy both have real effects even under flexible prices. Parallel to Geanakoplos and Tsomocos (2002), Tsomocos (2008) proves generic determinacy and money non-neutrality of international monetary equilibria. The author obtains price-level determinacy and the endogenous determination of exchange rates in a rich general equilibrium. Further enriching Geanakoplos and Tsomocos (2002), Peiris and Tsomocos (2015) develop an international finance model with incomplete markets and relax the assumption of fully committed debt repayment. The authors prove the equilibrium existence and obtain a non-trivial role for monetary policy with incomplete markets and credit risks. These frameworks incorporate money and financial frictions into international trade, sharing a similar spirit to Manova (2012).

In this paper, I simplify and modify Peiris and Tsomocos (2015) to consider the special case of a currency union. Rather than assuming each country has one independent central bank as in Peiris and Tsomocos (2015), I assume that countries share the same central bank, and I also consider the risk-shifting of domestic commercial banks, which are not present in Peiris and Tsomocos (2015). These modifications allow me to isolate the impact of sharing a common currency on the seigniorage split between domestic commercial banks and the union-wide

central bank (see Reis 2013).

Money and liquidity creation via bank credit are key features of this paper. This mechanism was much emphasised by early economists when the banking sector was just booming. Classic works by Macleod (1866), Wicksell (1906), Hahn (1920), Hawtrey (1923), Schumpeter (1954), Keynes (1931), Tobin (1963) and Minsky (1977) have all provided insight into this monetary operation and its macro-financial implications. The early formalisation of this mechanism can be found in the general equilibrium theory of money. In this literature, there is an assumed requirement that money must be used to carry out transactions formalised through cash-in-advance constraints similar to Grandmont and Younes (1972, 1973); Lucas Jr and Stokey (1987). Inside money enters the economy against an offsetting obligation that guarantees its departure, and it is issued when borrowing agents apply for loans from the banks. As in Tsomocos (2003), commercial banks can be viewed as creators of "money" à la Tobin (1963). Some quantity of money, called outside money, is present as agents' initial monetary endowment that is used to pay for loan interest. The banking sector therefore can be either an intermediary of existing money or a creator of new inside money, as in Shubik and Tsomocos (1992), Dubey and Geanakoplos (1992, 2003b, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), and Goodhart et al. (2006, 2013).

Following the 2007-2009 Global Financial Crisis, more and more empirical evidence has been provided on the role of bank credit and money in the macroeconomy and financial stability (see Schularick and Taylor 2012). Thus, there has been a revival of inside money modelling due to the renewed interest in banks' balance sheet transformation for credit extension and liquidity creation and the associated macro-financial outcomes. Recent advances include and are not limited to Bigio and Weill (2016), Brunnermeier and Sannikov (2016) , Faure and Gersbach (2017), Donaldson et al. (2018), Kumhof and Wang (2018), Bianchi and Bigio (2018), Piazzesi and Schneider (2018), McMahon et al. (2018), Kiyotaki and Moore (2018a), Kiyotaki and Moore (2018b), and Tsomocos and Wang (2019). Sharing a similar spirit to inside money provision against bank credit, liquidity creation is also much emphasised in the literature on banking (see Gorton and Pennacchi 1990; Diamond and Rajan 2001; Stein 2012; Hart and Zingales 2014; DeAngelo and Stulz 2015) and safe assets (see J Caballero and Farhi 2017).

In addition to banks and liquidity, the second key ingredient of my work is endogenous default,

and it connects with a large body of literature on strategic sovereign default. Although I do not explicitly model the default decision by a separate government, in my model, the default decision of the atomistic households in a given country is interpreted as the aggregate default at the country level. Typically there are two ways of thinking about default at the country level: 1) strategic default via explicit default costs (e.g. Eaton and Gersovitz 1981; Aguiar and Gopinath 2006; Arellano 2008; Arellano and Ramanarayanan 2012; Na et al. 2018) and 2) default without explicit costs but driven by political considerations (e.g.Guembel and Sussman 2009; D'Erasmo and Mendoza 2016). My paper belongs to the first group. As argued in Eaton and Gersovitz (1981), strategic default is suitable to analyse the trade-off of country-level default, because any negative net worth criterion for a country-level default is essentially irrelevant.

At the country level, default punishment can take a myriad of forms that range from credit or market exclusion (e.g., Eaton and Gersovitz 1981; Aguiar and Gopinath 2006; Arellano and Ramanarayanan 2012; Na et al. 2018) to sanctions (see the discussion in Bulow and Rogoff 1989), and from the loss of insurance opportunities (e.g., Bloise et al. 2017) to internal devaluation (e.g., Regime A of this paper). In light of this consideration, in this paper, I do not model the various specific forms of punishment but assume a non-pecuniary default penalty à la Shubik and Wilson (1977) and Dubey et al. (2005). The intensity parameter λ of the default penalty is interpreted as the bankruptcy code in my model. Unlike Eaton and Gersovitz (1981); Aguiar and Gopinath (2006); Arellano and Ramanarayanan (2012); Na et al. (2018) that model default as a binary decision, my paper emphasises that the social cost of default depends on the severity of default; hence, partial default is also considered. Modelling partial default is also found in Calvo (1988); Bolton and Jeanne (2007); Corsetti and Dedola (2013); Adam and Grill (2017) and is in line with empirical evidence (see Trebesch and Zabel 2017) and quantitative findings (see Gordon and Guerron-Quintana 2018). I acknowledge that an alternative way of modelling default punishment would be to collateralise lending. However, because I model aggregate debt positions at a country level, seizing "collaterals" at a country level would imply further political frictions outside the scope of this paper. In light of this issue, I have only considered uncollateralised lending.

Moreover, the model extension of this paper connects with the body of literature on the cost and benefit of flexible exchange rates and the nexus between nominal exchange rates and default. For example, Neumeyer (1998) acknowledges that the general belief that "excessive"

exchange rate variability harms the economy is difficult to prove in a formal setting. However, the author shows that when the excess exchange rate risk is driven by political factors that influence monetary affairs, flexible exchange rates cause inefficiency. Guembel and Sussman (2004) use a market microstructure approach to obtain optimal exchange rates, and the authors assume markets are incomplete so that the cost of flexible exchange rates stems from its volatility that impedes risk sharing. In the model extension of my paper in which national currencies are considered, I deliberately choose not to model any cost of flexible exchange rates but only consider the potential benefits. The reason is that I want to pin down the upper bound of the lost benefits by removing nominal exchange rates and see how much cross-border default in currency unions can recoup the lost benefits of the flexible exchange rates. Indeed, a key benefit of flexible exchange rate in my model extension is to neutralise domestic credit risks such that banks remain solvent. The role of nominal exchange rates therefore is to provide a buffer for country-level default, an insight reminiscent of a key point from Uribe (2006).

Finally, as my modelling environment features agent heterogeneity, banking and liquidity, and financial assets, it follows that default risk premium, rents extracted by the banking sector, bailout costs, and the value of the currency all affect the stochastic discount factor (SDF) for asset pricing. The exact specification for SDF depends on each regime considered. Such asset pricing formulae complement the growing body of the theoretical and empirical literature on intermediary asset pricing (see He and Krishnamurthy 2013; Adrian et al. 2014; He et al. 2017; Bongaerts et al. 2017; Kondor and Vayanos 2019).

3. The Model - Currency Union

The model is a simple two-country endowment economy with uncertainty, and both aggregate endowment risks and idiosyncratic income risks are present. There are two types of consumption goods available for international trade, and each country has only one type of consumption good. In each country reside a domestic commercial banking sector and a continuum of households. A union-wide central bank acts as the lender of last resort of issuing the common currency to the two national commercial banking sectors. The common currency is fiat because it does not enter utility functions. Households borrow from commercial banking sectors to obtain the common currency for transactions.

3.1. Model Description

The economy has three periods, $t \in T = \{0, 1, 2\}$, with date $t = 1$ having S states of nature which I index with $\boldsymbol{s} \in S = \{1, .., S\}$. Including date $t = 0$, there are $S + 1$ date-events in the set $S^* = \{0, 1, .., S\}$. Consumption happens at $t = 0, 1$, and date $t = 2$ is for any outstanding loan settlement. For simplicity there is no discounting. The two countries are indexed by $H \in \{I, J\}$ where trade occurs at prices denominated in a common currency. Country I has a measure 1 of households i and the commercial banking sector i, and country J has a measure 1 of households j and the commercial banking sector j.

Households in both countries are risk-averse and consumption goods are all perishable. In country I, households i are endowed with outside money m^i in the common currency and domestic consumption good e^i_{I0} at $t = 0$. At $t = 1$, households i are endowed with state contingent domestic consumption goods $e^i_I = (e^i_{I1}, .., e^i_{I\boldsymbol{s}}, .., e^i_{IS}) \in \mathbb{R}^S_+$. Similarly, in country J, households are endowed with outside money m^j in the common currency and domestic consumption good c^j_{J0} at $t = 0$. At $t = 1$, households j are endowed with state contingent domestic consumption goods $e^j_J = (e^j_{J1}, .., e^j_{J\boldsymbol{s}}, .., e^j_{JS}) \in \mathbb{R}^S_+$. In every state of nature, the two types of goods are traded at nominal spot prices $p_I = (p_{I0}, p_{I1}, ..., p_{I\boldsymbol{s}}, ...p_{IS}) \in \mathbb{R}^{S^*}_+$ and $p_J = (p_{J0}, p_{J1}, ..., p_{J\boldsymbol{s}}, ..., p_{JS}) \in \mathbb{R}^{S^*}_+$ in the common currency. Given two types of contingent endowments and households' preferences, both aggregate endowment risks and idiosyncratic income risks can be captured.

To link cross-country trade and capital flows, I make available state-contingent *nominal* financial securities. These financial securities are akin to Arrow securities, but the payoff of the financial security for state $\boldsymbol{s}$ is 1 unit of the common currency, rather than 1 unit of good I or J. I assume the number of these financial securities is the same as the number of states, and I call these securities as the nominal Arrow securities. The set of state prices is denoted as $\pi = (\pi_1, ..\pi_l, .., \pi_S) \in \mathbb{R}^S_+$. These financial securities are traded on exchanges, so I have in mind this huge anonymous international capital market in a currency union. Therefore, cross-country lenders and borrowers do not have one-on-one interactions.

In addition to the financial contracts, there are inter-period domestic loan contracts and interbank loan contracts that provide liquidity in the common currency as the only stipulated means of exchange. The union-wide central bank lends interbank loans (μ^i_{CB}, μ^j_{CB}) to provide the common currency to the commercial banking sectors in the two countries. In each country,

there is a domestic commercial bank sector that extends loans (μ_I^i or μ_J^j) to provide liquidity in the common currency to its respective domestic households, as in Assumption 1.

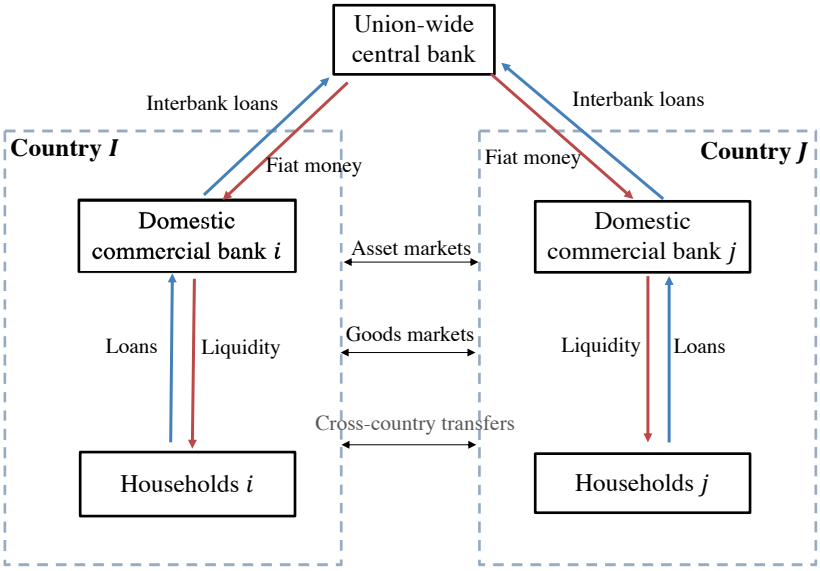
Assumption 1 (bank lending). *In terms of loans to non-bank sectors, commercial banks only grant loans to domestic non-bank sectors, but not foreign non-bank sectors.*

This assumption is based on the strong "home bias" of bank lending in the Eurozone widely documented in the empirical literature (see Acharya and Steffen 2015; Becker and Ivashina 2017; Gabrieli and Labonne 2018; Ongena et al. 2018). It also reflects the doom-loop in the Eurozone à la Brunnermeier et al. (2016) and Farhi and Tirole (2017) that banks in the Eurozone hold a disproportionately large amount of national debt or bonds issued by their own sovereigns.[10]

The capital markets union takes the form of financial asset markets that facilitate cross-country capital flow. Following Shubik and Wilson (1977) and Dubey et al. (2005), market participants choose how much to deliver for asset payoffs, and the asset market is assumed an anonymous market with promises between different sellers not allowed to be distinguished even though they may deliver differently. This assumption implies that the expected delivery rates of the financial securities denoted as K are macro variables taken as given by the households, in the same tradition as the competitive market environment. All deliveries are pooled, and buyers of the pool for each financial security receive a pro-rata share of the net deliveries. Each ownership share of the pool of the financial security $\boldsymbol{s}$ receives a fraction $K_{\boldsymbol{s}} \in [0, 1]$ of the promised delivery in state $\boldsymbol{s}$.

[10] As many existing works have endogenised this home bias or relationship lending either in the Eurozone context or in a broader context (see Acharya and Rajan 2013; Gennaioli et al. 2014; Uhlig 2014; Acharya et al. 2014; Farhi and Tirole 2017); therefore, I do not seek to provide further microfoundations for Assumption 1 in this paper.

Figure 2.3: Nominal flows of the economy



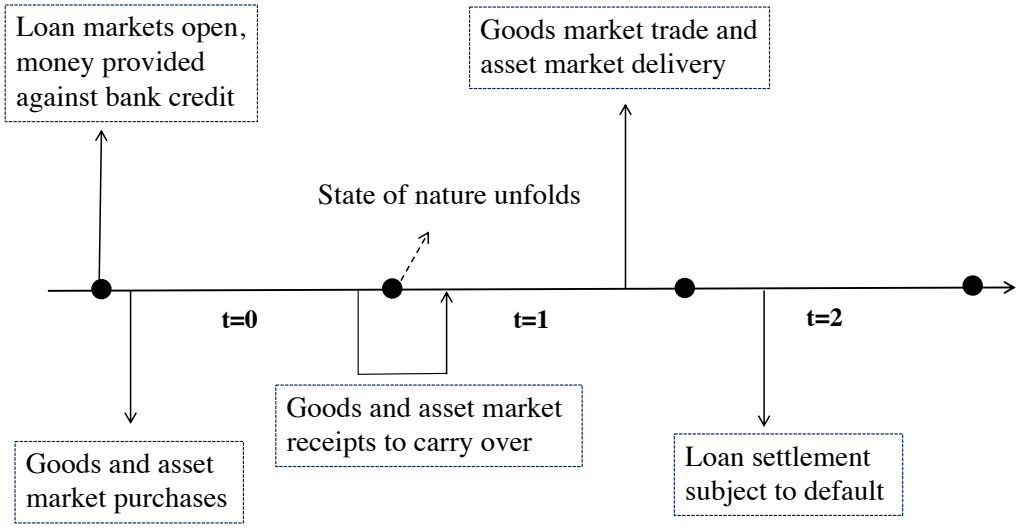
The model structure and agents' interactions are depicted in Fig (2.3). Linking the two member countries are the union-wide central bank and interbank markets, capital asset markets, goods markets, and possibly cross-country transfers via a fiscal/banking union.

Assumption 2 (means of transaction). *Money is used to facilitate transactions due to a high searching cost and lack of double coincidence of wants.*

Assumption 2 together with the banking structure illustrated in Fig (2.3) implies that all transactions are carried out in the common currency and that households face cash-in-advance constraints akin to Lucas Jr and Stokey (1987). This assumption helps to make explicit the issuance of the single currency against credit.[11] Figure (3.2) shows the timeline. At $t = 0$, loan markets open so that fiat money in the common currency is issued against bank loans. Households use money to buy assets and imports, and they carry the monetary proceeds of selling assets and exports to $t = 1$. Uncertainty unfolds at $t = 1$, and assets deliver nominal payoffs and goods are traded. At $t = 2$, households use money at hand to settle outstanding loans. I make the sequence precise when I formally describe the budget constraints and the flow of funds.

[11] For a detailed characterisation of money and credit in a more general setting, please see Gu et al. (2016) who incorporate frictions such as spatial or temporal separation, imperfect information and limited commitment.

Figure 2.4: Timeline



3.2. Country I

Country I's modelling is described in detail. The modelling of country$J$ is exactly symmetric to that of country I, and the endowment shocks are asymmetric (see country J in Appendix 1.).

Households i

Households i consume at $t = 1, 2$ and derive utility from the two tradable goods, i.e. the domestic consumption good of $c^i_{Is^*}$ and the foreign consumption good of $c^i_{Js^*}$. Additionally, households i will suffer a non-pecuniary penalty if they default.

Let $(\forall \boldsymbol{s} \in S)$,

$v^i_{\boldsymbol{s}} \equiv$ the households' choice of repayment rate on domestic loans (i.e., the NPL rate is $1 - v^i_{\boldsymbol{s}}$),

$\theta^i_{\boldsymbol{s}} \equiv$ the long position in the asset markets,

$\phi^i_{\boldsymbol{s}} \equiv$ the short position in the asset markets,

$D^i_{\boldsymbol{s}} \equiv$ the choice of asset delivery,

$q^i_I \equiv$ the quantity of exports,

$b^i_J \equiv$ the amount of money spent on imports,

$p_{\boldsymbol{s}} \equiv$ the union-wide price level index at $t = 1$,

$[d^i_{\boldsymbol{s}}]^+ \equiv$ the size of default on domestic loans in real terms, where

$$[d^i_{\boldsymbol{s}}]^+ = \frac{max[(1-v^i_{\boldsymbol{s}})\mu^i_I, 0]}{p_{\boldsymbol{s}}},$$

$[f^i_{\boldsymbol{s}}]^+ \equiv$ the size of default in asset markets in real terms, where

$$[f^i_{\boldsymbol{s}}]^+ = \frac{max[\phi^i_{\boldsymbol{s}} - D^i_{\boldsymbol{s}}, 0]}{p_{\boldsymbol{s}}}.$$

Formally households' preference is given as follows:

$$\underbrace{Max}_{\mu^i_I,\theta^i,\phi^i,c^i_I,c^i_J,q^i_I,b^i_J,v^i,D^i} E_0\Big\{U^i(c^i_{I0}, c^i_{J0}, c^i_{I\boldsymbol{s}}, c^i_{J\boldsymbol{s}}) - \lambda^i[d^i_{\boldsymbol{s}}]^+ - \lambda[f^i_{\boldsymbol{s}}]^+\Big\},$$

where the preference over consumption goods $U(\cdot)$ is assumed to be homothetic, strictly increasing, concave, and differentiable. The disutility from default is separable from consumption utility and is linear in the amount of default. The λ^i denotes the domestic default penalty harshness, modelled as a proxy for the domestic bankruptcy code throughout the paper. I denote the union-wide bankruptcy code as λ. Default can be either strategic or due to ill fortune, but creditors cannot observe why borrowers default. The households evaluate their marginal benefit from default and their marginal cost of default. If the former is larger than the latter, households default strategically even if there are resources at hand.

Households i choose the amount of domestic loans of μ^i_I to borrow, the quantity of nominal Arrow securities of θ^i to buy, the quantity of nominal Arrow securities of ϕ^i to sell, the quantity of domestic goods of c^i_I to consume, the amount of importing goods of c^i_J to consume, the amount of exporting goods of q^i_I, the amount of money of b^i_J to spend on imports, the loan repayment rate of v^i, and total asset delivery of D^i.

Let Δ denote any unused money from the corresponding flow of funds constraint, let $\eta^i_0, \eta^i_{1\boldsymbol{s}}, \eta^i_{2\boldsymbol{s}}$ be the shadow price of the corresponding constraint, let r_I be the domestic loan rate and $\tau_{I\boldsymbol{s}}$ be the domestic tax rate, let $K_{\boldsymbol{s}}$ be the aggregate delivery rates of the nominal Arrow security $l = \boldsymbol{s}$, and let $\delta^i_{\boldsymbol{s}}$ be any *potential* cross-country transfer. When a fiscal union is absent, then

$\delta^i_{\boldsymbol{s}}$ is simply set to 0 for all states. Households i are subject to the following budget sets and flow of funds constraints.

At $t = 0$:

$$b^i_{J0} + \sum_{l=1}^{S} \pi_l \theta^i_l \leq \frac{\mu^i_I}{1 + r_I} + m^i. \qquad \eta^i_0 \quad (2.1)$$

At $t = 1$ $\forall \boldsymbol{s} \in S$:

$$b^i_{J\boldsymbol{s}}(1 + \tau_{I\boldsymbol{s}}) + (D^i_{\boldsymbol{s}} - K_{\boldsymbol{s}}\theta^i_{\boldsymbol{s}}) + \phi^i_{\boldsymbol{s}}\tau_{I\boldsymbol{s}} \leq \Delta(2.1) + \sum_{l=1}^{S} \pi_l \phi^i_l + p_{I0}q^i_{I0} + p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}} + \delta^i_{\boldsymbol{s}}. \qquad \eta^i_{1\boldsymbol{s}} \quad (2.2)$$

At $t = 2$:

$$v^i_s \mu^i_I \leq \Delta(2.2)_{\boldsymbol{s}}. \qquad \eta^i_{2\boldsymbol{s}} \quad (2.3)$$

And for $\boldsymbol{s}^* \in S^*$, the feasibility constraints are satisfied, i.e., $c^i_{I\boldsymbol{s}^*} \leq e^i_{I\boldsymbol{s}^*} - q^i_{I\boldsymbol{s}^*}$ and $c^i_{J\boldsymbol{s}^*} \leq \frac{b^i_{J\boldsymbol{s}^*}}{p_{J\boldsymbol{s}^*}}$.

Condition (2.1) states that at $t = 0$, households apply for an inter-period loan[12] of μ^i_I from the domestic commercial banking sector at the loan rate r_I to obtain inside money. Households i use the money inflow from the domestic commercial banking sector, plus any outside money of m^i to buy nominal Arrow securities and imports (*money as a means of transaction*). At the same time, households i receive monetary income from selling securities and exports for a total of $\sum_{l=1}^{S} \pi_l \phi^i_l + p_{I0}q^i_{I0}$ and carry it over into $t = 1$ (*money as a store of value*).

Condition (2.2) states that at $t = 1$, households i use the monetary income from $t = 0$ and export income of $t = 1$ plus any unused money $\Delta(2.1)$ and cross-country fiscal transfer of $\delta^i_{\boldsymbol{s}}$ (if any) to spend on the imports of $b^i_{J\boldsymbol{s}}$ and to deliver the net monetary payoff of $D^i_{\boldsymbol{s}} - K_{\boldsymbol{s}}\theta^i_{\boldsymbol{s}}$ for the security $l = \boldsymbol{s}$. Moreover, import expenditures and cross-country borrowing are subject

[12] The modelling of the inter-period loan reflects the reality that the bank's asset is typically less liquid than its liability, i.e., money in this case.

to a state-contingent tax levied by the national government for a possible bailout fund.

At $t = 2$, households use the residual money from $t = 1$ to settle the domestic loan and choose how much to repay or default (see Condition (2.3)). This loan settlement constraint is equivalent to the transversality condition in infinite horizon models.

Domestic Commercial Banking Sector i

Bank i is the domestic commercial banking sector in country I. Bank i extends loans to domestic households and provides liquidity for the households to make purchases. To ensure the liquidity bank i provides would have one-to-one convertibility to the common currency the union-wide central bank issues, bank i needs to borrow interbank loans from the union-wide central bank. In this sense, commercial banks act as the "creators of money" à la Tobin (1963), with the central bank being the ultimate fiat money issuer.[13]

Bank i needs to make the following choices. It needs to choose the amount of domestic liquidity of $\mu_I^i/(1 + r_I)$ to supply to the household, the amount of interbank loans μ_{CB}^i to borrow from the union-wide central bank to obtain the common currency, and the amount of interbank liquidity L^i to make available to ensure that the liquidity supplied to domestic households has a one-to-one convertibility to the common currency obtained from the central bank. Bank i maximises its franchise value, defined as the average payoff across states weighted by the risk-neutral probabilities. Formally,

$$\underbrace{Max}_{\mu_{CB}^i, \mu_I^i, L^i, \omega^i} \sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} \omega_s^i,$$

where ω_s^i is bank i's nominal profits for state $\boldsymbol{s}$ and $z_{\boldsymbol{s}}$ is the risk-neutral probability for state $\boldsymbol{s}$. Let ρ be the interbank rate, and let $R_{\boldsymbol{s}}^i$ be the bank's expected repayment rate of the households. Bank i is subject to the following flow of funds constraints:

$$L^i \leq \frac{\mu_{CB}^i}{1 + \rho}, \tag{2.4}$$

[13] In practice, when individual commercial banks supply loans they immediately write deposits as IOU notes for the borrowers, but the deposits are convertible to central bank reserves with the central bank being the lender of the last resort. Therefore, ultimately fiat money is issued by the central bank, and the commercial banks are a risk-shifting "pass-through" of central bank fiat money.

$$\frac{\mu_I^i}{1+r_I} \leq L^i, \tag{2.5}$$

$$\omega_{\boldsymbol{s}}^i = \Delta(2.4) + \Delta(2.5) + R_{\boldsymbol{s}}^i \mu_I^i - \mu_{CB}^i. \tag{2.6}$$

At $t = 0$, bank i borrows interbank loans from the union-wide central bank and obtains fiat money in the common currency, ready to be extended as interbank liquidity of L^i as in Condition (2.4).

Meanwhile, when bank i extends commercial loans of μ_I^i to the households, it must ensure the liquidity bank i provides against the bank loans has one-to-one convertibility to the fiat money issued by the central bank. This is shown in Condition (2.5) and Lemma 2, which shall prove that Condition (2.5) is binding whenever $\rho > 0$. Eq (2.6) states at $t = 2$, $\forall \boldsymbol{s} \in S$, bank i uses the households' loan repayment to pay back the interbank loans[14] to the union-wide central bank, and the difference between these two repayments adds to bank i's net cash flow, i.e., profits.

Depending on the NPL rate of $1 - v_{\boldsymbol{s}}^i$ for state $\boldsymbol{s} \in S$, bank i's nominal profits $\omega_{\boldsymbol{s}}^i$ could be negative and that bank i becomes insolvent. Given the characteristics of different regimes to be specified in Proposition 2, there may be cross-country transfers of $\delta_{\boldsymbol{s}}^{bI}$ or domestic government bailout funds of $T_{I\boldsymbol{s}}$ injected to bank i. I define $\omega_{\boldsymbol{s}}^{i'}$ as the after-bailout net cash inflow to bank i, $\forall \boldsymbol{s} \in S$, i.e., $\omega_{\boldsymbol{s}}^{i'} = \omega_{\boldsymbol{s}}^i + \delta_{\boldsymbol{s}}^{bI} + T_{I\boldsymbol{s}}$.

National Government i

National government i collects taxes from domestic households to build a state-contingent bailout fund of $T_{I\boldsymbol{s}}$. Assumption 3 implies that the national government will levy a tax to bail out the domestic banking sector, should the government foresee domestic banking insolvency in a particular state. The households and the domestic commercial banking sector are assumed uninformed at $t = 0$ of the national government's contingent action at $t = 1$. At $t = 1$, they take the government's action as given.

[14] Interbank loans are modelled as non-defaultable. When the Euro Crisis emerged, the authorities arranged the form of the rescue to make sure that there was no default on the interbank loans that French and German banks had provided to the Greeks.

Assumption 3 (bailout). *The insolvency of the domestic banking sector incurs a high social cost.*

The social cost in Assumption 3 can be interpreted in two dimensions. When the domestic commercial banking sector incurs negative profits and becomes insolvent, it is unable to pay back the interbank loans to the union-wide central bank. One dimension of the social cost is that domestic banking insolvency means defaulting on the union-wide central bank. The implication is that the country as a whole may lose the membership of being in the currency union. The other dimension is that domestic banking insolvency would require enormous resources for the national government to restore its domestic banking system. Given such considerations, the national government will bail out the domestic banking system should it foresee domestic banking insolvency in a particular state.

To collect the bailout fund, the national government levies taxes based on import expenditures and cross-country borrowing as in Eq (43),[15] reflecting the point that in a bad state, the government resorts to fiscal austerity to bail out the domestic banking system.

$$T_{Is} = p_{Js} c^i_{Js} \tau_{Is} + \phi^i_s \tau_{Is}. \tag{2.7}$$

National government i uses the bailout funds to rescue the domestic commercial banking sector whenever the banking sector's nominal profits (adjusting for possible cross-country transfers) would drop to negative, i.e., the bank fails. In short, in the bad state the national government makes a state-contingent transfer to ensure $\omega^{i'}_s = \omega^i_s + \delta^{bI}_s + T_{Is} = 0$.

3.3. Union-wide Central Bank

The union-wide central bank lends interbank loans of μ^h_{CB}, $\forall h \in \{i, j\}$, and provides fiat money in the common currency to the two national commercial banking sectors. The union-wide central bank sets the interbank target rate of ρ as the policy rate.

To guarantee the determinacy of the price level, the union-wide central bank, through the flow of funds of the banking system, collects households' outside money as the seigniorage, but it does not redistribute the seigniorage within the same period. In this sense, the treat-

[15] Using tax rates rather than a lump-sum leads to more explicit analytical expressions for propositions. The results are also robust to a lump-sum tax levy instead.

ment of seigniorage in this model is non-Ricardian (Sims 1994; Buiter 1999). This approach follows Dubey and Geanakoplos (1992, 2006) and Tsomocos (2003). It resonates with the institutional separation between a central bank and a government and takes the view that price-level determinacy in equilibrium reflects the central bank mandate on price stability.

3.4. Equilibrium

The currency union equilibrium is defined as an allocation $(c^i_{Is^*}, c^i_{Js^*}, c^j_{Is^*}, c^j_{Js^*}, b^j_{Is^*}, b^i_{Js^*}, q^i_{Is^*}, q^j_{Js^*}, \theta^h_l, \phi^h_l, D^h_{\boldsymbol{s}}, \mu_I, \mu_J, \mu_{CB})$ with prices $(p_{I\boldsymbol{s}^*}, p_{J\boldsymbol{s}^*}, \pi_l, r_I, r_J, v^h_{\boldsymbol{s}}, R^h_{\boldsymbol{s}})$, given bankru-ptcy codes (λ^h, λ) and policy rate and fiscal rules (ρ, τ_H, δ^h, δ^{bH}), $\forall \boldsymbol{s}^* \in S^*$, $\forall \boldsymbol{s} \in S$, $\forall l \in S$, $h \in \{i, j\}$, $H \in \{I, J\}$ such that agents maximise subject to liquidity-in-advance constraints and budget constraints, markets clear, and expectations are rational.

- Goods markets:

$$p_{I\boldsymbol{s}^*} q^i_{I\boldsymbol{s}^*} = b^j_{I\boldsymbol{s}^*},$$

$$p_{J\boldsymbol{s}^*} q^j_{J\boldsymbol{s}^*} = b^i_{J\boldsymbol{s}^*},$$

- Asset markets for the nominal Arrow security $\boldsymbol{s} = l$:

$$\sum_{h \in \{i,j\}} \phi^h_l = \sum_{h \in \{i,j\}} \theta^h_l,$$

- Domestic loan markets:

$$\frac{\mu^h_H}{1 + r_H} = L^h,$$

- Interbank loan and money market:

$$1 + \rho = \frac{\mu^i_{CB} + \mu^j_{CB}}{M},$$

- Rational expectation:

$$K_{\boldsymbol{s}} = \left\{ \begin{array}{cc} \frac{\sum_{h\in\{i,j\}} D^h_{\boldsymbol{s}}}{\sum_{h\in\{i,j\}} \phi^h_{\boldsymbol{s}}} & \text{if } \sum_{h\in\{i,j\}} \phi^h_{\boldsymbol{s}} > 0 \\ \text{arbitrary} & \text{if } \sum_{h\in\{i,j\}} \phi^h_{\boldsymbol{s}} = 0 \end{array} \right\},$$

$$R^h_{\boldsymbol{s}} = \left\{ \begin{array}{cc} v^h_{\boldsymbol{s}} & \text{if } 1 - v^h_{\boldsymbol{s}} > 0 \\ \text{arbitrary} & \text{if } 1 - v^h_{\boldsymbol{s}} = 0 \end{array} \right\}.$$

3.5. Equilibrium and Regime Characterisation

This subsection characterises the equilibrium and regimes. Suppose state s is a good state for country I and a bad state for country J, and state s' is a bad state for country I and a good state for country J, i.e. $e^i_{Is} > e^i_{Is'}$, $e^j_{Js} < e^j_{Js'}$. The subsequent analysis focuses on such asymmetric endowment shocks. Let $\gamma_{\boldsymbol{s}}$ the probability state $\boldsymbol{s}$ occurs, $\forall \boldsymbol{s} \in S$.

Lemmas 1-3 prove the binding conditions of the flow of funds constraints to ensure both nominal and real determinacy. Lemma 4 states the shadow price of the flow of funds constraint at $t = 1$. Lemma 5 and Proposition 1 characterise the equilibrium. Proposition 2 designs regimes of a currency union.

Lemma 1. Binding conditions of the Liquidity-in-advance constraints.

If $r_I > 0$, then $\Delta(2.1) = 0$.

If $\rho > 0$, then $\Delta(2.4) = 0$.

Proof. See Appendix 3.1..

Lemma 2. Interbank liquidity and the single currency convertibility.

If $\rho > 0$, then $\Delta(2.5) = 0$.

Proof. See Appendix 3.2..

Remark: That (2.5) binds means that the interbank liquidity the domestic banking sector i extends to the households is pegged one-to-one to the common currency issued by the union-wide central bank. The convertibility is not imposed *a priori* but rather a result of the non-arbitrage conditions from the interbank market.

Lemma 3. No worthless money at the end.

If $r_I > 0$, then $\Delta_{\boldsymbol{s}}(2.3) = 0$.

If $\rho > 0$, then $\Delta_{\boldsymbol{s}}(2.6) = 0$.

Proof. See Appendix 3.3..

Lemma 4. Heterogeneous tightness of nominal constraints.

In a currency union with trades in goods market and asset market, if $r_I, r_J > 0$ and no full default on loans, then $\eta^i_{1s} \neq \eta^i_{1s'}$ and/or $\eta^j_{1s} \neq \eta^j_{1s'}$.

Proof. See Appendix 3.4..

Lemma 5. (zero credit risks and the loss of exchange rate): If in the currency union $\forall \boldsymbol{s} \in S$, $h \in \{i, j\}$, $v^h_{\boldsymbol{s}} = 1$, given markets are complete, domestic banking sectors break even for all states, i.e. $\omega^h_{\boldsymbol{s}} = 0$.

Proof. See Appendix 3.5..

Claim. *With domestic credit risks, the loss of floating nominal exchange rates (i.e., currency unions) translates into a currency crisis, disguised as a banking debt crisis, i.e.,* $\omega^h_{\boldsymbol{s}} < 0, \exists \boldsymbol{s} \in S, h \in \{i, j\}$.

The above claim implies that the banking sectors in a currency union become more vulnerable due to losing the flexibility of exchange rates. Having a floating exchange rate might neutralise domestic credit risks and prevent such crises. Not to jump ahead of myself, I shall revisit this claim with a formal argument and proof in Proposition 4 of the equilibrium analysis of the currency union and Proposition 6 in Section 5 in which I consider national currencies and the role of nominal exchange rates.

Given that in a currency union, zero domestic credit risks in all states of nature as in Lemma 5 is unlikely to hold in reality, in the subsequent analysis, I only focus on the cases when domestic credit risks are present in a currency union. I also do not consider the case of 100 % non-performing loans where there exists a state in which the household defaults on domestic loans completely. Formally, let,

$$\overline{\Lambda}^h = \{\lambda^h : v^h_{\boldsymbol{s}} = 1, \forall \boldsymbol{s} \in S, h \in \{i,j\}\},$$

$$\underline{\Lambda}^h = \{\lambda^h : v^h_{\boldsymbol{s}} = 0, \exists \boldsymbol{s} \in S, h \in \{i,j\}\}.$$

Thus, $\overline{\Lambda}^h$ covers the cases of full delivery of domestic loans in all states, and $\underline{\Lambda}^h$ covers the cases in which there exists a state of full default on domestic loans. In *all* the subsequent analysis I restrict λ^h to be an intermediate default penalty for domestic loans, i.e. for $h \in \{i,j\}$, $\lambda^h \notin \overline{\Lambda}^h$ and $\lambda^h \notin \underline{\Lambda}^h$.

Proposition 1. (the Fisher effect, Quantity Theory of Money, and money non-neutrality):

- **The Fisher effect**: Suppose for households i, $b^i_{J\boldsymbol{s}^*} > 0$, $\forall \boldsymbol{s}^* \in S^*$. Suppose further that households i have some money left over the moment the domestic loan comes due at $\boldsymbol{s}$, then in equilibrium,

$$1 + r_I = (E_0(\frac{U^i_{c^i_{J\boldsymbol{s}}}}{U^i_{c^i_{J0}}})(\frac{p_{J0}}{p_{J\boldsymbol{s}}})\frac{1}{(1+\tau_{I\boldsymbol{s}})})^{-1},$$

  where $U^i_{c^i_{J0}}$ and $U^i_{c^i_{J\boldsymbol{s}}}$ are household i's marginal utilities of consuming imports at $t = 0$ and in state $\boldsymbol{s}$. A similar expression of the Fisher effect obtains for country J as well.

  Taking the logarithm of the above Fisher equation and interpreting it loosely, the nominal interest rate equals the real interest rate plus the expected inflation adjusted by any bailout tax. Any tax needed for bank bailout in a currency union also distorts real allocation and inflation. As the bailout tax puts downward pressure on inflation and the real interest rate, and it resembles fiscal austerity, I call this distortionary effect the *internal devaluation* effect.

- **Quantity Theory of Money**: If $\rho > 0$, the aggregate income of the currency union, namely the nominal value of consumption goods sales is equal to the total stock of bank money and outside money, adjusted by asset trades and the bailout tax levy. Let $\Delta^i_{\boldsymbol{s}} = \Delta(2.2) - p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}}$, and likewise for household j,

$$p_{I0}q^i_{I0} + p_{J0}q^j_{J0} = M - \sum_{h\in\{i,j\}}\sum_{l=1}^{S}\pi_l\theta^h_l + \sum_{h\in\{i,j\}} m^h,$$

$$p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}} + p_{J\boldsymbol{s}}q^j_{J\boldsymbol{s}} = M + \sum_{h\in\{i,j\}} m^h - \sum_{H\in\{I,J\}} T_{H\boldsymbol{s}} - \sum_{h\in\{i,j]} \Delta^h_{\boldsymbol{s}}.$$

- **Money non-neutrality**: Suppose $\rho > 0$, any change in ρ results in a different equilibrium in which some households' consumption is different.

  Remark: Even with flexible prices, money and default render monetary policy non-neutral.

  Proof. See Appendix 3.6..

Corollary 1.1. (credit risks and the term-structure of interest rates): Suppose $\rho > 0$, in a currency union with idiosyncratic credit risks, suppose $v^i_s > \sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^i_{\boldsymbol{s}} > v^i_{s'}$ and $v^j_s < \sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^j_{\boldsymbol{s}} < v^j_{s'}$, $\forall \boldsymbol{s} \in S$, the term structure of interest rates incorporates credit risks, and $\omega^i_s, \omega^j_{s'} > 0$.

In state s:

$$\rho M + (\frac{v^j_s}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v^j_{\boldsymbol{s}}} - 1)\mu^j_{CB} + T^j_s = \sum_{h\in\{i,j\}} m^h - \omega^i_s. \tag{2.8}$$

In state s':

$$\rho M + (\frac{v^i_{s'}}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v^i_{\boldsymbol{s}}} - 1)\mu^i_{CB} + T^i_{s'} = \sum_{h\in\{i,j\}} m^h - \omega^j_{s'}. \tag{2.9}$$

Proof. See Appendix 3.7..

Corollary 1.2. (Monetary policy rate pass-through): For $H \in \{I, J\}, h \in \{i, j\}, \forall \boldsymbol{s} \in S$,

$$1 + r_H = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^h_{\boldsymbol{s}}}. \tag{2.10}$$

Corollary 1.1 states that both the liquidity creation by banks and the credit risks of house-

holds affect the term structure of the interest rates. The left-hand side of the Eqs (2.8) (2.9) is the union-wide central bank's interest rate revenue for issuing the common currency. It equates the total outside money minus the rents extracted by commercial banks, to be collected by the union-wide central bank at $t = 2$. Note that the union-wide central bank does not collect all the outside money as profits. This amount of profits collected by the central bank is called seigniorage. No matter how small it is, it serves to obtain price-level determinacy.[16] Isomorphically, the term structure of interest rate in relation to the seigniorage can be interpreted as the nexus between fiat money and the fiscal sovereign. Indeed, Goodhart (1998) argues that seigniorage is part of the government's taxation plan, and as Tsomocos (2003) puts it, by collecting the seigniorage, "the government compels the acceptance of fiat money as a final discharge of debt".

Corollary 1.2 or Eq (2.10) shows the imperfect pass-through of the union-wide monetary policy hampered by credit risks. It states the borrowing cost at the national level equates to the the union-wide monetary policy rate adjusted for the expected domestic NPL rates. The implication is that a fall in the union-wide monetary policy rate does not necessarily translate to a loosened monetary condition at the national level, because the monetary policy pass-through is augmented with terms of financial contracts at the national level.

Apart from the classic results above, the key step forward of this international finance model is that it includes regime designs of a currency union by varying the domestic and cross-country bankruptcy codes ($\lambda^h, \lambda, h \in \{i, j\}$) and then their respective welfare properties are ranked. Which regime the currency union falls under is endogenous to the relative harshness of domestic and union-wide bankruptcy code. In different regimes, the terms in the term structure equations shall take on different values, and the term structure equations summarise the driving force of the specific structural assumptions in the various regimes considered. Proposition 2 formalises the regime design.

Proposition 2. (domestic and union-wide bankruptcy codes):

- If the union-wide bankruptcy code is harsher than the domestic bankruptcy code, households fully deliver on financial assets. i.e., for $h \in \{i, j\}$,
  - if $\lambda > \lambda^h$, $D^h_{\boldsymbol{s}} = \phi^h_{\boldsymbol{s}}$ at state s.

[16] For a general proof of determinacy, please see Dubey and Geanakoplos (2006) and Tsomocos (2008).

- If the union-wide bankruptcy code is more lenient, households may default on financial assets. i.e., for $h \in \{i, j\}$,

  - if $\lambda < \lambda^h$, $0 \leq D_{\boldsymbol{s}}^h \leq \phi_{\boldsymbol{s}}^h$ at state s.

Proof. See Appendix 3.8..

Proposition 2 states when the union-wide bankruptcy code is harsher than domestic bankruptcy codes, default in the cross-border capital markets does not occur; when the domestic bankruptcy code is harsher than the union-wide bankruptcy code, default in the cross-border capital markets may occur in equilibrium. Proposition 2 establishes the foundation for the design of the following three regimes. Formally, define $CA_{\boldsymbol{s}}^H$ as country H's current account net flow and $FA_{\boldsymbol{s}}^H$ as country H's capital account net flow at $t = 1$, i.e.,

$$
\begin{aligned}
CA_{\boldsymbol{s}}^I &= p_{I\boldsymbol{s}} q_{I\boldsymbol{s}}^i - p_{J\boldsymbol{s}} c_{J\boldsymbol{s}}^i, \\
FA_{\boldsymbol{s}}^I &= K_{\boldsymbol{s}} \theta_{\boldsymbol{s}}^i - D_{\boldsymbol{s}}^i, \\
CA_{\boldsymbol{s}}^J &= p_{J\boldsymbol{s}} q_{J\boldsymbol{s}}^j - p_{I\boldsymbol{s}} c_{I\boldsymbol{s}}^j, \\
FA_{\boldsymbol{s}}^J &= K_{\boldsymbol{s}} \theta_{\boldsymbol{s}}^j - D_{\boldsymbol{s}}^j.
\end{aligned}
$$

A positive CA means the current account is a running surplus, and a positive FA means international capital inflow, and vice versa. With these definitions, I state the following regime designs.

- **Regime A (baseline)**: $\lambda > \lambda^h$, $\delta_{\boldsymbol{s}}^h = \delta_{\boldsymbol{s}}^{bH} = 0$, $T_{H\boldsymbol{s}} = -\omega_{\boldsymbol{s}}^h$ whenever $\omega_{\boldsymbol{s}}^h < 0$, and $T_{H\boldsymbol{s}} = 0$ whenever $\omega_{\boldsymbol{s}}^h \geq 0$, where $h \in \{i, j\}$, $H \in \{I, J\}$, $\forall \boldsymbol{s} \in S$.

  Regime A is the baseline currency union in which a punitive union-wide bankruptcy code prevents default in the cross-border capital markets, and a fiscal union is also ruled out. The domestic bailout tax is levied in the respective bad state to bail out the domestic banking system.

- **Regime B (fiscal union)**: A currency union supported by a fiscal union, and a punitive union-wide bankruptcy code prevents default in the cross-border capital markets, i.e., $\lambda > \lambda^h, T_{H\boldsymbol{s}} = 0$, for $h \in \{i, j\}$, $H \in \{I, J\}$, $\forall \boldsymbol{s} \in S$. I consider two cases for

Regime B as follows.

- **Regime B.a**: A fiscal union that makes cross-country fiscal transfers of $\delta^h_{\boldsymbol{s}}$ directly between households, and $\delta^h_{\boldsymbol{s}} = -FA^H_{\boldsymbol{s}} - CA^H_{\boldsymbol{s}}$ and $\delta^{bH}_{\boldsymbol{s}} = 0$. It follows that $\sum_{h\in\{i,j\}} \delta^h_{\boldsymbol{s}} = 0$.[17]

- **Regime B.b**: A fiscal union that makes cross-country fiscal transfer of $\delta^{bH}_{\boldsymbol{s}}$ directly between domestic commercial banks, such that $\omega^h_{\boldsymbol{s}} + \delta^{bH}_{\boldsymbol{s}} \geq 0$ and $\sum_{H\in\{I,J\}} \delta^{bH}_{\boldsymbol{s}} = 0$, $\delta^h_{\boldsymbol{s}} = 0$. Regime B.b can be interpreted as a banking union supported by a common fiscal entity.

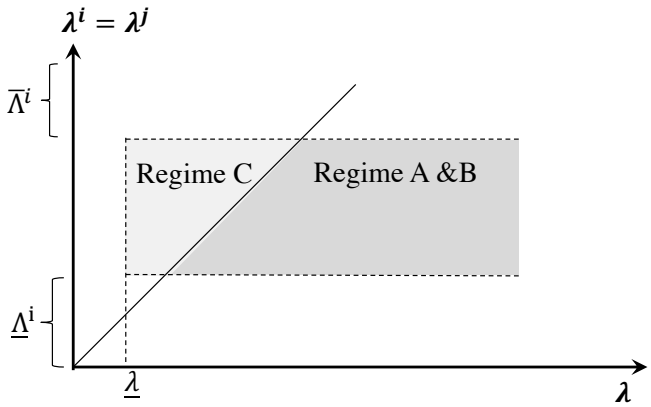
- **Regime C (bankruptcy leniency)**: $\underline{\lambda} < \lambda < \lambda^h$, $\delta^h_{\boldsymbol{s}} = \delta^{bH}_{\boldsymbol{s}} = 0$, and $T_{H\boldsymbol{s}} = 0$.

  Regime C is a currency union with a more lenient union-wide bankruptcy code, but a fiscal union is ruled out and no domestic bailout tax is levied. In this regime, the bankruptcy code can induce endogenous default in the cross-border capital markets to emerge in equilibrium.

Note that the lower bound $\underline{\lambda}$ of the union-wide bankruptcy code in Regime C ensures the financial markets do not collapse. The reason is that if the union-wide bankruptcy code is too lenient, households in both countries would fully default on the financial assets; hence, assets would not be traded at $t = 0$. To sum up, Fig (2.5) illustrates the regions of default penalty harshness and the corresponding regimes of the currency union. The horizontal axis denotes the union-wide default penalty harshness λ, and the north-pointing vertical axis denotes domestic default penalty harshness λ^i and λ^j. For the ease of illustration, $\lambda^i = \lambda^j$, but equality does not need to hold in general. Focusing on the intermediate domestic default penalty harshness, Regime C belongs to the region where domestic bankruptcy codes are harsher than the union-wide bankruptcy code, and Regimes A and B belong to the region where the union-wide bankruptcy code is harsher than domestic bankruptcy codes.

[17] Note that country H's Balance of Payment ($BoP^H_{\boldsymbol{s}}$) in state $\boldsymbol{s}$ is $BoP^H_{\boldsymbol{s}} = CA^H_{\boldsymbol{s}} + FA^H_{\boldsymbol{s}} + \delta^h_{\boldsymbol{s}}$.

Figure 2.5: Regimes and bankruptcy codes



3.6. Equilibrium Analysis

In this subsection, I show the welfare properties of each regime for allocations, risk sharing, and asset prices. In particular, propositions are given to demonstrate the mechanism in which a lenient bankruptcy code for the capital markets union could improve welfare. A caveat also highlights the possibility of cross-border default could impede international risk sharing if certain conditions are not met.

The intuition of the potential benefit of cross-border default in the capital markets is that it provides extra liquidity for the borrower in the bad state such that risk sharing improves. Before formalising welfare improvement, we need to understand the mechanism of how a lenient union-wide bankruptcy code can incentivise the borrower to grab the option to default in the bad state strategically. Suppose we are in Regime C with a relatively lenient cross-country bankruptcy code. The households in the bad state may fully default on its cross-country borrowing, whereas the other households in the other country may fully repay if they both have short positions on the Arrow security of this state. The reason being the poor households have a high marginal utility of consumption, which would outweigh the marginal cost of default on Arrow securities, given a lenient cross-country bankruptcy code. However, the other households are rich in this state, and the marginal utility of consumption is low, which would push down the marginal benefit of default. When the marginal benefit of default is less than the marginal cost of default, these rich households would fully deliver despite the poor households' full default. Therefore, although the poor households would fully default, the aggregate default rate on the nominal Arrow security of that state actually would fall

between 0 and 1.

Moreover, the poor households may enter both the short and long positions of the nominal Arrow security of the bad state. The poor households would buy this Arrow security to insure against the bad shock, but they may also sell this Arrow security at the same time because selling gives the option to default fully. The option to default on Arrow securities provides extra liquidity leading to a possible increase in consumption or a higher domestic loan repayment rate, which implies an increase in the households' utility. An interior solution can be obtained because on the one hand selling more of the Arrow security leads to extra liquidity due to default, and on the other hand, the market-clearing condition necessitates the poor households also buy more of this Arrow security, and buying incurs more cost of liquidity. Proposition 3 formalises the mechanism of cross-border default. Later on, Proposition 5 builds on Proposition 3 and proves Pareto improvement as a result of endogenous default in the cross-border capital markets.

Proposition 3. (strategic default on financial securities):

- When the union-wide bankruptcy code is lenient enough, households in the bad state may long and short the Arrow security of that state at the same time, and fully default on this Arrow security.
- Consider the case where $S = \{1, 2\}$, let $\gamma_1 = \gamma_2$, $e_1^i > e_2^i$, and $e_1^j < e_2^j$. Suppose that in equilibrium $\lambda < p_2 \eta_{12}^i < \lambda^i$, $\eta_{12}^j < \frac{\lambda}{p_2}$ and $\eta_{11}^i < \eta_{12}^i$ holds. Then, $\phi_2^i, \phi_2^j, \theta_2^i > 0$, $\theta_2^j = 0$, $D_2^i = 0, D_2^j = \phi_2^j$, and $0 < K_2 < 1$ whenever $(K_2 - \pi_2(v_2^i(1 + r_I) - 1))/p_{I2} > \pi_2 r_I / p_{I1}$. Similar logic follows for the other state.[18]

Proof. See Appendix 4..

Corollary 3.1. When the union-wide bankruptcy code is too lenient, it impedes international risk sharing in the currency union.

Corollary 3.2. As domestic bankruptcy codes become more lenient, the room to adjust the union-wide bankruptcy code in the capital markets union decreases.

The insight of Proposition 3 is reminiscent of Example 2 in Dubey et al. (2005). A lenient

[18] In Section 4, an equilibrium with these characteristics is obtained.

cross-country bankruptcy code encourages the households in the bad state to default fully. Even though the poor households have nominal inflows on hand for delivery, they do not deliver anything while the rich households deliver fully! Default in this case is strategic and makes asset payoffs endogenous. Assets are still traded despite strategic default: the households in the poor country enter both long and short positions of Arrow securities, and the households in the rich country only short Arrow securities of that state.

Note that financial securities are voluntarily traded despite the possibility of default, and no market participants are forced to buy or sell the financial securities. In this sense, the invisible hand of the markets provides "voluntary liquidity transfers" via endogenous default. This mechanism is in principle different from Regime B where a fiscal union employs a visible hand to move nominal resources directly. However, a caveat remains for Regime C (Corollary 3.1). Suppose now the union-wide bankruptcy code λ is set ultra-low, i.e. $\lambda < p_{s'}\eta^j_{1s'}$ or $\lambda < p_s\eta^i_{1s}$, then Arrow securities are not traded. The currency union loses risk sharing altogether. Therefore, there exist a lower bound and an upper bound for the union-wide bankruptcy code of the capital markets union.

Moreover, for the currency union to retain risk sharing and for the aforementioned default to occur in the cross-border capital markets in equilibrium, the union-wide bankruptcy code λ must fall into the interval $(p_{s'}\eta^j_{1s'}, \lambda^i) \cap (p_s\eta^i_{1s}, \frac{\lambda^j}{a_s})$ in equilibrium. As the domestic bankruptcy code λ^i or λ^j decrease, $||(p_{s'}\eta^j_{1s'}, \lambda^i) \cap (p_s\eta^i_{1s}, \lambda^j)||$ decreases. Thus, as domestic bankruptcy codes become more lenient, the range to set cross-country bankruptcy code shrinks (Corollary 3.2).

A key condition for Proposition 3 to go through is $\eta^j_{12} < \frac{\lambda}{p_2}$ in equilibrium (and its equivalent for state 1), which says the union-wide bankruptcy code is strict enough to prevent default of the rich households. This condition ensures that defaultable Arrow securities are still traded in equilibrium even when the households of the poor country in the bad state fully default. I call this condition *within-union standard*. When the two countries' fundamentals differ exceptionally or when domestic bankruptcy code(s) are too lenient or discretionary, the "within-union standard" may fail to satisfy. In this case Regime C causes asset trades to collapse.

In contrast to Regime C, Regime B.a and Regime B.b advocate using the visible hand of a

common fiscal entity to make cross-country transfers. Whereas a fully-fledged fiscal union in a currency union may be highly controversial and politically infeasible, in practice, there have been small steps towards building union-wide transfer funds, for example, the concept of a banking union in the Eurozone. Therefore, it is of interest to investigate the properties of Regimes B.a and B.b.

Let $var(1 - v_{\boldsymbol{s}}^{h,B.a})$ be the variance of non-performing loan rate of households h in Regime B.a, let $var(1 - v_{\boldsymbol{s}}^{h,B.b})$ be that of households h in Regime B.b, and $var(1 - v_{\boldsymbol{s}}^{h,A})$ that of Regime A, where $h \in \{i, j\}$. Lemma 6 says the domestic credit risk volatility across states is smaller in Regime B.a than in Regime B.b and Regime A.

Lemma 6 (credit risk volatility):

- A fiscal union that mediates transfers between households can reduce domestic credit risk volatility across states.
- In Regime B.a, for $h \in \{i, j\}, H \in \{I, J\}$, suppose $\delta_{\boldsymbol{s}}^{h} = -FA_{\boldsymbol{s}}^{H} - CA_{\boldsymbol{s}}^{H}$, it follows that $\delta_{\boldsymbol{s}}^{i} + \delta_{\boldsymbol{s}}^{j} = 0$, and moreover,

$$var(1 - v_{\boldsymbol{s}}^{h,B.a}) \leq var(1 - v_{\boldsymbol{s}}^{h,B.b}),$$

$$var(1 - v_{\boldsymbol{s}}^{h,B.a}) \leq var(1 - v_{\boldsymbol{s}}^{h,A}).$$

Proof. See Appendix 4..

Proposition 3 and Lemma 6 equip the currency union with distinct institutional features for the common objective to reduce domestic banking stress. Proposition 4 formalises the mechanisms whereby this objective is achieved.

Proposition 4. (capital flow and banking crisis): Suppose $\lambda^h \notin \overline{\Lambda}^h$ and $\lambda^h \notin \underline{\Lambda}^h$, for $h \in \{i, j\}, H \in \{I, J\}, \forall \boldsymbol{s} \in S$.

- In Regime A, the volatility of domestic credit risks and international capital flow can lead to domestic banking insolvency.
  - If $\lambda > \lambda^h$ and $\delta_{\boldsymbol{s}}^{h} = \delta_{\boldsymbol{s}}^{bH} = 0$, whenever $v_{\boldsymbol{s}}^{h} < \sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^{h}$, then $\omega_{\boldsymbol{s}}^{h} < 0$ and

$T_{Hs} = -\omega_s^h$.

- In Regime B.a, international capital flows do not drive domestic banking insolvency.
  - If $\lambda > \lambda^h$, $\delta_s^{bH} = 0$, and $T_{Hs} = 0$, setting $\delta_s^h = -FA_s^H - CA_s^H$, then $\omega_s^h = 0$.
- In Regime B.b, the banking union funds alleviate domestic banking stress.
  - If $\lambda > \lambda^h$, $\delta_s^h = 0$, and $T_{Hs} = 0$, as long as $\omega_s^j + \omega_s^i \geq 0$, a banking union fund of δ_s^{bH} can be set to transfer between bank i and bank j such that $\omega_s^h + \delta_s^{bH} \geq 0$ and $\sum_{H\in\{I,J\}} \delta_s^{bH} = 0$.
- In Regime C, default in the cross-border capital markets may prevent domestic banking insolvency.
  - If $\underline{\lambda} < \lambda < \lambda^h$, $\delta_s^h = \delta_s^{bH} = 0$, and $T_{Hs} = 0$, under the conditions in Proposition 3 on strategic default, $\omega_s^h = 0$.

Proof. See Appendix 4..

Corollary 4.1. Under Proposition 4, Regimes B and C obviate the need for national bailout taxes whereas Regime A needs it.

Proposition 4 shows whether international capital flow may lead to domestic banking stress under various regimes in a currency union. In Regime A, if domestic bailout funds are unavailable, the domestic commercial banking sector fails in the bad state.

In Regime B.a, the visible hand of a fiscal union sets the amount of cross-country fiscal transfers mediated directly between households in different countries. Such transfers remove the stress from capital flows on member countries' domestic banking system. Domestic commercial banks survive even in the bad state. In Regime B.b, the fiscal union makes transfers directly between commercial banks of different countries, subject to the total banking union fund constraint $\omega_s^i + \omega_s^j \geq 0$. However, Regime B.a faces no such constraint. This constraint is in line with Bolton and Oehmke (2018) that study bank resolution of global banks and show that the loss-absorbing capital is shared across jurisdictions but faces implementation constraints.

In Regime C, despite cross-country fiscal transfers being unavailable, a softened union-wide bankruptcy code can help domestic banks bypass the pressure from international capital flow such that banks survive. The intuition is that a softened union-wide bankruptcy code gives the domestic households the choice to default on their cross-country borrowing in the bad state. Because the domestic bankruptcy code is tougher than the union-wide bankruptcy code in this regime, the marginal cost of default on domestic bank loans is higher than the household's marginal benefit of default. Rationally, the households choose not to default on domestic loans even in the bad state. The takeaway is the relative stance of domestic and cross-country bankruptcy codes can change incentives on the margin and shift domestic credit risks to international capital markets, relieving domestic banks from distress. By adjusting the union-wide bankruptcy code, cross-border default provides a "voluntary" liquidity transfer via the capital markets, in the absence of a fiscal union.

With different extents of domestic banking stress and accordingly distinct needs for national level bailout tax, the regimes designed above bear different implications for allocation efficiency, risk sharing, and asset prices. Under the conditions of Propositions 3 and 4, the corollaries below formalise these implications for $h \in \{i, j\}$.

Corollary 4.2 (allocation efficiency within state):

- In Regime A, optimal allocation does not obtain in $t = 0$ due to domestic credit risks and the cost of liquidity; optimal allocation within state does not obtain in $t = 1$ due to the national bailout tax causing the internal devaluation effect.

  At $t = 0$,

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} \frac{1}{(1+r_I)(1+r_J)},$$

  and at $t = 1$, $\boldsymbol{s} \in S$

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}} \frac{1}{(1+\tau_{I\boldsymbol{s}})(1+\tau_{J\boldsymbol{s}})}.$$

- In Regime B, optimal allocation efficiency does not obtain at $t = 0$ due to domestic

credit risks and the cost of liquidity; optimal allocation within state obtains at $t = 1$.

At $t = 0$,

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} \frac{1}{(1 + r_I)(1 + r_J)},$$

and at $t = 1$, $\boldsymbol{s} \in S$

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}}.$$

- In Regime C, default in the cross-border capital markets obviates the need for national bailout tax, and optimal allocation does not obtain at $t = 0$ due to the cost of interbank liquidity; optimal allocation within state obtains at $t = 1$.

  At $t = 0$,

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} \frac{1}{(1 + \rho)^2},$$

  and at $t = 1$, $\boldsymbol{s} \in S$

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}}.$$

Proof. See Appendix 4..

We can observe that the wedge between the households' marginal rate of substitution across goods distorts allocation efficiency within state. Regime A has the highest wedge due to domestic borrowing costs and bailout tax rates, and the domestic borrowing cost incorporates the cost of liquidity and commands domestic credit risk premia. Regime C has the lowest wedge which only results from the interbank transaction cost. Note that the transaction cost of money is Regime C is just the interbank transaction cost, and it is lower than the borrowing cost in Regime B. This is because the borrowing cost in Regime B commands the credit risk premium of domestic loans, but that of Regime C precludes it owing to the shield

of default in the cross-border capital markets.

Corollary 4.3. (risk sharing):

- In Regime A, optimal risk sharing does not obtain due to domestic credit risks, the cost of liquidity, and the bailout tax.

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{1}{(1+\tau_{Js})(1+\tau_{Is})(1+r_I)(1+r_J)},$$

$$\frac{U^i_{c^i_{Js}}}{U^i_{c^i_{Js'}}} = \frac{U^j_{c^j_{Js}}}{U^j_{c^j_{Js'}}} \frac{1}{(1+\tau_{Is'})(1+\tau_{Js'})(1+r_I)(1+r_J)}.$$

- In Regime B, optimal risk sharing does not obtain due to borrowing costs which command the domestic credit risk premium and incorporate the cost of liquidity.

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{1}{(1+r_I)(1+r_J)},$$

$$\frac{U^i_{c^i_{Js}}}{U^i_{c^i_{Js'}}} = \frac{U^j_{c^j_{Js}}}{U^j_{c^j_{Js'}}} \frac{1}{(1+r_I)(1+r_J)}.$$

- In Regime C when default in the cross-border capital markets obviates the need for national bailout tax, optimal risk sharing does not obtain due to two sources of inefficiency: the cost of interbank liquidity and the default premium in the capital markets union.

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{K_s K_{s'}}{(1+\rho)^2},$$

$$\frac{U^i_{c^i_{Js}}}{U^i_{c^i_{Js'}}} = \frac{U^j_{c^j_{Js}}}{U^j_{c^j_{Js'}}} \frac{K_s K_{s'}}{(1+\rho)^2}.$$

Proof. See Appendix 4..

The above expressions tell us that the wedge between the households' marginal rate of substitution across states distorts risk sharing, and that the wedge in Regime A is the highest because of the extra distortion stemming from the bailout tax. Between Regime B and Regime C, however, it is not obvious whose wedge is higher. Both wedges in these two regimes incorporate the interbank transaction cost and credit/default risk premia.

Corollary 4.4. (asset prices): Financial, monetary, and fiscal factors all affect the stochastic discount factor.

- In Regime A, state prices are affected by the domestic credit risks, the cost of liquidity, and the bailout tax directly.

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}}/p_{Js}}{U^i_{c^i_{I0}}/p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}}/p_{Is}}{U^j_{c^j_{J0}}/p_{J0}(1+\tau_{Js})(1+r_J)},$$

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}}/p_{Js'}}{U^i_{c^i_{I0}}/p_{I0}(1+\tau_{Is'})(1+r_I)} = \gamma_{s'} \frac{U^j_{c^j_{Is'}}/p_{Is'}}{U^j_{c^j_{J0}}/p_{J0}}.$$

- In Regime B state prices are only directly affected by the domestic credit risks and the cost of liquidity.

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}}/p_{Js}}{U^i_{c^i_{I0}}/p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}}/p_{Is}}{U^j_{c^j_{J0}}/p_{J0}(1+r_J)},$$

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}}/p_{Js'}}{U^i_{c^i_{I0}}/p_{I0}(1+r_I)} = \gamma_{s'} \frac{U^j_{c^j_{Is'}}/p_{Is'}}{U^j_{c^j_{J0}}/p_{J0}}.$$

- In Regime C state prices are affected by the interbank transaction cost and the cross-border default premium directly.

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}}/p_{Js}}{U^i_{c^i_{I0}}/p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}}/p_{Is}K_s}{U^j_{c^j_{J0}}/p_{J0}(1+\rho)},$$

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}}/p_{Js'}K_{s'}}{U^i_{c^i_{I0}}/p_{I0}(1+\rho)} = \gamma_{s'} \frac{U^j_{c^j_{Is'}}/p_{Is'}}{U^j_{c^j_{J0}}/p_{J0}}.$$

Proof. See Appendix 4..

Asset prices are typically suppressed by the transaction wedge. The interbank transaction cost, domestic loan credit risk premium, cross-border default premium, and the bailout tax all constitute the transaction wedge. We can observe from Corollary 4.4 that the state prices in Regime A are typically lower than those in Regime B and Regime C, because Regime A is distorted by the bailout tax as the extra transaction wedge. Since the total transaction cost in Regime A is the highest, in this regime one unit of currency tomorrow is worth the lowest level of consumption goods today. Thus, using internal devaluation to sustain a currency union would also put downward pressure on asset prices. This mechanism is confirmed by the numerical analysis in Section 4.2.

4. Welfare and Numerical Analysis

4.1. Default and Welfare

The analysis so far suggests that both cross-country transfers and default in the capital markets union can reduce the transaction wedge distorting allocations and prices. Table 2.1 provides a summary of the transaction wedge in Corollaries 4.1-4.4. The dash "-" indicates the relative degree of inefficiency. The more dashes assigned, there are more sources of distortions to allocations, risk sharing, and asset prices.

Table 2.1: Regime comparison

	Regime A benchmark	**Regime B** fiscal union	**Regime C** default
Allocation within state	**- - -**	**- -**	**-**
Risk sharing	**- - -**	**-**	**-**
Asset prices	**- - -**	**-**	**-**
Austerity tax	yes	no	no
Banking crises	yes	no	no

[a] "-" indicates the relative degree of inefficiency.

Let us observe that compared with Regime A, Regime C's allocations, risk sharing, and asset prices are all much less distorted. The reason being bankruptcy leniency in the capital markets union can reduce the transaction cost for both countries in the currency union; thus, naturally, one expects Pareto improvement. Proposition 5 formalises this claim.

Proposition 5. (Endogenous default and Pareto improvement):

- In the absence of a fiscal union, endogenous cross-border default can Pareto improve a currency union.
- Consider the case where $S = \{1, 2\}$, let $\gamma_1 = \gamma_2$, $e_1^i > e_2^i$, and $e_1^j < e_2^j$. Consider Regime A equilibrium, i.e. $\lambda^i, \lambda^j < \lambda$ and $v_2^i, v_1^j < 1$. Now reduce λ to $\lambda^{'}$ such that $\lambda^i, \lambda^j > \lambda^{'}$, whenever $(1 - \pi_2(v_2^i(1 + r_I) - 1))/p_{I2} > \pi_2 r_I/p_{I1}$ and $(1 - \pi_1(v_1^j(1 + r_J) - 1))/p_{J1} > \pi_1 r_J/p_{J2}$, it leads to a utility increase for both households i and j on the margin, while the expected utilities of domestic banking sectors remain unchanged.

Proof. See Appendix 4..

Interestingly, the philosophy underpinning the Pareto improvement here is to introduce an additional friction. Typically when a friction is added, there is one more imperfection, and one might expect a worse outcome. Here, it is exactly the opposite. The currency union modelled so far bears two imperfections: the interbank transaction cost of money and the possibility to default on domestic loans, i.e., domestic credit risks. Suppose directly removing these two imperfections is not possible; Regime C simply introduces the possibility to default on financial assets as a third imperfection. The third imperfection is introduced in such a way that the most "harmful" imperfection, i.e., state-varying domestic credit risks, is simply not manifested in equilibrium, leading to a superior outcome. Indeed, the possibility to default on financial assets as in Regime C can exactly shift borrowers' incentive on the margin to bypass the state-varying domestic credit risks, such that banks survive obviating the need for the national bailout tax.

I hasten to add that the conditions identified in Proposition 5 are only sufficient but not necessary. The proof of Proposition 5 does not require setting the bailout tax rate to zero, which would provide an additional liquidity boost at $t = 1$ and increase consumption. However, as the softened bankruptcy code shifts the default incentive on the margin, eventually the economy shifts to the Regime C equilibrium where the bailout tax is not even needed. Therefore, one can expect to further relax the conditions in Proposition 5 for Pareto improvement to occur. As analytic solutions are not available, the exact sufficient and necessary conditions are difficult to pin down. Therefore, I provide numerical analysis in the next subsection.

4.2. Numerical Analysis

This subsection assumes two states (state s and state s') in $t = 1$ and solves the model numerically. Table 4.1 exhibits the exogenous parameters and functional forms.

Table 2.2: Exogenous variables

Preference	$U^i = \alpha_0^i ln(c_{I0}^i) + (1-a_0^i) ln(c_{J0}^i) + \beta^i E_0[\alpha_{\boldsymbol{s}}^i ln(c_{I\boldsymbol{s}}^i) + (1-a_{\boldsymbol{s}}^i) ln(c_{J\boldsymbol{s}}^i)]$
	$U^j = \alpha_0^j ln(c_{J0}^j) + (1-a_0^j) ln(c_{I0}^j) + \beta^j E_0[\alpha_{\boldsymbol{s}}^j ln(c_{J\boldsymbol{s}}^j) + (1-a_{\boldsymbol{s}}^j) ln(c_{I\boldsymbol{s}}^j)]$
	$\alpha_0^i = \alpha_0^j = 0.5 \quad \alpha_s^i = \alpha_{s'}^j = 0.7 \quad \alpha_{s'}^i = \alpha_s^j = 0.3$
Prob. of states	$\gamma_s = \gamma_{s'} = 0.5$
Discount factor	$\beta^i = \beta^j = 1$
Endowment	$e_{I0}^i = e_{J0}^j = 10 \quad e_{Is}^i = e_{Js'}^j = 15 \quad e_{Is'}^i = e_{Js}^j = 5$
Bankruptcy code	$\lambda^i = \lambda^j = 0.1036 \quad \lambda^C = 0.098 \quad \lambda^A = \lambda^B = 0.12$
Outside money	$m^i = m^j = 0.1$
Policy rate	$\rho = 0.01$

Cross-border Default and Pareto Improvement

Table 2.3 shows the numerical solutions of the endogenous variables of Regime A, Regimes B.a and B.b, and Regime C.[19] Let W^I denote country I's utility of consuming goods in both periods, SU^I denote country I's social utility, i.e., the consumption utility minus the social cost of default, and df denote the default rate. Regime A leads to the least desirable equilibrium among the four regimes considered: the default rate on domestic loans in the bad state is high, asset prices are suppressed, domestic commercial bank loan rates are much higher than the policy rate due to a high credit risk premium, and bailout tax turns out positive as the domestic bank would become insolvent in the bad state. Hence, both the allocation welfare and social utility of Regime A are quite low.

[19] As country J is symmetric to country I, here I only display the prices and allocations of country I for conciseness.

Table 2.3: Endogenous variables

Regime A Equilibrium (Baseline)					
$W^I = 3.2921$	$SU^I = 3.2496$	$df^i_{s'} = 13.02\%$	$\pi_{\boldsymbol{s}} = 0.4807$	$r^I = 8.03\%$	$\tau_{Is'} = 6.45\%$
Regime B.a Equilibrium					
$W^I = 3.2943 \uparrow$	$SU^I = 3.2879 \uparrow$	$df^i_{\boldsymbol{s}} = 3.8\% \downarrow$	$\pi_{\boldsymbol{s}} = 0.4875 \uparrow$	$r^I = 4.49\% \downarrow$	$\tau_{Is'} = 0\% \downarrow$
Regime B.b Equilibrium					
$W^I = 3.2943 \uparrow$	$SU^I = 3.2711 \uparrow$	$df^i_{s'} = 6.75\% \downarrow$	$\pi_{\boldsymbol{s}} = 0.4889 \uparrow$	$r^I = 4.53\% \downarrow$	$\tau_{Is'} = 0\% \downarrow$
Regime C Equilibrium					
$W^I = 3.2947 \uparrow$	$SU^I = 3.2916 \uparrow$	$df_{s'} = 1.63\% \downarrow$	$\pi_{\boldsymbol{s}} = 0.4934 \uparrow$	$r^I = 1\% \downarrow$	$\tau_{Is'} = 0\% \downarrow$

[a] Arrows indicate the direction of travel compared with Regime A.

Regime B.a is a fiscal union with no banking union. Default rates on domestic loans are the same across states, and are lower than Regime A, the internal devaluation regime; hence, the domestic commercial bank loan rates are lower. Moreover, asset prices, social utility, and allocation welfare all improve upon Regime A, and the bailout tax is not needed. Regime B.b, a fiscal union with a banking union, exhibits a similar improvement as Regime B.a.

Regime C assumes away cross-country fiscal transfers, but a lenient union-wide bankruptcy code allows for cross-border default in the capital markets. Regime C's default rate is of asset payoffs. Since the union-wide bankruptcy code induces the default risks to move away from domestic loans to alleviate domestic banking stress, the domestic loan rate is equal to the monetary policy rate. Similar to Regime B.a and Regime B.b, allocation welfare, social utility, and asset prices are all higher than in Regime A, and the bailout tax is also not needed in Regime C.

Figure 2.6: Allocation welfare (shock variance)

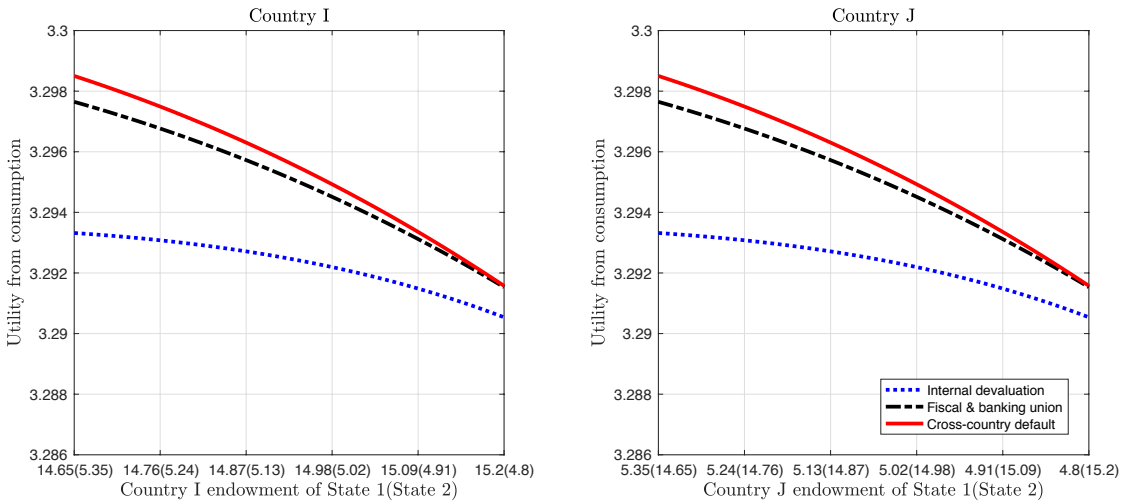


Figure 2.6 conducts the robustness check of the numerical solution in Table 2.3 by varying income risks around the initial parameterisation of $e^h_{Hs}(h \in \{i,j\}, H \in \{I,J\})$ set out in Table 4.1. The horizontal axis represents the state-contingent endowments of the two states in each country. The further to the right, the greater the variance of the state-contingent endowments while the mean remains unchanged at 10. The vertical axis represents the households' utility from consuming home and foreign goods, which I call allocation welfare. As might be expected, Regime C with cross-border default in the capital markets union Pareto dominates the Regime A which suffers from internal devaluation. Regime B.b, the fiscal-banking union, is superior to Regime A as well but is slightly worse off than Regime C. This is because the transaction cost due to default on financial securities is lower than the transaction cost due to default on commercial bank loans.

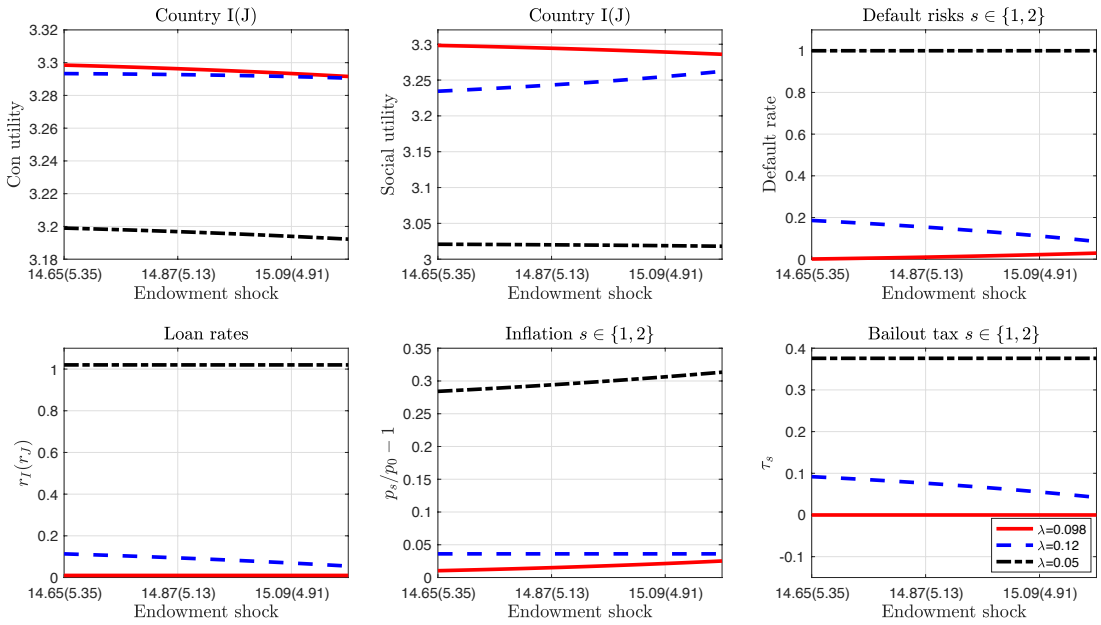
Interestingly, as the variance of state-contingent endowments widens, the welfare improvement of Regime C upon Regime A decreases. This is due to the substitution effect between default and consumption goods being dominated by the income effect, which reduces default risks in Regime A equilibrium. The widening variance implies a lower endowment in the bad state, a higher marginal benefit of defaulting on domestic loans. The substitution effect thus would increase the default rate. Meanwhile, a lower endowment in the bad state increases the value of this good and its relative price increases, which leads to an increase in liquidity inflow from goods sale to repay domestic bank loans. Default rate hence decreases. The overall decrease in default rates push down the borrowing costs and the bailout tax rates in Regime A. Thus, Regime A's allocation welfare deteriorates less as the variance widens, and the gap between Regime A and Regime C narrows. Adjusting the allocation welfare with the social cost of default, Figure 13 in Appendix 5.1. replaces the vertical axis with social utility (i.e., consumption utility minus the social cost of default) and shows a similar picture. For more robustness check, I also replace the horizontal axis with country I's state 2 endowment e^i_{I2} and shock the economy asymmetrically. Figure 14 in Appendix 5.2. displays the social utility of both countries while changing e^i_{I2}. Again, cross-border default Pareto improves upon the internal devaluation regime.

When Does Cross-border Default Not Work?

Nevertheless, a caveat remains on the welfare-improving role of default in the cross-border capital markets. As Corollary 3.1 states, when the union-wide bankruptcy code λ is set too

low, no households in either country would ever repay cross-country borrowing, leading to a collapse of international financial markets. Figure 2.7 provides numerical support to this claim. As in Figure 2.6, the horizontal axis represents the state-contingent endowments of the two states in each country. The solid line represents the economy when the union-wide bankruptcy code is set to 0.098, only slightly more lenient than the domestic bankruptcy codes ($\lambda^h = 0.1036, h \in \{i, j\}$). The dashed line shows the economic allocation and prices when the union-wide bankruptcy code is set to 0.12, much harsher than the domestic bankruptcy codes. The dashed line essentially represents Regime A. The dash-dotted line represents financial autarky, where an ultra-low union-wide bankruptcy code ($\lambda = 0.05$) causes the collapse of financial markets and impedes risk sharing.

Figure 2.7: Union-wide VS domestic bankruptcy codes



As illustrated in Figure 2.7, the case with a slightly softened union-wide bankruptcy code obtains the best allocation and social utility. In this case, assets are defaultable but are still traded, domestic borrowing costs in both countries are low, and neither country needs to levy bailout taxes since banks do not experience insolvency even in the bad state. A harsher union-wide bankruptcy code, represented by the dashed line, shifts the equilibrium to Regime A. Domestic borrowing costs are higher and bailout taxes are levied. The worst case among those considered here is financial autarky. It is when cross-border default backfires due to an ultra-lenient union-wide bankruptcy code. In this case, no financial assets are traded for risk sharing, and the limited risk sharing is provided by money and state-dependent inflation, which acts as a shock "absorber". Because of the impediment to risk sharing,

countries in the bad state are poorer than the case with risk sharing, hence, their marginal utility of consumption increases, implying a high marginal benefit of defaulting on domestic loans. It turns out quite dramatically that, given the domestic bankruptcy codes as $\lambda^h = 0.1036, h \in \{i, j\}$, both countries default 100 % on their domestic loans in their respective bad states. Banks would become insolvent if not for the national governments' bailout. As a consequence, borrowing costs and default risks are exorbitantly high, and bailout tax rates increase to around 37.6 %. Because limited risk sharing implies a collapse of goods trade at $t = 1$, and the Quantity Theory of Money holds, inflation in both states soars up.

Union-wide Bankruptcy Stance

It is fair to say the case of financial autarky is engineered by an unrealistically ultra-lenient union-wide bankruptcy code because it would imply that a currency union has an extremely weak institution to enforce repayment and implement default punishment. But what if the union-wide bankruptcy code is just slightly softened ($\lambda = 0.098$), as the solid line represents in Figure 2.7, and then we additionally soften the union-wide bankruptcy by a small increment, how would the economy behave? Figure 2.8 conducts such an experiment.

Figure 2.8: Cross-country bankruptcy code and default

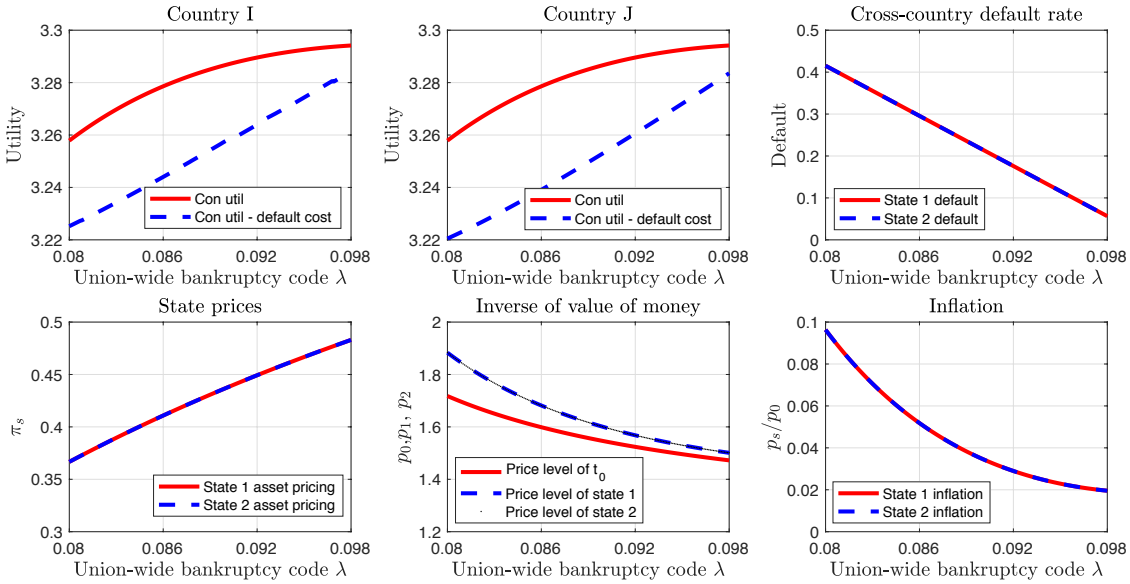


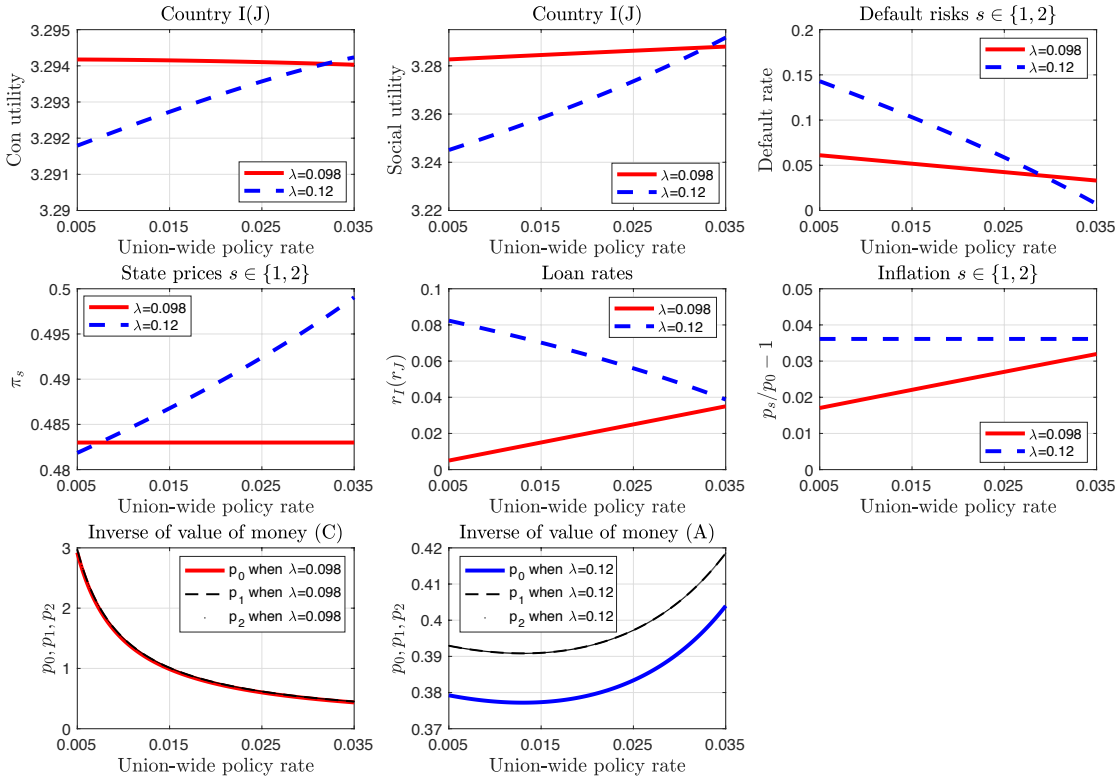
Figure 2.8 varies the union-wide bankruptcy code (i.e., the horizontal axis λ) by small amounts but ensures it is slightly more lenient than domestic bankruptcy codes. Therefore, what we observe is the comparative statics within Regime C with default in the cross-border capital markets. As λ decreases, the further left horizontally, the marginal cost of default

decreases and the substitution effect dominates in equilibrium. Further to the left, therefore, default risks in the capital markets union increase, pushing down asset prices and generating inflationary pressure. As default risks in the cross-border capital markets increase, the value of the common currency decreases. The modelling of inside money and strategic default naturally enables the model to produce the endogenous relationship between default and the value of money.

Union-wide Monetary Policy

Albeit a currency union has a single monetary authority, and the "one size" of its policy tool does not fit all, it remains to be of interest to study the properties of such monetary regime, particularly the interplay of credit risks and value of the currency. This is a relevant exercise because after the Eurozone crisis, the ECB has kept rates low based on the classic argument about stimulating aggregate demand; however, the union-wide output recovery has turned out sluggish and goods prices remain subdued despite large quantities of reserve injection via asset purchase programmes. This phenomenon has sparked off a heated debate on "monetary hysteresis". Figure 2.9 conducts such policy experiment. It suggests that when the Eurozone has limited cross-country transfers and a tough stance on cross-border default, the classic demand effect of low policy rates may not prevail, because we also need to consider the related impact on the demand and supply of credit and liquidity.

Figure 2.9: Union-wide monetary policy



The first two rows in Figure 2.9 display the equilibrium of Regime C (the solid line) and that of Regime A (the dashed line), while varying the union-wide monetary policy rate (the horizontal axis). Counterintuitively, when the currency union is in the internal devaluation regime (Regime A), a lower policy rate actually worsens allocation and tends to push down price level of goods (see the last subplot of Figure 2.9), which might help explain the slow growth and subdued prices in the Eurozone after the crisis. In Regime A, a lower policy rate, i.e., further to the left on the horizontal axis, means a lower repayment pressure on domestic banks to the union-wide central bank. On the margin, this lower repayment pressure on the domestic banks transmits to a lower repayment pressure on domestic borrowers. In the bad state, this propagation causes a low repayment on domestic loans and a rise in NPLs. Therefore, domestic borrowing costs rise and stifle goods trade. Moreover, the rise in domestic borrowing costs hampers domestic credit extension, leading to a contraction in the price levels of goods. This result suggests that in Regime A, the union-wide monetary policy should not follow the secular trend and perhaps it may even set the secular trend.

We can also observe, however, when the currency union is in Regime C (the solid line), the effect of monetary policy is more conventional. A lower policy rate decreases borrowing costs

and improves allocation welfare, although the social cost of default decreases.

5. National Currencies

So far, the model has shown the possibility of welfare improvement as a result of bankruptcy leniency in the cross-border capital markets in a currency union, but the model has not explicitly explained why the cross-border bankruptcy leniency is *particularly* vital in a currency union. To understand this question, one needs to know what benefits a currency union has given up and whether cross-border bankruptcy leniency can recoup these benefits. As such, it is natural and unavoidable to ask what if the currency union were to dissolve, a question largely unaddressed by existing literature.

Therefore, in this section I assume the seemingly provocative scenario of currency union dissolution and consider national currencies priced by floating exchange rates. I call this scenario Regime D. Not to complicate the model exceedingly, I do not consider the transition from a currency union to national currencies but only conduct comparative statics of equilibria of a currency union and of national currencies. I also do not consider the scenario in which national governments intervene in the foreign exchange market, nor do I assume heterogeneous bankruptcy codes between countries. Consequently, the floating exchange rate movements in this section are purely competitive due to income shocks, rather than due to different policy or institutional stances.

Regime D considers a frictionless foreign exchange market that opens at $t = 0$ and $t = 1$. As in Regime A, Regime D assumes a harsh bankruptcy code for cross-country borrowing and no cross-country fiscal transfers. It only considers the friction of possible domestic credit risks stemming from idiosyncratic income shocks. Rather than having a union-wide central bank, each country now has its own national central bank that issues its own national currency. Moreover, each country issues its own *currency-specific Arrow securities* whose payoffs are in the respective national currencies. Outside money and accordingly seigniorage in each country are also denominated in the respective national currencies. Linking the countries are asset markets, goods markets, and particularly frictionless foreign exchange markets. The model structure and agents' interactions are depicted in Fig (11) in Appendix 2.1..

Therefore, compared with a currency union, this regime has an additional market, i.e., the

foreign exchange market, and for each state, there are two types of Arrow securities issued by country I and country J respectively. Rather than having a common interbank loan and money market, this regime has two interbank loan and money markets, one in each country. The foreign exchange market is assumed to meet twice. At $t = 0$, it opens immediately after the loan markets, and at $t = 1$. it opens before import purchases. The other features remain the same as in the benchmark regime, particularly financial assets are *not* defaultable, i.e. $\lambda > \lambda^h$, and the fiscal union is ruled out, i.e. $\delta^h_{\boldsymbol{s}} = \delta^{bH}_{\boldsymbol{s}} = 0$, $h \in \{i, j\}, H \in \{I, J\}, \boldsymbol{s} \in S$. The timeline is illustrated in Figure (12) in Appendix 2.2..

5.1. Country I

Country I's modelling is described in detail. The modelling of country$J$ is exactly symmetric to that of country I (see country J in Appendix 2.3.).

Households i

Households' preference is the same as in the currency union except that the price deflator $p^I_{\boldsymbol{s}}$ indexing the default cost is now a country-wide price index rather than a union-wide price index. Household i's choice variables include the amount of domestic loans to borrow, foreign exchange to trade, domestic and foreign assets to trade, quantities of consumption goods to consume, the quantity of domestic goods to sell, the amount of money to spend on foreign goods, and the loan repayment rate. In particular, let $f^i_{IJ\boldsymbol{s}^*}(\forall \boldsymbol{s}^* \in S^*)$ be the amount of domestic currency I the households spend on purchasing foreign currency J. Let $\chi_{\boldsymbol{s}^*}(\forall \boldsymbol{s}^* \in S^*)$ be the floating exchange rate such that one unit of currency J is worth $\chi_{\boldsymbol{s}^*}$ units of domestic currency I. An increase in $\chi_{\boldsymbol{s}^*}$ means a depreciation of currency I and an appreciation of currency J. Let $\nu^i_1, \nu^i_2, \nu^i_{3\boldsymbol{s}}, \nu^i_{4\boldsymbol{s}}, \nu^i_{5\boldsymbol{s}}$ be the shadow price of the respective flow of funds constraint. Households i are subject to the following budget sets and flow of funds constraints.

At $t = 0$,

$$f^i_{IJ} \leq \frac{\mu^i_I}{1 + r^I} + m^i, \qquad \nu^i_1, \quad (2.11)$$

$$b^i_{J0} + \sum_{l=1}^{S} \pi_{Jl}\theta^i_{Jl} \leq \frac{f^i_{IJ}}{\chi}, \qquad \nu^i_2 \quad (2.12)$$

at $t = 1$ in state $\boldsymbol{s}$,

$$f^i_{IJ\boldsymbol{s}} + \phi^i_{I\boldsymbol{s}}(1 + \tau_{I\boldsymbol{s}}) \leq \sum_{l=1}^{S} \pi_{Il}\phi^i_{Il} + p_{I0}q^i_{I0} + p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}} + \Delta(2.11), \qquad \nu^i_{3\boldsymbol{s}} \quad (2.13)$$

$$b^i_{J\boldsymbol{s}}(1 + \tau_{I\boldsymbol{s}}) \leq \theta^i_{J\boldsymbol{s}} + \frac{f^i_{IJ\boldsymbol{s}}}{\chi_{\boldsymbol{s}}} + \Delta(2.12), \qquad \nu^i_{4\boldsymbol{s}} \quad (2.14)$$

at $t = 2$,

$$v^i_{\boldsymbol{s}}\mu^i_I \leq \Delta(2.13)_{\boldsymbol{s}}. \qquad \nu^i_{5\boldsymbol{s}} \quad (2.15)$$

And the feasibility constraints are satisfied, i.e. $c^i_{I\boldsymbol{s}^*} \leq e^i_{I\boldsymbol{s}^*} - q^i_{I\boldsymbol{s}^*}$ and $c^i_{J\boldsymbol{s}^*} \leq \frac{b^i_{J\boldsymbol{s}^*}}{p_{J\boldsymbol{s}^*}}$, $\boldsymbol{s}^* \in S^*$. At $t = 0$, housholds i borrow from the domestic commercial banking sector and obtain local currency to buy foreign currency (2.11). The households then use foreign currency to buy foreign assets (2.12) and imports. At the same time households sell domestic assets and exports, and carry the monetary proceeds to the next period.

At $t = 1$ when the state of nature is realised, the households use existing monetary proceeds in the local currency plus this period's export income to deliver the payoffs of domestic assets sold (2.13) and to purchase foreign currency. The households use the foreign currency at hand and foreign asset payoffs to pay for foreign goods (2.14).

At $t = 2$, the households use any unused local currency from (2.13) to pay back loans, subject to their default choice (2.15).

Domestic Commercial Banking Sector i

Bank i's actions are the same as in the benchmark model except that bank i now borrows interbank loans from the national central banking sector rather than the union-wide central bank. Therefore, the ultimate fiat money in country I is issued by the national central bank and is the national currency. Let μ^i_{CBI} be the interbank loans bank i borrows from the national central bank and ρ_I as the policy rate set by the national central bank. Bank i's maximisation problem is specified as follows.

$$\underbrace{Max}_{\mu^i_{CBI},\mu^i_I,L^i,\omega^i} \sum_{\boldsymbol{s}}^{S} z_{\boldsymbol{s}}\omega^i_{\boldsymbol{s}}.$$

Bank i is subject to the following flow of funds constraints:

$$L^i \leq \frac{\mu^i_{CBI}}{1+\rho_I}, \tag{2.16}$$

$$\frac{\mu^i_I}{1+r_I} \leq L^i, \tag{2.17}$$

$$\omega^i_{\boldsymbol{s}} = \Delta(2.16) + \Delta(2.17) + R^i_s\mu^i_{I\boldsymbol{s}} - \mu^i_{CBI}. \tag{2.18}$$

National Government i

National government i collects taxes from domestic households to build a state-contingent bailout fund of $T_{I\boldsymbol{s}}$.

$$T_{I\boldsymbol{s}} = p_{J\boldsymbol{s}}c^i_{J\boldsymbol{s}}\tau_{I\boldsymbol{s}} + \phi^i_{\boldsymbol{s}}\tau_{I\boldsymbol{s}}. \tag{2.19}$$

National government i uses the bailout funds to rescue the domestic commercial bank whenever the bank's nominal profits would drop to negative, i.e., when the bank would fail. In short, in the bad state the national government makes a state-contingent transfer to ensure $\omega^i_{\boldsymbol{s}} + T_{I\boldsymbol{s}} = 0$.

National Central Bank i

The national central bank lends interbank loans μ^i_{CBI} to the domestic commercial banking sector and provides fiat money in the national currency. The national central bank sets the interbank rate ρ_I and collects seigniorage in a non-Ricardian way.

5.2. Equilibrium

I define the equilibrium of this floating exchange rate model as Regime D equilibrium. It is an allocation $(c_I, c_J, f_{IJ}, f_{JI}, b_I, b_J, q_I, q_J, \theta_I, \theta_J, \phi_I, \phi_J, \mu_I, \mu_J, \mu_{CBI}, \mu_{CBJ})$ with prices $(p_I, p_J, \pi_I, \pi_J,$
$\chi, r_I, r_J, v, R)$, given policy instruments and regime parameters (ρ_I, ρ_J, λ^i, λ^j, λ) and government action τ such that agents maximise subject to liquidity-in-advance constraints and budget constraints, markets clear, and expectations are rational.

- Goods markets:

$$p_{I\boldsymbol{s}^*} q^i_{I\boldsymbol{s}^*} = b^j_{I\boldsymbol{s}^*},$$

$$p_{J\boldsymbol{s}^*} q^j_{J\boldsymbol{s}^*} = b^i_{J\boldsymbol{s}^*},$$

- Foreign exchange market:

$$f^i_{IJs^*} = \chi_{s*} f^j_{JI^*},$$

- Asset markets:

$$\phi^i_{Il} = \theta^j_{Il},$$

$$\phi^j_{Jl} = \theta^i_{Jl},$$

- Domestic loan markets:

$$\frac{\mu^i_I}{1 + r_I} = L^i,$$

$$\frac{\mu^j_J}{1 + r_J} = L^j,$$

- Interbank loans and money markets:

$$1 + \rho_I = \frac{\mu^i_{CBI}}{M_I},$$

$$1 + \rho_J = \frac{\mu^j_{CBJ}}{M_J},$$

- Rational expectation:

$$R^i_{\boldsymbol{s}} = \left\{ \begin{array}{cc} v^i_{\boldsymbol{s}} & \text{if } 1 - v^i_{\boldsymbol{s}} > 0 \\ \text{arbitrary} & \text{if } 1 - v^i_{\boldsymbol{s}} = 0 \end{array} \right\},$$

$$R^j_{\boldsymbol{s}} = \left\{ \begin{array}{cc} v^j_{\boldsymbol{s}} & \text{if } 1 - v^j_{\boldsymbol{s}} > 0 \\ \text{arbitrary} & \text{if } 1 - v^j_{\boldsymbol{s}} = 0 \end{array} \right\}.$$

5.3. Equilibrium Analysis

Lemma 7: Liquidity-in-advance binds and no worthless money at the end.

If $r_I > 0, \forall \boldsymbol{s} \in S$, then $\Delta(2.11) = 0$.

If $r_I > 0$, then $\Delta_{\boldsymbol{s}}(2.15) = 0$.

If $\rho_I > 0$, then $\Delta(2.16), \Delta(2.17)$, and $\Delta_{\boldsymbol{s}}(2.18) = 0$.

Proof. See Appendix 4..

Lemma 8. (PPP and UIP):

- **Purchasing Power Parity**: At any Regime D equilibrium, for $h \in \{i, j\}$, suppose $\tau^h_{\boldsymbol{s}} = 0, \forall \boldsymbol{s} \in S$,
  - at $t = 0$ if household h chooses $b^h_{I0} > 0, b^h_J > 0$ and if household h does not spend all his domestic currency on foreign currency, then

$$\frac{U^h_{c^h_{I0}}}{U^h_{c^h_{J0}}} = \frac{p_{I0}}{\chi p_{J0}},$$

– at $t = 1$ $\forall \boldsymbol{s} \in S$,

$$\frac{U^h_{c^h_{I\boldsymbol{s}}}}{U^h_{c^h_{J\boldsymbol{s}}}} = \frac{p_{I\boldsymbol{s}}}{\chi_{\boldsymbol{s}} p_{J\boldsymbol{s}}}.$$

- **Uncovered Interest Rate Parity**: Suppose at $t = 0$ household h ($h \in \{i, j\}$) can obtain foreign currency by either trading in the FX market or borrowing from the foreign commercial bank. Then if we are in Regime D equilibrium, we must have that

$$\frac{1 + r_I}{1 + r_J} = \frac{E_0 \nu^i_{3\boldsymbol{s}} \chi_{\boldsymbol{s}}}{E_0 \nu^i_{3\boldsymbol{s}} \chi} = \frac{E_0 \nu^j_{3\boldsymbol{s}} / \chi}{E_0 \nu^j_{3\boldsymbol{s}} / \chi_{\boldsymbol{s}}}.$$

Proof. See Appendix 4..

The purchasing power parity tells us that if households are purchasing a consumption good from country I and another good from country J that gives the same marginal utility, then these two goods must have the same real price. Note in equilibrium, at $t = 0$ household i could be buying consumption good J and selling consumption good I, and household j could be buying consumption good I and selling consumption good J. In this case, due to the cost of liquidity we could have $U^i_{c^i_{I0}} / U^i_{c^i_{J0}} = p_{I0} / [\chi p_{J0}(1 + r_I)]$ and $U^j_{c^j_{I0}} / U^j_{c^j_{J0}} = [(1 + r_J) p_{I0}] / (\chi p_{J0})$. The uncovered interest parity is simply a non-arbitrage result on asset prices. It tells us that if the nominal rate of a country is lowered, say, due to a lower credit risk premium, then its currency is expected to appreciate, and vice versa.

Lemma 8 shows that competitive floating exchange rates affect the relative price between goods and link the nominal rates of the two countries. As the nominal rates incorporate credit risk premia of domestic loans, naturally, these credit risk premia are linked by floating exchange rates as well. Proposition 6 examines this relationship between exchange rates and credit risks formally.

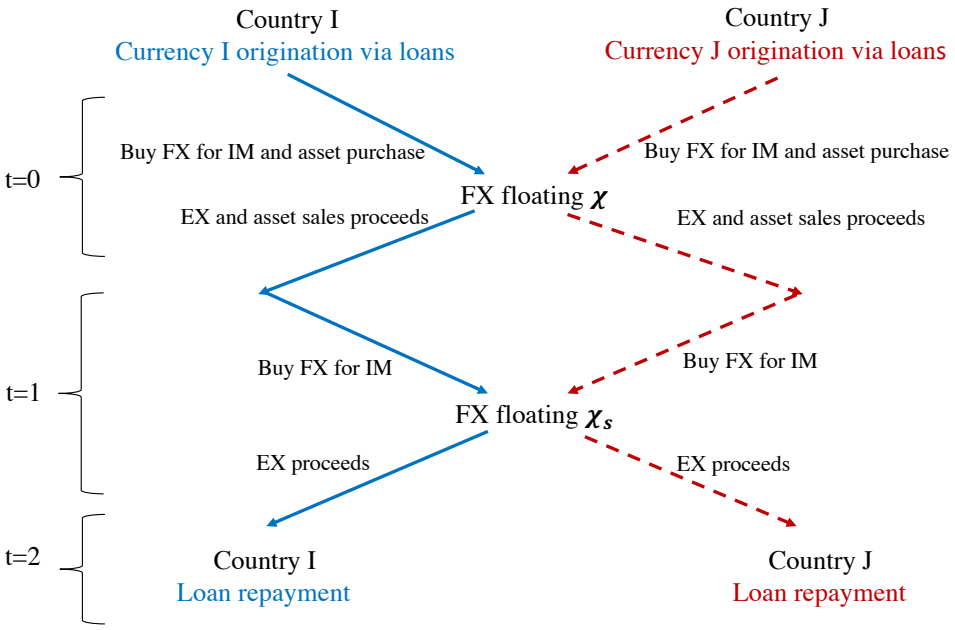
Proposition 6 (credit risk neutralisation): With competitive floating exchange $\chi_{\boldsymbol{s}}$, set the bailout tax to zero, the domestic credit risk turns out state invariant, i.e., $v^h_{\boldsymbol{s}} = v^h, \forall \boldsymbol{s} \in S, h \in \{i, j, \}, H \in \{I, J\}$.

Proof. See Appendix 4..

The proof of Proposition 6 4. shows that at $t = 2$, household i's loan settlement equation can be rearranged as $v^i_{\boldsymbol{s}}\mu^i_I = \frac{\mu^i_I}{1+r_I} + m^i$, and household j's loan settlement equation can be rearranged as $v^j_{\boldsymbol{s}}\mu^j_J = \frac{\mu^j_J}{1+r_J} + m^j$. We can observe that currency I, which is issued against bank loan μ^i_I in country I at $t = 0$, ends up repaying the very same loan against which the currency itself is issued. Similarly, currency J ends up repaying the very same loan against which currency J is issued. Because the face value of the loans is state invariant, the loan repayments must also be state invariant. Therefore, currency exits the system exactly from its own originating country. This is made possible by the FX markets and the floating exchange rates.

To see why I use Figure (2.10) as a graphic representation of the proof of Proposition 6. The solid arrows represent the flows of currency I and the dashed arrows represent the flows of currency J. At $t = 0$, currency I is originated against bank credit μ^i_I. Together with outside money, it is used to purchase currency J via the FX market. Country I then uses this amount of currency J to buy imports and foreign assets from country J. Meanwhile, country J spends currency J purchasing currency I via the FX market. This amount of currency I is then spent on buying country I's exports and assets. Thus, currency I flows back to country I and currency J flows back to country J. Similarly, at $t = 1$ country I spends some amount of currency I on purchasing some amount of currency J via the FX market. Country I then uses this amount of currency J to buy imports from country J. Country J uses this amount of currency I to buy imports from country I. Thus, this amount of currency I flows back to country I due to its export sales, and this amount of currency J flows back to country J due to country J's export sales. Therefore, currency flows back to its own originating country due to the swap at the FX markets. Whenever the two flows of these currencies meet at the FX markets, the relative strength of these two flows determines the floating exchange rate.

Figure 2.10: FX flows



Therefore, the floating exchange rate neutralises the domestic credit risks such that the domestic NPL rate turns out the same across states. To see exactly how the floating exchange rate adjusts, take country I as an example and $v_s^i = v_{s'}^i$. Let us now suppose household I wants to repay ϵ_s more in state s to achieve $v_s^i > v_{s'}^i$ instead. I now demonstrate that due to the exchange rate adjustment, $v_s^i > v_{s'}^i$ will turn out a contradiction.

Invoking Lemma 7 and combining (2.13) and (2.15), it follows that

$$v_s^i \mu_I^i = \sum_{l=1}^{S} \pi_{Il} \phi_{Il}^i + p_{I0} q_{I0}^i + p_{Is} q_{Is}^i - \phi_{Is}^i - f_{IJs}^i. \tag{2.20}$$

Household i can increase the loan repayment by ϵ through either decreasing f_{IJs}^i or increasing $p_{Is} q_{Is}^i$ at $t = 1$. Since ϕ_{Is}^i is the position of asset sales of the Arrow security $l = s$ at $t = 0$, it cannot be adjusted at $t = 1$. Suppose household i sells ϵ less f_{IJs}^i, this leads currency I to appreciate, χ_s decreases and $\chi_s f_{JIs}^j$ decreases by ϵ. Thus, country J ends up having ϵ less currency I to buy imports from country I, and $p_{Is} q_{Is}^i$ therefore decreases by ϵ. Overall, the right-hand side of (2.20) remains unchanged. This is a contradiction.

If household i increases $p_{Is}q^i_{Is}$ by ϵ instead, that means the amount of currency I used to purchase household i's exports has to increase by ϵ and χ_s increases, leading to a depreciation. The same contradiction arises. Similar logic obtains if household i wants to achieve $v^i_s < v^i_{s'}$, which also causes contradiction.

Corollary 6.1. (capital flow and banks' survival): Competitive floating exchange rates χ and $= \chi_{\boldsymbol{s}}$ prevents domestic banking insolvency, $\omega^h_{\boldsymbol{s}} = 0$, $\forall \boldsymbol{s} \in S$, $h \in \{i, j\}$, and there is no need for national bailout tax.

Proof. See Appendix 4..

Corollary 6.2. Under the conditions of Proposition 5, if currency union is the regime *a priori*, cross-border default due to bankruptcy leniency obviates the need for floating exchange rates to alleviate domestic banking stress.

Proof. See Appendix 4..

Corollary 6.1 holds under very general conditions. It states that when there are domestic credit risks, floating exchange rates can help absorb the pressure of international capital flow such that domestic banks survive for all states. However, if member countries are in a currency union *a priori*, cross-country default may obviate such a need for floating exchange rates. In an ideal scenario with zero domestic credit risks, banks get loans repaid in full for all states of nature, and given markets are complete, the role of floating exchange rates is trivialised (Lemma 5). In other words, if countries do not have domestic credit risks in all states of nature, even without a fiscal union or default in the cross-border capital markets, sharing a common currency brings no particular harm to the health of the banking sector.

As the floating exchange rate neutralises domestic credit risks, one would expect a lower transaction wedge in Regime D than in Regime A, because there is no need to level national bailout tax. Lemma 9 refines the FX constraints at $t = 0$ and under Lemma 9, Corollaries 6.3-6.6 probe into the BoP dynamics and the welfare implications for allocations, prices, and risk sharing.

Lemma 9: FX-in-advance binds.

If $cov(\frac{1}{\chi_{\boldsymbol{s}}}, \nu^i_{2\boldsymbol{s}}) > 0$ and $cov(\chi_{\boldsymbol{s}}, \nu^j_{2\boldsymbol{s}}) > 0$, focusing on symmetric equilibrium, $r_I = r_J$, then

$\Delta(2.12) = 0$.

Proof. See Appendix 4..

Corollary 6.3. (Balance of Payments): Under competitive floating exchange rates and when FX-in-advance binds, current account and capital account exactly balance, $CA^H_{\boldsymbol{s}} + FA^H_{\boldsymbol{s}} = 0, H \in \{I, J\}, \boldsymbol{s} \in S$.

Proof. See Appendix 4..

Corollary 6.4. (allocation efficiency within state): Under Lemma 7, optimal allocation efficiency at $t = 0$ does not obtain due to domestic credit risks and the cost of liquidity; optimal allocation within state obtains at $t = 1$.

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} \frac{1}{(1+r_I)(1+r_J)},$$

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}}.$$

Proof. See Appendix 4..

Corollary 6.5. (risk sharing): Under Lemma 7, optimal risk sharing does not obtain due to the borrowing cost which commands the credit risk premium of domestic loans.

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{1}{(1+r_J)(1+r_I)},$$

$$\frac{U^i_{c^i_{Js}}}{U^i_{c^i_{Js'}}} = \frac{U^j_{c^j_{Js}}}{U^j_{c^j_{Js'}}} \frac{1}{(1+r_J)(1+r_I)}.$$

Proof. See Appendix 4..

Corollary 6.6. (state prices): With national currencies and competitive floating exchange rates, state prices are affected by the borrowing cost and currency appreciation or depreciation.

$$\pi_{Is} = \gamma_s \frac{U^i_{c^i_{Is}}/p_{Is}}{U^i_{c^i_{I0}}/p_{I0}} = \gamma_s \frac{U^j_{c^j_{Js}}/p_{Js}\chi}{U^j_{c^j_{J0}}/p_{J0}\chi_s(1+r_J)},$$

$$\pi_{Js'} = \gamma_{s'} \frac{U^i_{c^i_{Is'}}/p_{Is'}\chi_{s'}}{U^i_{c^i_{I0}}/p_{I0}(1+r_I)\chi} = \gamma_{s'} \frac{U^j_{c^j_{Js'}}/p_{Js'}}{U^j_{c^j_{J0}}/p_{J0}}.$$

Proof. See Appendix 4..

5.4. Numerical Analysis

Table (2.4) displays the numerical result of national currencies and compares it with those of currency unions. Note that the functional forms and exogenous variables are the same as in the baseline regime in a currency union. The unique endogenous variables in the national currency case are the exchange rates at $t = 0$ and $t = 1$.

Table 2.4: National currencies and currency unions

Currency union with internal devaluation (Regime A)					
$W^I = 3.2921$	$SU^I = 3.2496$	$df^i_{s'} = 13.02\%$	$r^I = 8.03\%$	$\tau_{Is'} = 6.45\%$	$\chi = NA$
Currency union with cross-border default (Regime C)					
$W^I = 3.2947 \uparrow$	$SU^I = 3.2916 \uparrow$	$df_{s'} = 1.63\% \downarrow$	$r^I = 1\% \downarrow$	$\tau_{Is'} = 0\% \downarrow$	$\chi = NA$
National currencies and floating exchange rates (Regime D)					
$W^I = 3.2943 \uparrow$	$SU^I = 3.2713 \uparrow$	$df_{s'} = 3.35\% \downarrow$	$r^I = 1\% \downarrow$	$\tau_{Is'} = 0\% \downarrow$	$\chi_0 = 1$
					$\chi_1 = 1.07$
					$\chi_2 = 0.94$

[a] Arrows indicate the direction of travel compared with Regime A.

The national currency case obtains a superior equilibrium to the internal devaluation regime of a currency union. This is because competitive floating exchange rates neutralise domestic credit risks and banks survive for all states, such that bailout taxes are not required. Exchange rate determination obtains via the FX markets. At country I's good state $s = 1$, currency I depreciates and at country I's bad state $s = 2$, currency I appreciates. Therefore, the domestic liquidities flowing back to country I for domestic loan repayment turn out the same for both states, domestic credit risk is state-invariant, and domestic banks do not encounter insolvency due to the shortage of liquidity causing credit risk volatilities. Nevertheless, the equilibrium of the national currency case is slightly inferior to the cross-border default regime in a currency union, suggesting default in the cross-border capital markets in a currency union

under this parameterisation obviates the need for floating exchange rates.

6. Discussions and policy implications

6.1. Discussion of results

The first key result of the model is that adjusting the bankruptcy code to allow for default in the cross-border capital markets can improve a currency union in the absence of a fiscal union. Because cross-border default is strategic, it provides an extra boost of liquidity for the borrowing country in the bad state. This extra liquidity acts like "cross-country liquidity transfers" to adjust for the country heterogeneity in a currency union, and consequently it proves to be a close substitute for a fiscal union. The key difference is that a fiscal union resembles a supranational entity that uses a visible hand to move nominal resources between countries. In contrast, cross-border default works through the invisible hand of markets: default is a choice and assets are conditionally traded voluntarily.

This key difference can be regarded as the strength of cross-border default compared to a fiscal union. Indeed, the fiscal union modelled in Regime B is assumed to be benevolent. This is quite a leap of faith because there is no obvious mechanism to prevent the fiscal union from using the visible hand to make preferential transfers to selected member countries. Once the model relaxes the benevolence assumption, it would add further support to Regime C (bankruptcy leniency) as a feasible approach to sustain currency unions.

However, the limitation of Regime C (bankruptcy leniency) is that it relies on the assumption that the institutional qualities or the economic fundamentals of member countries in the currency union do not differ significantly. Suppose the two countries have divergent economic fundamentals to start with, for example, country J in its good state is much poorer than country I in its respective good state. Then in state s', i.e., country I's bad state and country J's good state, such a lenient union-wide bankruptcy code may encourage country J to even fully default in its good state. In this scenario, capital markets union collapses, impeding international risk sharing and leading to a welfare loss. In this case, the within-union standard fails, and there is simply no room to adjust for the union-wide bankruptcy code. If the model is extended to incorporate production and capital accumulation for multi-periods, the issue becomes more acute. Adjusting the bankruptcy code would need to be timely because a

delay would lead countries to fall out of the within-union standard endogenously due to the persistent internal devaluation effect. Moreover, even if their fundamentals do not differ too much, if country I has a lower institution quality, i.e., its domestic bankruptcy code λ^i is much weaker than that of country J, Corollary 3.2 suggests that there simply may not be any space left to adjust the union-wide bankruptcy code λ; otherwise the financial markets would unravel.

The second key result is that adjusting the bankruptcy code in a currency union can obviate the need for nominal exchange rates to neutralise domestic credit risks. Strategic default in the capital markets union essentially provides a compensation for the lost benefits of nominal exchange rates. However, assuming away potential costs of nominal exchange rates, the conditions for bankruptcy leniency to allow for cross-border default to neutralise domestic credit risks are more exacting than those for nominal exchange rates. The conditions for the former entail a lenient cross-country bankruptcy code, a sufficiently low cost of liquidity and a sufficiently high number of bad states, but the conditions for the latter are more general. However, nominal exchange rates could potentially incur (unmodelled) costs, such as competitive devaluation because of discretionary intervention by national governments. Such considerations would render cross-country default in a currency union a more attractive regime.

Furthermore, this model sets the union-wide bankruptcy code of the capital markets union conditional on domestic bankruptcy codes, which are taken as structural parameters. In contrast, Franks and Sussman (2005) constructed an endogenous evolutionary theory of bankruptcy codes, in which bankruptcy codes can emerge either due to freedom of contracting of market participants or because of state activism in law-making. In this paper, I do not model the endogenous emergence of the bankruptcy codes, but I acknowledge that in practice the softening of the bankruptcy code in the capital markets union could emerge via either market forces or law-making, or a combination of both.

6.2. Policy implications and implementation

The immediate policy recommendation is that a currency union needs a capital markets union that features a slightly softened bankruptcy environment. Softening the cross-border bankruptcy environment can take measures to encourage more reorganisation rather than

immediate liquidation of assets when companies become insolvent, to shorten the period of credit market exclusion for the defaulters, or to allow for debt discharges and adjustments. To increase the space to design such a union-wide bankruptcy code to induce benign default in the capital markets union, the domestic bankruptcy code, however, should not be too lenient. Thus, when a fiscal union is absent in a currency union, member countries should strengthen their domestic institutions by toughening the domestic bankruptcy code for domestic borrowing, and at the same time mutually agree on a softened union-wide bankruptcy code for cross-country borrowing. An important caveat remains that the union-wide bankruptcy code cannot be too lenient. If it is sufficiently lenient, no country would ever repay in any state, leading to the collapse of the capital markets union and impeding risk sharing.

This scope for policy is relevant not just for the Eurozone but also for China which has been experiencing prolonged soaring local government debt. The issue for China is more nuanced because the local government debt is largely collateralised by land and real estate. It is further complicated by the Chinese government's implicit guarantee. Consequently, the talk of default of the local government financing vehicle in China has sparked off a heated debate among policy makers and academics. This real-world example and the associated macro-financial questions could be modelled in the framework of this paper.

As for the implementation of setting the union-wide bankruptcy code that induces default in the capital markets union, the union-wide bankruptcy code should be common knowledge to all market participants and should be strictly enforced. In this environment, market participants would know that default in cross-border capital markets is a possibility and *ex ante* they know precisely the severity of the default punishment conditional on the size of default. Accordingly, default risks are priced in when assets are traded prior to the realisation of uncertainty. For example, suppose the union-wide bankruptcy code takes the form of credit exclusion as the default punishment, and for simplicity suppose borrowers are countries in the currency union. Market participants should know how many periods the defaulter is to be excluded given the size of default. Once a country announces default, it should be excluded from credit to the extent that market participants have come to expect. This kind of implementation, therefore, ensures orderly default. It is essential to note the distinction between this type of orderly default and the unanticipated default whose risk is not correctly priced in.

The model is kept stylised such that the results and transmission mechanisms are clear; therefore, the model does not specify the exact form of default punishment. A fully-fledged and more realistic quantitative model could certainly provide further micro-foundations for default punishment, such as credit exclusion or sanctions. Nevertheless, no matter what the exact form of default punishment is, as long as it feeds into the marginal rate of substitution across consumptions, the essence of the current stylised model remains.

6.3. Institutional Details

The TARGET2 System

The model abstracted away from the national central banks; thus, it is difficult to find an exact mapping between the model and the TARGET2 system, which is the Eurozone payment system connecting national central banks (NCB)) and the European Central Bank (ECB). However, the two key results of this model can still shed light on the ongoing debate on the imbalance of the TARGET2 system (see Sinn 2011; Sinn and Wollmershäuser 2012; Whelan 2014).

TARGET is the acronym for *Trans-European Automated Real-time Gross Settlement Express Transfer System*. In the TARGET2 system, all Eurosystem banks maintain reserve accounts with their national central banks, which are ultimately connected by ECB as the lender of last resort. The TARGET2 system equips the national central banks with some degree of money creation power such that the creation of the euro via ECB becomes less rigid. Therefore, the TARGET2 system allows some national central banks to hold TARGET2 claims and some other national central banks to hold TARGET2 liabilities.

During the Eurozone Crisis, capital flight from the weak periphery mainly took the form of depositors moving deposits from weak banks in the periphery into the stronger banks in the core. This transfer of funds would have bankrupted many banks in the periphery, but it was recycled back through the TARGET2 system. In this sense, the TARGET2 system provides some cross-country transfers already, partly resembling the fiscal transfers in Regime B (fiscal union) of my model. Therefore, in reality, the TARGET2 system has likely reduced the bailout costs of the Eurozone Crisis and dampened the internal devaluation effect in Regime A of this model.

Nevertheless, the imbalance of the TARGET2 system is not completely the same as the cross-country fiscal transfers in Regime B. This is because the imbalance of TARGET2 system takes the form of claims and liabilities. These positions are debt positions that eventually need to be settled, whereas Regime B makes fiscal transfers that are free and clear of any debt obligation. If the debt positions on the TARGET2 system need to be repaid in full eventually, it would merely imply the delay of national bailout costs and internal devaluation. If the debt positions on the TARGET2 system were to carry priced-in credit risks and allow for default, a similar welfare-improving benefit could arise as that of Regime C (bankruptcy leniency) in this paper.

Cross-border Insolvency Reforms in Practice

A variety of financial securities are traded in the cross-border capital markets in the Eurozone. These financial securities can be sovereign bonds of member countries, corporate bonds and equities, or structured products of both the public and private debt. The main result of this paper on softening the bankruptcy code in the cross-border capital markets union is a simplification. The insight is the role of a softened bankruptcy environment as a compensation for the removal of flexible nominal exchange rates.

Now let us turn to the practical interpretations of this result in conjunction with the institutional details of both the default punishment for sovereign debt and the cross-border insolvency reforms for private debt in the context of the Eurozone. There was a wide misperception of the sovereign debt default risks before the Eurozone Crisis. The misperception was that member countries in the Eurozone simply would not default, for example, quoting the Economics Commissioner Joaquin Almunia at the time: "No, Greece will not default. Please. In the euro area, the default does not exist." However, the synchronisation of sovereign yields between the core and the periphery before the crisis does not mean the sovereign debt of the periphery was default-free. This synchronisation was largely a result of the reduction in the inflation premium in the periphery, and the inflation premium was a proxy for the sovereign's credit risk profile. The reduction in the inflation premium was a natural result of removing the nominal exchange rates, but it does not imply the underlying credit risks suddenly magically vanished.

Therefore, it would be sensible to correct such misperception and to acknowledge and allow for sovereign default in a currency union, particularly when a fiscal union is not present. In

this paper I only model the aggregate country-level debt and I do not model the sovereign debt separately; however, the logic of softening the bankruptcy code extends to the sovereign bond markets. In practice, the bankruptcy code for the sovereign debt often takes the form of such default punishment as credit market exclusion. Softening this type of default punishment could mean shorten the period of credit market exclusion per unit of default. In this scenario, when the marginal cost of default is low enough, countries in the Eurozone can declare default and the punishment should be strictly enforced. What is crucial is the correct pricing of default risks in the sovereign yields.

As for private debt, a softened bankruptcy code can be a result of contracting or legal reforms. Regarding the latter, there have been practical steps in the European Union cross-border insolvency reform, albeit not for the specific context of the Eurozone. In 2012, the European Commission proposed to recast the 2000 Insolvency Regulation with the main purpose to help identify the competent jurisdiction and applicable law insolvency proceedings. As the 2000 Insolvency Regulation carries legal uncertainty with some of its key concepts defined in general terms (see Sussman 2006), then the 2015 recast regulation provided further clarification on the "centre of main interest" (COMI). More importantly, in 2016, the European Commission proposed to adopt a directive on business restructuring and giving the troubled businesses a second chance, softening the traditionally punitive stance on default.

In spirit, the 2016 directive is similar to Chapter 11 of the US Bankruptcy Code, and it seems broadly consistent with the policy implication of my model. Nevertheless, in practice, the cross-border insolvency reforms in EU or the Eurozone are extremely complicated because the national-level bankruptcy codes are very diverse (see Davydenko and Franks 2008). My model speaks to this issue because my result on softening the cross-border bankruptcy code is exactly conditional on national-level bankruptcy codes and takes into consideration of their heterogeneity. Thus, my result does not lead to the conclusion of an unconditional top-down harmonisation.

7. Conclusion

This paper has proposed an international finance model specifically for currency unions to address the following question: what alternative arrangements can improve the financial stability and viability of currency unions when a fiscal union is absent? This question is

important due to the potential for member countries in a currency union to refuse to establish a fiscal union for political reasons. The model is able to show that one alternative arrangement is a financial regime that features a softened bankruptcy environment in the cross-border capital markets within a currency union.

There are two contributions of this proposed theory. First, the model shows that when domestic credit risks are present and when there is no fiscal union to make cross-country transfers, endogenous default in the capital markets union within a currency union can lead to a Pareto improvement and enhance the viability of a currency union. Second, the model answers the question of why default in the cross-border capital markets is particularly vital for currency unions. That is, under very general conditions competitive floating exchange rates are shown to neutralise domestic credit risks and improve welfare, and sharing a common currency loses such benefits of exchange rates. However, default in the cross-border capital markets under certain conditions recoups the lost benefits of exchange rates. Therefore, when countries join a currency union with an incomplete fiscal union or banking union, the bankruptcy code needs to adjust.

I acknowledge that the endogenous determination of default punishment and the endogenous adoption of currency unions should be the subject of further research. The bankruptcy code λ is the key parameter of default punishment, and it is essentially the price of default. Suppose countries take the price of default as given and "demand" default, then the system would need the "supply" of default to endogenise the price. This issue sits right at the intersection between law, finance, and political economy. Moreover, this paper takes currency unions as given and the model does not explicitly explain why countries choose to adopt a currency union. One possible explanation is that some countries do not have the institutional capacity to implement a credible domestic bankruptcy code and excessively choose inflation or devaluation as "soft default". Again, this argument goes back to the first point on endogenising the price of default. Excessive inflation or devaluation incurs the cost of persistent capital outflow and further political costs. Therefore, countries adopt a currency union by giving up their monetary autonomy as a self-commitment device.

In conclusion, a broader role of this paper is an initial attempt to bridge the gap between the value of money, exchange rate determination and bankruptcy codes in international finance.

This opens new avenues for research on the endogenous emergence of dominant international currencies and global financial cycles.

Appendices

1. Currency Union - country J

Country J

Household j

Household j consumes both the domestic goods and foreign goods at $t = 0$ and $t = 1$ and suffers a non-pecuniary penalty from default. Household j's maximisation problem is outlined as follows:

$$\underbrace{Max}_{\mu_J^j,\theta^j,\phi^j,c_J^j,c_I^j,q_J^j,b_I^j,v^j,D^j} E_0\Big\{U^j\left(c_{J0}^j, c_{I0}^j, c_{J\boldsymbol{s}}^j, c_{I\boldsymbol{s}}^j\right) - \lambda^j[d_{\boldsymbol{s}}^j]^+ - \lambda[f_{\boldsymbol{s}}^j]^+\Big\},$$

where $\lambda^j[d_{\boldsymbol{s}}^j]^+ = \lambda^j max[(1 - v_{\boldsymbol{s}}^j)\mu_J^j/p_{\boldsymbol{s}}, 0]$ is the non-pecuniary cost of domestic loan default, and $\lambda[f_{\boldsymbol{s}}^j]^+ = \lambda max[(\phi_{\boldsymbol{s}}^j - D_{\boldsymbol{s}}^j)/p_{\boldsymbol{s}}, 0]$ is the non-pecuniary cost of cross-country default.

Subject to

$$b_{I0}^j + \sum_{l=1}^{S} \pi_l \theta_l^j \leq \frac{\mu_J^j}{1 + r_J} + m^j, \tag{21}$$

$$b_{I\boldsymbol{s}}^j(1 + \tau_{J\boldsymbol{s}}) + (D_{\boldsymbol{s}}^j - K_{\boldsymbol{s}}\theta_{\boldsymbol{s}}^j) + \phi_{\boldsymbol{s}}^j \tau_{J\boldsymbol{s}} \leq \Delta(21) + \sum_{l=1}^{S} \pi_l \phi_l^j + p_{I0} q_{I0}^i + p_{J\boldsymbol{s}} q_{J\boldsymbol{s}}^j + \delta_{\boldsymbol{s}}^j, \tag{22}$$

$$v_{\boldsymbol{s}}^j \mu_J^j \leq \Delta(22)_{\boldsymbol{s}}. \tag{23}$$

And for $\boldsymbol{s}^* \in S^*$, the feasibility constraints are satisfied, i.e. $c_{J\boldsymbol{s}^*}^j \leq e_{J\boldsymbol{s}^*}^j - q_{J\boldsymbol{s}^*}^j$ and $c_{I\boldsymbol{s}^*}^j \leq \frac{b_{I\boldsymbol{s}^*}^j}{p_{I\boldsymbol{s}^*}}$. At $t = 0$, household j borrows from the domestic commercial bank j to get money to buy nominal Arrow securities and imports. Household j also gets monetary income by selling nominal Arrow securities and exports that gets carried over to the next period. At $t = 1$, household j sells exports and uses existing money to purchase imports and deliver (net) asset payoffs subject to domestic tax levy. At $t = 2$, household j uses unused money to settle outstanding loans and chooses how much to repay or default.

Domestic Commercial Bank j

Bank j extends loans and provides liquidity for household j. To ensure the liquidity bank j provides has a one-to-one convertibility with the common currency the union-wide central bank issues, bank j needs to borrow interbank loans from the union-wide central bank. Similar to bank i, bank j's maximisation problem is outline as follows,

$$\underbrace{Max}_{\mu^j_{CB},\mu^j_J,L^j,\omega^j} \sum_{s=1}^{S} z_s \omega^j_s,$$

subject to

$$L^j \leq \frac{\mu^j_{CB}}{1+\rho}, \tag{24}$$

$$\frac{\mu^j_J}{1+r_J} \leq L^j, \tag{25}$$

$$\omega^j_s = \Delta(24) + \Delta(25) + R^j_s \mu^j_J - \mu^j_{CB}. \tag{26}$$

At the beginning of $t = 0$, bank j borrows from the union-wide central bank and obtain fiat money in the common currency, ready to be extended as interbank liquidity L^j. Then bank j extends loans to the domestic households but has to ensure the liquidity bank j provides against the bank loans has a one-to-one convertibility with the fiat money issued by the central bank. At $t = 2$, bank j uses the households' loan repayments to pay back the interbank loans to the union-wide central bank.

National Government j

National government j collects taxes from the domestic household based on import expenditures and cross-country borrowing to build a state-contingent bailout fund of T_{Js}.

$$T_{Js} = p_{Is} c^j_{Is} \tau_{Js} + \phi^j_s \tau_{Js}.$$

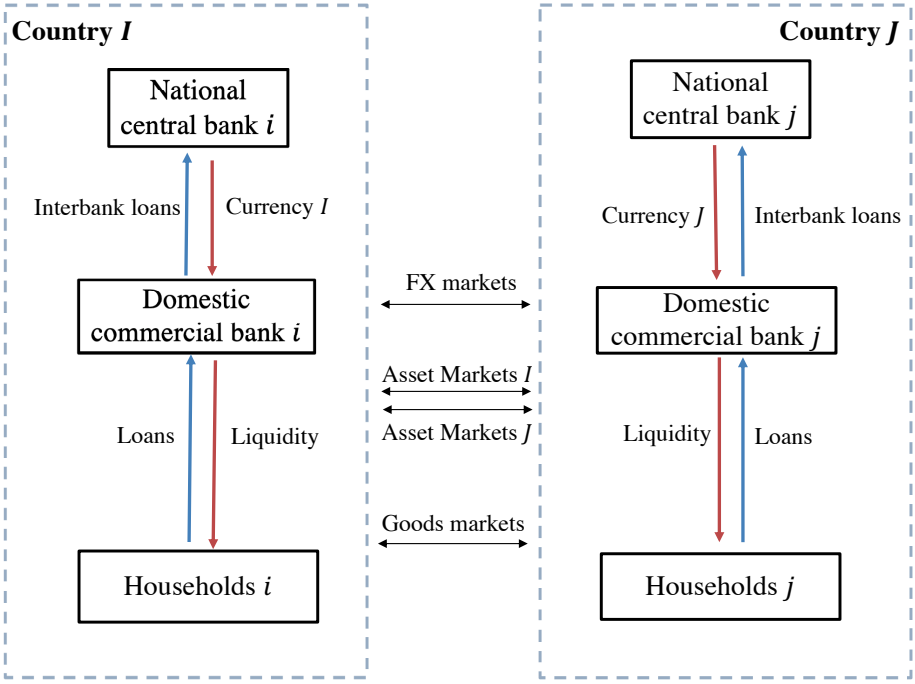
National government j uses the bailout funds to rescue the national commercial bank when-

ever the bank's nominal profits would drop to negative. This is to ensure $\omega_{\boldsymbol{s}}^{j} + T_{J\boldsymbol{s}} = 0$ at the bad state.

2. Regime D - Country J

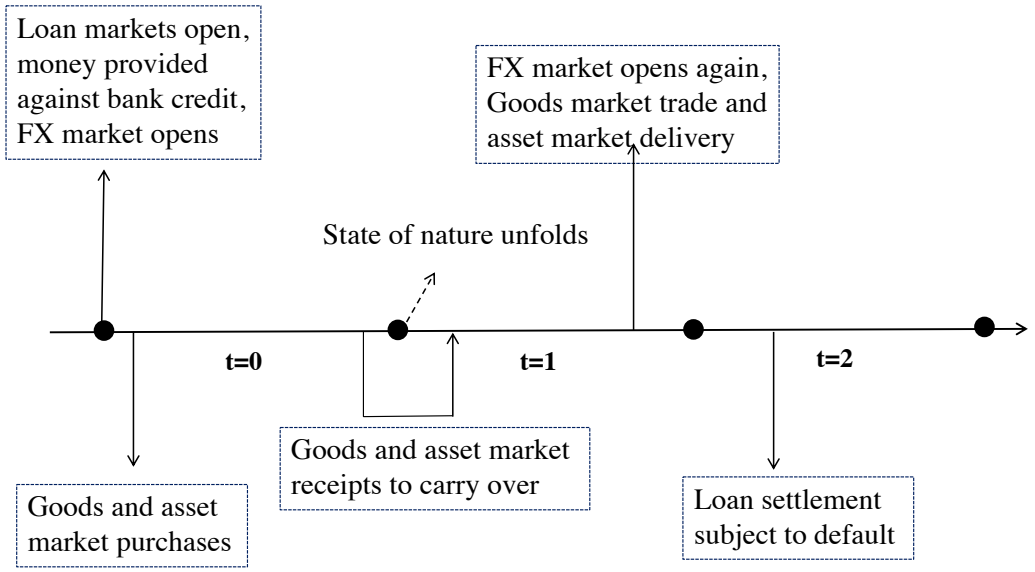
2.1. Structure and Flows

Figure 11: Nominal flows of the economy



2.2. Regime D Timeline

Figure 12: Timeline



2.3. Country J

The modelling of country$J$ is exactly symmetric to that of country I. The brief model outline and description are provided below for completeness.

Household j

Household j's preference is the same as in the benchmark model except that the price deflator p_s^J is a country-wide price index rather than a union-wide price index. The household's maximisation problem is as follows,

$$\underbrace{Max}_{\mu_J^j, f_{JI}^j, \theta^j, \phi^j, c_J^j, c_I^j, q_J^j, b_I^j, v^j} E_0\Big\{U^j(c_{J0}^j, c_{I0}^j, c_{J\boldsymbol{s}}^j, c_{I\boldsymbol{s}}^j) - \lambda^j \frac{max[(1-v_{\boldsymbol{s}}^j)\mu_J^j, 0]}{p_{\boldsymbol{s}}^J}\Big\},$$

subject to

at $t = 0$:

$$f_{JI}^j \leq \frac{\mu_J^j}{1+r_J} + m^j, \tag{27}$$

$$b^j_{I0} + \sum_{l=1}^{S} \pi_{Il}\theta^j_{Il} \leq \chi f^j_{JI}, \tag{28}$$

at $t = 1$ in state s:

$$f^j_{JI\boldsymbol{s}} + \phi^j_{J\boldsymbol{s}}(1 + \tau_{J\boldsymbol{s}}) \leq \sum_{l=1}^{S} \pi_{Jl}\phi^j_{Jl} + p_{J0}q^j_{J0} + p_{J\boldsymbol{s}}q^j_{J\boldsymbol{s}} + \Delta(27), \tag{29}$$

$$b^j_{I\boldsymbol{s}}(1 + \tau_{J\boldsymbol{s}}) \leq \theta^j_{I\boldsymbol{s}} + \chi_{\boldsymbol{s}} f^j_{JI\boldsymbol{s}} + \Delta(28), \tag{30}$$

$$v^j_{\boldsymbol{s}}\mu^j_J \leq \Delta(29)_{\boldsymbol{s}}, \tag{31}$$

$$c^j_{J\boldsymbol{s}^*} \leq e^j_{J\boldsymbol{s}^*} - q^j_{J\boldsymbol{s}^*}, \tag{32}$$

$$c^j_{I\boldsymbol{s}^*} \leq \frac{b^j_{I\boldsymbol{s}^*}}{p_{I\boldsymbol{s}^*}}. \tag{33}$$

Domestic Commercial Bank j

Bank j's actions are the same as in the benchmark model except that bank j now borrows interbank loans from the national central bank rather than a union-wide central bank. Therefore, ultimately fiat money in country J is issued by the national central bank and is in the national currency. Denote μ^j_{CBJ} as the REPO loans bank j borrows from the national central bank and ρ^J as the policy rate set by the national central bank. Bank j's maximisation problem is specified as follows,

$$\underbrace{Max}_{\mu^j_{CBJ}, \mu^j_J, L^j, \omega^j} \sum_{\boldsymbol{s}}^{S} z_{\boldsymbol{s}}\omega^j_{\boldsymbol{s}},$$

subject to

$$L^j \leq \frac{\mu^j_{CBJ}}{1+\rho_J}, \tag{34}$$

$$\frac{\mu^j_J}{1+r_J} \leq L^j, \tag{35}$$

$$\omega^j_{\boldsymbol{s}} = \Delta(34) + \Delta(35) + R^j_{\boldsymbol{s}}\mu^j_{J\boldsymbol{s}} - \mu^j_{CBJ}. \tag{36}$$

National Government j

National government j collects taxes from domestic households to build a state-contingent bailout fund of $T_{J\boldsymbol{s}}$.

$$T_{J\boldsymbol{s}} = p_{I\boldsymbol{s}}c^j_{I\boldsymbol{s}}\tau_{J\boldsymbol{s}} + \phi^j_{\boldsymbol{s}}\tau_{J\boldsymbol{s}}. \tag{37}$$

National government j uses the bailout funds to rescue the domestic commercial bank whenever the bank's nominal profits would drop to negative, i.e. the bank fails. In short, at the bad state the national government makes a state-contingent transfer to ensure $\omega^j_{\boldsymbol{s}} + T_{J\boldsymbol{s}} = 0$.

National Central Bank j

The national central bank lends REPO loans μ^J_{CBJ} to the domestic commercial bank and provides fiat money in the national currency. The national central bank sets the REPO loan rate ρ_J.

3. Equilibrium and Regime Characterisation

3.1. Proof of Lemma 1.

Proof. First, I identify the condition for household i's liquidity-in-advance constraint to bind. Suppose $r_I > 0$ and suppose further household i does not spend on all the money at hand, i.e. $\Delta(2.1) > 0$. The household can borrow ϵ less loan, but it only leads to $\epsilon/(1+r_I)$ reduction on the money at hand from (2.1).

Moreover, from (2.3), the reduction of loan needing to repay is $v^i_{\boldsymbol{s}}\epsilon$, and the pecuniary

benefit due to the reduction of default cost amounts to $(1-v_{\boldsymbol{s}}^i)\epsilon$. Thus, there is extra money $(v_{\boldsymbol{s}}^i - 1/(1+r_I) + 1 - v_{\boldsymbol{s}}^i)/\epsilon = r_I\epsilon/(1+r_I)$ at $t=2$. Household i can either use this extra money to consume more or increase loan repayment, and both lead to welfare improvement. This is a contradiction; hence, $\Delta(2.1) = 0$.

Second, I prove the binding condition for bank i's liquidity-in-advance constraint. Suppose bank i does not extend all the money at hand as interbank liquidity to household i, i.e. $\Delta(2.4) > 0$. Bank i can borrow ϵ less interbank loan, but it only leads to $\epsilon/(1+\rho)$ reduction on the money at hand in (2.6). The reduction of loan needing to repay is ϵ, which means there is an extra money of $\rho\epsilon/(1+\rho)$ in (2.6) that adds to bank i's cash flow, increasing its utility. This is a contradiction. Hence, $\Delta(2.4) = 0$. □

3.2. Proof of Lemma 2

Proof. Suppose $\Delta(2.5) > 0$, bank i can reduce the interbank liquidity L^i by ϵ, given (2.4) binds, it means bank i borrows $(1+\rho)\epsilon$ less interbank loans. From (2.6), the money at hand is reduced by ϵ, but the interbank loan needing to repay is reduced by $(1+\rho)\epsilon$. This means there is an extra money of $\rho\epsilon$ that adds to bank i's cash flow at $t=2$, increasing its utility. This is a contradiction. Hence, $\Delta(2.5) = 0$. □

3.3. Proof of Lemma 3.

Proof. Suppose $\Delta_{\boldsymbol{s}}(2.3) > 0$, then household i can either increase repayment rate $v_{\boldsymbol{s}}^i$ or borrow ϵ more at the interest rate of r_I. If household i increases $v_{\boldsymbol{s}}^i$, it leads to an immediate increase in utility because the cost of default decreases This improvement of welfare means a contradiction. If household i borrows ϵ more, then household i has an extra money of $\epsilon/(1+r_I)$ and uses it to buy more imports or sell less exports, leaving all other actions unchanged, without violating the inequality (2.3), because the household has enough money at hand to repay the extra loan. The improvement of welfare means a contradiction.

Similarly contradiction arises if $\Delta_{\boldsymbol{s}}(2.6) > 0$. Therefore, $\Delta_{\boldsymbol{s}}(2.3) = 0$ and $\Delta_{\boldsymbol{s}}(2.6) = 0$. □

3.4. Proof of Lemma 4.

Proof. Suppose $\phi_s^i > 0, \theta_{s'}^i > 0$. From household i's perspective, the FOC for ϕ_s^i leads to $\pi_s \frac{U_{c_{I0}^i}^i}{p_{I0}} = (1+\tau_{Is})\gamma_s\eta_{1s}^I$. FOC for $\theta_{s'}^i$ leads to $\pi_{s'}\frac{U_{c_{J0}^i}^i}{p_{J0}} = \gamma_{s'}\eta_{1s'}^i$. Suppose $\eta_{1s}^i = \eta_{1s'}^i$, and also

the FOCs for c^i_{I0}, c^i_{J0}, and μ^i_I lead to $\frac{U^i_{c^i_{J0}}}{p_{J0}} = (1+r_I)\frac{U^i_{c^i_{I0}}}{p_{I0}}$, it follows $\frac{\pi_s}{(1+\tau_{Is})\gamma_s} = \frac{\pi_{s'}(1+r_I)}{\gamma_{s'}}$. Hence,

$$\pi_s\gamma_{s'} > \pi_{s'}\gamma_s. \tag{38}$$

On the other hand, from household j's perspective, household j's FOC for θ^j_s leads to $\pi_s\frac{U^j_{c^j_{I0}}}{p_{I0}} = \gamma_s\eta^j_{1s}$, FOC for $\phi^j_{s'}$ gives $\pi_{s'}\frac{U^j_{c^j_{J0}}}{p_{J0}} = \gamma_{s'}(1+\tau_{Js'})\eta^j_{1s'}$. Given $\eta^j_{1s} = \eta^j_{1s'}$, and also the FOCs for $c^j_{J0}, c^j_{I0}, \mu^j_J$ lead to $\frac{U^j_{c^j_{I0}}}{p_{I0}} = (1+r_J)\frac{U^j_{c^j_{J0}}}{p_{J0}}$, it follows that $\frac{\pi_s(1+r_J)}{\gamma_s} = \frac{\pi_{s'}}{(1+\tau_{Js'})\gamma_{s'}}$. Hence,

$$\pi_1\gamma_2 < \pi_2\gamma_1. \tag{39}$$

We can see that (39) contradicts (38).

Suppose $\theta^i_s > 0, \phi^i_{s'} > 0$, by the same logic, a contradiction also arises. Therefore, it is not possible that $\eta^i_{1s} = \eta^i_{1s'}$ and $\eta^j_{1s} = \eta^j_{1s'}$. □

3.5. Proof of Lemma 5

Proof. It follows from the banks' FOC that $\forall \boldsymbol{s} \in S$, $h \in \{i,j\}$, $\omega^h_{\boldsymbol{s}} = (\frac{v^h_{\boldsymbol{s}}}{\sum_{\boldsymbol{s}=1}^{S}\eta_{\boldsymbol{s}}v^h_{\boldsymbol{s}}} - 1)\mu^h_{CB}$. Given the assumption that $v^h_{\boldsymbol{s}} = 1$, $\forall \boldsymbol{s} \in S$, $\omega^h_{\boldsymbol{s}} = 0$. □

3.6. Proof of Proposition 1

- The Fisher effect

  Denote η^i_0, $\eta^i_{\boldsymbol{s}1}$, and $\eta^i_{\boldsymbol{s}2}$ as the shadow prices of the three flow of funds constraints of household i. Suppose that household i has some money left over the moment the inter-period domestic loan comes due. From household i's FOCs for c^i_{J0} and μ^i_I, it follows that $\eta^i_0 = (1+r_I)E_0\eta^i_{\boldsymbol{s}2}$, namely, $\frac{U^i_{c^i_{J0}}}{p_{J0}} = (1+r_I)E_0\frac{U^i_{c^i_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}}$. And also household i's FOCs for $c^i_{I\boldsymbol{s}}$ and $c^i_{J\boldsymbol{s}}$ give $\frac{U^i_{c^i_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}} = \frac{U^i_{c^i_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}(1+\tau_{I\boldsymbol{s}})}$. It follows that

$$1+r_I = (E_0(\frac{U^i_{c^i_{J\boldsymbol{s}}}}{U^i_{c^i_{J0}}})(\frac{p_{J0}}{p_{J\boldsymbol{s}}})\frac{1}{(1+\tau_{I\boldsymbol{s}})(1+\iota_{I\boldsymbol{s}})})^{-1}.$$

- Quantity Theory of Money

  Invoking Lemma 1, summing up the flow of funds constraints of both households at $t = 0$, and using market clearing conditions for goods market, domestic loan markets and interbank loan and money market, it follows that

$$p_{I0}q^i_{I0} + p_{J0}q^j_{J0} = M_0 - \sum_{h\in\{i,j\}}\sum_{m=1}^{S}\pi_m\theta^h_m + \sum_{h\in\{i,j\}} m^h.$$

  For $t = 1$, summing up the flow of funds constraints of both households at $t = 1$, and using market clearing conditions for goods market, domestic loan markets, interbank loan and money market, and asset markets, it follows that

$$p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}} + p_{J\boldsymbol{s}}q^j_{J\boldsymbol{s}} = M + \sum_{h\in\{i,j\}}\epsilon^h - \sum_{H\in\{I,J\}} T_{H\boldsymbol{s}} - \sum_{h\in\{i,j\}}\Delta^h_{\boldsymbol{s}}.$$

- Money non-neutrality

  For the general method of proof on money non-neutrality, please see Tsomocos (2001, 2003). Here a specific proof by contradiction is provided. Combine household i's FOCs for c^i_{I0}, c^i_{J0}, and μ^i_I, we obtain

$$\frac{U^i_{c^i_{J0}}}{p_{J0}} = (1 + r_I)\frac{U^i_{c^i_{I0}}}{p_{I0}}, \tag{40}$$

  combine household j's FOCs for c^j_{J0}, c^j_{I0}, and μ^j_J, we obtain

$$\frac{U^j_{c^j_{I0}}}{p_{I0}} = (1 + r_J)\frac{U^j_{c^j_{J0}}}{p_{J0}}. \tag{41}$$

  Suppose the union-wide central bank increases the interbank rate ρ. Suppose consumption and default remain unchanged. Based on banks' FOCs that $1+r_I = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}}v^i_{\boldsymbol{s}}}$ and $1 + r_J = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}}v^j_{\boldsymbol{s}}}$, we can see that r_I and r_J both increase. Eq(40) implies $\frac{p_{I0}}{p_{J0}}$ has to increase, whereas Eq(3.11) implies that $\frac{p_{J0}}{p_{I0}}$ has to increase. This is a contradiction. □

3.7. Proof of Corollary 1.1

Proof. Let $z_{\boldsymbol{s}}$ be the risk-neutral probabilities $\forall \boldsymbol{s} \in S$. Bank i's FOC has $1 + r_I = \frac{1+\rho}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^i}$, $\omega_{\boldsymbol{s}}^i = v_{\boldsymbol{s}}^i \mu_I^i - \mu_{CB}^i = (\frac{v_{\boldsymbol{s}}^i}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^i} - 1)\mu_{CB}^i$. Given the assumption $v_s^i > \sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^i$, and $v_{s'}^i < \sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^i$, then $\omega_s^i > 0$, and $\omega_{s'}^i < 0$. Similarly, for bank j, $\omega_{s'}^j > 0$ and $\omega_s^j < 0$.

At state s, the union-wide central bank's profits $\omega_s^{CB} = \mu_{CB}^i - \frac{\mu_{CB}^i}{1+\rho} + v_s^j \mu_s^j - \frac{\mu_{CB}^j}{1+\rho} + T_s^j$.

Rearranging the algebra and plugging in the market clearing condition for interbank loans and money, as well as bank j's FOCs,

$$
\begin{aligned}
\omega_s^{CB} =& \mu_{CB}^i - \frac{\mu_{CB}^i}{1+\rho} + v_s^j \mu_J^j - \frac{\mu_{CB}^j}{1+\rho} + T_s^j \\
=& \mu_{CB}^i - \frac{\mu_{CB}^i}{1+\rho} + v_s^j \mu_J^j - \frac{1+\rho}{1+r_J}\mu_J^j + \frac{1+\rho}{1+r_J}\mu_J^j - \frac{\mu_{CB}^j}{1+\rho} + T_s^j \\
=& \frac{\rho}{1+\rho}(\mu_{CB}^i + \mu_{CB}^j) + (v_s^j - \frac{(1+\rho)\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^j}{1+\rho})\mu_J^j + T_s^j \\
=& \frac{\rho}{1+\rho}(\mu_{CB}^i + \mu_{CB}^j) + (v_s^j - \frac{(1+\rho)\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^j}{1+\rho})\frac{(1+\rho)}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^j}\frac{\mu_{CB}^j}{1+\rho} + T_s^j \\
=& \rho M + (\frac{v_s^j}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^j} - 1)\mu_{CB}^j + T_s^j,
\end{aligned}
$$

Moreover, via the flow of funds and budget constraints of the households and commercial banks, total outside money that flows into the union-wide central bank equals $\sum_{h\in\{i,j\}} m^h - \omega_s^i$. Thus,

$$
\rho M + (\frac{v_s^j}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^j} - 1)\mu_{CB}^j + T_s^j = \sum_{h\in\{i,j\}} m^h - \omega_s^i.
$$

Similar proof follows for state s',

$$
\rho M + (\frac{v_{s'}^i}{\sum_{s=1}^{S} z_{\boldsymbol{s}} v_{\boldsymbol{s}}^i} - 1)\mu_{CB}^i + T_{s'}^i = \sum_{h\in\{i,j\}} m^h - \omega_{s'}^j.
$$

□

3.8. Proof of Proposition 2

Proof. At country I's bad state s' when credit risks are present, suppose $\lambda > \lambda^i$, it means the marginal cost of default on financial securities is larger than the marginal cost of default on domestic loans. At the bad state s', household i's FOC for $v^i_{s'}$ gives $\frac{\lambda^i}{p_{s'}} = \frac{U^i_{c^i_{Is'}}}{p_{Is'}}$, it follows that

$$\frac{\lambda}{p_{s'}} > \frac{U^i_{c^i_{Is'}}}{p_{Is'}}. \tag{42}$$

The left-hand side of (42) is the marginal cost of default on financial securities and the right-hand side of (42) is the marginal benefit. Since the marginal cost of default on financial securities is larger than the marginal benefit, household i fully delivers on cross-country borrowing, i.e. $D^i_{s'} = \phi^i_{s'}$.

At the good state household i's FOC for v^i_s gives $\frac{\lambda^i}{p_s} \geq \frac{U^i_{c^i_{Is}}}{p_{Is}}$. Since $\lambda > \lambda^i$, it follows that $\frac{\lambda}{p_s} > \frac{U^i_{c^i_{Is}}}{p_{Is}}$. Hence, $D^i_s = \phi^i_s$.

Overall, $\forall \boldsymbol{s} \in S$, $D^i_{\boldsymbol{s}} = \phi^i_{\boldsymbol{s}}$.

Now suppose the cross-country bankruptcy code is more lenient, i.e. $\lambda < \lambda^i$. It means the marginal cost of default on financial securities is smaller than the marginal cost of default on domestic loans. At the bad state, $\lambda \leq \frac{U^i_{c^i_{Is'}}}{p_{Is'}}$, and $\frac{\lambda^i}{p_{s'}} \geq \frac{U^i_{c^i_{Is'}}}{p_{Is'}}$. It is less costly to default on financial securities, so household would default on financial securities first instead of domestic loans, i.e. $D^i_{s'} < \phi^i_{s'}$.

At the good state household i's FOC for v^i_s gives $\frac{\lambda^i}{p_{s'}} \geq \frac{U^i_{c^i_{Is'}}}{p_{Is'}}$, since $\lambda < \lambda^i$, the relationship between $\frac{\lambda}{p_{s'}}$ and $\frac{U^i_{c^i_{Is'}}}{p_{Is'}}$ is ambiguous. The marginal cost of default on financial securities can be larger than, or equal to, or smaller than the marginal benefit. Therefore, $D^i_s \leq \phi^i_s$.

Overall, $\forall \boldsymbol{s} \in S$, $D^i_{\boldsymbol{s}} \leq \phi^i_{\boldsymbol{s}}$. The same logic follows for the case of country J. □

4. Equilibrium Analysis

Proof of Proposition 3

Proof. Since $\frac{\bar{\lambda}}{p_2} = \eta^i_{11}$, $\frac{a_2\bar{\lambda}}{p_2} = \eta^i_{22}$ holds. Given $\eta^j_{12} < \frac{\lambda}{p_2}$ and $a_2\lambda < a_2\bar{\lambda} < \lambda^i$, then $\eta^j_{12} < \frac{\lambda}{p_2} < \eta^i_{12}$. These conditions are the on-the-verge conditions between the households' marginal benefit of default and their marginal cost of default on Arrow securities. Thus, if holding short positions, household i defaults on Arrow security $l = 2$ fully while household j fully delivers the payoff of Arrow security $l = 2$.

Due to risk-aversion, it is straightforward to see that household i buys Arrow security $l = 2$ because $e^i_1 > e^i_2$, $\eta^i_{11} < \eta^i_{12}$, and household j sells Arrow security $l = 2$ because $e^j_1 < e^j_2$, $\eta^j_{11} > \eta^j_{12}$. However, to see why household i also sells Arrow security $l = s'$ at the same time whenever $\big(K_2 - \pi_2(v^i_2(1 + r_I) - 1)\big)/p_{I2} > \pi_2 r^l/p_{I1}$ holds, I show via proof by contradiction.

Suppose $\phi^i_2 = 0$ is the equilibrium outcome. Suppose now household i sells ϵ amount of Arrow security $l = 2$. According to the market clearing condition of Asset markets, household i would need to buy ϵ amount of Arrow security $l = 2$. This means household i needs to borrow $\pi_2\epsilon$ more money at $t = 0$ while needing to pay back $\pi_2\epsilon v^i_2(1 + r_I)$ at state 2, so the extra monetary cost is $\pi_2\epsilon\big(v^i_2(1 + r_I) - 1\big)$. However, because household i can default fully on the ϵ amount of Arrow security sold, the extra money inflow due to default amounts to $K_2\epsilon$, where $K_2 = 1 - \frac{\epsilon}{\sum_{h\in i,j}\phi^h_2}$. Thus, the total money inflow $K_2\epsilon - \pi_2\epsilon\big(v^i_2(1 + r_I) - 1\big)$ is positive. For the good state 1, $\eta^i_{21} < \frac{\lambda^i}{p_1}$ holds, $v^i_1 = 1$, so the extra monetary cost is $\pi_2\epsilon r_l$. If $\Big(K_2 - \pi_2\big(v^i_2(1 + r_I) - 1\big)\Big)/p_{I2} > \pi_2 r^l/p_{I1}$ holds, then $\nabla U^i(\cdot)(K_2\epsilon - \pi_2\epsilon\big(v^i_2(1 + r_I) - 1\big)) > \nabla U^i(\cdot)(\pi_2\epsilon r^l)$ holds, leading to an overall increase in household i's expected utility. This is inconsistent with $\phi^i_2 = 0$ as an equilibrium outcome. □

First-order conditions of Currency Unions

FOCs of Regimes A & B

:

$$\frac{U^i_{c^i_{J0}}}{p_{J0}} = (1 + r_I)E_0\frac{U^i_{c^i_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}}, \tag{43}$$

$$\frac{U^i_{c^i_{I0}}}{p_{I0}} = E_0\frac{U^i_{c^i_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}(1 + \tau_{I\boldsymbol{s}})}, \tag{44}$$

$$\frac{U^j_{c^j_{I0}}}{p_{I0}} = (1+r_J)E_0\frac{U^j_{c^j_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}}, \tag{45}$$

$$\frac{U^j_{c^j_{J0}}}{p_{J0}} = E_0\frac{U^j_{c^j_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}(1+\tau_{J\boldsymbol{s}})}, \tag{46}$$

$$1+r_I = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^i_{\boldsymbol{s}}}, \tag{47}$$

$$1+r_J = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^j_{\boldsymbol{s}}}, \tag{48}$$

for state s:

$$\frac{U^i_{c^i_{Is}}}{p_{Is}} = \frac{U^i_{c^i_{Js}}}{p_{Js}(1+\tau_{Is})}, \tag{49}$$

$$\pi_s\frac{U^i_{c^i_{I0}}}{p_{I0}} = \gamma_s\frac{U^i_{c^i_{Js}}}{p_{Js}}, \tag{50}$$

$$\frac{\lambda^i}{p_s} \geq \frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{51}$$

$$\frac{\lambda}{p_s} > \frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{52}$$

$$\pi_s\frac{U^j_{c^j_{I0}}}{p_{I0}} = \gamma_s\frac{U^j_{c^j_{Is}}}{p_{Is}(1+\tau_{Js})}, \tag{53}$$

$$\frac{U^j_{c^j_{Js}}}{p_{Js}} = \frac{U^j_{c^j_{Is}}}{p_{Is}(1+\tau_{Js})}, \tag{54}$$

$$\frac{\lambda^j}{p_s} \geq \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{55}$$

$$\frac{\lambda}{p_s} > \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{56}$$

for state s':

$$\pi_{s'} \frac{U^i_{c^i_{J0}}}{p_{J0}} = \gamma_{s'} \frac{U^i_{c^i_{Js'}}}{p_{Js'}(1+\tau_{Is'})}, \tag{57}$$

$$\frac{U^i_{c^i_{Is'}}}{p_{Is'}} = \frac{U^i_{c^i_{Js'}}}{p_{Js'}(1+\tau_{Is'})}, \tag{58}$$

$$\frac{\lambda^i}{p_{s'}} \geq \frac{U^i_{c^i_{Is'}}}{p_{Is'}}, \tag{59}$$

$$\frac{\lambda}{p_{s'}} > \frac{U^i_{c^i_{Is'}}}{p_{Is'}}, \tag{60}$$

$$\pi_{s'} \frac{U^j_{c^j_{J0}}}{p_{J0}} = \gamma_{s'} \frac{U^j_{c^j_{Is'}}}{p_{Is'}}, \tag{61}$$

$$\frac{U^j_{c^j_{Js'}}}{p_{Js'}} = \frac{U^j_{c^j_{Is'}}}{p_{Is'}(1+\tau_{Js'})}, \tag{62}$$

$$\frac{\lambda^j}{p_{s'}} \geq \frac{U^j_{c^j_{Js'}}}{p_{Js'}}, \tag{63}$$

$$\frac{\lambda}{p_{s'}} > \frac{U^j_{c^j_{Js'}}}{p_{Js'}}. \tag{64}$$

FOCs of Regime C

The following FOCs are derived under the conditions of Proposition 5. Under the conditions of Proposition 5, $\phi^i_{s'}, \phi^j_{s'}, \theta^i_{s'} > 0$, $\theta^j_{s'} = 0, D^i_{s'} = 0, D^j_{s'} = \phi^j_{s'}$, $\phi^j_s, \phi^i_s, \theta^j_s > 0, \theta^i_s = 0, D^j_s = 0, D^i_s = \phi^i_s$, and $\tau^i_s, \tau^j_s, \tau^i_{s'}, \tau^j_{s'} = 0$.

$$\frac{U^i_{c^i_{J0}}}{p_{J0}} = (1+r_I)E_0\frac{U^i_{c^i_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}}, \tag{65}$$

$$\frac{U^i_{c^i_{I0}}}{p_{I0}} = E_0\frac{U^i_{c^i_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}}, \tag{66}$$

$$\frac{U^j_{c^j_{J0}}}{p_{J0}} = E_0\frac{U^j_{c^j_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}}, \tag{67}$$

$$\frac{U^j_{c^j_{I0}}}{p_{I0}} = (1+r_J)E_0\frac{U^j_{c^j_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}}, \tag{68}$$

$$1+r_I = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^i_{\boldsymbol{s}}}, \tag{69}$$

$$1+r_J = \frac{1+\rho}{\sum_{\boldsymbol{s}=1}^{S} z_{\boldsymbol{s}} v^j_{\boldsymbol{s}}}, \tag{70}$$

for state s

$$\pi_s\frac{U^i_{c^i_{I0}}}{p_{I0}} = \gamma_s\frac{U^i_{c^i_{Js}}}{p_{Js}}, \tag{71}$$

$$\frac{\lambda}{p_s} > \frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{72}$$

$$\frac{\lambda^i}{p_s} > \frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{73}$$

$$\frac{U^i_{c^i_{Is}}}{p_{Is}} = \frac{U^i_{c^i_{Js}}}{p_{Js}}, \tag{74}$$

$$\pi_s\frac{U^j_{c^j_{I0}}}{p_{I0}} = \gamma_s K_s\frac{U^j_{c^j_{Is}}}{p_{Is}}, \tag{75}$$

$$\pi_s \frac{U^j_{c^j_{J0}}}{p_{J0}} = \gamma_s \frac{\lambda_s}{p_s}, \tag{76}$$

$$\frac{\lambda}{p_s} < \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{77}$$

$$\frac{U^j_{c^j_{Is}}}{p_{Is}} = \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{78}$$

$$\frac{\lambda^j}{p_s} > \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{79}$$

for state s':

$$\frac{\lambda}{p_{s'}} < \frac{U^i_{c^i_{Is'}}}{p_{Is'}}, \tag{80}$$

$$\pi_{s'} \frac{U^i_{c^i_{I0}}}{p_{I0}} = \gamma_{s'} \frac{\lambda_{s'}}{p_{s'}}, \tag{81}$$

$$\pi_{s'} \frac{U^i_{c^i_{J0}}}{p_{J0}} = \gamma_{s'} K_{s'} \frac{U^i_{c^i_{Js'}}}{p_{Js'}}, \tag{82}$$

$$\frac{U^i_{c^i_{Is'}}}{p_{Is'}} = \frac{U^i_{c^i_{Js'}}}{p_{Js'}}, \tag{83}$$

$$\frac{\lambda^i}{p_{s'}} > \frac{U^i_{c^i_{Is'}}}{p_{Is'}}, \tag{84}$$

$$\pi_{s'} \frac{U^j_{c^j_{J0}}}{p_{J0}} = \gamma_{s'} \frac{U^j_{c^j_{Is'}}}{p_{Is'}}, \tag{85}$$

$$\frac{U^j_{c^j_{Is'}}}{p_{Is'}} = \frac{U^j_{c^j_{Js'}}}{p_{Js'}}, \tag{86}$$

$$\frac{\lambda^j}{p_{s'}} > \frac{U^j_{c^j_{Js'}}}{p_{Js'}}, \tag{87}$$

$$\frac{\lambda}{p_{s'}} > \frac{U^j_{c^j_{Js'}}}{p_{Js'}}. \tag{88}$$

Proof of Lemma 6

Proof: Given $\lambda > \lambda^h$, $h \in \{i, j\}$. at state s, $FA^I_s = -\phi^i_s$, then $\delta^i_s = \phi^i_s - p_{Is}q^i_{Is} + p_{Js}c^i_{Js}$, and $\delta^j_s = -\theta^j_s - p_{Js}q^j_{Js} + p_{Is}c^j_{Is}$. Because $\phi^i_s = \theta^j_s$, $p_{Is}q^i_{Is} = p_{Is}c^j_{Is}$, and $p_{Js}c^i_{Js} = p_{Js}q^j_{Js}$, it follows that $\delta^i_s + \delta^j_s = 0$. Moreover, invoking Lemma 1, $v^i_s\mu^i_I = \frac{\mu^j_J}{1+r_J} + m^j + p_{Is}q^i_{Is} - p_{Js}c^i_{Js} - \phi^i_s + \delta^i_s = \frac{\mu^j_J}{1+r_J} + m^j$, and $v^j_s\mu^j_J = \frac{\mu^i_I}{1+r_I} + m^i$.

Similarly, for state s', $\delta^i_{s'} + \delta^j_{s'} = 0$, $v^i_{s'}\mu^i_I = \frac{\mu^j_J}{1+r_J} + m^j$, $v^j_{s'}\mu^j_J = \frac{\mu^i_I}{1+r_I} + m^i$.

Therefore, $v^i_s = v^i_{s'} = v^i$, and $v^j_s = v^j_{s'} = v^j$, i.e. $var(1 - v^{h,B.a}_{\boldsymbol{s}}) = 0$.

□

Proof of Proposition 4

Proof: Commercial bank h's FOC gives $\omega^h_{\boldsymbol{s}} = (v^h_{\boldsymbol{s}} - \sum^S_{\boldsymbol{s}=1} z_{\boldsymbol{s}} v^h_{\boldsymbol{s}})\mu^h_H$. In Regime A, $\lambda > \lambda^h$ and $\delta^h_{\boldsymbol{s}} = 0$ for $h \in \{i, j\}$, $\forall \boldsymbol{s} \in S$. Given $v^h_{\boldsymbol{s}} < \sum^S_{\boldsymbol{s}=1} z_{\boldsymbol{s}} v^h_{\boldsymbol{s}}$, $\omega^h_{\boldsymbol{s}} < 0$. In Regime B.a, $\lambda > \lambda^h$, and $\delta^h_{\boldsymbol{s}} = -FA^H_{\boldsymbol{s}} - CA^h_{\boldsymbol{s}}$, as shown in Proof of Lemma 6 $v^h_{\boldsymbol{s}} = v^h$. It follows $v^h_{\boldsymbol{s}} - \sum^S_{\boldsymbol{s}=1} z_{\boldsymbol{s}} v^h_{\boldsymbol{s}} = 0$ and $\omega^h_{\boldsymbol{s}} = 0$.

For the case of Regime C, the conditions are more exacting. Given the conditions in Proposition 3, i.e. consider the case where $S = \{1, 2\}$, let $\gamma_1 = \gamma_2$, $e^i_1 > e^i_2$, and $e^j_1 < e^j_2$. Suppose that in equilibrium $\lambda < p_2\eta^i_{12} < \lambda^i$, $\eta^j_{12} < \frac{\lambda}{p_2}$ and $\eta^i_{11} < \eta^i_{12}$ holds. Suppose $\big(K_2 - \pi_2(v^i_2(1+r_I) - 1)\big)/p_{I2} > \pi_2 r_I/p_{I1}$ holds, then, $\phi^i_2, \phi^j_2, \theta^i_2 > 0$, $\theta^j_2 = 0$, $D^i_2 = 0, D^j_2 = \phi^j_2$, and $0 < K_2 < 1$. Assume similar conditions for the other state. Thus, households purchase and sell the Arrow security of their respective bad state in order to default fully on the Arrow security, without defaulting on domestic loans. It follows that $v^h_{\boldsymbol{s}} = 1$ and $\omega^h_{\boldsymbol{s}} = 0$, where $\boldsymbol{s} \in \{1, 2\}$.

□

Proof of Corollary 4.2

Proof: Suppose the conditions of Proposition 4 are met. For the allocation at $t = 0$, combine households i's FOCs (43), (44), (49), (58), we have

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{p_{I0}}{p_{J0}} \frac{1}{1 + r_I}. \tag{89}$$

Likewise, combining household j's FOCs (45), (46), (54), (62) leads to

$$\frac{U^j_{c^j_{J0}}}{U^j_{c^i_{I0}}} = \frac{p_{J0}}{p_{I0}} \frac{1}{1 + r_J}. \tag{90}$$

Combine (89) and (90), we have

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} \frac{1}{(1 + r_I)(1 + r_J)}. \tag{91}$$

For the allocation at $t = 1$ at state $\boldsymbol{s}$, $\boldsymbol{s} \in S$, household i's FOCs for $c^i_{I\boldsymbol{s}}$ and $c^i_{J\boldsymbol{s}}$ give

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}} = \frac{U^i_{c^i_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}(1 + \tau_{I\boldsymbol{s}})}. \tag{92}$$

Household j's FOCs for $c^j_{J\boldsymbol{s}}$ and $c^j_{I\boldsymbol{s}}$ give

$$\frac{U^j_{c^j_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}(1 + \tau_{J\boldsymbol{s}})}. \tag{93}$$

Combine (92) and (93), we have

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}} \frac{1}{(1 + \tau_{I\boldsymbol{s}})(1 + \tau_{J\boldsymbol{s}})}. \tag{94}$$

In Particular, for Regime B and Regime C, $\tau_{H\boldsymbol{s}} = 0$, and therefore,

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}}, \tag{95}$$

□

Proof of Corollary 4.3

Proof: Under the conditions of Proposition 4. For Regime A, combine (49) and (50), we obtain

$$\frac{U^i_{c^i_{Is}}}{p_{Is}} = \frac{\pi_s U^i_{c^i_{I0}}}{\gamma_s p_{I0}(1+\tau_{Is})}. \tag{96}$$

Combine (57) and (58) we obtain

$$\frac{U^i_{c^i_{Is'}}}{p_{Is'}} = \frac{\pi_{s'} U^i_{c^i_{J0}}}{p_{J0}\gamma_{s'}}. \tag{97}$$

Combine (96), (97) and (89), we have

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{\pi_s \gamma_{s'} p_{Is}}{\pi_{s'}\gamma_s p_{Is'}(1+\tau_{Is})(1+r_I)}. \tag{98}$$

Combine (53), (61) and (90), we have

$$\frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} = \frac{\pi_s(1+\tau_{Js})\gamma_{s'} p_{Is}(1+r_J)}{\pi_{s'}\gamma_s p_{Is'}}. \tag{99}$$

Combine (98) and (99), we have

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{1}{(1+\tau_{Is})(1+\tau_{Js})(1+r_I)(1+r_J)}. \tag{100}$$

The same rearrangement of FOCs in Regime B gives us exactly the same risk sharing conditions as in (102) except that $\tau_{Hs} = 0$ in Regime B, i.e.,

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{1}{(1+r_I)(1+r_J)}. \tag{101}$$

For Regime C, combine (71) and (74):

$$\frac{U^i_{c^i_{Is}}}{p_{Is}} = \frac{\pi_s U^i_{c^i_{I0}}}{\gamma_s p_{I0}}. \tag{102}$$

Rearrange (75):

$$\frac{U^j_{c^j_{Is}}}{p_{Is}} = \frac{\pi_s U^j_{c^j_{I0}}}{\gamma_s K_s p_{I0}}. \tag{103}$$

Combine (82) and (83):

$$\frac{U^i_{c^i_{Is'}}}{p_{Is'}} = \frac{\pi_{s'} U^i_{c^i_{J0}}}{\gamma_{s'} K_{s'} p_{J0}}. \tag{104}$$

Rearrange (85):

$$\frac{U^j_{c^j_{Is'}}}{p_{Is'}} = \frac{\pi_{s'} U^j_{c^j_{J0}}}{\gamma_{s'} p_{J0}}. \tag{105}$$

Note that as Proposition 4 shows that $v^h_{\boldsymbol{s}} = 1$ in Regime C; thus, $r^h_{\boldsymbol{s}} = \rho$. Combining (102), (103), (104) and (105), we have

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} \frac{K_s K_{s'}}{(1+\rho)^2}.$$

Similar expressions obtain for risk sharing with respect to consumption good J. □

Proof of Corollary 4.4

Proof: Under the conditions of Proposition 4. in Regime A, for state s household i' sells the Arrow security of that state. Rearrange (50), i.e. household i's FOC for ϕ^i_s, we obtain

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}}/p_{Js}}{U^i_{c^i_{I0}}/p_{I0}}. \tag{106}$$

Household j' buys the Arrow security of that state. Combine (53) and (90), we obtain

$$\pi_s = \gamma_s \frac{U^j_{c^j_{Is}} / p_{Is}}{U^j_{c^j_{J0}} / p_{J0}(1+\tau_{Js})(1+r_J)}. \tag{107}$$

For state s', household i's buys the Arrow security of that state. Combine (57) and (89) we obtain

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}} / p_{Js'}}{U^i_{c^i_{I0}} / p_{I0}(1+\tau_{Is'})(1+r_I)}. \tag{108}$$

Household j sells the Arrow security of that state. Rearrange (61), i.e. household j's FOC for $\phi^j_{s'}$, we obtain

$$\pi_{s'} = \gamma_{s'} \frac{U^j_{c^j_{Is'}} / p_{Is'}}{U^j_{c^j_{J0}} / p_{J0}}. \tag{109}$$

It follows that

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}} / p_{Js}}{U^i_{c^i_{I0}} / p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}} / p_{Is}}{U^j_{c^j_{J0}} / p_{J0}(1+\tau_{Js})(1+r_J)},$$

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}} / p_{Js'}}{U^i_{c^i_{I0}} / p_{I0}(1+\tau_{Is'})(1+r_I)} = \gamma_{s'} \frac{U^j_{c^j_{Is'}} / p_{Is'}}{U^j_{c^j_{J0}} / p_{J0}}.$$

For Regime B, similar rearrangements of FOCs give

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}} / p_{Js}}{U^i_{c^i_{I0}} / p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}} / p_{Is}}{U^j_{c^j_{J0}} / p_{J0}(1+r_J)},$$

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}} / p_{Js'}}{U^i_{c^i_{I0}} / p_{I0}(1+r_I)} = \gamma_{s'} \frac{U^j_{c^j_{Is'}} / p_{Is'}}{U^j_{c^j_{J0}} / p_{J0}}.$$

For Regime C, for state s let us rearrange (71):

$$\pi_s \frac{U^i_{c^i_{I0}}}{p_{I0}} = \gamma_s \frac{U^i_{c^i_{Js}}}{p_{Js}}. \tag{110}$$

Combine (68), (75), (78), and (86), we obtain

$$\pi_s \frac{U^j_{c^j_{I0}}}{p_{I0}} = \gamma_s K_s \frac{U^j_{c^j_{Is}}}{p_{Is}}. \tag{111}$$

Moreover, as shown in Proposition 4 and Corollary 4.3, $r_h = \rho$ in Regime C. It follows that

$$\pi_s = \gamma_s \frac{U^i_{c^i_{Js}}/p_{Js}}{U^i_{c^i_{I0}}/p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}}/p_{Is}K_s}{U^j_{c^j_{J0}}/p_{J0}(1+\rho)}.$$

Similarly for state s' we obtain

$$\pi_{s'} = \gamma_{s'} \frac{U^i_{c^i_{Js'}}/p_{Js'}K_{s'}}{U^i_{c^i_{I0}}/p_{I0}(1+\rho)} = \gamma_{s'} \frac{U^j_{c^j_{Is'}}/p_{Is'}}{U^j_{c^j_{J0}}/p_{J0}}.$$

□

Proof of Proposition 5

Proof. First I show decreasing λ to $\lambda^{'}$ leads to utility increase for both household i and household j on the margin.

In the Regime A equilibrium, $p_2\eta^i_{12} = \lambda^i < \lambda$, it follows that

$$\frac{\lambda}{p_2} > \eta^i_{12}. \tag{112}$$

The marginal cost of default on financial securities is larger than the marginal benefit, so household i fully delivers on assets. Given $\eta^i_{11} < \eta^i_{12}$, $\phi^i_2 = 0$ and $\theta^i_2 > 0$.

Now let us decrease λ to $\lambda^{'}$, and $\lambda^{'} < p_2\eta^i_{12} = \lambda^i$. It follows that

$$\frac{\lambda^{'}}{p_2} < \eta^i_{12}. \tag{113}$$

Equation (113) states the marginal cost of default on financial securities is larger than the marginal benefit, so household i would fully default if holding short positions.

Suppose now household i sells an infinitesimal ϵ of Arrow security $l = 2$, i.e. $\phi_2^i = \epsilon$. According to the market clearing condition of asset markets, household i would need to buy ϵ amount of Arrow security $l = 2$. This means household i needs to borrow $\pi_2\epsilon$ more money at $t = 0$ while needing to pay back $\pi_s\epsilon v_2^i(1 + r_I)$ at $t = 2$, so the extra monetary cost is $\pi_2\epsilon(v_2^i(1 + r_I) - 1)$. However, because household i fully defaults on the ϵ amount of Arrow security sold, so the extra money inflow due to default amounts to $K_2\epsilon$, where $K_2 = 1 - \frac{\epsilon}{\sum_{h\in\{i,j\}}\phi_s^h}$. Thus the total money inflow at state 2 is $K_s\epsilon - \pi_2\epsilon(v_2^i(1+r_I)-1)$. For the good state 1, the monetary cost is $\pi_s\epsilon r_I$. Since $\Big(K_2 - \pi_2(v_2^i(1 + r_I) - 1)\Big)/p_{I2} > \pi_2 r_I/p_{I1}$ holds, then on the margin $\nabla U^i(\cdot)(K_2\epsilon - \pi_2\epsilon(v_2^i(1 + r_I) - 1)) > \nabla U^i(\cdot)(\pi_2\epsilon r_I)$ holds, leading to an overall increase in household i's expected utility.

Similarly, setting $\lambda = \lambda^C$ leads to an overall increase in household j's expected utility on the margin.

Second I show that the expected utilities of commercial banks are zero and remain unchanged. From Proposition 4, $\omega_{\boldsymbol{s}}^h = (v_{\boldsymbol{s}}^h - \sum_{\boldsymbol{s}=1}^S z_{\boldsymbol{s}} v_{\boldsymbol{s}}^h)\mu_H^h$, $h \in \{i, j\}, H \in \{I, J\}$. It follows that $U^h(\cdot) = \sum_{\boldsymbol{s}=1}^S z_{\boldsymbol{s}}\omega_{\boldsymbol{s}}^h = \sum_{\boldsymbol{s}=1}^S(z_{\boldsymbol{s}}(v_{\boldsymbol{s}}^h - \sum_{\boldsymbol{s}=1}^S z_{\boldsymbol{s}} v_{\boldsymbol{s}}^h)\mu_H^h) = (\sum_{\boldsymbol{s}=1}^S z_{\boldsymbol{s}} v_{\boldsymbol{s}}^h - \sum_{\boldsymbol{s}=1}^S z_{\boldsymbol{s}} \sum_{\boldsymbol{s}=1}^S z_{\boldsymbol{s}} v_{\boldsymbol{s}}^h)\mu_H^h = 0$. □

Proof of Lemma 7

Proof. See the the proofs in 3.1., 3.2., and 3.3.. □

Proof of Lemma 8

Proof. Set $\tau_{\boldsymbol{s}}^h = 0\ \forall \boldsymbol{s} \in S$, $h \in \{i, j\}$.

- Purchasing Power Parity

  At $t = 0$, suppose household i purchases consumption good I and good J. FOC for c_{I0}^i gives

$$U_{c_{I0}^i}^i = p_{I0}\nu_1^i. \tag{114}$$

FOC for c^i_{J0} gives

$$U^i_{c^i_{J0}} = p_{J0}\nu^i_2. \tag{115}$$

FOC for f^i_{IJ} gives

$$\nu^i_1 = \frac{1}{\chi}\nu^i_2. \tag{116}$$

Combine (114), (115), and (116):

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{p_{I0}}{\chi p_{J0}}. \tag{117}$$

If household i only purchases good J and sells consumption good I, then FOC for c^i_{I0} becomes

$$U^i_{c^i_{I0}} = p_{I0}E_0\nu^i_{3\boldsymbol{s}}. \tag{118}$$

FOC for μ^i_I gives

$$\nu^i_1 = (1+r_I)E_0\nu^i_{3\boldsymbol{s}}. \tag{119}$$

Combine (115), (116), (118), and (119) :

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{p_{I0}}{\chi p_{J0}(1+r_I)}. \tag{120}$$

Similarly, if household j buys both good I and good J, then $\frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} = \frac{p_{I0}}{\chi p_{J0}}$, and if household only buys good I and sells good J, then $\frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}} = \frac{(1+r_J)p_{I0}}{\chi p_{J0}}$.

At $t=1$, household h's FOCs for $c^h_{I\boldsymbol{s}}$, $c^h_{J\boldsymbol{s}}$, and the FOC for FX lead to

$$\frac{U^h_{c^h_{Is}}}{U^h_{c^h_{Js}}} = \frac{p_{Is}}{\chi_s p_{Js}}. \tag{121}$$

- Uncovered Interest Rate Parity

  Suppose household i can obtain currency J via FX market and foreign bank j. If household i obtains currency J via FX market, then household i's FOC for $\theta^i_{s'}$ gives

$$\pi_{Js'}\nu^i_2 = \gamma_{s'}\nu^i_{4s'}. \tag{122}$$

  Household i's FOC for f^i_{IJ} gives

$$\nu^i_1 = \frac{1}{\chi}\nu^i_2. \tag{123}$$

  Household i's FOCs for μ^i_I and $\Delta^i_{\boldsymbol{s}}$(2.13) give

$$\nu^i_1 = (1 + r_I)E_0\nu^i_{3\boldsymbol{s}}. \tag{124}$$

  Household i's FOC for $f^i_{IJ\boldsymbol{s}}$ gives

$$\nu^i_{3\boldsymbol{s}}\chi_{\boldsymbol{s}} = \nu^i_{4\boldsymbol{s}}. \tag{125}$$

  Combine (122), (123), (124), and (125):

$$\pi_{Js'}\chi(1 + r_I)E_0\nu^i_{3\boldsymbol{s}} = \gamma_{s'}\nu^i_{4s'}. \tag{126}$$

  If household i obtains currency J by borrowing μ^i_J from foreign bank j. Let $\nu^{i'}_0$ be the shadow price of the liquidity-in-advance constraint, then household i's FOC for $\theta^i_{s'}$ gives

$$\pi'_{Js'}\nu^{i'}_0 = \gamma_{s'}\nu^i_{4s'}. \tag{127}$$

Household i's FOC for μ_J^i gives

$$\nu_0^{i'} = (1 + r_J) E_0 \nu_{4\boldsymbol{s}}^i. \tag{128}$$

Combine (125), (127) and (128):

$$\pi'_{Js'}(1 + r_J) E_0 \chi_{\boldsymbol{s}} \nu_{3\boldsymbol{s}}^i = \gamma_{s'} \nu_{4s'}^i. \tag{129}$$

To exclude arbitrage, it must be $\pi_{Js'} = \pi'_{Js'}$, and combine (126) and (129):

$$\frac{1 + r_I}{1 + r_J} = \frac{E_0 \nu_{3\boldsymbol{s}}^i \chi_{\boldsymbol{s}}}{E_0 \nu_{3\boldsymbol{s}}^i \chi}. \tag{130}$$

Now suppose household j can obtain currency I via FX market and foreign bank i. If household j obtains currency I via FX market, then household j's FOC for θ_s^i gives

$$\pi_{Is} \nu_2^j = \gamma_s \nu_{4s}^j. \tag{131}$$

Household j's FOC for f_{JI}^j gives

$$\nu_1^j = \chi \nu_2^j. \tag{132}$$

Household j's FOC for μ_J^j gives

$$\nu_1^j = (1 + r_J) E_0 \nu_{3\boldsymbol{s}}^j. \tag{133}$$

Household j's FOC for $f_{JI\boldsymbol{s}}^j$ gives

$$\nu_{3\boldsymbol{s}}^j = \chi_{\boldsymbol{s}} \nu_{4\boldsymbol{s}}^j. \tag{134}$$

Combine (131), (132), (133) and (134):

$$\pi_{Is}\frac{1}{\chi}(1+r_J)E_0\nu^j_{3\boldsymbol{s}}=\gamma_s\nu^j_{4s}. \tag{135}$$

If household j obtains currency I by borrowing μ^j_I from bank i. Let $\nu^{j'}_0$ be the shadow price of the liquidity-in-advance constraint, then household j's FOC for θ^j_s gives

$$\pi'_{Is}\nu^{j'}_0=\gamma_s\nu^j_{4s}. \tag{136}$$

Household j's FOC for μ^j_I gives

$$\nu^{j'}_0=(1+r_I)E_0\nu^j_{4\boldsymbol{s}}. \tag{137}$$

Combine (136), (137) and (134):

$$\pi'_{Is}(1+r_J)E_0\frac{\nu^j_{3\boldsymbol{s}}}{\chi_{\boldsymbol{s}}}=\gamma_s\nu^j_{4s}. \tag{138}$$

To rule out arbitrage, it must be $\pi_{Is}=\pi'_{Is}$, so it follows that

$$\frac{1+r_I}{1+r_J}=\frac{E_0\nu^j_{3\boldsymbol{s}}/\chi}{E_0\nu^j_{3\boldsymbol{s}}/\chi_{\boldsymbol{s}}}. \tag{139}$$

□

Proof of Proposition 6

Proof. Invoking Lemma 4, substitute (2.13) into (2.15), given $\tau_{H\boldsymbol{s}}=0$, we have

$$v^i_{\boldsymbol{s}}\mu^i_I=\sum_{l=1}^{S}\pi_{Il}\phi^i_{Il}+p_{I0}q^i_{I0}+p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}}-f^i_{IJ\boldsymbol{s}}-\phi^i_{I\boldsymbol{s}}. \tag{140}$$

Since $\sum_{l=1}^{S}\pi_{Il}\phi^i_{Il}+p_{I0}q^i_{I0}=\sum_{l=1}^{S}\pi_{Il}\theta^j_{Il}+b^j_{I0}=\chi f^j_{JI}-\Delta^j_2=f^i_{IJ}-\Delta^j_2$. Substitute it in (140), we have

$$v^i_{\boldsymbol{s}}\mu^i_I=f^i_{IJ}-\Delta^j_2+p_{I\boldsymbol{s}}q^i_{I\boldsymbol{s}}-f^i_{IJ\boldsymbol{s}}-\phi^i_{I\boldsymbol{s}}. \tag{141}$$

With market clearing conditions $\theta^j_{Is} = \phi^i_{Is}$, $f^i_{IJs} = f^j_{JIs}\chi_s$ and $p_{Is}q^i_{Is} = b^j_{Is}$, and also $\theta^j_{Is} + f^j_{JIs}\chi_s + \Delta^j_2 = b^j_{Is}$, (141) becomes

$$v^i_s \mu^i_I = f^i_{IJ}. \tag{142}$$

Given Δ(2.11), (142) becomes

$$v^i_s \mu^i_I = \frac{\mu^i_I}{1 + r_I} + m^i. \tag{143}$$

Similarly for country J

$$v^j_s \mu^j_J = \frac{\mu^j_J}{1 + r_J} + m^j. \tag{144}$$

Thus, $v^i_s = v^i$ and $v^j_s = v^j$. □

Proof of Corollary 6.1

Proof. As shown in the proof of Corollary 1.1, bank h's FOC gives $\omega^h_s = (\frac{v^h_s}{\sum_{s=1}^S \eta_s v^h_s} - 1)\mu^h_{CBH}$, $s \in S, h \in \{i, j\}, H \in \{I, J\}$. As shown in the proof of Proposition 6, $v^h_s = v^h$, thus $\frac{v^h_s}{\sum_{s=1}^S \eta_s v^h_s} - 1 = 0$, $\omega^h_s = 0$, and there is no need for national bailout tax. □

Proof of Corollary 6.2

Proof. Under the conditions of Proposition 5, $\omega^h_s = 0$, $s \in S, h \in \{i, j\}$. □

Proof of Lemma 9

Proof. Let $\Delta^i_{02} = \Delta$(2.12), and denote Δ^j_{02} for the equivalent of household j. Suppose $\Delta^i_{02} \neq 0$ and $\Delta^j_{02} \neq 0$. Household i's FOC for Δ^i_{02} and household j's FOC for Δ^j_{02} lead to

$$\nu^i_2 = E_0 \nu^i_{4s}, \tag{145}$$

$$\nu^j_2 = E_0 \nu^j_{4s}. \tag{146}$$

Household i and household j's FOCs for FX give $\nu_1^i = \nu_2^i/\chi$ and $\nu_1^j = \chi\nu_2^j$. Combine these two equations with (145) and (146), we have

$$\chi\nu_1^i = E_0\nu_{4\boldsymbol{s}}^i, \tag{147}$$

$$1/\chi\nu_2^j = E_0\nu_{4\boldsymbol{s}}^j. \tag{148}$$

Moreover, household i's FOC for μ_I^i gives $\nu_1^i = (1+r_I)E_0\nu_{5\boldsymbol{s}}^i$. Substitute it in (147), we have $\chi(1+r_I)E_0\nu_{5\boldsymbol{s}}^i = E_0\nu_{4\boldsymbol{s}}^i$. Also, FOC for $f_{IJ\boldsymbol{s}}^i$ gives $\nu_{3\boldsymbol{s}}^i = 1/\chi_{\boldsymbol{s}}\nu_{4\boldsymbol{s}}^i$, and $\nu_{3\boldsymbol{s}}^i = \nu_{5\boldsymbol{s}}^i$, it follows that

$$E_0\frac{(1+r_I)\chi}{\chi_{\boldsymbol{s}}}\nu_{4\boldsymbol{s}}^i = E_0\nu_{4\boldsymbol{s}}^i. \tag{149}$$

Similarly for household j

$$E_0\frac{(1+r_J)\chi_{\boldsymbol{s}}}{\chi}\nu_{4\boldsymbol{s}}^j = E_0\nu_{4\boldsymbol{s}}^j, \tag{150}$$

which are equivalent to

$$cov(\frac{(1+r_I)\chi}{\chi_{\boldsymbol{s}}}, \nu_{4\boldsymbol{s}}^i) + E_0\frac{(1+r_I)\chi}{\chi_{\boldsymbol{s}}}E_0\nu_{4\boldsymbol{s}}^i = E_0\nu_{4\boldsymbol{s}}^i, \tag{151}$$

$$cov(\frac{(1+r_J)\chi_{\boldsymbol{s}}}{\chi}, \nu_{4\boldsymbol{s}}^i) + E_0\frac{(1+r_J)\chi_{\boldsymbol{s}}}{\chi}E_0\nu_{4\boldsymbol{s}}^j = E_0\nu_{4\boldsymbol{s}}^j. \tag{152}$$

Given $cov(\frac{1}{\chi_{\boldsymbol{s}}}, \nu_{4\boldsymbol{s}}^i) > 0$ and $cov(\chi_{\boldsymbol{s}}, \nu_{4\boldsymbol{s}}^j) > 0$, from (151) and (152) it follows that

$$E_0\frac{(1+r_I)\chi}{\chi_{\boldsymbol{s}}} < 1, \tag{153}$$

and

$$E_0 \frac{(1+r_J)\chi_{\boldsymbol{s}}}{\chi} < 1. \tag{154}$$

Given $r_I = r_J$, (153) and (154) contradict each other. □

Proof of Corollary 6.3

Proof. When FX-in-advance binds, the current account net inflow of country I is

$$CA^I_{\boldsymbol{s}} = p_{I\boldsymbol{s}} q^i_{I\boldsymbol{s}} - \chi_{\boldsymbol{s}} b^i_{J\boldsymbol{s}} = p_{I\boldsymbol{s}} q^i_{I\boldsymbol{s}} - \chi_{\boldsymbol{s}} \theta^i_{J\boldsymbol{s}} - f^i_{IJ\boldsymbol{s}}. \tag{155}$$

The capital account net inflow of country I is

$$FA^I_{\boldsymbol{s}} = -\phi^i_{I\boldsymbol{s}} + \chi_{\boldsymbol{s}} \theta^i_{J\boldsymbol{s}}. \tag{156}$$

The net position of the BoP is

$$CA^I_{\boldsymbol{s}} + FA^I_{\boldsymbol{s}} = p_{I\boldsymbol{s}} q^i_{I\boldsymbol{s}} - f^i_{IJ\boldsymbol{s}} - \phi^i_{I\boldsymbol{s}}. \tag{157}$$

From (2.13) we know

$$p_{I\boldsymbol{s}} q^i_{I\boldsymbol{s}} = \Delta(2.13) + f^i_{IJ\boldsymbol{s}} + \phi^i_{I\boldsymbol{s}} - (\sum_{l=1}^{S} \pi_{Il} \phi^i_{Il} + p_{I0} q^i_{I0}). \tag{158}$$

Combine (157) and (158) we have

$$CA^I_{\boldsymbol{s}} + FA^I_{\boldsymbol{s}} = \Delta(2.13) - (\sum_{l=1}^{S} \pi_{Il} \phi^i_{Il} + p_{I0} q^i_{I0}). \tag{159}$$

As shown in Lemma 6, $\Delta(2.13) = \frac{\mu^i_I}{1+r_I} + m^i$. Also $\sum_{l=1}^{S} \pi_{Il} \phi^i_{Il} + p_{I0} q^i_{I0} = f^j_{JI} \chi = f^i_{IJ} = \frac{\mu^i_I}{1+r_I} + m^i$. Therefore, $CA^I_{\boldsymbol{s}} + FA^I_{\boldsymbol{s}} = 0$. Likewise for country J $CA^J_{\boldsymbol{s}} + FA^J_{\boldsymbol{s}} = 0$. □

First-order conditions of Regime D

The following FOCs are derived under Lemma 7.

$$(1+r_I)E_0\frac{U^i_{c^i_{Is}}}{p_{Is}}=\frac{1}{\chi}\frac{U^i_{c^i_{J0}}}{p_{J0}}, \tag{160}$$

$$\frac{U^i_{c^i_{I0}}}{p_{I0}}=E_0\frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{161}$$

$$(1+r^J)E_0\frac{U^j_{c^j_{Js}}}{p_{Js}}=\chi\frac{U^j_{c^j_{I0}}}{p_{I0}}, \tag{162}$$

$$\frac{U^j_{c^j_{J0}}}{p_{J0}}=E_0\frac{U^j_{c^j_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}}, \tag{163}$$

$$1+r_I=\frac{1+\rho_I}{\sum_{\boldsymbol{s}=1}^{S}z_{\boldsymbol{s}}v^i_{\boldsymbol{s}}}, \tag{164}$$

$$1+r_J=\frac{1+\rho_J}{\sum_{\boldsymbol{s}=1}^{S}z_{\boldsymbol{s}}v^j_{\boldsymbol{s}}}, \tag{165}$$

For state s:

$$\frac{U^i_{c^i_{Is}}}{p_{Is}}=\frac{1}{\chi_s}\frac{U^i_{c^i_{Js}}}{p_{Js}}, \tag{166}$$

$$\pi_{Is}\frac{U^i_{c^i_{I0}}}{p_{I0}}=\gamma_s\frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{167}$$

$$\frac{\lambda^i}{p^I_s}\geq\frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{168}$$

$$\frac{\lambda}{p^I_s}>\frac{U^i_{c^i_{Is}}}{p_{Is}}, \tag{169}$$

$$\frac{U^j_{c^j_{Js}}}{p_{Js}}=\chi_s\frac{U^j_{c^j_{Is}}}{p_{Is}}, \tag{170}$$

$$\pi_{Is}\frac{U^j_{c^j_{I0}}}{p_{I0}} = \gamma_s \frac{U^j_{c^j_{Is}}}{p_{Is}}, \tag{171}$$

$$\frac{\lambda^j}{p^J_s} \geq \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{172}$$

$$\frac{\lambda}{p^J_s} > \frac{U^j_{c^j_{Js}}}{p_{Js}}, \tag{173}$$

For state s':

$$\frac{U^i_{c^i_{Is'}}}{p_{Is'}} = \frac{1}{\chi_{s'}}\frac{U^i_{c^i_{Js'}}}{p_{Js'}}, \tag{174}$$

$$\frac{U^i_{c^i_{J0}}}{p_{J0}}\pi_{Js'} = \gamma_{s'}\frac{U^i_{c^i_{Js'}}}{p_{Js'}}, \tag{175}$$

$$\frac{\lambda^i}{p^I_{s'}} \geq \frac{U^i_{c^i_{Is'}}}{p_{Is'}}, \tag{176}$$

$$\frac{\lambda}{p^I_{s'}} > \frac{U^i_{c^i_{Is'}}}{p_{Is'}}, \tag{177}$$

$$\frac{U^j_{c^j_{Js'}}}{p_{Js'}} = \chi_{s'}\frac{U^j_{c^j_{Is'}}}{p_{Is'}}, \tag{178}$$

$$\pi_{Js'}\frac{U^j_{c^j_{J0}}}{p_{J0}} = \gamma_{s'}\frac{U^j_{c^j_{Js'}}}{p_{Js'}}, \tag{179}$$

$$\frac{\lambda^j}{p^J_{s'}} \geq \frac{U^j_{c^j_{Js'}}}{p_{Js'}}, \tag{180}$$

$$\frac{\lambda}{p^J_{s'}} > \frac{U^j_{c^j_{Js'}}}{p_{Js'}}. \tag{181}$$

□

Proof of Corollary 6.4

Proof. To obtain the MRS between goods at $t = 0$, let us combine (160) and (161):

$$(1 + r_I)\frac{U^i_{c^i_{I0}}}{p_{I0}} = \frac{1}{\chi}\frac{U^i_{c^i_{J0}}}{p_{J0}}. \tag{182}$$

Combine (162) and (163):

$$(1 + r_J)\frac{U^j_{c^j_{J0}}}{p_{J0}} = \chi\frac{U^j_{c^j_{I0}}}{p_{I0}}. \tag{183}$$

Combine (182) and (183):

$$\frac{U^i_{c^i_{I0}}}{U^i_{c^i_{J0}}} = \frac{U^j_{c^j_{I0}}}{U^j_{c^j_{J0}}}\frac{1}{(1 + r_I)(1 + r_J)}. \tag{184}$$

To obtain the MRS between goods at $t = 1$, combine (166) and (174), and combine (170) and (178), we obtain $\forall \boldsymbol{s} \in S$:

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}} = \frac{1}{\chi_{\boldsymbol{s}}}\frac{U^i_{c^i_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}}, \tag{185}$$

$$\frac{U^j_{c^j_{J\boldsymbol{s}}}}{p_{J\boldsymbol{s}}} = \chi_{\boldsymbol{s}}\frac{U^j_{c^j_{I\boldsymbol{s}}}}{p_{I\boldsymbol{s}}}. \tag{186}$$

Combine (185) and (186):

$$\frac{U^i_{c^i_{I\boldsymbol{s}}}}{U^i_{c^i_{J\boldsymbol{s}}}} = \frac{U^j_{c^j_{I\boldsymbol{s}}}}{U^j_{c^j_{J\boldsymbol{s}}}}. \tag{187}$$

□

Proof of Corollary 6.5

Proof. To derive the risk sharing condition between households with respect to consumption good I, let us rearrange (167):

$$U^i_{c^i_{Is}} = \frac{\pi_{Is} p_{Is} U^i_{c^i_{I0}}}{p_{I0}\gamma_s}. \tag{188}$$

Combine (160), (161), (174), and (175):

$$U^i_{c^i_{Is'}} = \frac{\pi_{Js'}\chi(1+r_I)p_{Is'}U^i_{c^i_{I0}}}{p_{I0}\chi_{s'}\gamma_{s'}}. \tag{189}$$

Combine (188) and (189):

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{\pi_{Is}p_{Is}\chi_{s'}\gamma_{s'}}{\gamma_s\pi_{Js'}\chi(1+r_I)p_{Is'}}. \tag{190}$$

Rearrange (171):

$$U^j_{c^j_{Is}} = \frac{p_{Is}\pi_{Is}U^j_{c^j_{I0}}}{p_{I0}\gamma_s}. \tag{191}$$

Combine (162), (163), (178), and (179):

$$U^j_{c^j_{Is'}} = \frac{\chi U^j_{c^j_{I0}}\pi_{Js'}p_{Is'}}{p_{I0}(1+r_J)\gamma_{s'}\chi_{s'}}. \tag{192}$$

Combine (191) and (192):

$$\frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}} = \frac{p_{Is}\pi_{Is}(1+r_J)\gamma_{s'}\chi_{s'}}{\gamma_s\chi\pi_{Js'}p_{Is'}}. \tag{193}$$

Combine (190) and (193)

$$\frac{U^i_{c^i_{Is}}}{U^i_{c^i_{Is'}}} = \frac{U^j_{c^j_{Is}}}{U^j_{c^j_{Is'}}}\frac{1}{(1+r_J)(1+r_I)}. \tag{194}$$

Similar rearrangements of algebra lead to a similar expression as follows for the risk sharing

condition with respect to consumption good J:

$$\frac{U^i_{c^i_{Js}}}{U^i_{c^i_{Js'}}} = \frac{U^j_{c^j_{Js}}}{U^j_{c^j_{Js'}}} \frac{1}{(1+r_J)(1+r_I)}. \tag{195}$$

□

Proof of Corollary 6.6

Proof. For the state price of state s, combine (167) (170), (171), and (183):

$$\pi_{Is} = \gamma_s \frac{U^i_{c^i_{Is}}/p_{Is}}{U^i_{c^i_{I0}}/p_{I0}} = \gamma_s \frac{U^j_{c^j_{Js}}/p_{Js}\chi}{U^j_{c^j_{J0}}/p_{J0}\chi_s(1+r_J)}. \tag{196}$$

For the state price of state s', combine (174), (175), (179), and (182):

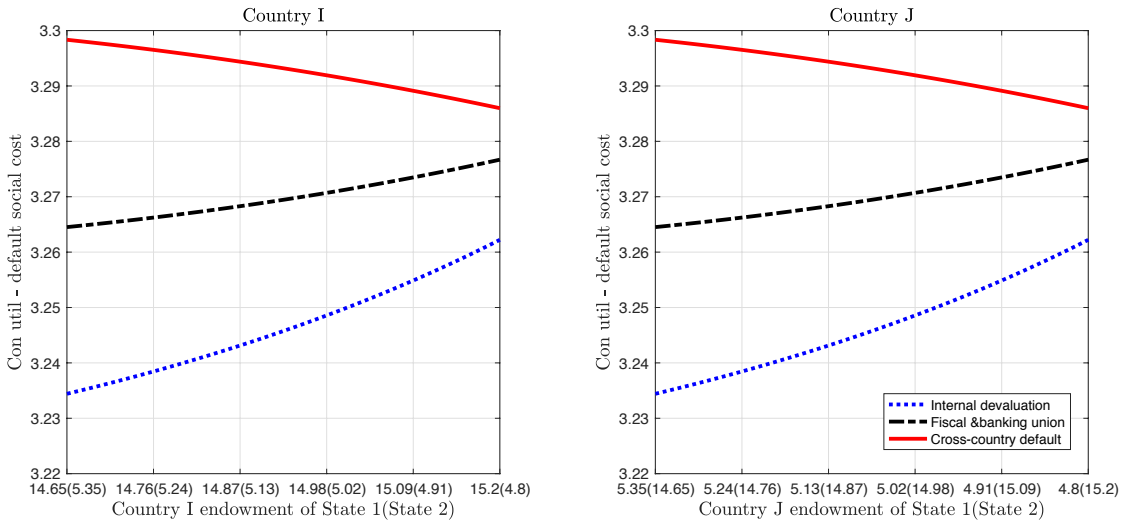
$$\pi_{Js'} = \gamma_{s'} \frac{U^i_{c^i_{Is'}}/p_{Is'}\chi_{s'}}{U^i_{c^i_{I0}}/p_{I0}(1+r_I)\chi} = \gamma_{s'} \frac{U^j_{c^j_{Js'}}/p_{Js'}}{U^j_{c^j_{J0}}/p_{J0}}. \tag{197}$$

□

5. Numerical Illustrations

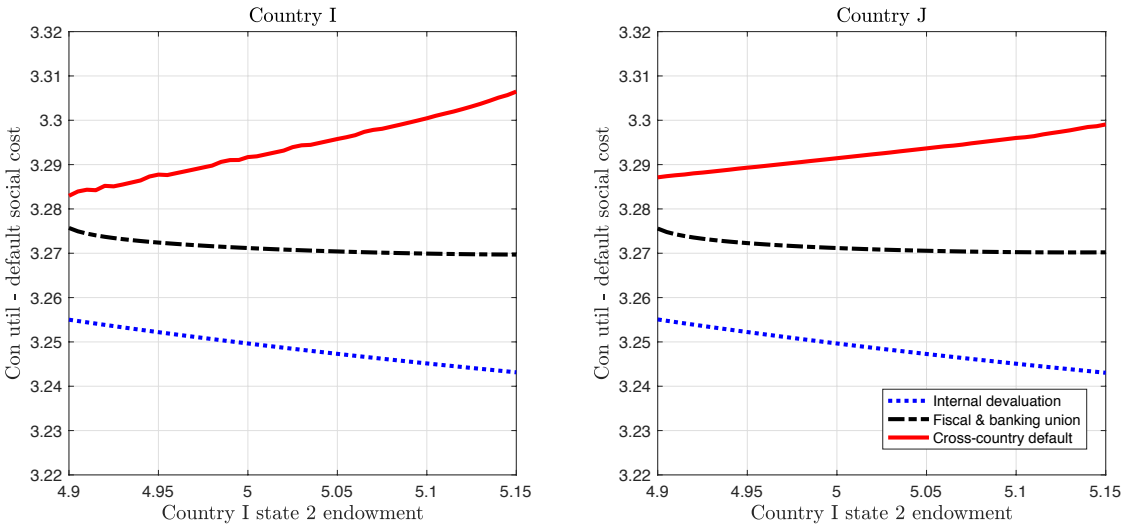
5.1.

Figure 13: Social utility (shock variance)



5.2.

Figure 14: Social utility (e^i_{I2})



Chapter 3

Bank Credit and Default in Infinite Horizon

[1]

Ever since the Great Financial Crisis, if not before, it has become clear that there are complex interactions between the real and nominal sectors of the economy. When do monetary and financial policy goals conflict with each other? When is monetary policy a complement to or a substitute for macroprudential policy? What is the role of money-financed fiscal expansion and its impact on allocations, prices, and financial stability? We develop a dynamic stochastic general equilibrium (DSGE) model featuring deposit issuance via bank credit and endogenous default. We argue that the official policy rate and the financial wedge, namely the spread between loan and deposit rates, are the key variables for the analysis of the interaction between price stability and financial fragility. We show that both the monetary policy rate and the financial wedge exert real effects, even though prices are fully flexible. We establish, first, that contractionary monetary policy is, typically, unable to lean effectively against the wind during periods of financial deregulation; second, that capital requirements often have procyclical effects; third, that monetary policy is more effective when the economy is more liquidity-constrained; and fourth, that money-financed fiscal expansion is effective in raising output and inflation, and accompanied with lower credit risks.

[1] This chapter derives from my joint work with Charles A.E. Goodhart at Financial Markets Group and London School of Economics and Dimitrios Tsomocos at Saïd Business School and University of Oxford.

1. Introduction

Ever since the Great Financial Crisis (GFC), if not before, it has become clear that financial frictions are as, or more, important than price/wage stickiness in explaining the manifold deviations of our economies from a perfectly flexible real business cycle. Many of such financial frictions, though not all, relate to liquidity problems whereby agents do not have, or fear that they may not have, sufficient liquidity to meet contractual payments. While there have been a number of recent commendable papers analysing such liquidity problems, both theoretically, e.g., de Fiore et al. (2019), and empirically (see Caballero et al. 2019; Brogaard et al. 2017; Eser and Schwaab 2016), most of these papers either assume away the probability that agents may default, or confine default probabilities to the non-financial corporate sector, or model default as an out of equilibrium, never really occurring in equilibrium, phenomenon as in Gertler and Kiyotaki (2010) and Alvarez and Jermann (2000). Yet even a cursory reading of history would indicate that the main occasions of serious crisis and depression were intimately related to the default, or potential default, of financial intermediaries, notably banks; Lehman Bros being just the latest, typical example.

An analogy that we like to use is that the relationship between liquidity and default is like the relationship between theology and sin; the latter in each case is unfortunate but essential. If it was certain that any agent, in any sector, would never, under any circumstances, default on their liabilities, that agent's liabilities would be riskless and fully liquid at all times. If, for example, either households or firms never defaulted, then their IOUs would be fully acceptable in payment for anything at all times. They would have no needs for banks. Indeed, if other agents within the system could default, then the agents who would never default would also, depending on other frictions, probably become financial intermediaries. For all such reasons, models involving banks who are never allowed to default are not only historically totally unrealistic, but also subject to the contradiction that they appear to need liquidity, but without default no such liquidity problem could ever arise in practice. We understand why models incorporating such an inherent contradiction exist and persist. The problem is that modelling default is inherently difficult, because default represents a discontinuity, and our standard mathematical models cannot cope with such discontinuities in the main.

The way that we seek to deal with this is to utilise the approach developed by Shubik and Wilson (1977) and Dubey et al. (2005) to turn the problem around by replacing the

discontinuity of bankruptcy by the decision of the amount to repay, which can be treated as a continuous variable. The less that an agent repays, whether by strategic choice or by adverse exogenous shock, the greater is the extent and expectation of default. While this may not be a perfect way of dealing with the discontinuity of bankruptcy, it is, we claim, a better way of doing so than any other present alternative. Thus, the purpose of our present paper is to explore, within the simplest possible model that we can construct, a system whereby the main players, non-financial companies and banks, can both have time and state varying repayment rates, i.e., that their probability of default can vary. In some cases, the repayment rate can go down (default probability rise) because of purely exogenous developments, e.g., the governance structure of banks changes, or a bank finds itself subject to fraud, or alternatively, the repayment rate can vary because of endogenous developments, e.g., the repayment rate of corporates goes down because of an adverse technological development, leading to rising non-performing loans (NPLs), and therefore putting pressure on banks to repay less. So the focus of this paper is to examine how both exogenous and endogenous shocks lead to changing repayment rates, and how these in turn have broader macroeconomic consequences.

For this purpose, we develop a simple DSGE model, where the commercial banks issue deposit contracts to finance firms' purchase of production factors. The key feature is the deposit contract, which plays a dual role as the stipulated means of exchange and a portfolio asset bearing interest payments. New deposit balances are issued against bank credit and are nominal. At the beginning of each period, a firm applies for loans from the banker who writes deposits to the firm against such bank credit involving a spread, or financial wedge, between the loan and deposit rates. This spread provides a buffer against the risk of borrowers' failing to repay and a source of profit on the banks' capital base. The firm uses the newly issued deposit balances to purchase labour from households, and households receive wages in terms of deposit balances. As banks are required to hold intra-period government bonds as safe assets, the government issues intra-period government bonds to the banks who write deposits to the government. Meanwhile, households use their deposit balances from wage payment to pay taxes and invest in riskless inter-period government bonds and deposit holdings that carry credit risks from the banking sector. After production, households utilise the deposit balances available to buy output from the firm and pay end-period taxes to the government. At the end of the period, the firm receives sales revenue and chooses the loan amount to repay to the bank, and finally distributes positive profits back to the households. The government

fully pays back government bonds held by the banks.

The need for banks to maintain a capital base for their lending operations provides a basis for the achievement of price stability, somewhat akin to the way that the availability of outside money does so in other models. We show that both the official monetary policy rate and the financial wedge exert real effects, even though in our model prices are fully flexible. In our analysis of the interaction between price stability and financial fragility, we describe how the interactions between the official policy rate and the financial wedge are crucial. In this exercise we find that contractionary monetary policy, attempting to offset periods of boom, is typically unable to lean effectively against the wind when coinciding with periods of financial deregulation. Although, since the Great Financial Crisis, a rich body of literature has emerged to model the interaction between monetary policy and financial frictions in a canonical DSGE model, the real effects of monetary policy in most of this body of literature are achieved by price stickiness in the non-financial sector. Our paper shows, instead, that the financial sector can exert significant effects on the real economy, even when all prices are flexible.

In addition, we also model a system in which households exhibit heterogeneity, with a set of rich households who undertake inter-period utility maximisation, and poor households who are liquidity constrained, spending all the wage income that they get on current consumption at all times.

Furthermore, to understand the nature of post-GFC central bank balance sheet expansion by Quantitative Easing, in our model, fiscal deficits are financed by government bonds, some of which are bought by banks. Thus, we are able to evaluate the real effect of money financed government debt in the presence of credit risks and to examine the nexus between money financing and fiscal policy. We find that money-financed fiscal expansion is typically effective in raising output and inflation, accompanied with lower credit risks.

The rest of the paper is structured as follows: Section 2 reviews the related literature. Section 3 presents the model. Section 4 characterises the equilibrium. Section 5 conducts numerical analysis and policy experiments. Section 6 is a conclusion.

2. Related literature

Our paper first and foremost connects with the growing body of literature on the financial spread and the effectiveness of monetary policy. For example, Curdia and Woodford (2010) and Cúrdia and Woodford (2016) model the financial spread as a time varying premium due to exogenous default, while the real effect of monetary policy is achieved via price stickiness in non-financial sectors. Lagos and Zhang (2019) model this spread via differing bargaining powers of agents with brokers with whom they have to transact and model money as an exogenous endowment. Drechsler et al. (2017) model this spread via the market power in deposit markets, and model the liquidity service of money via a reduced form approach (money-in-utility). In these works, the issuance of money and financial frictions are decoupled. Our model focuses on the actual issuance of fiat money via the banking sector and we model the financial spread as the lending to deposit rate spread partly due to endogenous default. The advantage of our approach is that the feedback loop between money and endogenous default, which are co-determined, can be examined.

More widely, a rich body of literature has emerged after the Global Financial Crisis to investigate the interplay between monetary policy and financial frictions (see Christiano et al. 2014; Aksoy and Basso 2014; Angeloni and Faia 2013; Ottonello and Winberry 2018). Most of these papers, to our knowledge, model monetary expansion separately from financial frictions. In these works, the issuance of money and financial frictions are decoupled, since there is no banking sector issuing fiat money in such models. Our contribution is to incorporate the banking sector into the DSGE model. Our model focusses on the actual issuance of fiat money by the banking sector and models the financial spread as, in some large part, due to endogenous default. We show how default and interest rates are co-determined, and an advantage of our approach is that the feedback loop between monetary expansion and endogenous default can be examined.

Moreover, our model reflects an insight of the fiscal theory of the price level (Buiter 1999, Sims 1994, and Cochrane 2001). In our model fiscal deficits are financed by government bonds, some of which are bought by banks, so our model allows banks' balance sheets to interact with nominal government bond issuance. Thus, we are able to evaluate the real effect of money financed government debt in the presence of credit risks and shed light on the nexus between money financing and fiscal policy. This is particularly relevant after the

Global Financial Crisis, because the decade-long central bank balance sheet expansion via quantitative easing after the crisis has blurred the boundary between monetary and fiscal interventions. Most recently, Galí (2019) examines the nexus between money financing and fiscal stimulus by modelling the government bond purchase via money creation. Thus, our work is also related to Galí (2019), but the one-step forward in our work is that we achieve non-neutrality of money via the cost of liquidity and default, whereas Galí (2019) obtains monetary non-neutrality by appealing to price stickiness in non-financial sectors.

Technically, the two key ingredients of our model are the modelling of money and liquidity provision via bank credit and the modelling of endogenous default and credit risks. The creation of fiat money via bank credit was extensively written about by early economists when the banking sector was booming. Classic works by Macleod (1866), Wicksell (1906), Hahn (1920), Hawtrey (1923), Keynes (1931), Schumpeter (1954), Tobin (1963) and Minsky (1977) have all provided insights into this mechanism and its macro-financial implications. The early formalisation of this mechanism is to be found in the general equilibrium theory of money. In this group of literature, there is an assumed requirement that money must be used to carry out transactions formalised through cash-in-advance constraints, similar to Grandmont and Younes (1972, 1973); Lucas Jr and Stokey (1987). Inside money enters the economy against an offsetting obligation that guarantees its departure, and it is issued when borrowing agents apply for loans from the banks. As in Tsomocos (2003), commercial banks can be viewed as creators of "money" à la Tobin (1963). In this model bank capital requirements play the same role as, exogenously given, outside money in most other such models in guaranteeing price level determinacy. In these models, the banking sector can be either an intermediary of existing money or a creator of new inside money, as in Dubey and Geanakoplos (1992, 2003b, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), and Goodhart et al. (2006, 2013).

After the Global Financial Crisis, there has been a revival of inside money modelling. Recent advances include and are not limited to Bigio and Weill (2016), Brunnermeier and Sannikov (2016) , Faure and Gersbach (2017), Donaldson et al. (2018), Kumhof and Wang (2018), Bianchi and Bigio (2018), Piazzesi and Schneider (2018), McMahon et al. (2018), and Kiyotaki and Moore (2018a). Our work complements this body of literature by focusing on the interaction between the financial wedge and monetary and fiscal policies.

The second ingredient of our model, endogenous default and credit risks, borrows the technique from Shubik and Wilson (1977) and Dubey et al. (2005). We introduce the choice of default via a non-pecuniary penalty. The cost of default increases with the size of default, following a similar treatment in Dubey et al. (2005); Adam and Grill (2017). In equilibrium, the borrower compares the marginal cost of default and marginal benefit of default, and may repay fully or partially, or default completely at a given state, depending on the states of nature.

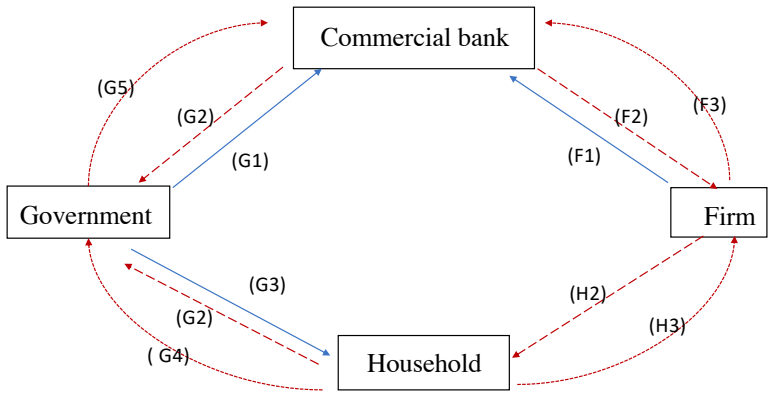
3. A Dynamic Model

3.1. Model Description and Timeline

The model has four agents and infinite periods. The households consist of a continuum of workers and entrepreneurs, and a competitive banking sector. Households own the firms and the banks. Workers supply labour, and entrepreneurs operate the firms and demand labour to produce consumption goods. The bankers operate the commercial banks that extend credit, against which deposits are issued to finance the entrepreneurs' purchase of labour. Both entrepreneurs and bankers pay dividends to the households. Households consume the final output. The model also allows the households to access inter-period government bonds as an inter-temporal nominal saving device. Thus, a government exists to issue both risk-less inter-period and intra-period government bonds. The inter-period bonds are held by the households whereas the intra-period bonds are issued to the commercial banks which are required to hold safe assets. The government is a combined fiscal-monetary authority that decides on the total supply of riskless government bonds and sets the intra-period government bond rate as the monetary policy rate.

The model operates in a competitive environment. The key feature is the function of the deposit contract. Note that the deposit contract in this model plays a dual role as the stipulated means of exchange and a portfolio asset that brings interest payment. New deposit balances are issued against bank credit. Figure 3.1 displays the model structure and nominal flows. The solid line arrow illustrates nominal borrowing, the dashed line arrow illustrates the deposit balances issued against bank credit, and the dotted line arrow illustrates deposit balances used for repayment.

Figure 3.1: Model Structure and Nominal Flows

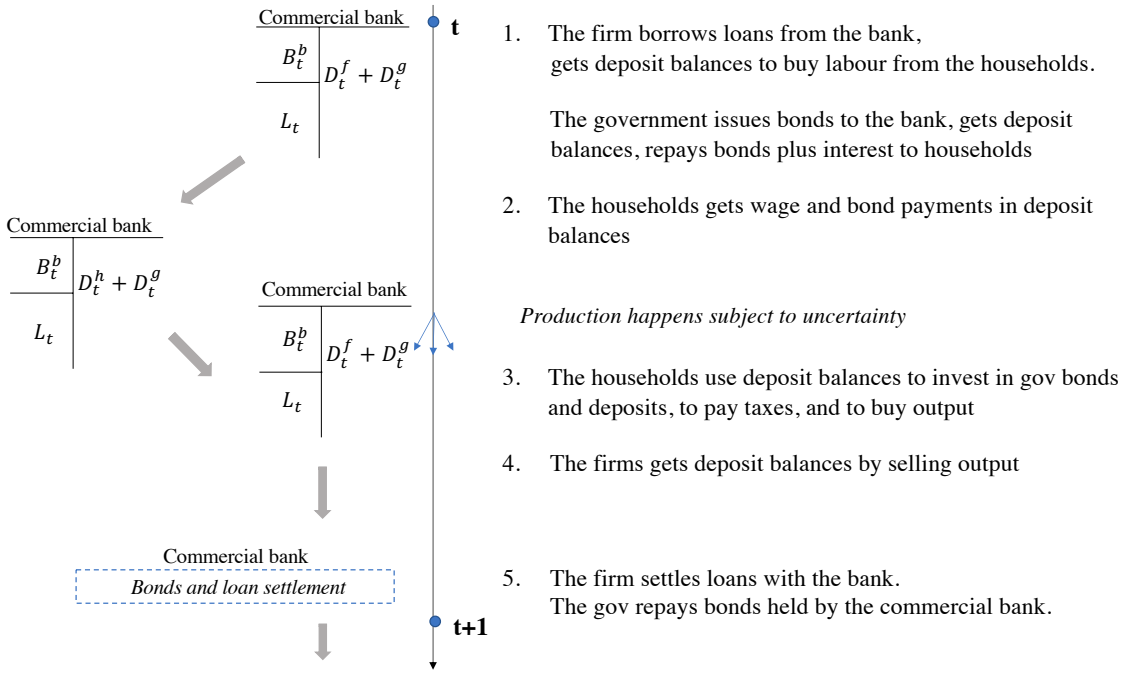


F1: Firm borrows loans
G1: Gov issues bonds to the bank
F2: Firm gets deposit balances
G2: Gov gets deposit balances and income tax
H2: Household gets wages
G3: Gov issues rolls over bonds held by the household and pays interest
H3: Household buys output
F3: Firm pays back loans
G4: Gov collects end-period taxes
G5: Gov pays back bonds held by the bank

At the beginning of t, the firm applies for loans from the banker who writes deposits to the firm against bank credit. The firm uses the newly issued deposit balances to purchase labour from households, and households receive wages in terms of deposit balances. As banks are required to hold intra-period government bonds as safe assets, the government issues intra-period government bonds to the banks who write deposits to the government. Meanwhile, households use their deposit balances from wage payment to pay tax and invest in new inter-period government bonds and deposit holdings. After production, households use the deposit balances at hand to buy output from the firm and pay end-period tax to the government. At the end of t, the firm receives sales revenue and chooses the amount of loan to repay the bank and distributes positive profits back to the households. The government fully pays back government bonds held by the banks. The banker then pays dividends to the households.

Figure 3.2 illustrates the timeline along with balance sheet changes, and the sequence of events in each sub-period.

Figure 3.2: Timeline of the Dynamic Model



Core Mechanism

Our model combines both monetary and financial frictions. It works as follows. The spread between loan and deposit rates, as we call the financial wedge, serves as a borrowing cost to the entrepreneurs who need credit and liquidity to finance their production factors. This borrowing cost is a transaction cost that affects the economic allocation in a similar way as a distortionary tax. This spread consists of the pass-through of policy rate, credit risk premia and profits to the financial sector. Monetary policy and macro-prudential policy affect both the demand side and the supply side of the economy through various components of this spread.

Moreover, because the entire circulation of deposits can be traced, the model is able to capture the interaction between this financial wedge and price level or inflation. To illustrate, suppose, *ceteris paribus*, we hold retained bank equity constant, an increase in the financial wedge corresponds to a decrease of credit demand and deposit issuance, leading to an endogenous reduction in total money supply and deflationary pressure. The deflationary pressure exacerbates the debt burden of both the entrepreneurs and the bankers; note that the deposits the banks issue are in fact the debt obligation of the bankers. Fisherian debt deflation leads to a higher cost of default, which would feed back to the financial wedge, reinforcing its

real effect. Consequently, our modelling of liquidity and default offers a better framework for analysing monetary policy and financial regulation simultaneously. This approach removes the dichotomy between price stability and financial stability, and no exogenous assumption is needed to generate price stickiness, *a priori*.

In short, the key step forward of our model from the existing macro-finance banking models is the interface between the financial wedge and inflation and its interaction with the real economy.

3.2. Firm

The firms are owned by households, and the entrepreneurs are assumed to be designated actors on behalf of households. The entrepreneur maximises the real value of the firm's profits from the perspective of the households, subject to a non-pecuniary default penalty cost.

Let,

$\Lambda_t \equiv$ the marginal utility of consumption of the household,

$\omega_t^f \equiv$ the real profits of the firm,

$L_t \equiv$ the face value of the loan the firm borrows,

$v_t^f \equiv$ firm's loan repayment rate,

$P_t \equiv$ the price level of the consumption good (i.e. value of money $= \frac{1}{P_t}$),

$\lambda_t^f [\mathbb{I}_t^f]^+ \equiv$ the non-pecuniary penalty cost if the firm fails to fully repay the loan, where

$$[\mathbb{I}_t^f]^+ = \left\{ \begin{array}{cc} [\frac{(1-v_t^f)L_t}{P_t}]^2 & \text{if } 1-v_t^f > 0 \\ 0 & \text{if } 1-v_t^f = 0 \end{array} \right\}.$$

The firm's choices include the labour demand of h_t^f, the loan demand of L_t, and the repayment rate of v_t^f on the outstanding loans. Formally, the firm's preference is given as follows:

$$\underset{h_t^f, L_t, v_t^f}{Max} E_t \Big\{ \Lambda_t \omega_t^f - \lambda_t^f [\mathbb{I}_t^f]^+ \Big\},$$

where λ_t^f can be interpreted as a non-bank sector credit quality shock, and it is a proxy for the entrepreneur's creditworthiness. A decrease in λ_t^f *ceteris paribus* leads to an increase in the credit risks of the corporate sector. We assume λ_t^f follows a mean-reverting AR(1) process.

To formally specify the flow of funds constraints the firm observes, let,

$W_t \equiv$ the nominal wage,

$r_t^l \equiv$ the loan rate,

$y_t \equiv$ final output,

and the firm is subject to the following constraints:

$$\underbrace{W_t h_t^f}_{\text{to pay wages}} \leq \underbrace{\frac{L_t}{1+r_t^l}}_{\text{apply for bank loan to get new deposit balances } D_t^f}, \tag{3.1}$$

$$\underbrace{P_t \omega_t^f}_{\text{nominal profits}} = \underbrace{P_t y_t}_{\text{sales revenue}} + \Delta_t(3.1) - \underbrace{v_t^f L_t}_{\text{partially repay bank loan and interest}}, \tag{3.2}$$

where $\Delta_t(3.1)$ is the unused deposit balances from the flow of funds constraint (3.1). Condition (3.1) states that at the beginning of t, the firm demands a loan to get new deposit balances to purchase labour. Against the loan L_t, the commercial bank issues deposit balances of D_t^f $(= \frac{L_t}{1+r_t^l})$ to the firm to finance its labour purchase.

Then the firm produces subject to a productivity shock A_t which follows an AR(1) process. For simplicity production follows a risky linear technology as $y_t = A_t h_t$, where h_t is the equilibrium level of labour. Then the firm sells output and gets revenue in deposit balances. The sales revenue and any unused deposit balances from Condition (3.1) constitute firm's total deposit balances at the interim stage. Condition (3.2) says the firm uses its sales revenue plus any unused deposit balances from Condition (3.1) to pay back the loan (subject to its default choice) and obtain profits. The firm is assumed to rebate any positive profits back to the household at the beginning of the next period.

3.3. Government

The government is a combined fiscal-monetary authority. It sets the total supply of government bonds of B_t and targets the intra-period government bond rate r_t as the policy rate based on a standard Taylor principle. Let $\bar{P}$ be the steady-state price level, and let $\bar{y}$ be the steady-state output. Eq(4.15) states the monetary policy rule[2], and S_t^m is a monetary policy shock that follows an AR(1) process.

$$r_t = r(\frac{P_t}{\bar{P}})^{m_p}(\frac{y_t}{\bar{y}})^{m_y} S_t^m. \tag{3.3}$$

The government issues both intra-period bonds and inter-period bonds. The intra-period bonds are issued to the bank at the policy rate r_t. The inter-period bonds are held by the household as an inter-temporal nominal saving device at the inter-period bond rate $\bar{r}_t$. Throughout the paper, government bonds are assumed to be non-defaultable; hence, they are riskless. Moreover, the government collects income tax of T_t and end-period tax of τ_t from the household in every period.

At the beginning of t, the government issues intra-period government bond B_t^b to the bank at the policy rate r_t, and it immediately gets deposit balances of D_t^g, as in (3.4). The deposit balances of D_t^g would carry deposit interest rate of r_t^d subject to the anticipated banks' repayment rate R_t^b. Meanwhile, the government rolls over the inter-period government bonds held by the household and collects income tax. The net repayment on the inter-period government bonds amounts to $B_{t-1}^h(1+\bar{r}_{t-1}) - B_t^h$ and it is paid out of the income tax collected (see Condition (3.5)). At the end of t, the government spends the unused deposit balances plus the end-period tax collected from the household on paying back the intra-period bond B_t^b. This is summarised by (3.6).

$$D_t^g = \frac{B_t^b}{1+r_t}, \tag{3.4}$$

$$B_{t-1}^h(1+\bar{r}_{t-1}) - B_t^h \leq T_t, \tag{3.5}$$

[2] As the model obtains price-level determinacy, the Taylor rule reacts to the inflation defined as the ratio of price level to the steady-state price level.

$$B_t^b = R_t^b D_t^g (1 + r_t^d) + \Delta(3.5) + \tau_t, \tag{3.6}$$

where $\Delta(3.5)$ is the unused deposit balances from Condition (3.5). Combine (3.4), (3.5) and (3.6), we obtain the government's inter-temporal budget constraint as in (3.7),

$$B_{t-1}^h (1 + \bar{r}_{t-1}) + B_t^b = B_t^h + T_t + \tau_t + R_t^b \frac{B_t^b}{1 + r_t} (1 + r_t^d). \tag{3.7}$$

.

3.4. Household

The households are endowed with leisure of n_t and derive utility from consumption and leisure. The household chooses the labour supply of h_t, the deposit holdings of D_t^h, the inter-period government bonds of B_t^h, as well as the consumption of c_t.

We assume that households are divided into two classes. The poor, who are liquidity constrained, have no wealth, and are incapable of borrowing because of high credit risk and no collateral, use all the money available to them immediately to buy goods and services. Because they have no outside option of holding other assets, and because their deposit balances are generally very small and more costly to operate (although we do not model this here), we assume that the deposits of the poor, D_t^p, are non-interest bearing.

In contrast, the other category of households is wealthy, and because they have the outside option of holding government bonds, their deposits have to be remunerated in line. We also assume that all taxes are paid by the wealthy households. The ratio of liquidity constrained to wealthy households is given by the parameter ν_t, which is assumed to follow a mean-reverting process. As might be expected, the deposits of the poor are fully insured by the government, whereas the deposits of the rich are only insured up to their nominal value, i.e. the bank can fail to pay out part, or all, of the interest originally contracted.

Let,

$\gamma_t^h \equiv$ the preference parameter of consumption, and $\gamma^h \in (0, 1)$,

$1 - \gamma_t^h \equiv$ the preference parameter of leisure,

$r_t^d \equiv$ the deposit rate,

$\Omega_t^f \equiv$ the nominal profit rebate from the firm,

$Div_t^b \equiv$ bank dividends to the household.

Formally, the household's preference is given as follows:

$$\underset{\{c_t,h_t,D_t^h,B_t^h\}_{t=0}^{\infty}}{Max} E_0 \sum_{t=0}^{\infty} \beta^t \Big\{ \gamma_t^h log(c_t) + (1-\gamma_t^h) log(n_t - h_t) \Big\},$$

subject to

$$B_t^h + D_t^h + T_t \leq (1-\nu_t) W_t h_t + B_{t-1}^h (1+\bar{r}_{t-1}), \tag{3.8}$$

$$\tau_t + P_t c_t = \Delta_t(3.8) + R_t^b D_t^h (1+r_t^d) + D_t^p + \Omega_{t-1}^f + Div_{t-1}^b, \tag{3.9}$$

where γ_t^h is assumed to follow a mean-reverting AR (1) process, and a reduction in γ_t^h is interpreted as a negative consumption demand shock. At the beginning of t, the households receive wage payments of $W_t h_t$ as deposit balances. We assume that a fraction ν_t of the households are poor. These poor households have a liquidity preference and put wage payments in non-interest bearing and risk-free deposits D_t^p, as stated in (3.10),

$$D_t^p = \nu_t W_t h_t. \tag{3.10}$$

The liquidity parameter ν_t is assumed to follow a mean-reverting AR(1) process. An increase in ν_t implies a tightening liquidity shock, which would affect the transmission mechanism of monetary policy.

The wealthy households have wage payments amounting to $(1-\nu_t)W_t h_t$, and together with the income from the last period's inter-period government bonds, they invest in new government bonds and *interest-bearing* deposits D_t^h and pay income tax. This is summarised in Condition (3.8).

Note that the interest-bearing deposit holdings are subject to banks' default risks. At the end of t, the total balance of the interest-bearing deposit holding amounts to $R_t^b D_t^h(1+r_t^d)$, where R_t^b is the expected repayment rate of the bank. At the end of t, the household has the nominal inflow from any unused balance of Δ_t(3.8) from (3.8), the interest bearing deposit holdings of $R_t^b D_t^h(1+r_t^d)$, the balances from demand deposits that amount to $\nu_t W_t h_t$, and the firm's profits of Ω_{t-1}^f and bank dividends of Div_{t-1}^b from the previous period. Households together use the nominal inflow to purchase consumption goods and pay end-period tax. This is summarised in Eq(3.9).

When the wealthy households make a portfolio decision between the inter-period government bonds and the interest-bearing deposit holdings, they need to trade off the interest payments from these two assets, and their respective riskiness, and liquidity or illiquidity. The inter-period government bonds are riskless. Although they carry nominal returns in the next period, in the current period they cannot be used directly to purchase consumption goods. The interest-bearing deposit holdings carry deposit rate, and the total of deposit plus interest payment are subject to banks' default risks, but unlike the government bonds, the deposit balances can be used directly to purchase consumption goods at the end of the current period.

3.5. Bank

The banker maximises the real value of the bank dividends from the household's perspective and suffers a non-pecuniary penalty cost from defaulting on deposit principal plus interest payment. The default penalty for the banking sector is set high enough such that the household does not lose on the deposit principal, reflecting that the government guarantees that the deposit balances issued against commercial bank credit are "essentially" fiat money, the legal tender of the fiscal-monetary sovereign. Moreover, as part of macro-prudential regulation, the bank faces the capital requirement Capital Adequacy Ratio (CAR) akin to Andreev et al. (2019) and is required to hold a certain amount of risk-less government bonds as safe assets. The bank would suffer a non-pecuniary cost from violating the CAR.

The banker supplies loans and demands[3] deposits at the equilibrium rates subject to a cost

[3]Note that banks issues deposit balances to the firm against bank credit in the first place, and banks only in this instance are "suppliers" of deposits. However, subsequently, the deposit balances flow to the household and the household owns the title of the deposit balances. Household then becomes the supplier of deposits while the banks now demands deposits due to the balance sheet constraint.

of violating the CAR. The banker also purchases the intra-period government bonds and chooses the repayment rate of the deposit principal plus interest.

Let,

$\Omega_t^b \equiv$ bank's nominal profits,

$d_t \equiv$ the real value of the bank dividends,

$D_t^b \equiv$ the interest-bearing deposit holdings the household and the government deposit to the bank,

$v_t^b \equiv$ the bank's repayment rate on the interest-bearing deposit plus interest,

$\iota_t \equiv$ the CAR,

$TA_t \equiv$ be the bank's *ex post* total assets and $TA_t = R_t^f L_t + B_t^b$,

$e_t \equiv$ the bank's nominal equity,

$\lambda_t^b[\mathbb{I}_t^\lambda]^+ \equiv$ the penalty should the bank fail to fully repay the interest-bearing deposit plus interest, where

$$[\mathbb{I}_t^\lambda]^+ = \left\{ \begin{array}{cc} (\frac{(1-v_t^b)D_t^b(1+r_t^d)}{P_t})^2 & \text{if } 1-v_t^b > 0 \\ 0 & \text{if } 1-v_t^b = 0 \end{array} \right\},$$

$\eta_t^b[\mathbb{I}_t^\eta]^+ \equiv$ is penalty should the bank fail to satisfy the CAR, where

$$[\mathbb{I}_t^\eta]^+ = \left\{ \begin{array}{cc} (\iota_t - \frac{e_t}{TA_t})^2 & \text{if } \frac{e_t}{TA_t} < \iota \\ 0 & \text{if } \frac{e_t}{TA_t} \geq \iota \end{array} \right\}.$$

Formally, the banker's preference is represented by

$$\underset{\{L_t, D_t^b, B_t^b, v_t^b)\}_{t=0}^\infty}{Max} E_0 \sum_{t=0}^{\infty} \beta^t \Big\{ \Lambda_t d_t - \lambda_t^b [\mathbb{I}_t^\lambda]^+ - \eta_t^b [\mathbb{I}_t^\eta]^+ \Big\},$$

subject to

$$D_t^b = D_t^h + D_t^g, \tag{3.11}$$

$$\Omega_t^b = B_t^b + R_t^f L_t - v_t^b D_t^b (1 + r_t^d) - D_t^p, \tag{3.12}$$

$$e_t = (1 - \kappa) e_{t-1} + \Omega_t^b, \tag{3.13}$$

$$P_t d_t = \kappa e_t, \tag{3.14}$$

$$(1 - \kappa) e_t = \xi_t, \tag{3.15}$$

where κ is the dividend payout ratio, and ξ_t is the ex-dividend bank capital level that follows a mean-reverting AR(1) process. Technically speaking, ξ_t plays the same role as outside money in achieving price-level determinacy.

Eq(3.11) states that the total interest-bearing deposit contracts amount to the sum of the household's interest-bearing deposit holdings and the government's deposits issued against the intra-period government bonds.

Eq(3.12) states the nominal profits of the bank. The nominal inflow consists of the end-period full repayment of intra-period government bonds and the partial repayment of commercial loans subject to default risks of $1-v_t^f$. The nominal outflow consists of the wealthy households' deposit plus interest payment subject to bank's repayment rate of v_t^b plus the poor households' deposit balances of D_t^p.

Eq(3.13) states the law of motion of the bank's nominal equity e_t. The current end-period's equity consists of last period's retained equity plus this period's nominal profits. Eq(3.14) says the banker pays a fraction κ of the bank's total equity as dividends to the household. The retained bank equity is assumed to satisfy a capital level requirement as in Eq(3.15).

Moreover, we assume that the bank holds a certain amount of intra-period government bonds

as safe assets. That is to say, the government requires a ratio of government debt to business loans and the bank needs to satisfy this ratio, i.e. Eq(3.16). This ratio δ_t is assumed follows a mean-reverting AR(1) process. The Capital Adequacy Ratio (CAR) ι_t follows a counter-cyclical macro-prudential policy rule that responds to bank's NPL rate. Eq(3.17) states the CAR policy rule and S_t^ι is the macro-prudential policy shock that follows an AR(1) process. As the NPL rate goes up, the CAR increases to build up the real value of bank capital to absorb loan losses. As it will turn out in the simulation exercise, the stance of CAR is key to real effect of the loan-deposit rate spread in our framework.

$$B_t^b = \delta_t L_t, \tag{3.16}$$

$$\iota_t = \bar{\iota}(\frac{1 - v_t^f}{1 - \bar{v}^f})^{m_\iota} S_t^\iota. \tag{3.17}$$

Finally, the CAR punishment parameter η_t^b follows a mean-reverting AR(1) process, and a decrease in η_t^b is interpreted as a deregulation shock.

3.6. Equilibrium

Following Tsomocos (2003), Goodhart et al. (2006, 2012), given the exogenous shocks, this dynamic stochastic general equilibrium is a sequence of quantities (c_t, y_t, Ω_t^f, d_t h_t^f, h_t, L_t, D_t^f, D_t^h, D_t^b, D_t^g, B_t^h, B_t^b, T_t, e_t) and prices (P_t, W_t, r_t^l, r_t^d, $\bar{r}_t$, v_t^f, v_t^b), given policy instruments (r_t, ι_t), government action (B_t, δ_t), dividend policy and retained capital (κ, ξ_t), default penalty parameters (λ_t^f,λ_t^b), and CAR violation penalty parameter (η_t^b), agents maximise subjects to deposits-in-advance constraints, budget sets, and goods market, labour market, loan market, deposit market, and government bond market clear, and expectations are rational.

Market clearing conditions

- Goods market:

$$y_t = c_t; \tag{3.18}$$

- Labour markets:

$$\begin{gathered} h_t = h_t^f; \\ (\Rightarrow W_t) \end{gathered} \tag{3.19}$$

- Loan market:

$$D_t^f = \frac{L_t}{1 + r_t^l}; \tag{3.20}$$

- Government bond market:

$$D_t^g = \frac{B_t^b}{1 + r_t}, \tag{3.21}$$

$$B_t = B_t^h + B_t^b; \tag{3.22}$$

- Deposit market:

$$\begin{gathered} D_t^b = D_t^h + D_t^g; \\ (\Rightarrow r_t^d) \end{gathered} \tag{3.23}$$

- Rational expectation:

$$R^f = \left\{ \begin{array}{cc} v_t^f & \text{if } 1 - v_t^f > 0 \\ \text{arbitrary} & \text{if } 1 - v_t^f = 0 \end{array} \right\}, \tag{3.24}$$

$$R^b = \left\{ \begin{array}{cc} v_t^b & \text{if } 1 - v_t^b > 0 \\ \text{arbitrary} & \text{if } 1 - v_t^b = 0 \end{array} \right\}. \tag{3.25}$$

4. Equilibrium Characterisation

Lemma 1. Deposits-in-advance constraint binds.

If $r_t^l > 0$, then $\Delta_t(3.1) = 0$.

As long as the nominal borrowing cost is positive, the firm does not apply for more loans than necessary, so the deposit-in-advance constraint binds.

Proof. Suppose $\Delta_t(3.1) > 0$, then the firm can borrow ϵ less loan without violating (3.1). This leads to a reduction of deposit balances by $\epsilon/(1 + r_t^l)$ flowing to constraint (3.8). The loan needing to repay decreases by ϵ. Thus, there is an extra deposit balance of $r_t^l\epsilon/(1 + r_t^l)$ in (3.8). It either leads to an increase in firm's profits or repayment rate, both of which improve firm's utility. This is a contradiction; hence, $\Delta_t(3.1) = 0$. □

Lemma 2. No idle deposit balances in the portfolio.

If $R_t^b(1 + r_t^d) > 1$, then $\Delta_t(3.8) = 0$.

As long as bank's default on deposits plus deposit interest is small enough, i.e. it does not erode the principal of these deposit accounts, household invests the deposit balances at hand in either government bonds or the interest-bearing deposit holdings.

Proof. Suppose $\Delta_t(3.8) > 0$ and the household reduces $\Delta_b(3.8)$ by ϵ. The household invests this ϵ into the interest-bearing deposit holdings. The constraint (3.8) still holds. As uncertainty has already unfolded and $R_t^b(1 + r_t^d) > 1$, household gets an extra deposit balances of $(R_t^b(1 + r_t^d) - 1)\epsilon$ in (3.9). Household can use this extra deposit balances to increase consumption which increases utility. This is a contradiction. Hence, $\Delta_t(3.8) = 0$. □

Gven Lemma 1 and Lemma 2, Eq(3.26) - Eq(3.36) characterise the equilibrium. We obtain Eq(3.26) - Eq(3.36) by rearranging the key optimality conditions derived in Appendix 1.. Let Λ_t^b be the bank's Lagrangian multiplier of constraint (3.12) and its analytic expression is given in (3.26).

$$\Lambda_t^b - \beta(1-\kappa)\Lambda_{t+1}^b = \underbrace{\kappa_t \frac{\gamma^h}{P_t c_t}}_{\text{household's marginal utility}} + \underbrace{2\eta_t^b(\iota_t - \frac{\xi_t/(1-\kappa)}{(v_t^f P_t c_t + \delta P_t c_t)})\frac{1}{v_t^f P_t c_t + \delta P_t c_t}}_{\text{disutility from violating CAR regulation}}. \quad (3.26)$$

As the banking sector is owned by the household and is regulated by the government, equation (3.26) shows that the shadow price of bank's flow of funds constraint depends on the household's marginal utility and the disutility from violating CAR regulation. The following equations (3.27), (3.28), and

(3.29) characterise the real side of the economy. In particular, equation (3.28) is a consumption-based IS curve augmented with the bank default risks. These equations pin down consumption c_t, labour h_t and inter-temporal investment return $\bar{r}_t$. Let us observe that these three equations are augmented with financial variables v_t^f, v_t^b, r_t^l, r_t^d. Financial forces affect the real allocation and investment return.

Assuming partial default risks from the firm and the banking sector, the financial variables repayment rates, default and interest rates (v_t^f, v_t^b, r_t^l, r_t^d) and the nominal variables monetary policy rate (r_t) and price level (P_t)[4] are determined via the following equations (3.30), (3.31), (3.32), (3.33) (3.34), and (3.36). Equations (3.30), (3.31), (3.32), and (3.33) characterise the financial side of the economy. Equations (3.34), (3.35) and (3.36) characterise the nominal anchor, a micro-founded LM curve, and the policy rate. Note that the real side and the nominal and financial side interact with each other, and it is not possible to decouple equations (3.27) (3.28) (3.29) from equations (3.30) (3.31) (3.32) (3.33) (3.34) (3.35) (3.36).

1. **Real economy** (consumption, labour, real investment return):

$$\underbrace{\frac{1-\gamma^h}{n_t-h_t}}_{\text{marginal cost of labour}} = \underbrace{\frac{(1-\nu_t)\gamma^h}{h_t}\frac{v_t^b(1+r_t^d)}{1+r_t^l}+\frac{\nu_t\gamma^h}{h_t}\frac{1}{1+r_t^l}}_{\text{marginal benefit affected by the financial variables and the liquidity preference}}, \tag{3.27}$$

$$\underbrace{c_t^{-1}=\beta c_{t+1}^{-1}/\pi_{t+1}\frac{v_{t+1}^b(1+r_{t+1}^d)}{v_t^b(1+r_t^d)}(1+\bar{r}_t),}_{\text{Euler equation augmented with bank default risks}} \tag{3.28}$$

$$\underbrace{A_t h_t = c_t.}_{\text{resource constraint}} \tag{3.29}$$

2. **Financial side** (interest rates, spread, and default):

$$\underbrace{2\lambda_t^f(1-v_t^f)}_{\text{marginal cost of firm default}} = \underbrace{\gamma^h/c_t^2,}_{\text{marginal benefit}} \tag{3.30}$$

$$\underbrace{2\lambda^b(1-v_t^b)[D_t^h+\delta P_t c_t/(1+r_t)](1+r_t^d)/P_t^2}_{\text{marginal cost of bank default}} = \underbrace{\Lambda_t^b,}_{\text{marginal benefit}} \tag{3.31}$$

$$\underbrace{(v_t^f-(1-\nu_t)\frac{1+r_t^d}{1+r_t^l}-\frac{\nu_t}{1+r_t^l})\Lambda_t^b = 2\eta_t^b(\iota_t-\frac{\xi_t/(1-\kappa)}{(v_t^f P_t c_t+\delta P_t c_t)})\frac{v_t^f\xi_t/(1-\kappa)}{(v_t^f P_t c_t+\delta P_t c_t))^2},}_{\text{spread between } r_t^l \text{ and } r_t^d \text{ affected by firm default and CAR}} \tag{3.32}$$

[4] If price level is determined, then inflation π_t is also determined

$$\underbrace{(1-\frac{1+r_t^d}{1+r_t})\Lambda_t^b = 2\eta_t^b(\iota_t - \frac{\xi_t/(1-\kappa)}{(v_t^f P_t c_t + \delta P_t c_t)})\frac{\xi_t/(1-\kappa)}{(v_t^f P_t c_t + \delta P_t c_t)^2}}_{\text{spread between } r_t \text{ and } r_t^d \text{ affected by CAR}}. \tag{3·33}$$

3. **Money and price level**:

$$\underbrace{\frac{\xi_t}{1-\kappa} - \xi_{t-1} = (v_t^f + \delta)P_t c_t - v_t^b(1+r_t^d)[D_t^h + \frac{\delta P_t c_t}{1+r_t}] - \frac{\nu_t P_t c_t}{1+r_t^l}}_{\text{retained bank equity and price level}}, \tag{3·34}$$

$$\underbrace{(v_t^b(1+r_t^d)-1)D_t^h = P_t c_t[1+(1-\frac{v_t^b(1+r_t^d)}{1+r_t})\delta - \frac{1}{1+r_t^l}] - (1-v_{t-1}^f)P_{t-1}c_{t-1} - \frac{\kappa\xi_{t-1}}{1-\kappa}}_{\text{deposits as a portfolio choice and a source of liquidity}}, \tag{3·35}$$

$$\underbrace{r_t = r(\frac{P_t}{\bar{P}})^{m_p}(\frac{y_t}{\bar{y}})^{m_y} S_t^m}_{\text{Taylor rule}}. \tag{3·36}$$

Lemma 3. Money and credit risks.

Suppose in equilibrium $0 < v_t^f < 1$, $2\lambda_t^f(1-v_t^f)\frac{L_t}{P_t} = \Lambda_t$.

The value of money affects the on-the-verge condition of firm's default.

Proof. Suppose $0 < v_t^f < 1$, take the first-order conditions for ω_t^f and v_t^f, and combine these two first-order conditions. □

The equation $2\lambda_t^f(1-v_t^f)\frac{L_t}{P_t} = \Lambda_t$ is the on-the-verge condition of firm's default choice on the bank loans. The left-hand side of this equation is the marginal cost of default and the right-hand side is the marginal benefit of default. Given price-level determinacy, the value of money in terms of consumption goods, i.e. $\frac{1}{P_t}$, enters the marginal cost of firm's default decision. Therefore, as might be expected, the effect of money on default is a key channel that monetary policy affects the real economy, even without assuming any price stickiness. To be more precise, let f_t be the financial wedge, or the spread between the loan rate and the deposit rate, and Θ_t be the expected financial and liquidity wedge. Proposition 1 formalises the real effects of the expected financial and liquidity wedge.

Let us define,

$$f_t \equiv \frac{1+r_t^l}{1+r_t^d},$$

and

$$\Theta_t \equiv [(1-\nu_t)\frac{R_t^b}{f_t} + \nu_t \frac{1}{1+r_t^l}]^{-1}.$$

Proposition 1. The financial and liquidity wedge non-neutrality.

In equilibrium, $y_t = A_t n_t (1 + \frac{1-\gamma^h}{\gamma^h}\Theta_t)^{-1}$. Given $\gamma^h \in (0,1)$, $dy_t/d\Theta_t < 0$.

The output is a decreasing function of the expected financial and liquidity wedge Θ_t.

Proof. Combine (3.27), (3.29), and $y_t = A_t h_t$, and rearrange terms, we obtain $y_t = A_t n_t (1 + \frac{1-\gamma^h}{\gamma^h}\Theta_t)^{-1}$. Since A_t, n_t and γ^h are all exogenous, and $\gamma^h \in (0,1)$, it follows that $dy_t/d\Theta_t < 0$. □

Therefore, whenever the monetary policy rate r_t passes through to the expected financial and liquidity wedge, monetary policy exerts real effects despite prices being fully flexible. To examine in detail the real effects of monetary policy, Figure 7 in Appendix 2.1. displays the simulated effect of an expansionary monetary policy shock S_t^m. As we can observe that the stronger preference for liquidity the household exhibits (i.e. higher ν_t), the more effective monetary policy is.

As the monetary policy rate is lowered, both the loan rate and deposit rate decrease and appear to go in lockstep. The loosened monetary condition reduces the NPL rate and also tends to squeeze bank profits on the margin. To counteract the squeeze on bank profits, banks increase the default rate on their debt obligations such that the net impact on the financial wedge is positive. Thus, the overall picture on financial stability is mixed. As the loan rate decreases, the firm faces a lower financing cost for its production; hence, real output increases. Price level and inflation also go up because the stronger credit demand induces an overshoot of deposit and liquidity creation. Total endogenous money supply increases and price level goes up despite the increase of the real quantity of output.

To unpack the expected financial and liquidity wedge Θ_t, Propositions 2-4 formalise the term structures of various interest rates. Proposition 2 examines how firm's credit risks, monetary policy rate, and households' liquidity preference affect the loan rate, the key borrowing cost for non-bank sectors. Proposition 3 relates the CAR violation cost to the spread between the policy rate and the deposit rate. Proposition 4 derives the relationship between the financial wedge, CAR violation cost, firm's default, and the households' liquidity preference. Let the spread between the policy rate and deposit rate be $\tilde{r}_t^{pd}$, and let us define,

$$\tilde{r}_t^{pd} \equiv \frac{1+r_t}{1+r_t^d}.$$

Proposition 2. Loan rate, default, and liquidity preference.

In equilibrium, $(1+r_t^l) = (1-\nu_t)\frac{(1+r_t)}{R_t^f} + \nu_t \frac{\tilde{r}_t^{pd}}{R_t^f}$.

The loan rate is a function of policy rate, firm's default, liquidity preference, and policy-deposit rate spread.

Proof. Combine (3.32), (3.33), and the rational expectation of repayment rates (3.7.) and (3.25), the result obtains. □

Corollary 1. If $\nu_t = 0$, it follows that $(1+r_t^l) = \frac{(1+r_t)}{R_t^f}$.

Proof. Combine $\nu_t = 0$ with $(1+r_t^l) = (1-\nu_t)\frac{(1+r_t)}{R_t^f} + \nu_t \frac{\tilde{r}_t^{pd}}{R_t^f}$. □

Under Proposition 2, a decrease in R_t^f, or an increase in the expected default rate of the firm, increases the loan rate *ceteris paribus*. However, if the household exhibits strong liquidity preference, i.e. a high ν_t, it adds downward pressure to the loan rate. This is because as the household exhibits strong liquidity preference, she is content with more non-interest bearing deposit balances, which reduces the cost of bank's liability. Given a competitive banking structure, this downward pressure transmissions to the loan rate the bank charges. If the liquidity preference is nil, then the loan rate is a function of only the monetary policy rate and the default risk premium (Corollary 1).

From Proposition 2, we can also observe that the change in policy rate r_t does not perfectly pass through to the loan rate r_t^l. First, it depends on how much credit risks bank loans take on; second, the pass-through is also affected by the spread between policy rate and deposit rate, which in turn depends on the stance of macro-prudential policy CAR (see Proposition 3); third, it is further complicated by the households' liquidity preference ν_t. The resulting changes due to policy rate then need to feed into the financial and liquidity wedge Θ_t in order for monetary policy to exert real effects.

Proposition 3. Deposit rate, policy rate, and CAR.

Suppose in equilibrium $\frac{\eta_t^b}{\Lambda_t^b}(\iota_t - \frac{e_t}{TA_t})\frac{e_t}{TA_t^2} < \frac{1}{2}$, then,

$$\tilde{r}_t^{pd} = [1 - 2\frac{\eta_t^b}{\Lambda_t^b}(\iota_t - \frac{e_t}{TA_t})\frac{e_t}{TA_t^2}]^{-1}. \tag{3.37}$$

The spread between the policy rate and the deposit rate is a function of the adjustment cost for violating the CAR.[5]

Proof. It follows directly from the bank's first-order condition for B_t^b. □

[5]The condition $\frac{\eta_t^b}{\Lambda_t^b}(\iota_t - \frac{e_t}{TA_t})\frac{e_t}{TA_t^2} < \frac{1}{2}$ holds in our calibration.

This proposition sheds light on how effective monetary policy would be when interacted with different stances of CAR. Suppose the government wants to slow an economic boom by raising the policy rate r_t, but the economy happens to be experiencing a financial deregulation at the same time, i.e. η_t^b decreases. This latter leads to a reduction in the CAR violation cost, the right-hand side of (3.37). On the one hand, the rise of policy rate r_t, if it successfully passes through to the loan rate, increases the borrowing cost of the producing firms, which adds downward pressure on real output and deflationary pressure to prices, but on the other hand, the reduction in the CAR violation cost means that the wedge between policy rate and the deposit rate decreases, so deposit rate goes up more than the rise in policy rate.

This increase in the deposit rate implies extra liquidity in the household deposit balances increasing aggregate demand and reducing the NPL rate, and at the same time the increase in deposit rate would reduce the spread between the loan rate and deposit rate, contributing to a loosened financial condition. These forces, in contrast to the objective of the monetary policy, add upward pressure on output and inflationary pressure to prices. Therefore, overall the rise in policy rate in this case may fail to put a brake on the economic boom. We examine this case in detail in the simulated dynamic responses in Section 5.1.

Proposition 4. Loan-deposit rate spread, financial wedge, and liquidity.

The financial wedge f_t is a function of firms' default, loan rate, and the adjustments for CAR violation cost and liquidity preference. In equilibrium,

$$1 - \frac{\nu_t}{R_t^f(1+r_t^l)} - \frac{1-\nu_t}{R_t^f}\frac{1}{f_t} = 2\frac{\eta_t^b}{\Lambda_t^b}(\iota - \frac{e_t}{TA_t})\frac{e_t}{TA_t^2}. \tag{3.38}$$

Proof. It follows directly from the bank's first-order condition for L_t. □

We can observe from (27) that as default risk increases, R_t^f decreases, *ceteris paribus*, the financial wedge widens. If the CAR regulation becomes tougher, the right-hand side of (27) increases, *ceteris paribus* the financial wedge also widens. The effect of liquidity preference on the financial wedge is more nuanced. The increase in ν_t that implies a stronger liquidity preference means that households are more contented with holding non-interest bearing deposit balances, which should decrease the loan rate the bank charges and increase the deposit rate. This adds downward pressure to the spread. To show the interplay between the financial wedge, liquidity and the monetary policy in detail, Section 5 simulates the dynamic responses.

5. Simulation

The discount factor β is set to 0.9925 to fix the steady state value of the inter-temporal government bond rate to 3% per annum. For the model specific parameters, using recent US data from FDIC we calibrate the firm's default penalty against the net charge-offs to net loans ratio at 0.2% as the proxy for non-performing loans to total loans ratio. We calibrate the bank's default penalty such that the default rate on deposit interest and principal payment is 0.05 %. Labour endowment n is set to 1.25 such that labour supply at the steady state is 1. Total government bond supply is a free parameter and is set to be 0.5 at the steady state. Moreover, in our simulation, we also display the impulse responses of the term premium, an auxiliary variable defined as the ratio between the inter-period government bond rate and the intra-period government bond rate.

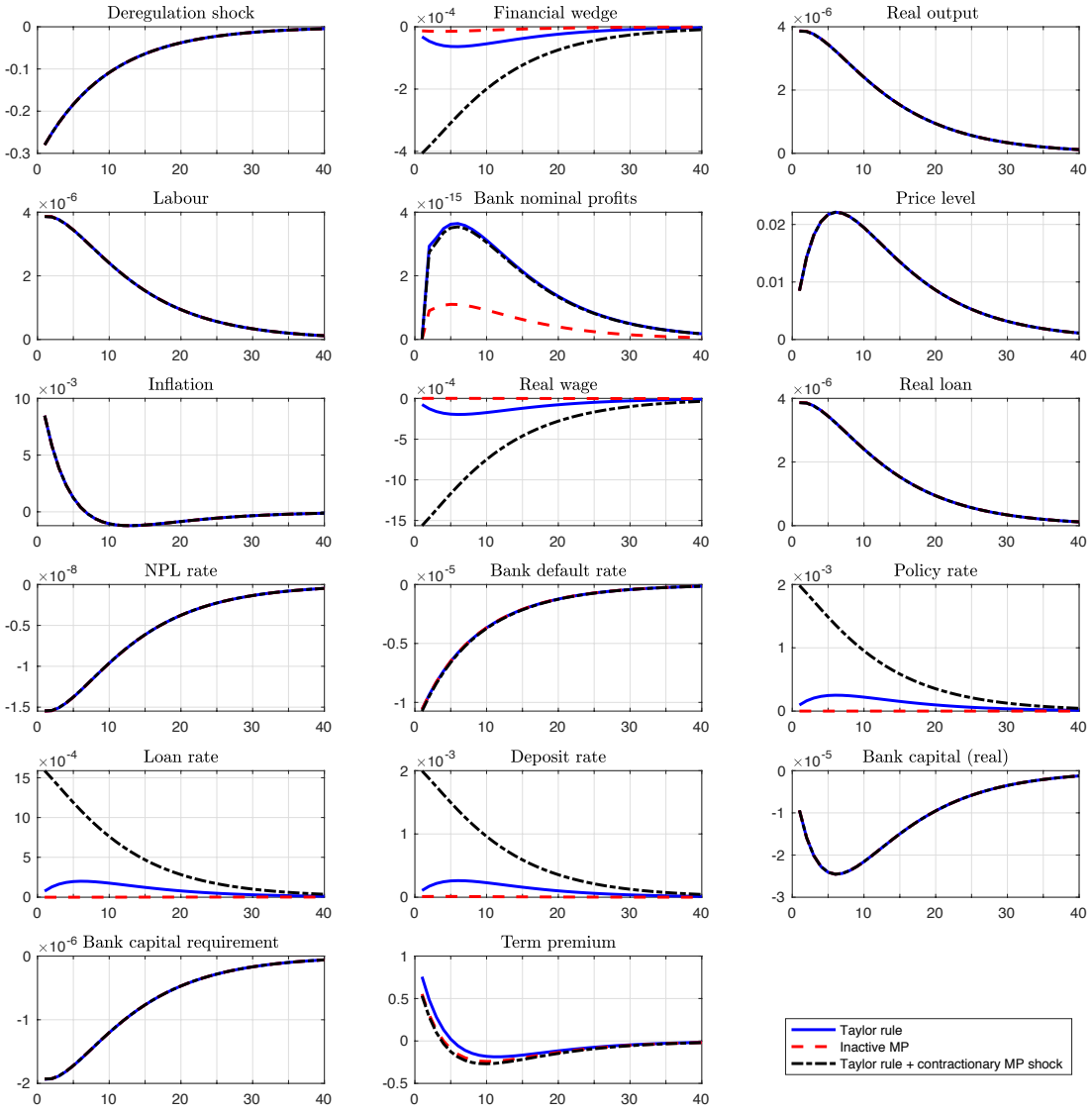
5.1. Deregulation and monetary policy

In Figure 3.3 we examine the following question: how effective can monetary policy be amidst financial deregulation. In this experiment, a negative shock lowers the CAR punishment parameter η_t^b, but CAR ι_t itself still follows the counter-cyclical macro-prudential policy rule. The solid line shows the impulse responses to the deregulation shock while monetary policy reacts endogenously to inflation and output via the Taylor rule. The dashed line exhibits the impulse responses to the deregulation shock while monetary policy remains inactive. The dashed dotted line displays the impulses responses to the deregulation shock while monetary policy not only reacts to inflation and output based on the Taylor rule, but also further increase to counteract the deregulation shock.

As can be seen, when the deregulation shock hits, the real value of bank capital decreases, CAR is loosened, the economy booms with both real output and inflation/price level going up. The reduction in the real value of bank capital and loosened CAR imply that the banking sector is less well positioned to buffer unexpected deterioration of its assets. Monetary policy increases the policy rate with the objective of counteracting the boom, as shown in the solid line and the dashed dotted line. As can be seen, the counteracting effect from monetary policy is minimal, as the responses of output, inflation and real credit supply do not differ much between those of the solid and the dashed dotted line, and those of the dashed line, where monetary policy remain inactive.

This experiment vindicates and provides a rationale for the stylised fact prior to the Global Financial Crisis, whereby, with a loosened financial environment in the face of deregulation shocks, the financial wedge decreases, so the effect of a tightened monetary policy rate does little to put a brake on the economic boom.

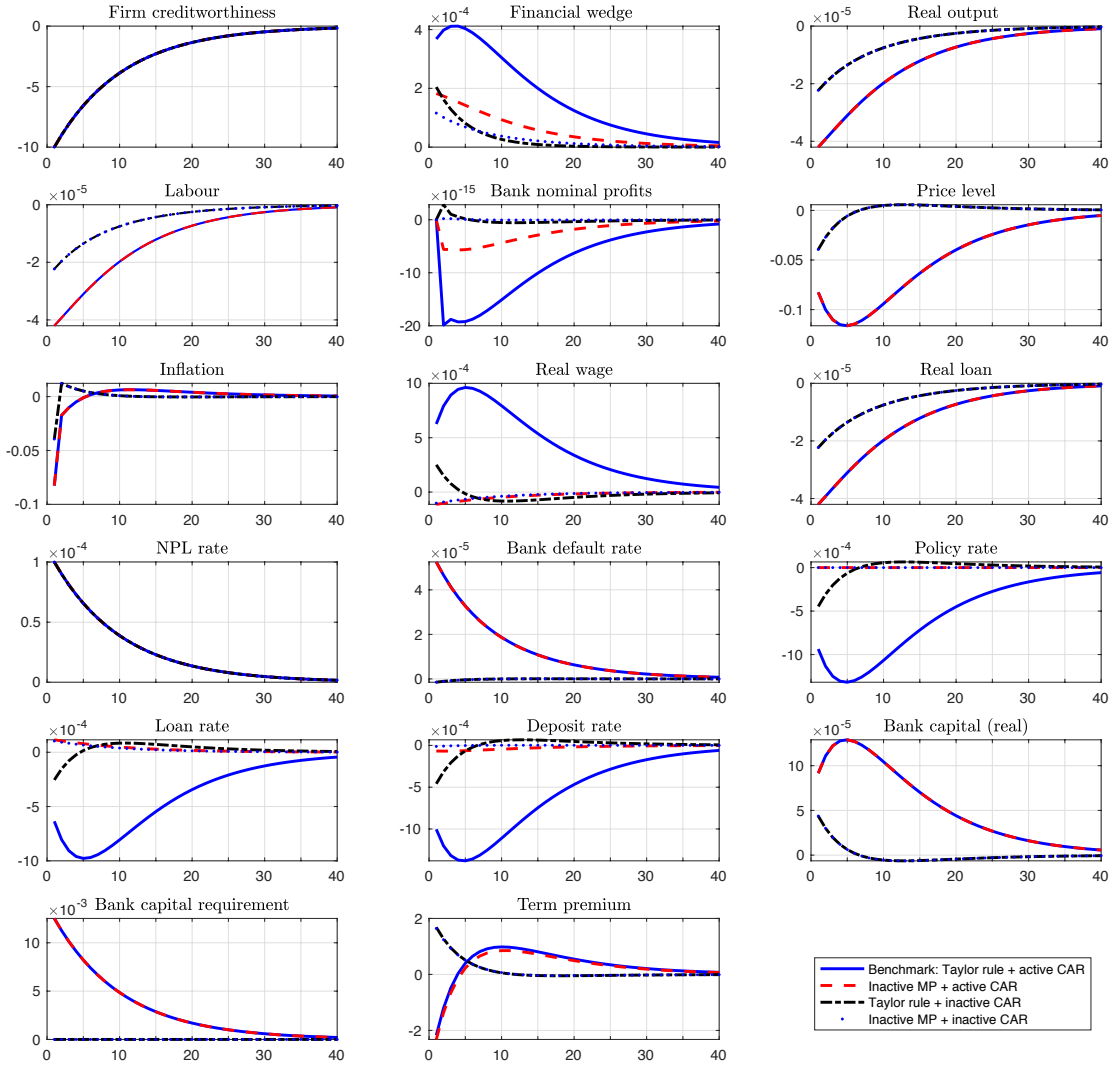
Figure 3.3: Deregulation shock and monetary policy



5.2. Rising NPLs and policy responses

Figure 3.4 shows how the economy responds to a deterioration of loan quality and rising NPLs. The initial shock is a temporary negative shock to firm's creditworthiness, i.e., λ_t^f. The financial wedge between the loan rate and the deposit rate goes up, real output falls, NPL rate and bank default risks both go up, and the economy enters temporary deflation. Overall, financial stability risks are higher. The solid line represents the impulse response when both monetary policy rule and the macro-prudential policy rule on CAR responds endogenously. The dashed line displays the impulse responses of an economy where monetary policy rate is kept inactive but the CAR rule remains active. The dashed dotted line shows the impulse responses of an economy where the monetary policy rule is active, but the CAR rule becomes inactive. And the dotted line illustrates the case of inactive monetary policy and inactive CAR rule.

Figure 3.4: Loan quality shock



Between the solid line and the dashed line, we can see that the effectiveness of active monetary policy on output, the real value of the bank capital, real credit supply is very weak, but its effectiveness on the loan rate, deposit rate, and the financial wedge is much more pronounced. However, the effectiveness of a CAR rule in the presence of a loan quality shock is much stronger and appears to be procyclical. As we can observe between the solid line and the dashed dotted line, when the CAR becomes inactive and does not respond to the rise in NPLs, real output decreases less, the increase in financial wedge is smaller, and price level and inflation go down much less than in the CAR-active case. However, in the CAR-inactive case, the real value of bank capital is much lower, and banks are in a worse position to absorb the rise in NPLs.

In short, as NPL rises, although the rise of CAR increases the real value of bank capital, it is procyclical and pushes output to drop further with stronger deflationary pressure. In the presence of this loan

quality shock, the loosening monetary position, i.e. the fall in policy rate, provides weak support to the economy. Thus, the procyclicality of CAR rule builds a case for a countercyclical bank capital buffer since monetary policy cannot be effectively used as a substitute nor a complement to the CAR rule in this case.

5.3. Macro-prudential policy experiments

Figure 3.5 displays the impulse responses when the CAR shock S_t^{ι} increases. In the event of a tightening CAR shock, bank capital requirement goes up to build up the real value of bank capital. Meanwhile, the financial wedge widened, output and prices both drop. The CAR, therefore, exhibits procyclical property.

Figure 3.5: CAR shock

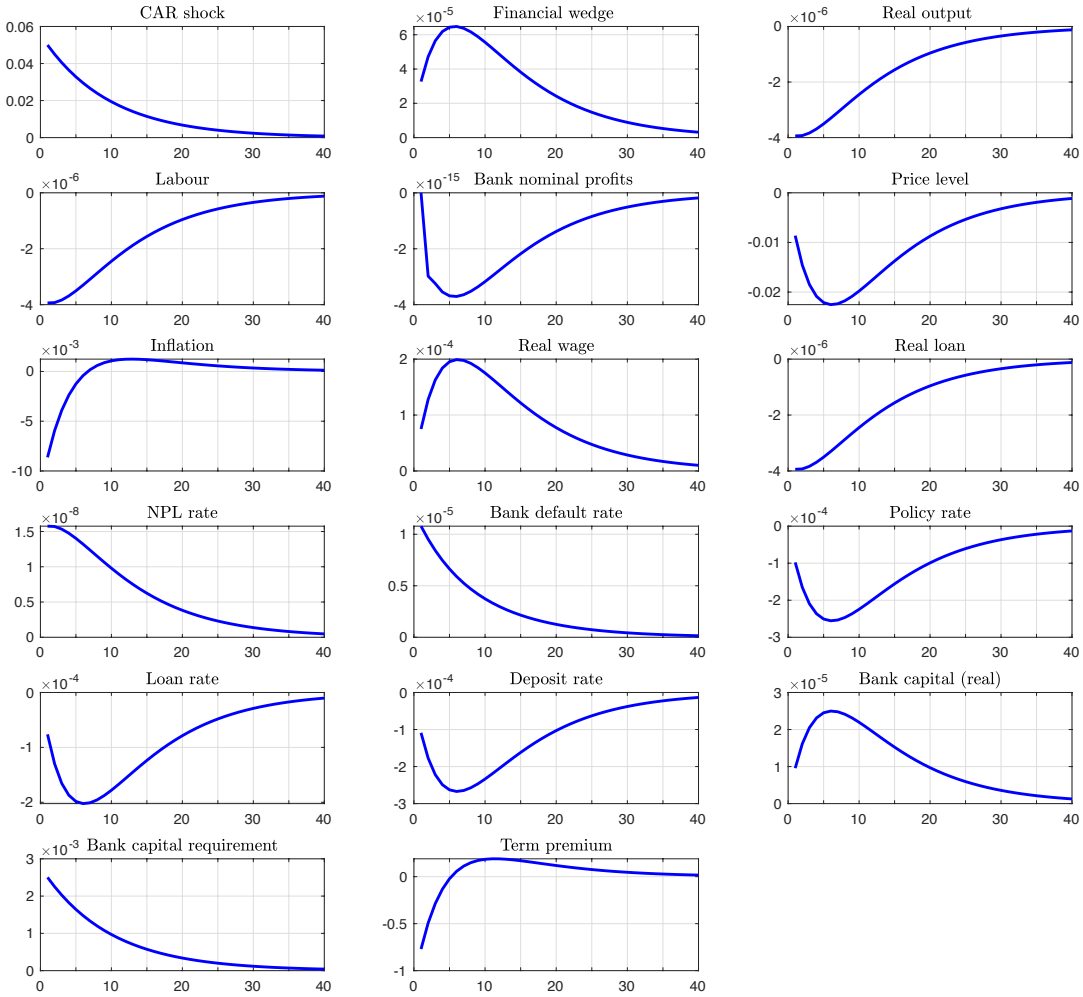
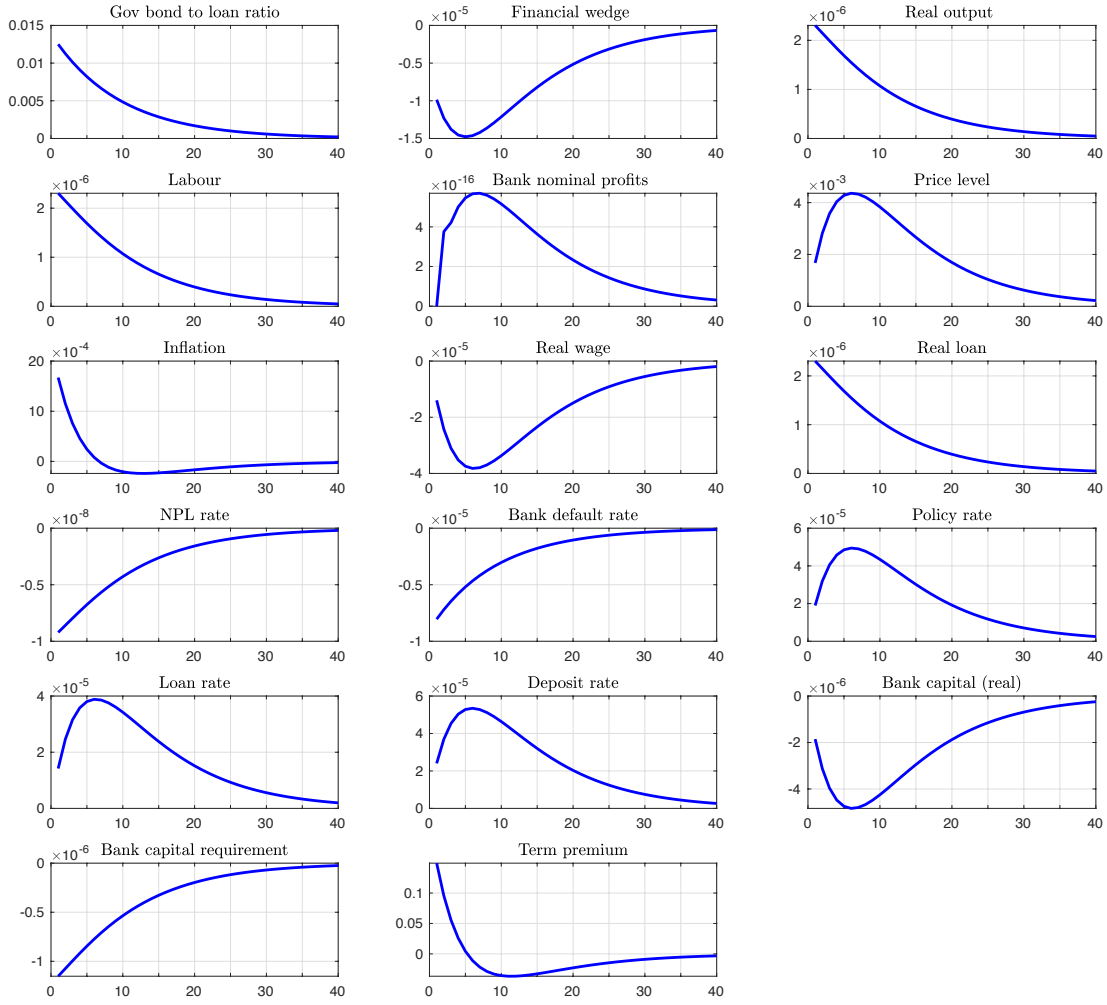


Figure 3.6 shows how the economy behaves when the government bond to loan ratio δ_t increases. As the bank holds more safe assets, the nominal profits of the bank face upward pressure, allowing the bank to extend more loans and increase repayment rate on its debt obligations. Thus, nominal

credit supplies increases contributing to inflationary pressure. At the same time, the drop in bank's default rate increases the household's liquidity on the margin. When the household uses deposit balances to purchase output from the firm, that extra liquidity flows to the firm which increases the firm's repayment rate. Thus, both NPL rate and bank's default risks decrease. Overall, the economy displays subdued financial stability risks, accompanied by a narrowing financial wedge and an improvement in real output.

Figure 3.6: Money-financed fiscal expansion



6. Conclusion

In this paper, we have proposed a tractable dynamic stochastic general equilibrium model addressing the interaction between the financial wedge and the monetary policy rate. The key feature of the model is the deposit contract, which is essentially inside money issued against an offsetting bank credit. The deposit contract plays a dual role as the stipulated means of exchange and a portfolio asset. The deposit contracts are issued and circulated via the banks' balance sheets. They mobilise

physical resources to facilitate production and trade, in the presence of endogenous default in both the banking and non-bank sectors, being the key financial friction.

With fully flexible prices, retained bank capital becomes the basis of price level determinacy, and money non-neutrality obtains. Therefore, the model is able to generate a feedback loop between the value of money and endogenous default and examine the effectiveness of money-financed fiscal expansions. The key equations that characterise the real side of an otherwise canonical business cycle model, i.e., a micro-founded consumption based IS curve, labour and consumption equation, and the resource constraint, are augmented with financial spreads and credit risk premia. To determine the financial spreads and credit risk premia, we derive a micro-founded LM curve and utilise the retained bank capital as the nominal anchor to obtain the price level. We show that the official policy rate and the financial wedge, namely the spread between loan and deposit rates, are the key variables for the analysis of the interaction between price stability and financial fragility. We also find, first, that contractionary monetary policy, typically, is unable to lean effectively against the wind during periods of financial deregulation; second, that capital regulation is generally procyclical; third, that monetary policy is more effective when the economy is more liquidity constrained; and fourth, that money-financed fiscal expansion is effective in raising output and inflation, accompanied by lower credit risks.

A broader role of this paper is to put fiat money issuance via banking, i.e., inside money, back into dynamic monetary models. We believe that explicitly modelling inside money and banking is the right direction to provide a better handle for choosing policies that address price stability and financial stability simultaneously.

Appendices

1. Characterisation equations

Firms

Given Lemma 1, let η_{1t} and η_{2t} be the Lagrangian multipliers of (3.1) and (3.2) respectively.

- FOC for h_t

$$-W_t\eta_{1t} + A_tP_t\eta_{2t} = 0$$

- FOC for L_t

$$-\frac{2\lambda_t^f}{P_t^2}(1-v_t^f)^2L_t + \frac{\eta_{1t}}{1+r_t^l} - v_t^f\eta_{2t} = 0$$

- FOC for v_t^f

$$\frac{2\lambda_t^f}{P_t^2}(1-v_t^f)L_t - \eta_{2t} = 0$$

- FOC for ω_t^f

$$\frac{\gamma^h}{c_t} - \eta_{2t}P_t = 0$$

- Simplify

$$W_t(1+r_t^l) = P_tA_t \tag{39}$$

$$\frac{2\lambda_t^f}{P_t}(1-v_t^f)L_t = \frac{\gamma^h}{c_t} \tag{40}$$

$$W_th_t = \frac{L_t}{1+r_t^l} \tag{41}$$

$$P_t\omega_t^f = P_tA_th_t - v_t^fL_t \tag{42}$$

Government

$$B_{t-1}^h(1+\bar{r}_{t-1}) + B_t^b = B_t^h + T_t + \tau_t + v_t^b\frac{B_t^b}{1+r_t}(1+r_t^d) \tag{43}$$

Household

Given lemma 2, let Λ_t^h be the Lagrangian multiplier of (3.9).

$$\frac{1-\gamma^h}{n_t-h_t}-(1-\nu_t)\frac{W_t}{P_t}\frac{\gamma^h}{c_t}v_t^b(1+r_t^d)-\nu_t\frac{W_t}{P_t}\frac{\gamma^h}{c_t}=0 \tag{44}$$

$$\frac{\gamma^h}{P_t c_t}v_t^b(1+r_t^d)=\beta\frac{\gamma^h}{P_{t+1}c_{t+1}}(1+\bar{r}_t)v_{t+1}^b(1+r_{t+1}^d) \tag{45}$$

Bank

Let Λ_t^b be the Lagrangian multiplier of (3.12)

$$-\Lambda_t^b+\beta(1-\kappa_t)\Lambda_{t+1}^b+\kappa_t\frac{\gamma^h}{P_t c_t}+2\eta_t^b(\iota-\frac{e_t}{v_t^f L_t+B_t^b})\frac{1}{v_t^f L_t+B_t^b}=0 \tag{46}$$

$$(v_t^f-(1-\nu_t)\frac{1+r_t^d}{1+r_t^l}-\frac{\nu_t}{1+r_t^l})\Lambda_t^b-2\eta_t^b(\iota-\frac{e_t}{v_t^f L_t+B_t^b})\frac{v_t^f e_t}{(v_t^f L_t+B_t^b)^2}=0 \tag{47}$$

$$(1-\frac{1+r_t^d}{1+r_t})\Lambda_t^b-2\eta_t^b(\iota-\frac{e_t}{v_t^f L_t+B_t^b})\frac{e_t}{(v_t^f L_t+B_t^b)^2} \tag{48}$$

$$\frac{2\lambda^b(1-v_t^b)D_t^b(1+r_t^d)}{P_t^2}-\Lambda_t^b=0 \tag{49}$$

Combine (39), (40), (41) and $y_t=A_t h_t=c_t$, we get

$$2\lambda_t^f(1-v_t^f)=\frac{\gamma^h}{c_t^2} \tag{50}$$

Combine (44), (39), and $y_t=A_t h_t=c_t$, we get

$$\frac{1-\gamma^h}{n_t-h_t}=\frac{(1-\nu_t)\gamma^h}{h_t}\frac{v_t^b(1+r_t^d)}{1+r_t^l}+\frac{\nu_t\gamma^h}{h_t}\frac{1}{1+r_t^l} \tag{51}$$

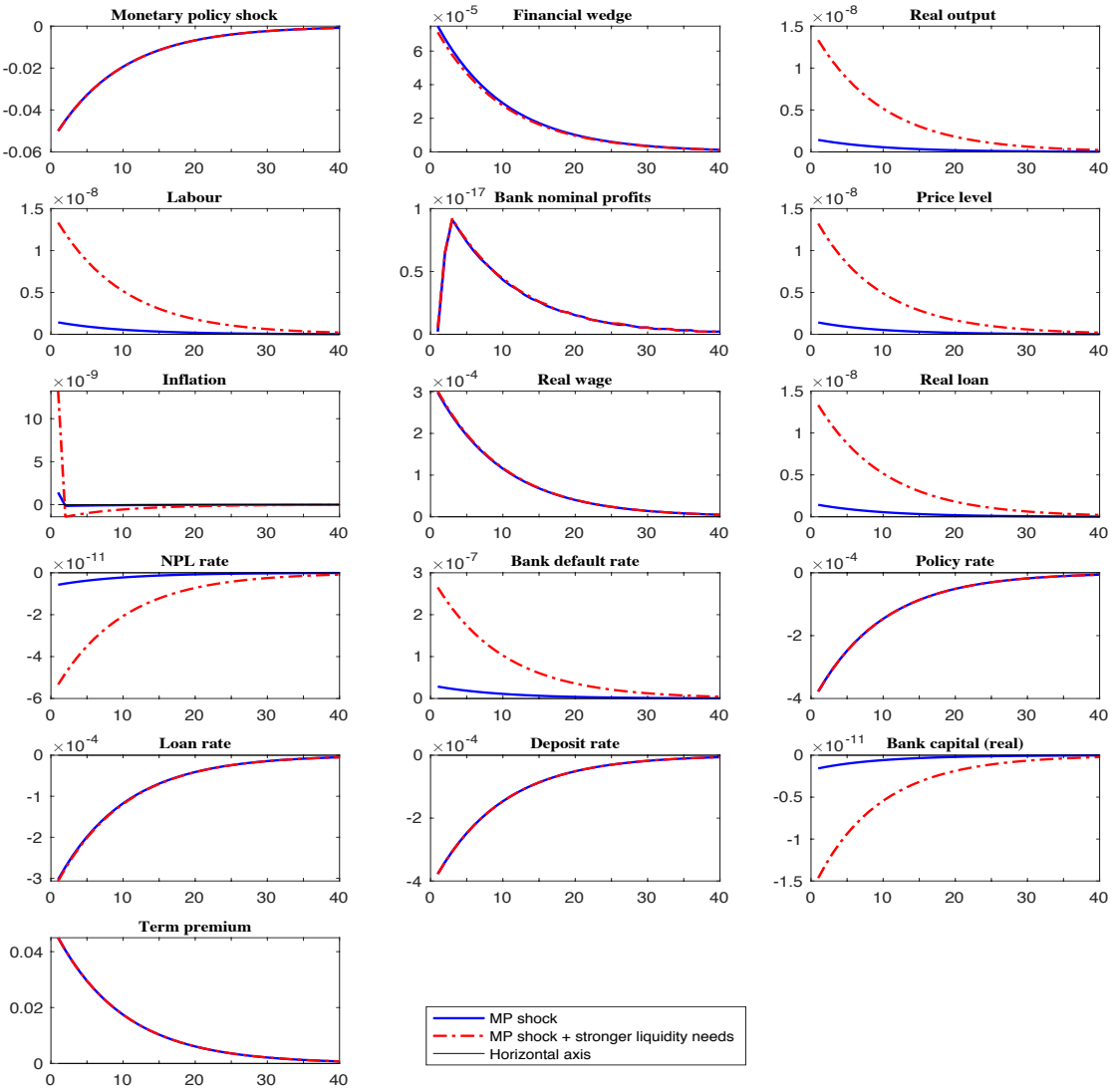
Rearrange (45)

$$c_t^{-1}=\beta c_{t+1}^{-1}/\pi_{t+1}\frac{v_{t+1}^b(1+r_{t+1}^d)}{v_t^b(1+r_t^d)}(1+\bar{r}_t) \tag{52}$$

2. Impulse responses

2.1. Monetary policy shock and liquidity preference

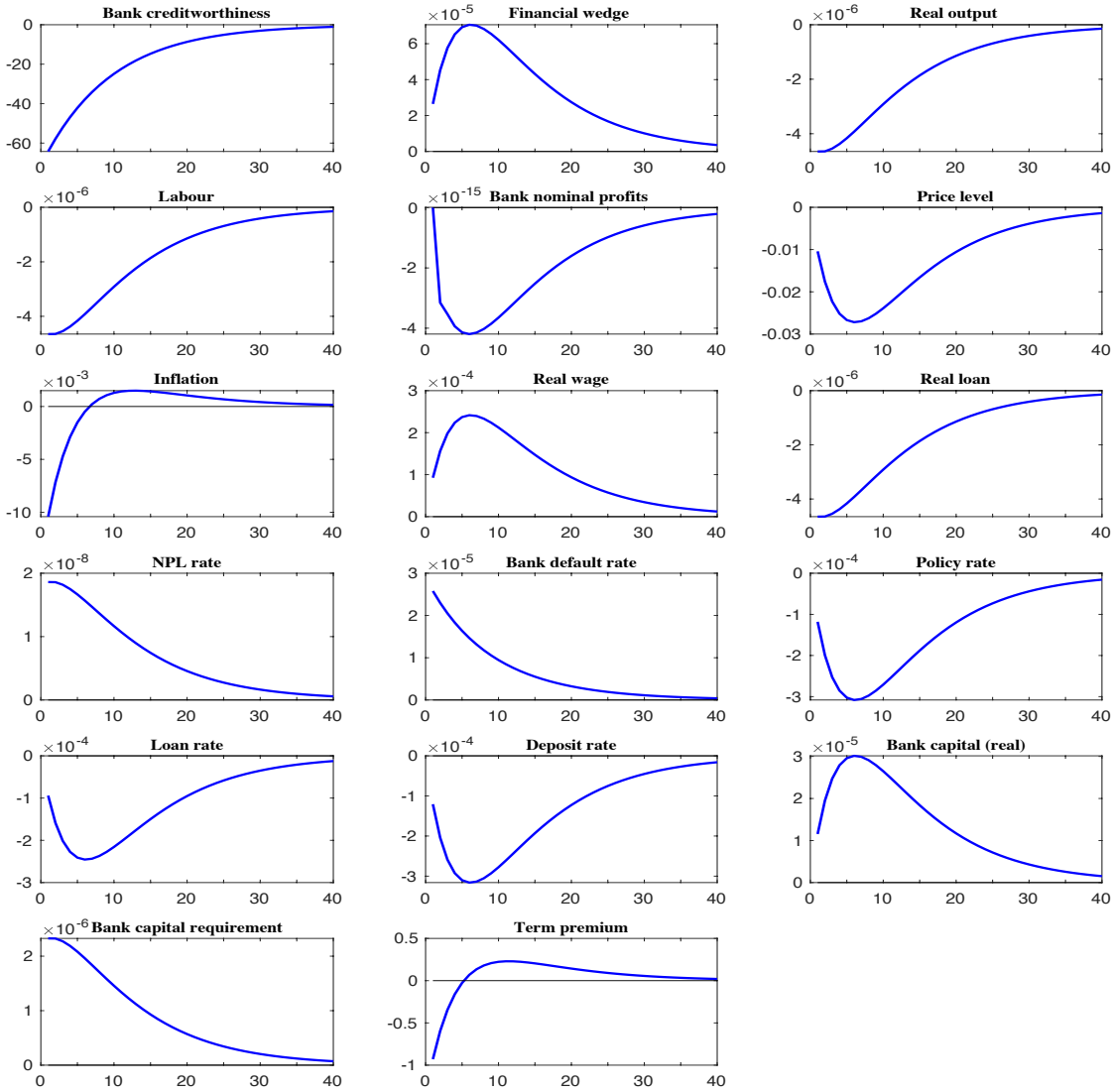
Figure 7: Monetary policy shock



2.2. Rising bank default risks

Figure 8 exhibits how the economy behaves when a negative shock hits the banks' default penalty parameter λ_t^b such that banks' default risks go up. As the household's total deposit balances go down due to the rising banking default risks, less liquidity is available to purchase final output from the firm. Thus, the firm finds it more difficult to repay the loan and NPLs thus rise. Therefore, bank's default sets a chain of default which eventually feeds back to its own asset quality, further exacerbating financial stability risks. On the other hand, the CAR rule reacts to the rising NPLs to build up the real value of bank capital, and thus, the financial wedge is widened. On the real economy side, output drops and unemployment rises despite the rise in real wage. The economy is in a deflationary realm.

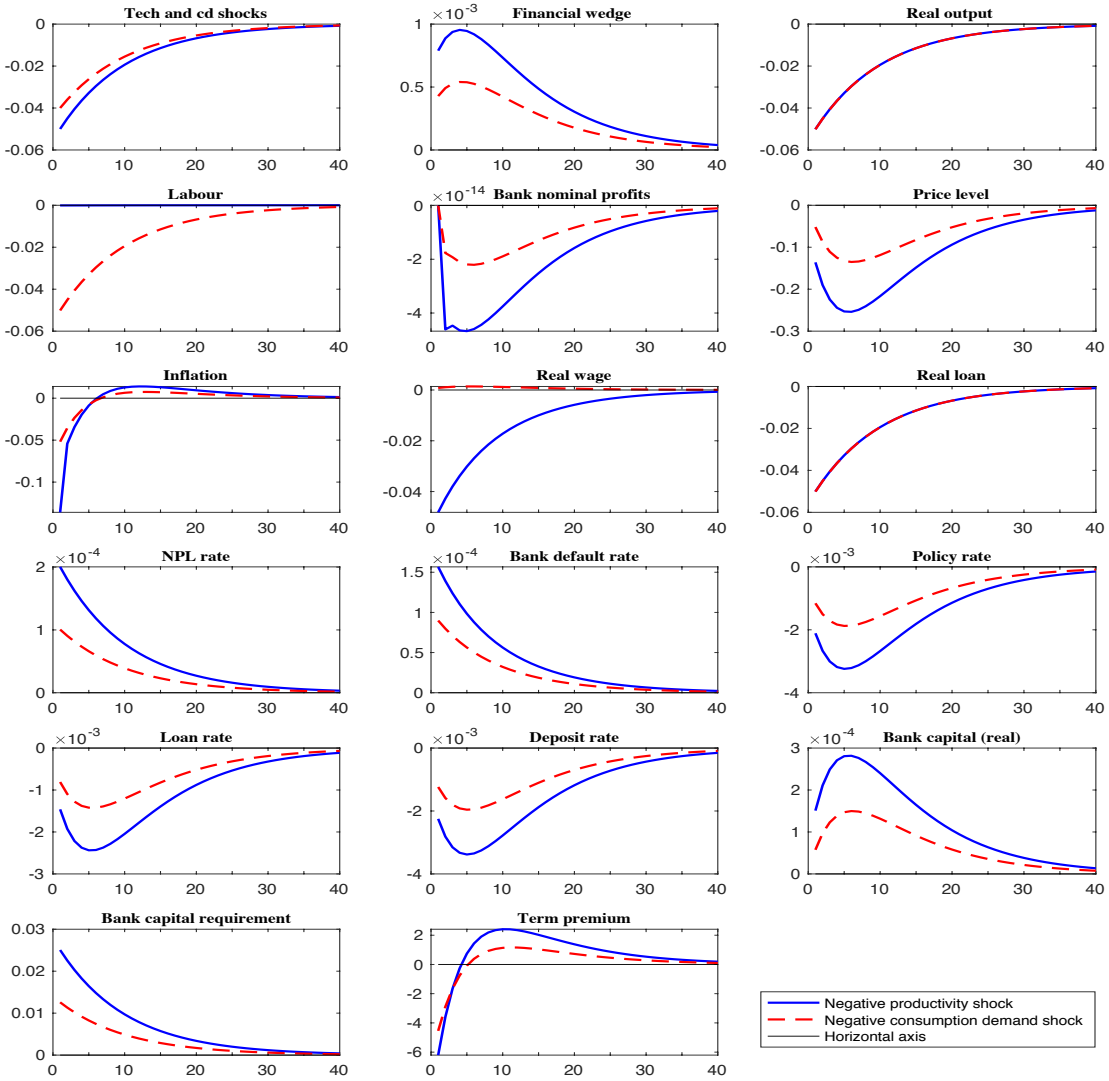
Figure 8: Rising bank default risks



2.3. Other shocks

In this subsection, Figure 9 displays the impulse responses of a negative productivity shock A_t and a negative consumption demand shock γ_t^h for completeness.

Figure 9: Technology shock and consumption demand shock



Chapter 4

A Macro-Financial Perspective to Analyse Maturity Mismatch and Default

[1]

The Basel Committee proposed the Net Stable Funding Ratio (NSFR) to curb excessive maturity mismatch of the banking sector. However, it remains to be ascertained as to what are the financial and real effects of the NSFR on banks' credit quality, investment, and the pass-through of monetary policy. This paper develops a nominal dynamic general equilibrium featuring banks' maturity mismatch and the moral hazard due to costly monitoring. First, I show that a tightening of the NSFR to move loan maturity towards the long-run capital investment cycle would only increase real investment if it sufficiently improves banks' credit quality. Then in the numerical example calibrated with the US data, I show that such tightening of the NSFR can indeed increase real investment and also reduce the aggregate fluctuation of the economy. In the steady states, a 10% tightening in the NSFR can decrease net charge-offs of non-performing loans by about 0.06 pp annually, despite squeezing banks' interest margin. Moreover, the moral hazard stemming from banks' unobserved monitoring effort impairs the pass-through of monetary policy. However, a 10% tightening in the NSFR improves the pass-through of a 20-bp policy rate reduction by around 17% annually. Finally, the model simulates the stochastic dynamic equilibrium path to study the propagation of shocks, demonstrating that the NSFR complements monetary policy in reducing financial frictions.

[1]This chapter draws on insights from a much revised version of my M.Phil. thesis. For useful comments and conversations, I would like to thank Dimitrios Tsomocos, Sophocles Mavroeidis, Oren Sussman, Udara Peiris, and Chris Bowdler.

1. Introduction

Before the 2007-2009 financial crisis, banks were engaging in activities with increasing severity in maturity mismatch relying more on short-term funding and illiquid assets - a practice that brings an inherent risk to the bank business models. If the bad future state is realised, short-term creditors pull out their liquidity from the banks, and such banks become vulnerable and may be unable to roll over their borrowings (see Diamond and Rajan 2009; Brunnermeier 2009; Acharya and Merrouche 2013, and Huang and Ratnovski 2011). Indeed, the most troubled banks in the financial crisis had severe mismatch issues on their balance sheets, as is the case with the three stand-alone US investment banks (Lehman Brothers, Merrill Lynch and Bear Stearns) and Northern Rock in the UK.

In response, the Basel Committee on Banking Supervision (BCBS) published two Basel III documents in December 2010[2] proposing a macro-prudential tool called the Net Stable Funding Ratio (hereafter the NSFR), with the plan to implement it in 2018 to incentivise banks to reduce the maturity mismatch of their assets and liabilities. To date, there has been applaudable theoretical and empirical research on maturity mismatch and the NSFR (see for example Farhi and Tirole 2012; Vazquez and Federico 2015; Segura and Suarez 2017), and the focus tends to be on the impact of the NSFR on banks' solvency. However, it remains to be ascertained as to what are the macro-financial effects of the NSFR on credit quality, non-banks' default, real investment, and the transmission of monetary policy. To this end, a crucial metric is banks' profitability, and yet, the empirical evidence of the NSFR on bank profitability seems mixed.[3] It remains ambiguous whether implementing the NSFR would reduce bank profitability, and in turn, increase the moral hazard of the banking system and obstruct the transmission of monetary policy. Therefore, a general equilibrium is needed to investigate the feedback effects of this regulation on both prices and quantities.

Given such, the purpose of this paper is to construct a dynamic macro-finance model to investigate both qualitatively and quantitatively the effects of reducing maturity mismatch on real investment, non-bank default, and the transmission of monetary policy from a general equilibrium perspective. I show that a tightening of the NSFR to move loan maturity towards the long-run capital investment cycle would increase real investment in the steady state if and only if it improves banks' credit quality sufficiently.

In the numerical example calibrated with the US data, I show that the tightening of the NSFR improves credit quality and reduce default risks, despite the squeeze of banks' net interest margin. This is because the response of maturity reduction in equilibrium decreases the NSFR regulation penalty, which offsets the reduction of banks' net interest margin. The net effect causes the banks to

[2] See "Basel III: A Global Regulatory Framework for More Resilient Banks and Banking Systems" and "Basel III: International Framework For Liquidity Risk Management, Standards and Monitoring".

[3] For example, papers by King (2013) and Dietrich et al. (2014) present empirical evidence on this. Section 2 discusses their differences and relevance.

exert a higher monitoring effort and increase the intensive margin of non-bank borrowers' default cost. Therefore, such tightening of the NSFR can indeed increase real investment and reduce the aggregate fluctuation of the economy. In the steady state, a 10 % tightening of the NSFR decreases the net charge-offs of non-performing loans by about 0.06 pp and improves the pass-through of a 20-bp policy rate reduction by around 17% annually. Then I simulate the model on the dynamic stochastic general equilibrium path to study the propagation of TFP and monetary policy shocks and investigate to what extent the NSFR complements monetary policy.

In terms of formalisation, the model is of infinite horizons with three major players: the households, the firms, and the banking sector. The households are endowed with durable goods in every period. The firms can transform durable goods into capital to produce perishable consumption goods, but they have no endowment of durable goods; thus, they are the non-bank borrowers of the economy. Firms do not borrow from the households directly because the households have no expertise to monitor firms' creditworthiness. The banks are assumed to have monitoring expertise which gives the role of bank financing. Thus, the firms borrow loans from the banking sector to obtain liquidity to finance their purchase of durable goods from households. Households sell durable goods and obtain sales revenues as deposits, which will be used to purchase final output after firms' production.

Thus, banks serve as a financing vehicle and a liquidity provider to finance the firms' capital investment. Moreover, at any point in time, to meet any possible deposits withdrawals, the banks sell assets to the central bank to obtain the reserves through the open market operation. This institutional constraint ensures the nominal feature of the model and the transmission of monetary policy to the broader economy. To introduce the inherent maturity mismatch between banks' assets and liabilities, the model departs from the standard business cycle models and features infrequent optimisation of the firms' capital financing decision in a similar spirit as Andreasen et al. (2013). The NSFR is modelled as a regulation penalty should the banks deviate from the NSFR target, in line with the formulation of financial regulations in Goodhart et al. (2006).

The two main ingredients of the model are the role of liquidity and credit in transmitting monetary policy and the financial frictions in the form of moral hazard of both the non-bank borrowers and the banking system. To model the transmission of monetary policy via the banking sector, I choose to model a liquidity-in-advance constraint via banking à la Shapley and Shubik (1977) and Lucas Jr and Stokey (1987). Upon loan extension, the banking sector issues deposits for transaction purchases. These deposits are sometimes referred to as inside money in the literature (see for example Dubey and Geanakoplos 2003a; Tsomocos 2003; Brunnermeier and Sannikov 2016; Bianchi and Bigio 2018). To meet deposits withdrawals, the banks sell nominal assets to the central bank to obtain reserves at the cost of the interbank market rate set by the central bank. As such, monetary policy passes through the wider banking sector and ultimately to the non-bank borrowers and creditors. The banks are

subject to the moral hazard of the non-bank borrowers. The economy is subject to the moral hazard of the private costs of banks' monitoring efforts.

Financial frictions in the form of moral hazards work as follows. First, banks have the expertise to monitor the loans and find out the borrowing firms' creditworthiness. By doing so, the banks would incur an unobserved monitoring cost, in line with Martinez-Miera and Repullo (2017). If banks' profitability is high enough, they would be incentivised to monitor loans properly and identify the firms that have higher creditworthiness. Second, banks are subject to the moral hazard of the borrowing firms who can choose to default on bank loans given the state of nature. I model the firms' choice of default à la Dubey et al. (2005) that the firms would face a non-pecuniary reputation damage if they choose to default on the loans. The reputation damage is essentially the default penalty cost which could be credit exclusion in the future if the borrowing firms choose to default. The total reputation damage increases with the real value of the defaulted amount, and firms with higher creditworthiness would incur a higher reputation damage per unit of default. Given the creditworthiness of the firms and the state of nature, the firms trade off the marginal benefit of default and the marginal cost of default. One contribution of this paper is to combine costly monitoring à la Holmstrom and Tirole (1997) and Martinez-Miera and Repullo (2017) with endogenous default in equilibrium à la Shubik and Wilson (1977) and Dubey et al. (2005).

With these two main ingredients in the model, I show that the tightening of the NSFR would only increase real investment if it reduces loan default. To obtain the results on default and bank credit quality, a numerical example is solved calibrated with the recent US data. The tightening of the NSFR reduces the loan maturity and increases the amount the loans that need to be settled in each period. This leads to an increase in the extensive margin of the borrowing firms' default cost and, in turn, a lower incentive to default. Meanwhile, when the decrease in maturity mismatch in equilibrium reduces the NSFR penalty cost and the reduction of the NSFR penalty cost offsets the squeeze in banks' net interest margin, banks would have a stronger monitoring incentive, which would increase the intensive margin of the borrowing firms' default cost so that the firms would have a lower propensity to default. The overall effect of the NSFR improves loan quality and reduces the net charge-offs of non-performing loans. I then conduct policy experiments to study how the NSFR affects monetary policy pass-through. In the benchmark, the NSFR is kept constant as the monetary policy rate decreases, and in the comparison case, the NSFR increases as monetary policy loosens. Furthermore, the model is simulated to run counterfactuals and study the property of the NSFR during business cycle fluctuations, as well as the shock propagations on the short-run stochastic equilibrium path. Overall, the results suggest that the NSFR, when it is not implemented excessively, complements monetary policy in reducing the effects of financial friction.

The rest of the paper is organised as follows. Section 2 reviews the relevant literature. Section 3

presents the model. Section 4 provides equilibrium analysis and key propositions and the theorem. Section 5 calibrates simple numerical examples, solves the general equilibrium, and conducts policy experiments. Section 6 is the conclusion.

2. Related Literature

Maturity transformation is one of the fundamental functions of the banking system (see Diamond and Dybvig 1983). However, the recent financial crisis underscores the possible detrimental effects of excessive maturity mismatch. Particularly, Morris and Shin (2008) analyse the potential consequences of banking interconnectedness and argue for structural liquidity requirements as a complement to risk-based capital requirements to constrain the composition of assets.

Since the introduction of the NSFR by the Basel Committee to curb excessive maturity mismatch, literature has caught up to examine the financial stability implication of this liquidity regulation both theoretically and empirically. Farhi and Tirole (2012) show that imposing a structural macro-prudential liquidity requirement such as NSFR can potentially overturn financial institutions' expectations for accommodative policy and socially costly rescue plans, reducing the effect of strategic complementarity in its engagement of excessive maturity mismatch, and possibly restoring financial stability. Walther (2016) expounds on the excessive systemic risk that is created by banks through leverage and maturity mismatch and explains how capital and maturity regulation are complementary in restoring financial stability. Segura and Suarez (2017) build a structural model and quantify the gains from regulating maturity transformation, and their focal point is on banking solvency. Wei et al. (2017) study the impact of the NSFR on banks' profitability and social welfare and identify conditions that the NSFR may reduce both bank failures and observed profits. Given much thinking of these theoretical or structural models is around banking stability and solvency, this paper turns to a slightly different focus. Rather than focusing on banking insolvency, this paper aims to understand the effects of NSFR on non-bank default and monetary policy transmission, as well as the broader macro-financial consequences and shock propagations on both the steady states and the stochastic dynamic equilibrium path. Furthermore, in contrast to these papers, this paper builds a nominal model in which the role of monetary policy can be assessed.

Empirically, López-Espinosa et al. (2012) find that short-term wholesale funding is a crucial determinant in triggering systemic risk episodes. Vazquez and Federico (2015) establish that banks with weaker liquidity and higher leverage before the global financial crisis were more likely to fail afterwards. Bologna (2015) highlights that structural funding position indeed is important in explaining the probability of bank defaults. However, the empirical evidence on the NSFR on banks' profitability seems *prima facie* mixed. For example, Dietrich et al. (2014) present evidence that the lower NSFR does not seem to translate into higher profitability of banks, whereas King (2013) finds that the im-

plementation of the NSFR reduces banks' net interest margin significantly. Thus, to understand the nuance and the feedback effects of the NSFR on banks' profitability and risk-taking, this paper adopts a structural modelling approach and solves the general equilibrium with key parameters calibrated with the US data.

The way this paper introduces the inherent maturity mismatch to the business cycle follows a similar approach to Andreasen et al. (2013). Andreasen et al. (2013) assume that firms in every period face a constant probability of being unable to adjust capital stock, leading to firms in need of loans with longer maturities than household deposits. This Calvo-style capital re-optimisation friction rationalises firms' needs of corporate loans with longer maturities, and matches the stylised fact that firms invest in a lumpy fashion as outlined in the literature on non-convex investment adjustment costs (Caballero and Engel 1999; Cooper and Haltiwanger 2006). However, in Andreasen et al. (2013) banks do not have a role in choosing the maturity of the loans, whereas this paper makes room for the choice of loan maturity by the banks, as well as the scope for the regulation of the NSFR.

Finally, this paper closely connects with the large literature on the role of financial frictions in macroeconomic modelling which follows a rich tradition (Bemanke and Gertler 1989; Kiyotaki and Moore 1997; Carlstrom and Fuerst 1997; Iacoviello 2005; Gertler and Kiyotaki 2010; Goodhart et al. 2013). This paper complements this literature by combining endogenous default à la Dubey et al. (1988, 2005) and Zame (1993) and banks' moral hazard of costly monitoring à la Holmstrom and Tirole (1997) and Martinez-Miera and Repullo (2017) in a dynamic macroeconomic setting. In this sense, the closest precursors of this paper are Tsomocos et al. (2018) and Goodhart et al. (2018). However, this paper adds the maturity mismatch and banks' moral hazard of costly monitoring channels to Tsomocos et al. (2018) and Goodhart et al. (2018).

3. The Model

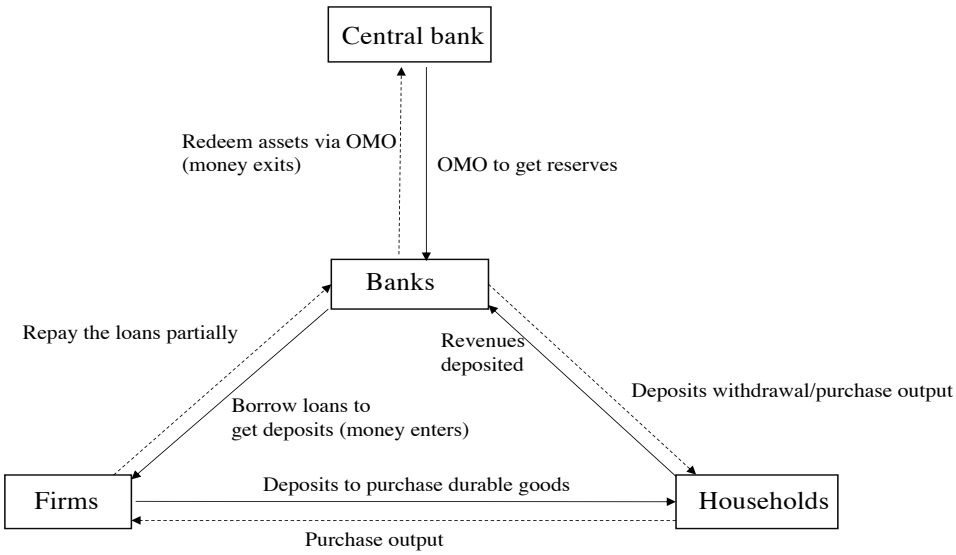
3.1. The Environment

The model is of infinite horizons with three major players: the households, the firms, and the banking sector. At the beginning of every period, the households are endowed with durable goods. The firms have the technology to transform durable goods into capital to produce perishable consumption goods, but they have no endowment of durable goods; thus, the firms are the non-bank borrowers of the economy. Firms do not borrow from the households directly because the households have no expertise to monitor firms' creditworthiness. The banks are assumed to have monitoring expertise which helps to establish the role of bank financing. As illustrated in the nominal flow of funds diagram in Figure 4.1, at the beginning of every period the firms borrow loans from the banking sector to obtain deposits to finance their purchase of durable goods from households. Households sell durable goods and obtain sales revenues as deposits, which will be used to purchase final output after firms' production at the

end of each period. Moreover, at any point in time, to meet any possible deposits withdrawals, the banks sell assets to the central bank to obtain the reserves through the open market operation. This institutional constraint ensures the nominal feature of the model and the transmission of monetary policy to the broader economy.

To introduce the inherent maturity mismatch between banks' assets and liabilities, the model departs from the standard business cycle models and features infrequent optimisation of the firms' capital financing decision in a similar spirit as Andreasen et al. (2013). Both the firms and the banks can choose the maturity of the loans; the firms demand the loan maturity and the banks supply the loan maturity.

Figure 4.1: Nominal flow of funds



3.2. A Primer on the NSFR

The macro-prudential tool NSFR requires the banks to hold more stable funding and fewer illiquid assets to reduce the maturity mismatch between the banks' assets and liabilities. A simplified formula of NSFR is illustrated as follows,[4]

$$\begin{aligned}\text{NSFR} &= \frac{\text{Available Amount of Stable Funding (ASF)}}{\text{Required Amount of Stable Funding (RSF)}} \\ &= \frac{\text{Equity} \times 100\% + \text{Stable Funding} \times 80\% + \text{Unstable Funding} \times 20\%}{\text{Liquid Asset} \times 20\% + \text{Iliquid Asset} \times 80\%}.\end{aligned}$$

[4]This formula is a start simplification for the ease of exposition. To see the exact specification of the NSFR, please see the BCBS Consultative Document Basel III: The Net Stable Funding Ratio.

The numerator is a weighted sum of various types of funding (debt and equity) of the banks, and generally the longer the maturity of the type of funding, the more weight is assigned. The denominator is a weighted sum of various types of assets, with assets of longer maturity bearing more weight. Banks comply with the regulation by meeting the minimum NSFR requirement of 100%. This requirement would incentivise the banks to hold borrowings with longer maturities and invest in assets with shorter maturities or more safe assets. Typically, the maturity of corporate loans is longer than that of the household deposits. Implementing NSFR would reduce the maturity difference between corporate loans and household deposits, and help to dampen maturity mismatch. This type of maturity mismatch is the focus of this paper.

3.3. Firms

There is a continuum of firms $i \in [0, 1]$ owned by the households. At the beginning of t, firms need to borrow bank loans to finance their purchase of durable goods, which they transform into capital for production. The financing of durable goods is the capital investment decision.

To model each firm's inherent need for loans with a maturity longer than one period, I assume that each firm re-optimises a fraction τ_t ($\tau_t \in (0, 1)$) of durable goods purchase in period t. The firm can not adjust the rest of the purchase of the durable goods and has to keep the fraction $1-\tau_t$ of them at the re-optimised level in the previous period $t-j$. One way to rationalise the restriction on the firm's infrequent adjustment of the durable goods is as follows. It usually involves some fixed costs for a firm to purchase a new machine or to build a new plant, as assumed in the literature (Thomas 2002, Khan and Thomas 2003, among others). These fixed costs come from gathering information, training the new workforce, decision making, and so on, and imply that the firm makes lumpy investment (Hamermesh and Pfann 1996, Cooper and Haltiwanger 2006).

The setup in this paper does not attempt to model the exact nature of the firm's infrequent adjustment of capital and capital-adjustment cost, but it still captures the macro-financial implications of the firm's capital re-optimisation process. This specification of lumpy investments, or infrequent capital adjustment, has been previously adopted by Kiyotaki and Moore (1997) and Sveen and Weinke (2007) in the context of firm-specific capital. However, I depart from their setup by assuming homogeneous capital across firms, a competitive rental market, and homogenous firms. In this manner, this paper introduces a capital financing cycle; thus, the firm's production cycle is greater than one period.[5] Andreasen et al. (2013) provide a more detailed explanation for this assumption.

Let,

[5]The average capital financing cycle would be $\tau+(1-\tau)(1+j)$. The starting point of the NSFR is assumed to move loan maturity towards the capital financing cycle.

$\omega_t^f \equiv$ the real profits of the firm,

$b_t \equiv$ firm's optimised demand for durable goods,

$b_t^{'} \equiv$ firm's non-optimised demand for durable goods, and $b_t^{'} = b_{t-j}$,

$\mu_t \equiv$ new loans,

$L_t \equiv$ outstanding loans,

$\delta_t \equiv$ the fraction of outstanding loans to settle, and maturity mismatch $= \frac{1}{\delta_t}$,

$v_t^f \equiv$ the firm's loan repayment rate, and loan default rate $d_t^f = 1 - v_t^f$,

$P_t \equiv$ the price level of the consumption good (i.e. value of money $= \frac{1}{P_t}$),

$P_t^k \equiv$ the price level of the durable good,

$\Lambda \equiv$ the marginal utility of consumption of the household, i.e., the pricing kernel,

$\lambda_t^f \equiv$ firm's creditworthiness, assumed to increase with the banks' monitoring efforts,

$\lambda_t^f [\mathbb{I}_t^f]^+ \equiv$ the reputation damage if the firm fails to fully repay the loan, where

$$[\mathbb{I}_t^f]^+ = \left\{ \begin{array}{cc} (\frac{(1-v_t^f)\delta_t L_{t-1}(1+\bar{r}_t^l)}{P_t})^2 & \text{if } 1 - v_t^f > 0 \\ 0 & \text{if } 1 - v_t^f = 0 \end{array} \right\}.$$

The firms are profit maximisers and would suffer a reputation damage if they do not fully repay the debt obligations to the banks. For tractability, the reputation damage is a non-pecuniary default cost à la Dubey et al. (2005), and it is assumed to increase with the real amount of default so that full default, partial default, or no default can all emerge in equilibrium depending on the state of nature. Particularly, a quadratic form is assumed to reflect that higher default is likely to accelerate the borrower's reputation damage and implies richer variations on the inter-temporal equilibrium path. Note that λ_t^f is the proxy for the firm's creditworthiness and is assumed to increase with the bank's monitoring effort. Further micro-foundation of the reputation damage of default is possible through costly debt renegotiation à la Goodhart et al. (2018) and Andreev et al. (2019), but it would not alter the main insight and results of this paper. Formally, the firm's preference is given as follows:

$$\underset{\{b_t, \mu_t, L_t, \delta_t, v_t^f\}_{t=0}^{\infty}}{Max} E_t \Big\{ \Lambda_t \omega_t^f - \lambda_t^f [\mathbb{I}_t^f]^+ \Big\},$$

subject to

$$\tau P_t^k b_t \leq \mu_t, \tag{4.1}$$

$$(1-\tau)P_t^k b_t^{'} = (1-\delta_t)L_{t-1}, \tag{4.2}$$

$$k_t = (1-d)k_{t-1} + \tau b_t + (1-\tau)b_t^{'}, \tag{4.3}$$

$$L_t = (1-\delta_t)L_{t-1} + \mu_t. \tag{4.4}$$

Eq(4.1) states that the firm borrows new loans to finance the optimised purchase of durable goods. In this flow of funds constraint, inside money is issued against the bank's new credit. Eq(4.2) states that the firm uses the outstanding loans that she does not plan to settle at t to finance the fraction of non-optimised purchase of durable goods. Eq(4.3) is the law of motion of capital stock accumulation. Capital depreciates at the rate of d at every period, and the firm refills her capital stock by $\tau b_t + (1-\tau)b_t^{'}$ at every period through new capital investment.

Eq(4.4) encapsulates the loan dynamics. At t only a proportion δ_t of previous outstanding loans are settled. The total outstanding loans demanded at period t equals the proportion of total outstanding loans at $t-1$ that has not been settled plus the new loans demanded by the firm at period t. Eq(4.4) implies the maturity of corporate loans is $\frac{1}{\delta_t}$.

Then the firm uses the total capital stock to produce output according to $y_t = A_t k_t$, where A_t is an AR(1) process of TFP shock. The firm sells output to obtain money inflow, part of which is used to repay the loans she decides to settle. The difference between monetary inflow and outflow amounts to her nominal profits, as stated in Eq(4.5). Particularly, the money outflow consists of the interest payment of the outstanding loans the firm decides to roll over, i.e., $(1-\delta_t)L_{t-1}\bar{r}_t^l$, the amount of money to purchase non-optimised durable goods, i.e., $(1-\tau)P_t^k b_t^{'}$, and the amount of loans she decides to settle with interest payment, subject to her choice of repayment rate (v_t^f). Particularly, the loan default rate d_t^f is simply equal to $1-v_t^f$, and let $\bar{d}_t^f$ denote the net charge-offs the non-performing loan rate, then $\bar{d}_t^f = \delta_t d_t^f$. Note that $\bar{r}_t^l$ is the interest rate on outstanding loans that will not be settled at t, and r_t^l is the interest payment on the fraction of outstanding loans that are settled for capital-optimisation. These two loan rates are prices that function to accommodate the two markets regarding loans: the loan market and the "market" for loan maturity.

$$P_t\omega_t^f = P_tA_tk_t - [(1-\delta_t)L_{t-1}\bar{r}_t^l + (1-\tau)P_t^k b_t^{'} + v_t^f\delta_t L_{t-1}(1+r_t^l)]. \tag{4.5}$$

Combine eq(4.2) and eq(4.5), the firm's profits can be re-expressed as follows,

$$P_t\omega_t^f = P_tA_tk_t - [(1-\delta_t)L_{t-1}(1+\bar{r}_t^l) + v_t^f\delta_t L_{t-1}(1+r_t^l)]. \tag{4.6}$$

Substitute (4.3) into (4.6), the firm chooses $\mu_t, L_t, b_t, \delta_t, v_t^f$ to maximise its utility subject to eqs (4.1), (4.2), (4.4), and (4.6). Let η_t^f and Λ_t^f be the shadow prices of eqs (4.6) and (4.4), the firm's optimality conditions are characterised as follows.

Lemma 1. firm's optimality conditions.

The firm's optimality conditions are characterised by the trade-off of financing capital investment (eq(4.7)), the on-the-verge condition of maturity mismatch (eq(4.8)), and the on-the-verge condition of default (eq(4.9)).

$$\eta_t^f P_tA_t\tau + \beta^j\eta_{t+j}^f P_{t+j}A_{t+j}(1-\tau) = \beta\eta_{t+1}^f(1+r_t^l)\tau P_t^k + \beta^{j+1}\eta_{t+j+1}^f(1+r_{t+j}^l)(1-\tau)P_{t+j}^k, \tag{4.7}$$

$$1+\bar{r}_t^l = 1+r_t^l, \tag{4.8}$$

$$\lambda_t^f\frac{(1-v_t^f)\delta_t L_{t-1}(1+r_t^l)}{P_t} = \Lambda_t. \tag{4.9}$$

Proof. *Appendix 1.1.*.

Eq(4.7) states that the marginal benefit of financing capital investment should equate the marginal cost of financing capital investment. The borrowing cost r_t^l enters the marginal cost of financial capital investment via inside money issuance against new bank credit. This is the key channel that monetary policy exerts real effects even without assuming price stickiness. Eq(4.8) states that the marginal cost of maturity mismatch (left-hand side) equates the marginal benefit of maturity mismatch (right-hand side).

Eq(4.9) is the on-the-verge condition of the firm's default decision on the loans to be settled. The left-hand side is the marginal cost of default, and the right-hand side is the marginal benefit of default.

This condition implies that during good times when the pricing kernel decreases, the marginal benefit of default goes down such that the firm defaults less on the loans. It also implies that if maturity mismatch decreases, according to eq(4.6), the firm's extensive margin of default cost would go up, and if we assume the firm's creditworthiness λ_t^f does not change, then the firm would default less on the loans. However, λ_t^f would also change due to the feedback effect of bank's unobserved monitoring effort in a general equilibrium. As I shall elaborate in the subsection on banks, the decrease of maturity mismatch would squeeze the banking spread, and due to the moral hazard of banks' monitoring effort, the marginal cost of the firm's default λ_t^f might change. Therefore, the overall effect of maturity mismatch on loan quality or non-performing loans is not obvious without solving for the feedback effects from a general equilibrium.

3.4. Households

The modelling of the household is relatively standard. The household derives utility from consuming perishable goods and durable goods. At the beginning of t the household is endowed with durable goods of e_t, and chooses to sell an amount of q_t durable goods to the firm for her capital investment. At the end of t, the household uses the total money inflow to purchase consumption goods and invest in deposits. The household's preference is represented by the utility function

$$\underset{\{c_t,q_t,D_t^h\}_{t=0}^{\infty}}{Max} E_0 \sum_{t=0}^{\infty} \beta^t [\chi log(c_t) + (1-\chi) log(e_t - q_t)],$$

and the household is subject to the following budget constraint or flow of funds,

$$D_t^h + P_t c_t = D_{t-1}^h (1 + r_t^d) + P_t^k q_t + \Omega_{t-1}^f + \xi_{t-1}. \tag{5}$$

The right-hand side of the household's budget constraint eq(5) consists of four monetary inflows: the bank's repayment on household's deposits plus interest payment, the revenue from selling durable goods, the firms' profit rebate, and the transfer of seigniorage profits ξ_{t-1} from the previous period made by the central bank.

3.5. Banks

There is a measure one of banks in the banking sector. The moral hazard of the banks is that they exert unobserved monitoring efforts to ensure the creditworthiness of the borrowing firms. The banks maximise their real profits. If the banks exert monitoring efforts, they incur an effort cost. Moreover, if the banks fall short of the Net Stable Funding Ratio, they will suffer a regulation penalty. Following the convention in the banking literature, the banks are risk-neutral; hence, convexity is assumed for the disutility of regulation penalty and of the monitoring efforts to obtain an interior solution, and in

particular, quadratic forms are used, in line with Martinez-Miera and Repullo (2017).

Let,

$\Omega_t^b \equiv$ the nominal profits of the bank, and ω_t^b is the real profits,

$m_t \equiv$ the bank's monitoring effort,

$M_t \equiv$ the aggregate amount of nominal assets the banks sell to the central bank via the open market operation,

$Res_t \equiv$ total reserves,

$r_t^p \equiv$ interbank market rate as the official monetary policy rate,

$\frac{1}{\delta_t^{TR}} \equiv$ regulation targeted loan maturity,

$\frac{\psi_t}{2}\mathbb{I}_t^m \equiv$ the regulation penalty if the bank deviates from the NSFR target, where $\mathbb{I}_t^m = (\frac{(\delta_t^{TR}-\delta_t)L_{t-1}}{P_t})^2$,

the bank's preference is represented as follows,

$$\underset{\{L_t, D_t^b, \delta_t, M_t\}_{t=0}^{\infty}}{Max} E_t\Big\{\frac{\Omega_t^b}{P_t} - \frac{\gamma}{2}m_t^2\frac{L_{t-1}}{P_t} - \frac{\psi_t}{2}\mathbb{I}_t^m\Big\},$$

Define the risk-adjusted loan rate as $r_t^{l'}$, i.e., $1 + r_t^{l'} = (1-\delta_t)(1+\bar{r}_t^l) + R_t^f\delta_t(1+r_t^l)$, and let $f_t = (1-\delta_t)(1+r_t^l) + R_t^f\delta_t(1+r_t^l) - (1+r_t^d)$, so f_t is the banking spread. Eq(4.10) expresses the bank's nomoinal profits,

$$\begin{aligned}\Omega_t^b = (1+r_t^{l'})\int_0^1 (L_{t-1} - M_t(i))di \\ - [(D_{t-1}^b(1+r_t^d) - \int_0^1 Res_t(i)di] \\ + (1+r_t^{l'})M_t - (1+r_t^p)Res_t.\end{aligned} \tag{4.10}$$

Note that for each individual bank, it faces an idiosyncratic deposit withdrawal. To meet such liquidity demand, each bank sells nominal asset $M_t(i)$ to the central bank to obtain reserves $Res_t(i)$ at a cost of r_t^p. Therefore, the bank's balance sheet should shrink if households withdraw deposits; hence, eq(4.10) subtracts $M_t(i)$ on the asset side and $Res_t(i)$ on the liability side. Eventually, the currency in circulation flows back to the banking sector to partly extinguish the loans for $(1+r_t^{l'})M_t$, and the banking sector repays the central bank $(1+r_t^p)Res_t$ to redeem the nominal assets via the open market operation. In aggregate, $M_t = \iota L_t$ and each bank is assumed to share the cost of obtaining reserves evenly. Since $L_{t-1} = D_{t-1}^b$ and $M_t = Res_t$, the banking sector's nominal profit in eq(4.10) can be

rewritten as

$$\Omega_t^b = f_t L_{t-1} - r_t^p Res_t,$$

and the banking sector's utility function can be re-expressed as

$$U_t^b = (f_t - \frac{\gamma}{2} m_t^2)\frac{L_{t-1}}{P_t} - r_t^p \frac{Res_t}{P_t} - \frac{\psi_t}{2}\mathbb{I}_t^m.$$

Banks take into consideration the possibility of firm's default decision in deciding their monitoring efforts. Drawing on insight from the underlying contractual friction in Martinez-Miera and Repullo (2017), the firm's creditworthiness is assumed to increase with the banks' monitoring effort, i.e., $\lambda_t^f = zm_t$. The reason is that when banks make more monitoring efforts, they identify firms with a higher creditworthiness so that firms default less in equilibrium and banks' assets bring a higher real return. Therefore, when banks decide their monitoring effort, they take into account the firm's on-the-verge conditions to default on bank loans as in eq(4.11),

$$\frac{\chi P_t}{c_t z m_t} = (1 - v_t^f)\delta_t L_{t-1}(1 + r_t^l). \tag{4.11}$$

Let η_t^b be the shadow price of the on-the-verge condition eq(4.11). The economic meaning of η_t^b is a proxy for the marginal reward of monitoring. When banks monitor, on the one hand, they incur a monitoring cost, and on the other hand, the monitoring effort increases the marginal cost of default for the firm, which would lead to a higher η_t^b and a higher repayment rate which would increase the banks' profits on the margin. The banks privately trade off the marginal cost of monitoring and the marginal benefit of monitoring. In short, the banking sector chooses $L_t, D_t^b, \delta_t, M_t, m_t$ to maximise utility subject to eq(4.10) and eq(4.11).

Lemma 2. Banks' optimality conditions.

The bank's optimality conditions are characterised by the pricing of loan rate (eq(4.12)), the trade-off of exerting monitoring effort (eq(4.13)),[6] and the supply curve of maturity mismatch (eq(4.14)).

$$1 + r_t^l = \frac{1 + r_t^p}{1 - \delta_t d_t^f}, \tag{4.12}$$

$$\gamma z m_t^3 L_{t-1} c_t = \chi P_t - \chi \psi_t (\delta_t^{TR} - \delta_t)\frac{L_{t-1}}{d_t^f (1 + r_t^l)}, \tag{4.13}$$

[6] As long as the marginal reward of monitoring $\eta_t^b > 0$, the right-hand side of (4.13) is positive.

$$\psi_t \frac{L_{t-1}}{P_t}(\delta_t^{TR} - \delta_t)\delta_t^{TR} + \frac{\gamma}{2}m_t^2 = r_t^l - r_t^d. \tag{4.14}$$

Proof. *Appendix 1.3.*.

Eq(4.12) is the non-arbitrage condition of the interbank market for reserves and it provides the pricing for the loan rate. Eq(4.13) equates the marginal cost of monitoring to the marginal benefit of monitoring. As long as the shadow price $\eta_t^b > 0$, the marginal benefit of monitoring is positive. Eq(4.14) states the trade-off of the banks' choice of maturity mismatch, which is affected by the NSFR regulation.

3.6. Central bank

The central bank conducts the open market operation and sets the interbank market rate as the policy rate. In conducting the open market operation (OMO), the central bank purchases nominal assets M_t from the banking sector and in return provides reserves Res_t while charging an interest rate of r_t^p. The central bank sets r_t^p based on the Taylor principle as in eq(4.15), where S_t^m denotes the monetary policy shock.

$$r_t^p = r_{ss}(\frac{P_t}{\bar{P}})^{m_p}(\frac{y_t}{\bar{y}})^{m_y}S_t^m. \tag{4.15}$$

At the end of each period t, the banking sector redeems the nominal assets by repaying $Res_t(1 + r_t^p)$ to the central bank. The central bank therefore obtains seigniorage profits of ξ_t, and $\xi_t = Res_t r_t^p$, and transfers it to the household in the next period. Such seigniorage transfer is non-Ricardian (Sims 1994; Buiter 1999), and it follows Dubey and Geanakoplos (1992, 2006) and Tsomocos (2003). Therefore, both real and nominal determinacy obtains, and naturally, price level, i.e., the real value of money, is determined in equilibrium. The non-Ricardian seigniorage transfer, together with the Taylor rule, resonates with the institutional separation between a central bank and a government, reflecting the central bank mandate on price stability.

3.7. Equilibrium

Following Tsomocos (2003) and Goodhart et al. (2006, 2012), given the exogenous shocks, this dynamic equilibrium is a sequence of quantities and prices, given policy instruments (r_t^p, δ_t^{TR}), agents maximise subjects to flow of funds constraints, budget sets, and goods market, capital market, loan and loan maturity markets, interbank market, and deposit market clear, and expectations are rational.

Market clearing conditions

- Goods market:

$$y_t = c_t + \omega_t^b.$$

- Capital market:

$$\tau_t b_t + (1 - \tau_t) b_t^{'} = q_t.$$

- Loan and loan maturity markets:[7]

$$L_t^f = L_t^b,$$

$$\delta_t^f = \delta_t^b.$$

- Interbank market:

$$M_t = Res_t.$$

- Deposit market:

$$D_t^h = D_t^b.$$

- Rational expectation:

$$R^f = \left\{ \begin{array}{cc} v_t^f & \text{if } 1 - v_t^f > 0 \\ \text{arbitrary} & \text{if } 1 - v_t^f = 0 \end{array} \right\},$$

4. Equilibrium Analysis

Proposition 1. Fisher Effect.

$$log(1 + r_{t+1}^d) = log(\frac{U_{c_t}^h}{\beta U_{c_{t+1}}^h}) + log(\pi_{t+1}),$$

Proof. It follows from the household's consumption decision and inter-temporal saving decision, and the bank's on-the-verge condition of default. □

[7]For the ease of exposition, I use the superscript f to denote the demand for loans and loan maturity from the firm, and b to denote the supply of loans and loan maturity by the banks. Similarly for the notation of deposits' supply and demand.

The risk-free nominal deposit rate is approximately equal to the real interest rate plus inflation. The "Fisher Effect" proposition links the nominal interest rate of deposits to consumption streams, and if the deposit rate is changed due to inflation or banks' risk-taking behaviour, consumption is affected as well.

Proposition 2. Monetary Policy Imperfect Passthrough.

- The passth-rough of the monetary policy rate is directly affected by loan default rate and loan maturity, i.e., $1 + r_t^l = \frac{1+r_t^p}{1-\delta_t d_t^f}$.

Proof. It follows directly from eq(4.8) and eq(4.12). □

Corollary 2.1. If $\frac{\partial \bar{d}_t^f}{\partial r_t^p} > 0$, the passthrough of the monetary policy rate is amplified.

Corollary 2.2. If $\frac{\partial \bar{d}_t^f}{\partial r_t^p} < 0$, the passthrough of the monetary policy rate is weakened.

Proof. Given eq(4.12) $1 + r_t^l = \frac{1+r_t^p}{1-\bar{d}_t^f}$, total differentiate with respect to r_t^l and r_t^p, it follows that $\frac{dr_t^f}{dr_t^p} = (1 - \bar{d}_t^f)^{-1} + (1 - \bar{d}_t^f)^{-2} \frac{\partial \bar{d}_t^f}{\partial r_t^p}$. □

The monetary policy rate does not perfectly pass through to the loan rate. The higher the non-performing loan rate is, *ceteris paribus*, the higher the default risk premium, and hence, the loan rate. The larger the maturity mismatch is, *ceteris paribus*, the lower the loan rate. When there is no maturity mismatch and no non-performing loans, the monetary policy rate perfectly passes through to the loan rate.

Proposition 3. Interest Rate Spreads.

- With maturity mismatch, loan rates are larger than the policy rate, and the policy rate is larger than the deposit rate, i.e.,

$$1 + r_t^l = 1 + \bar{r}_t^l > 1 + r_t^p > 1 + r_t^b.$$

Proof. It follows directly from the firm's demand for maturity mismatch that $r_t^l = \bar{r}_t^l$. Given maturity mistmach, eq(4.12) leads to $r_t^l > r_t^p$. Because a negative banking spread would contradict banks' maximisation behaviour, it follows that $f_t > 0$ and that $(1 - \delta_t d_t^f)(1 + r_t^l) > 1 + r_t^d$ holds. Combine the previous inequality with eq(4.12), it leads to $1 + r_t^p > 1 + r_t^d$. □

Proposition 4. The interplay between Maturity Mismatch and Loan Default.

- A decrease in maturity mismatch $\frac{1}{\delta_t}$ increases the extensive margin of the default penalty.

- The effect of a reduction in maturity mismatch on the intensive margin of the default penalty is ambiguous.

Suppose $d_t^f > 0$, the firm's default penalty per unit of default is $zm_t d_t^f \delta_t(1+r_t^l)$. An increase in δ_t, i.e., a decrease in loan maturity, exerts the direct effect of an increase in the extensive margin of the default penalty, i.e., $d_t^f \delta_t(1+r_t^l)$. However, an increase in δ_t has ambiguous effects on banks' monitoring effort (see eq(4.14)). The intuition as follows. Banks' monitoring effort and the NSFR regulation penalty contribute to the banks' net interest margin. On the one hand, an increase in δ_t means a reduction in maturity, which may cause the NSFR regulation penalty to decrease, adding upward pressure on the monitoring effort. On the other hand, an increase in δ_t decreases banks' net interest margin, adding downward pressure on the monitoring effort. Therefore, the overall effect on the intensive margin of the firm's default penalty is not evident without solving for the general equilibrium.

Corollary 4.1. Suppose $\frac{\psi_t}{2}\mathbb{I}_t^m$ remains constant, a decrease in bank's net interest margin reduces banks' monitoring effort.

Corollary 4.2. A tightening of NSFR does not necessarily reduce banks' monitoring effort.

Corollary 4.1 and Corollary 4.2 directly follow from eq(4.14). Corollary 4.1 states that if the NSFR regulation penalty stays unchanged, a squeeze in the bank's net interest margin, defined as the spread between the loan rate and deposit rate, results in a lower monitoring effort. A lower monitoring cost could impair the quality of bank credit. A loose intuition suggests that if the NSFR tightens, the shorter loan maturity that causes a reduction in the bank's net interest margin could lower the bank's monitoring effort and hence, worsen credit quality. However, as can be seen in eq(4.14), the tightening of the NSFR will almost certainly change $\frac{\psi_t}{2}[\mathbb{I}_t^m]^+$, and if the loan maturity decreases enough in response to regulation such that the NSFR regulation penalty decreases sufficiently, the banks' monitoring effort may increase, despite the squeeze in the net interest margin (Corollary 4.2).

Theorem. The Real Effect of Maturity Mismatch.

- In the steady state equilibirum, $\frac{\partial q}{\partial \delta} > 0$ holds *iff* $d^f + \delta \frac{\partial d^f}{\partial \delta} < 0$.
- Remark: a decrease in maturity mismatch only increases real investment iff the decrease in maturity mismatch improves bank credit quality sufficiently.

Proof. *Appendix 1.4.*.

To see why, let $\Theta \equiv \chi - (1-\chi)(1+r^p) + (1-\chi)(r^p\iota + \beta^{-1})$, the steady state real investment q is derived in eq(4.16),

$$q = \frac{\chi e}{(1-\chi)\beta \frac{1+r^p}{d(1-\delta d^f)} + \Theta}. \tag{4.16}$$

Since $\chi, \Theta, \beta, d, e$ are all exogenous and in the steady state r^p is constant, whether the decrease in maturity mismatch increases real investment depends on whether it improves the bank credit quality or decreases loan default sufficiently.

5. Numerical Examples

This section provides the solution for the steady-state equilibrium and the short-run dynamic equilibrium of shock propagations. A numerical example is calibrated with the recent US data and it conducts policy experiments to study the quantitative effects of the NSFR concerning how much it changes bank credit quality, real investment, inflation, and the effectiveness of monetary policy pass-through.

5.1. Calibration

To solve for the general equilibrium, I calibrate the model using quarterly US data and present numerical solutions. Table 4.1 presents the details of the model calibration, and rates are annualised. The household's discount factor β is set to fix the steady-state real deposit rate to 1% per annum, in line with the calibration of the economy away from the Zero Lower Bound in Kumhof and Wang (2018).[8] The steady-state real policy rate is set to 3% as in Benes and Kumhof (2015). In line with the recent US data, the depreciation rate d is set to fix the steady-state investment-to-GDP ratio to 20%, the parameter z is set to fix the steady state net charge-offs of US commercial and industrial loans to be 0.78% per annum, and the NSFR regulation penalty parameter ψ is set to target the corporate loan maturity to be 6.7 quarters. The reserve-to-loan ratio is set to reflect the maximum of reserve requirements in the US. This parameter affects the price level but does not matter for real and financial variables. The disutility parameter of monitoring effort γ is set to fix the steady-state monitoring effort to 1. Seigniorage is set to fix the steady-state price level to 1, and the household's durable goods endowment is exogenously set as 1.

[8] In this paper, I do not seek to characterise the equilibrium at the Zero Lower Bound. The banks' risk-taking behaviour at the ultra-low interest environment or with even negative interest rates is outside the scope of this particular exercise.

Table 4.1: Model Calibration

Description	**Calibration**	**Parameter**	**Value**
Real Deposit Rate (p.a.)	1%	β	0.9975
Investment/GDP	20%	d	0.2
Net Charge-offs (p.a.)	0.78%	z	1.86×10^3
Targeted Maturity Mismatch	6.7 quarters	ψ	14.54
Reserve to Loan Ratio		ι	0.1
Monitoring Effort	1	γ	3.78×10^{-2}
Consumption Preference	free	χ	0.5
Price Level	1	ξ	1.24×10^{-4}
Durable Goods Endowment		e	1
Real Policy Rate (p.a.)		r^p	3%
Policy Rate Inflation Feedback		m_p	1.1
Policy Rate Output Feedback		m_y	0.5
Shock Persistence S^m		ρ_m	0.9
TFP Shock Persistence A		ρ_a	0.9

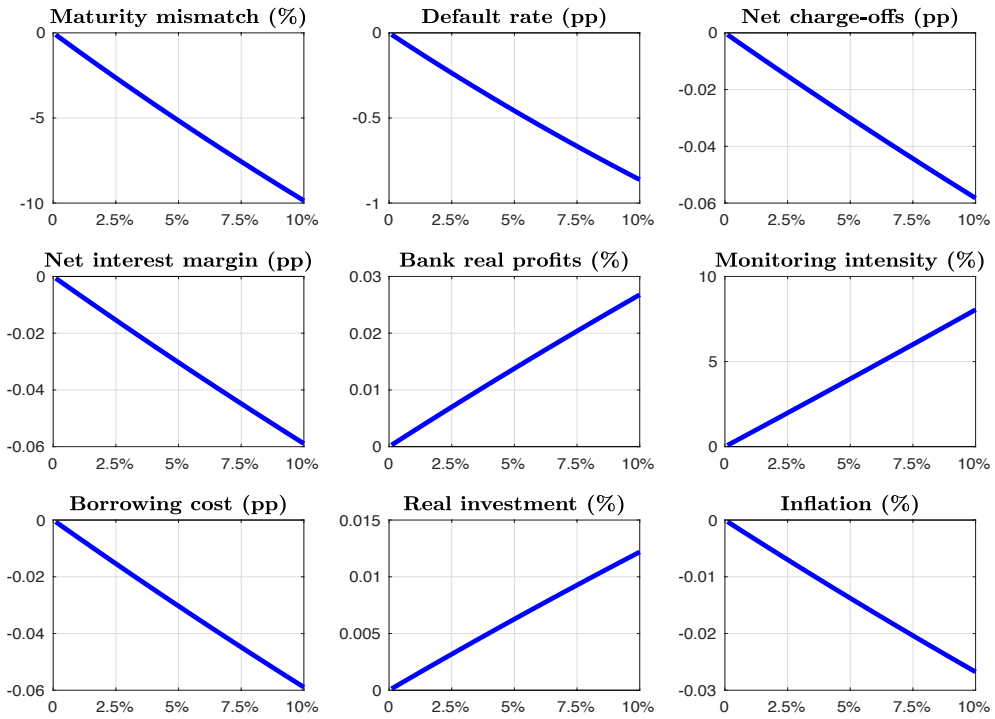
Data source: Board of Governors of the Federal Reserve System and FDIC Call Reports.

5.2. Steady-state Analysis

This section provides the steady-state numerical analysis and investigates the quantitative effects of the NSFR on investment, output, non-bank default, and monetary policy pass-through.

Figure 4.2 simulates the equilibrium of a 10% tightening of the NSFR. The horizontal axis is the tightening of the NSFR towards the capital financing cycle. As we can see, maturity mismatch decreases as the NSFR tightens. Loan default rate and net charge-offs of non-performing loans both decrease, because the decrease of maturity mismatch increases the extensive margin of the firms' default penalty. In particular, the net charge-offs decrease by around 0.06 pp annually. Despite the squeeze on banks' net interest margin, banks' real profits go up due to a higher quantity of bank credit extension. This corresponds to a higher monitoring intensity and a lower borrowing cost. Therefore, real investment increases by 0.012 % per quarter and inflation falls moderately.

Figure 4.2: NSFR tightening



The simulation illustrated in Figure 4.3 studies the transmission of monetary policy with and without the change of the NSFR. The horizontal axis indicates the loosening of the monetary policy rate. The further to the right, the more expansionary monetary policy is, up until a 20bp reduction of the annual policy rate. The solid line indicates the steady-state equilibrium that keeps the NSFR constant, and the dashed line indicates the steady-state equilibrium in which the NSFR moves towards a 10% tightening as monetary policy loosens. When the NSFR stays constant, the expansionary monetary policy increases real investment (by 0.03%) and inflation; however, it also increases maturity mismatch and reduces banks' net interest margin and monitoring intensity, causing deterioration of loan quality. The moral hazard of banks' private cost of monitoring obstructs the pass-through of monetary policy. When the NSFR tightens as monetary policy loosens, banks' monitoring effort increases, leading to a decrease in the default rate and net charge-offs. Therefore, real investment increases by around 0.037% per quarter. Using borrowing cost as the yardstick, the 10% tightening of the NSFR improves the pass-through of monetary policy by around 17 %.

Figure 4.3: Monetary policy pass-through and the NSFR

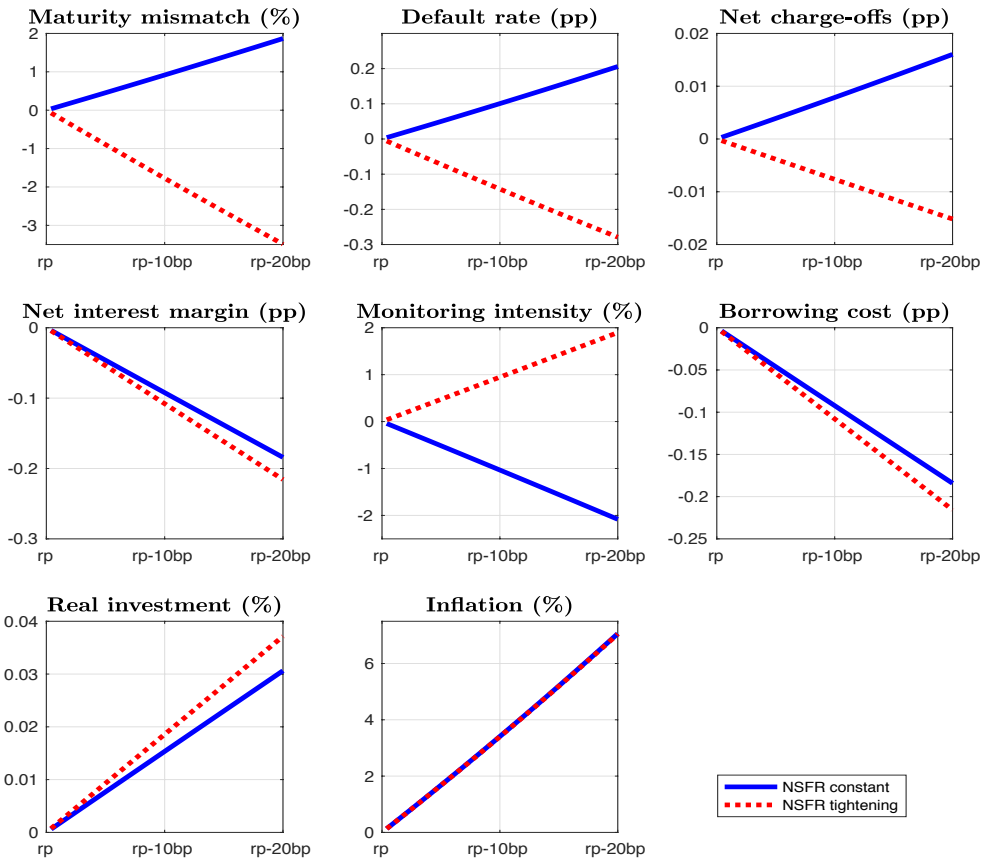
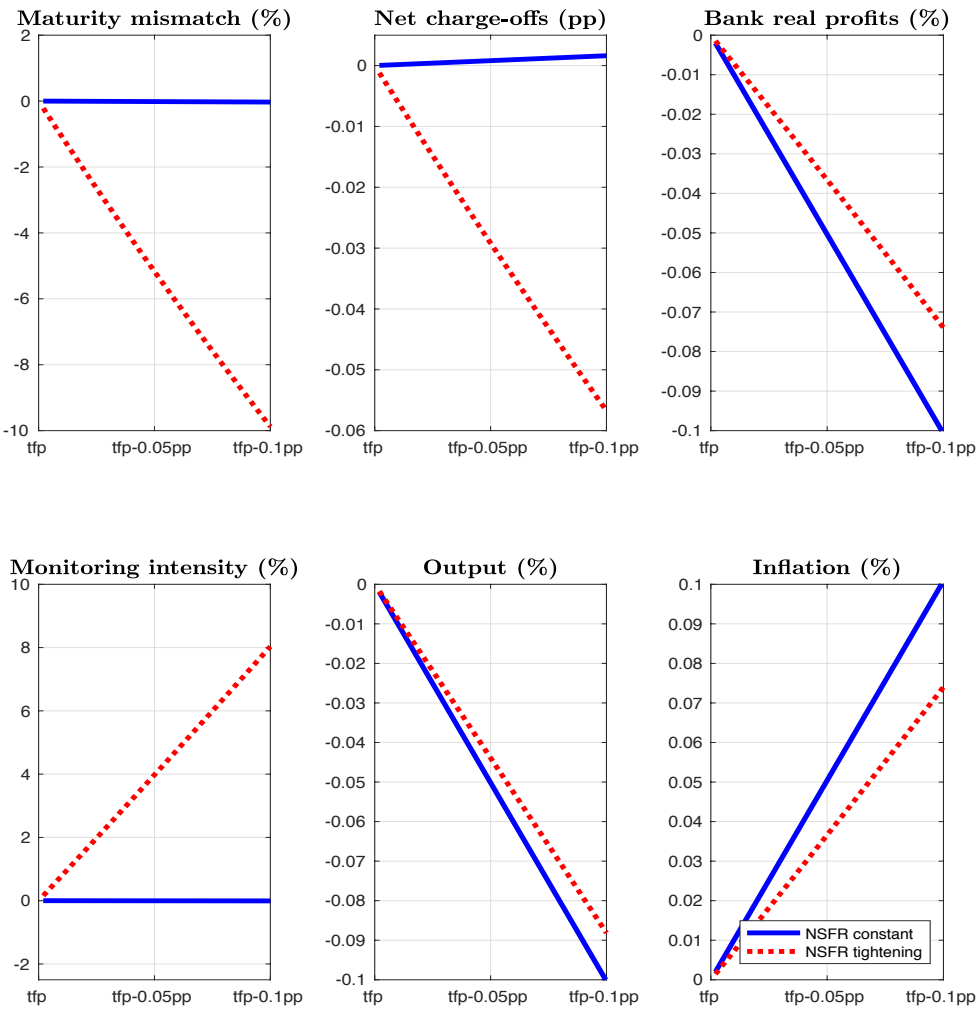


Figure 4.4 simulates the steady-state equilibrium responding to a negative TFP shock of up to 0.1 pp while varying the stance of the NSFR. It suggests that the NSFR, if appropriately implemented, can reduce the aggregate fluctuation of the economy by dampening the default channel and credit risk premium. The solid line illustrates the equilibrium in which the NSFR is kept constant, while the dashed line illustrates the equilibrium in which the NSFR tightens as the economy experiences the negative TFP shock. As can be seen, when the NSFR stays constant, as the economy experiences the downturn, default risk indicated by the net charge-offs go up, banks' real profits go down, and monitoring effort decreases mildly. As the TFP shock reaches a negative -0.1pp, maturity mismatch decreases moderately by 0.03 %, output decreases by 0.1 % per quarter, and inflation increases to 0.1 %. When the NSFR tightens alongside the negative TFP shock, bank credit quality improves as the net charge-offs decrease by almost up to 0.06 pp. Banks have a better incentive to monitor the loans; output drops less and inflation increases less than the case where the NSFR stays constant. Similarly, when the economy experiences a boom, i.e., a positive TFP shock, a loosening of the NSFR could dampen the rise in output and the fall in inflation.

Figure 4.4: TFP shock, default, and the NSFR



5.3. Short-run Dynamic Responses and Shock Propagations

This subsection simulates the stochastic dynamic equilibrium paths and studies the shock propagations in the short run, using second-order approximation around the steady states implemented in Dynare. Figure 4.5 displays the impulse responses of a negative TFP shock whereby output drops by 1% and the macro-prudential stance on the NSFR remains unchanged. Monetary policy that follows a standard Taylor rule reacts to counteract the downturn. Inflation increases and household consumption falls. Maturity mismatch decreases by around 2.24% at the third quarter due to the presence of the NSFR as a macro-prudential regulation. The fall in maturity mismatch results in a higher monitoring effort and a slight improvement in credit quality. In the initial period where the shock hits, the credit risk premium shoots up to 0.0076pp and then it immediately falls by 0.0079 pp from the steady state in the fifth quarter before slowly moving back to the steady state. Due to the support of monetary policy and the decrease in maturity mismatch, real investment increases slightly.

Figure 4.5: Negative TFP shock

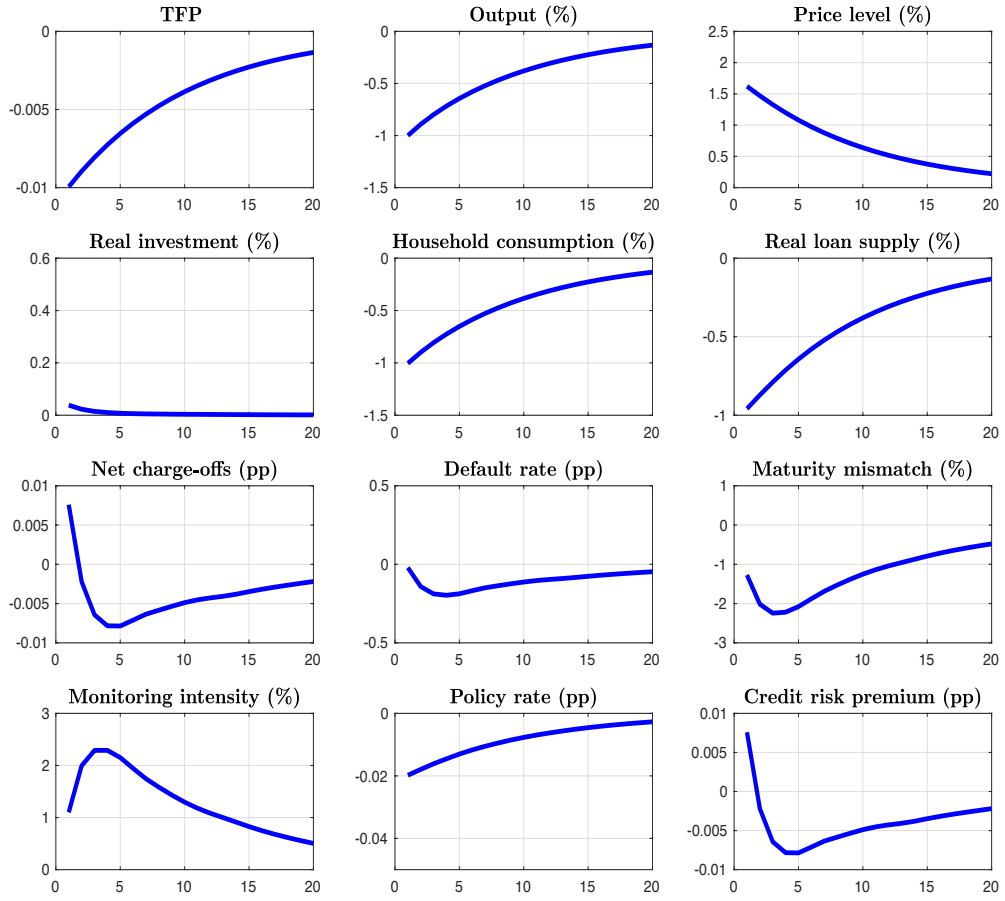
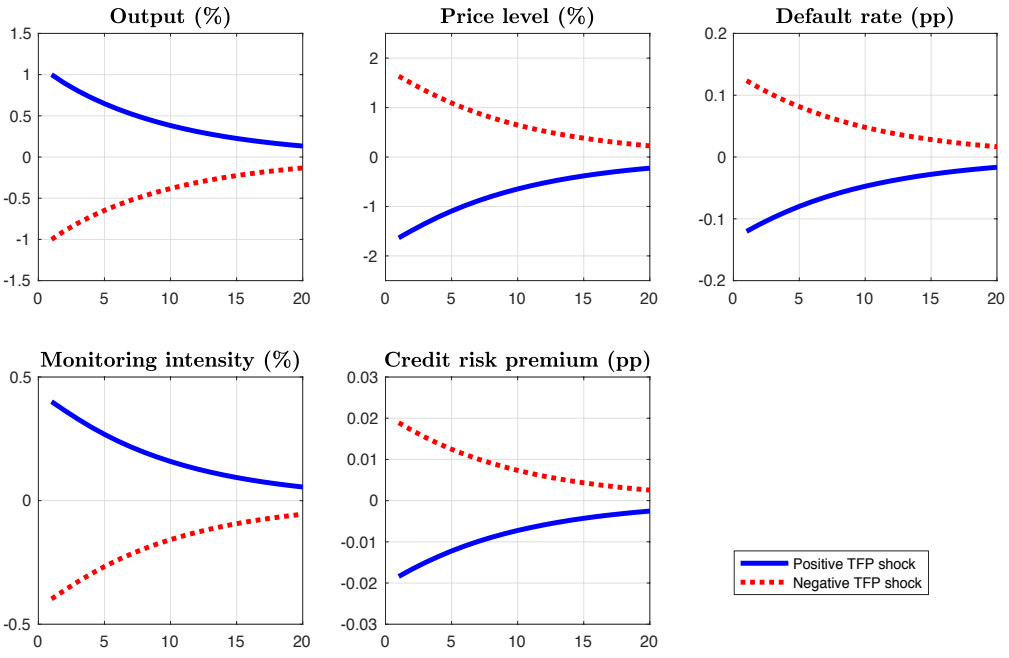


Figure 4.6: Default and aggregate fluctuations



The above analysis suggests that the mix of monetary policy and maturity mismatch can reduce the aggregate fluctuations partly by improving bank credit quality and reducing the moral hazard of banks' private costs of monitoring. To zoom in on this mechanism, Figure 4.6 demonstrates the default risks and banks' risk-taking during the business cycle fluctuations while shutting down the channel of monetary policy and maturity mismatch, and Figure 4.7 shows how the combination of monetary policy and the NSFR regulation can dampen the default channel and banks' risk-taking.

In Figure 4.6, the solid line corresponds to a positive TFP shock and the dashed line corresponds to a negative TFP shock. As can be seen during the economic boom, banks make more effort to monitor the loans due to more skin in the game. Thus, a higher monitoring effort leads to a higher marginal cost of default for the firms, and the economic boom implies a lower marginal utility of consumption, and hence, a lower marginal benefit of default. Accordingly, during the boom, the firms, i.e., the non-bank borrowers default less and the economic boom is accompanied by a lower credit risk premium. However, during the economic downturn, the incentives of non-bank borrowers and banks flip, and credit risk premium increases. It appears that the system looks strongest when it is most vulnerable, i.e., financial instability paradox à la Borio: credit growth is high and risk premium is low during the boom and credit supply decreases and risk premium shoots up during the bust.[9]

Figure 4.7 switches on the channels of monetary policy and the NSFR and studies how a mix of active monetary policy and the NSFR can reduce default risks during the downturn when the economy is hit by a negative TFP shock. The solid line corresponds to the case where the monetary policy rule and the NSFR regulation are kept constant, and the dashed line corresponds to the case where monetary policy follows a Taylor rule and the NSFR reacts in a countercyclical fashion. As can be seen, in the case where policy rules are active, monitoring intensity improves, default risks decrease, and credit risk premium drops, exerting positive effects on real investment.

[9]See Borio and White (2004) for a detailed discussion. The author would like to thank an anonymous referee for suggesting this point.

Figure 4.7: Default and the countercyclical mix of Taylor rule and the NSFR

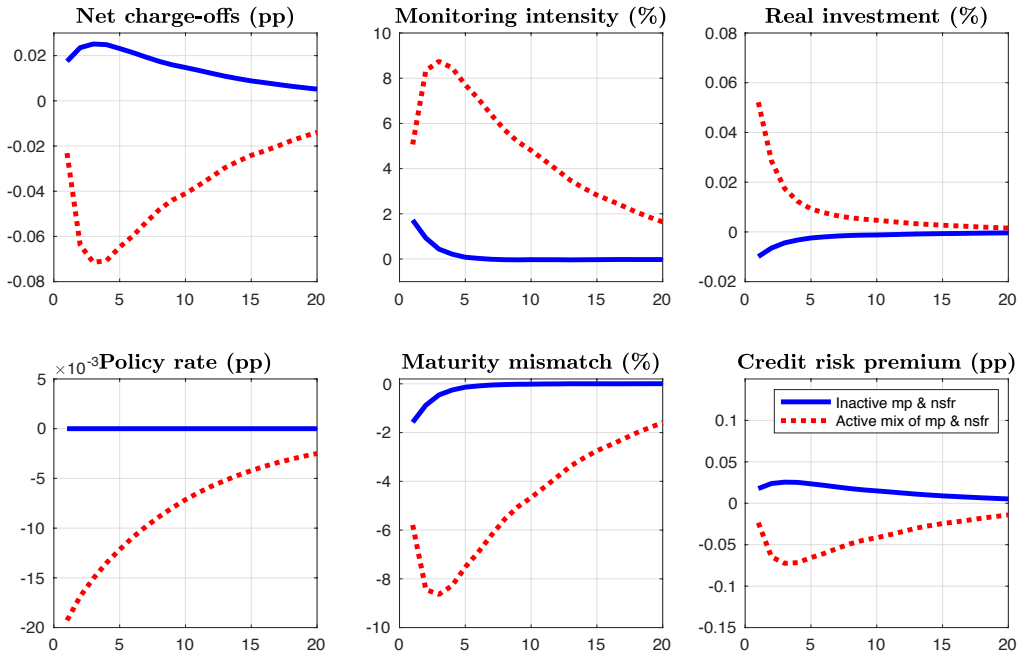
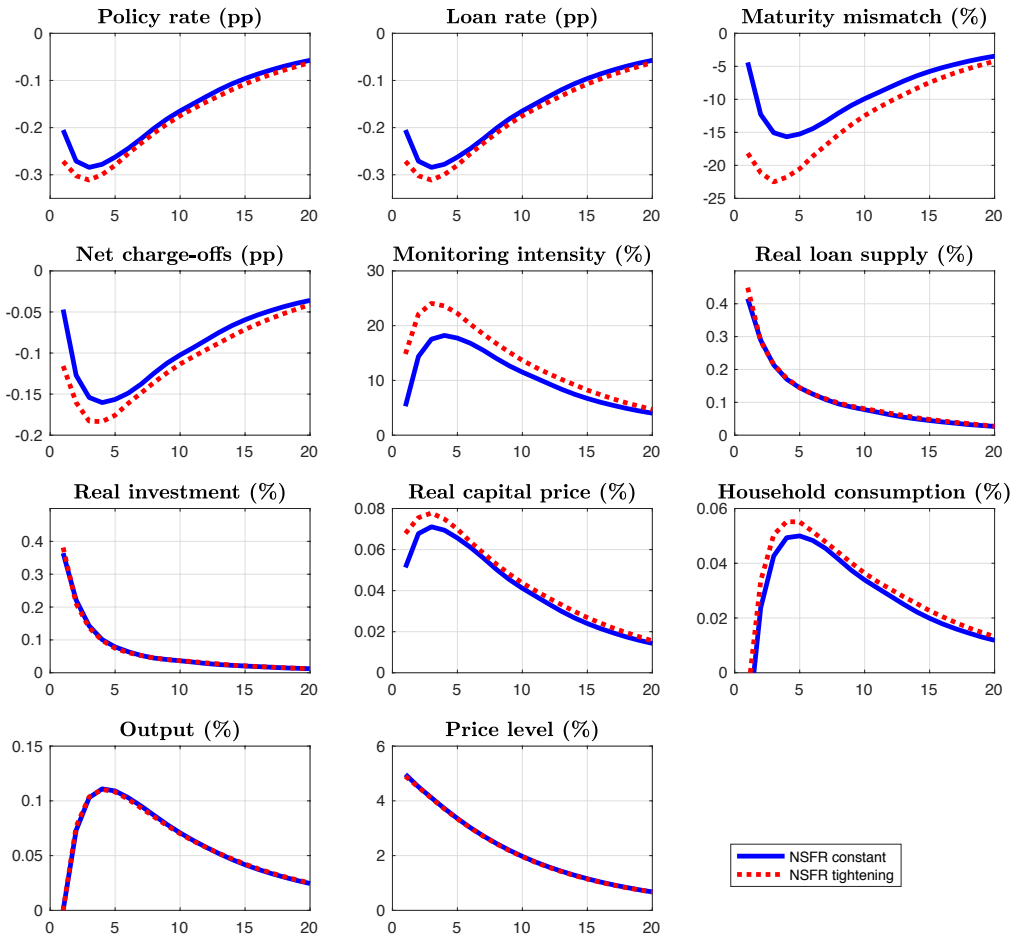


Figure 4.8 studies the effect of the same expansionary monetary policy shock with two different stances of the NSFR. The solid line corresponds to the case in which the policy rate falls by around 28 bp towards the third quarter and the NSFR is kept constant. The dashed line corresponds to the case of the same monetary policy shock but a tighter the NSFR, whereby the policy rate falls by around 31 bp towards the third quarter. The expansionary monetary policy shock boosts aggregate demand. The borrowing cost and default risks to go down, real investment and household consumption both decrease. Output increases by over 0.11 % in the fourth quarter, accompanied by inflationary pressure. Particularly, when the monetary policy shock is accompanied by a tighter the NSFR, the policy rate falls more and passes through more effectively to the loan rate or the borrowing cost. This is because a tighter the NSFR reduces maturity mismatch more aggressively, resulting in better credit quality, higher monitoring effort.

Figure 4.8: Expansionary monetary policy shock and the NSFR



6. Conclusion

This paper has proposed a dynamic stochastic general equilibrium to assess the effect of the NSFR on credit quality, investment, and the transmission of monetary policy. The emphasis is on the broader macro-financial consequences; thus, the perspective taken in this paper complements the current literature whose focus is on the effect of the NSFR on banking insolvency.

The main result is that the implementation of the NSFR would only increase real investment if it improves the bank credit quality and decreases the non-bank default rate. In the numerical example calibrated with the US data, the dynamic general equilibrium is solved, and the numerical solution with second-order approximation around the steady states is provided. The tightening of the NSFR to move maturity mismatch towards the long-run capital financing cycle indeed improves bank credit quality, as well as the transmission of monetary policy. A 10% tightening in the NSFR is shown to improve the pass-through of a 20-bp policy rate reduction by around 17%. I hasten to add that the policy experiments conducted in this paper do not focus on the very recent Zero Lower Bound episode or even the negative interest rate realm, which is outside the scope of this paper. However, with the insight from Martinez-Miera and Repullo (2017), Heider et al. (2019), and Brunnermeier and Koby (2018), the broad intuition is that in the ultra-low interest rate environment, the effect of the NSFR should be weaker, because the ultra-low interest rate environment squeezes banks' profit margin and encourages search-for-yield, which could limit the role of the NSFR in improving credit quality and the transmission of monetary policy.

A theoretical contribution of this paper is to combine the endogenous default literature à la Shubik and Wilson (1977) and Dubey et al. (2005) with the monitoring role of banking à la Holmstrom and Tirole (1997) and Martinez-Miera and Repullo (2017). This innovation provides a richer role of the banking sector. Embedding endogenous default and banks' moral hazard in a dynamic macroeconomic setting with money and credit, a well-defined role for monetary policy emerges. Thus, a broader purpose of this paper is to serve as a starting point to comprehensively assess the short-run dynamics of both the monetary policy and a mix of macro-prudential policy tools simultaneously.

Appendices

1. Optimality Conditions

1.1. Proof of Lemma 1.

Firms' optimality conditions:

Substitute (4.1) and (4.2) into (4.4) and take first-order condition for $L_t, b_t, \delta_t, v_t^f, \omega_t^f$, it follows that

$$-\beta\lambda_{t+1}^f \frac{(1-v_{t+1}^f)^2\delta_{t+1}^2(1+r_{t+1}^l)^2 L_t}{P_{t+1}^2} - \beta\eta_{t+1}^f((1-\delta_{t+1})(1+\bar{r}_{t+1}^l) + v_{t+1}^f\delta_{t+1}(1+r_{t+1}^l)) + \Lambda_t^f = 0,$$

$$\eta_t^f P_t A_t \tau + \beta^j \eta_{t+j}^f P_{t+j} A_{t+j}(1-\tau) - \Lambda_t^f P_t^k \tau - \beta^j \Lambda_{t+j}^f (1-\tau) P_{t+j}^k = 0,$$

$$-\lambda_t^f \frac{(1-v_t^f)^2\delta_t L_{t-1}^2(1+r_t^l)^2}{P_t^2} + \eta_t^f L_{t-1}(1+\bar{r}_t^l) - \eta_t^f v_t^f L_{t-1}(1+r_t^l) = 0,$$

$$\lambda_t^f \frac{(1-v_t^f)\delta_t L_{t-1}(1+r_t^l)}{P_t} = \Lambda_t,$$

$$\Lambda_t - P_t\eta_t^f = 0.$$

Reaggrange the above first-order conditions and substitute out Λ_t^f, it follows that

$$\eta_t^f P_t A_t \tau + \beta^j \eta_{t+j}^f P_{t+j} A_{t+j}(1-\tau) = \beta\eta_{t+1}^f(1+r_t^l)\tau P_t^k + \beta^{j+1}\eta_{t+j+1}^f(1+r_{t+j}^l)(1-\tau)P_{t+j}^k,$$

$$1+\bar{r}_t^l = 1+r_t^l,$$

$$\lambda_t^f \frac{(1-v_t^f)\delta_t L_{t-1}(1+r_t^l)}{P_t} = \Lambda_t,$$

where $\Lambda = \frac{\chi}{c_t}$. □

1.2. Households' Optimality

Let η_t^h be the shadow price of the budget constraint, and take first-order conditions for c_t, q_t, D_t^h.

$$-\eta_t^h + \beta\eta_{t+1}^h(1 + r_{t+1}^d) = 0,$$

$$\frac{\chi}{c_t} - P_t\eta_t^h = 0,$$

$$\frac{(1-\chi)}{e_t - q_t} = P_t^k\eta_t^h.$$

Rearrange the above equations and substitute out η_t^h,

$$1 + r_{t+1}^d = \frac{\pi_{t+1}c_{t+1}}{\beta c_t},$$

$$\frac{1-\chi}{e_t - q_t} = \frac{P_t^k\chi}{P_t c_t}.$$

1.3. Proof of Lemma 2.

Banks' optimality:

Combine the the market clearing condition of reserves $M_t = Res_t$ and (4.9) with (4.10), and take first-order condition for M_t,

$$1 + r_t^l = \frac{1 + r_t^p}{1 - \delta_t + v_t^f\delta_t}.$$

Take the first-order condition for L_t,

$$f_t - \frac{\gamma}{2}m_t^2 - \psi_t(\delta_t^{TR} - \delta_t)^2\frac{L_{t-1}}{P_t} + P_t\eta_t^b(1 - v_t^e)\delta_t(1 + r_t^l) = 0.$$

Take the first-order condition for m_t leads to

$$\gamma z m_t^3 L_{t-1}c_t = \eta_t^b\chi P_t^2.$$

Take the first-order condition for δ_t,

$$\underbrace{(1 - v_t^f)(1 + r_t^l)}_{\text{MB of maturity mismatch}} = \underbrace{\psi_t(\delta_t^{TR} - \delta_t)\frac{L_{t-1}}{P_t} + P_t\eta_t^b(1 - v_t^f)(1 + r_t^l)}_{\text{MC of maturity mismatch}}.$$

The above equations can be simplified as

$$1 + r_t^l = \frac{1 + r_t^p}{1 - \delta_t d_t^f},$$

$$\gamma z m_t^3 L_{t-1} c_t = \chi P_t - \chi \psi_t (\delta_t^{TR} - \delta_t) \frac{L_{t-1}}{d_t^f (1 + r_t^l)},$$

$$\psi_t \frac{L_{t-1}}{P_t} (\delta_t^{TR} - \delta_t) \delta_t^{TR} + \frac{\gamma}{2} m_t^2 = r_t^l - r_t^d.$$

□

1.4. Proof of Theorem

The steady state equilibrium is characterised by the following steady state equations. They jointly determine the endogenous variables $\omega^f, q, L, r^l, v^e, P^k, r^d, \delta, m, c, P, \eta^b, f$.

$$P\omega^f = PA\frac{q}{d} - [(1 - \delta)P^k q(1 + r^l) + v^f \delta P^k q(1 + r^l)], \tag{17}$$

$$P^k q = L, \tag{18}$$

$$zm(1 - v^f)\delta(1 + r^l)\frac{L}{P} = \frac{\chi}{c}, \tag{19}$$

$$PA = \beta P^k (1 + r^l), \tag{20}$$

$$1 = \beta(1 + r^d), \tag{21}$$

$$\frac{1 - \chi}{e - q} = \frac{A\chi}{\beta c(1 + r^l)}, \tag{22}$$

$$1 + r^l = \frac{1 + r^p}{1 - \delta + v^f \delta}, \tag{23}$$

$$\psi \frac{L}{P}(\delta^{TR} - \delta)\delta^{TR} + \frac{\gamma}{2}m^2 = r^l - r^d, \tag{24}$$

$$\gamma z m^3 L c = \eta^b P^2 \chi, \tag{25}$$

$$(1 - v^f)(1 + r^l) = \psi(\delta^{TR} - \delta)\frac{L}{P} + P\eta^b(1 - v^f)(1 + r^l), \tag{26}$$

$$f = (1 - \delta(1 - v^e))(1 + r^l) - (1 + r^d), \tag{27}$$

$$c + (f - r^p \iota)\frac{L}{P} = A\frac{q}{d}, \tag{28}$$

$$r^p \iota L = \xi. \tag{29}$$

Combine (18), (22), (27), and (28), it follows that

$$q = \chi e[\chi + (1 - \chi)\beta \frac{1 + r^p}{d(1 - \delta(1 - v^e))} - (1 - \chi)(1 + r^p) + (1 - \chi)(r^p \iota + \beta^{-1})]^{-1}. \tag{30}$$

Let $X = \chi + (1 - \chi)\beta(1 + r^p)(d(1 - \delta d^e))^{-1} - (1 - \chi)(1 + r^p) + (1 - \chi)(r^p \iota + \beta^{-1})$, then (30) can be written as $qX = \chi e$.

To see how q changes with respect to a reduction in maturity mistmach,

total differentiate $qX = \chi e$,

$X dq + q\frac{\partial X}{\partial \delta} d\delta = 0$.

We know $\frac{dX}{d\delta} = (1 - \chi)\beta(1 + r^p)d^{-1}(1 - \delta d^e)^{-2}[d^e + \delta \frac{\partial d^e}{\partial \delta}]$,

It follows that

$$\frac{dq}{d\delta} = -q\chi^{-1}(1 - \chi)\beta(1 + r^p)d^{-1}(1 - \delta d^e)^{-2}(d^e + \delta \frac{\partial d^e}{\partial \delta}).$$

Therefore,

If $d^e + \delta \frac{\partial d^e}{\partial \delta} > 0$, output decreases if maturity mismatch falls, and vice versa; if $d^e + \delta \frac{\partial d^e}{\partial \delta} < 0$, output increases if maturity mismatch increases, and vice versa.

□

Conclusion

This thesis focuses on the role of inside money, bank credit, and endogenous default in macro-finance and international finance general equilibrium models and provides the scope for policy. This is an exciting research avenue to understand the complex interactions between price stability and financial stability, and between the real and nominal forces of the economy.

Chapter 1 introduces inside money and deposit creation via bank credit in a New Keynesian framework so that both the financial channel and the sticky price channel of the monetary policy transmission can be assessed simultaneously. The policy focus of this chapter is on the effectiveness of monetary policy at the interest rate lower bound and the associated nominal puzzle of the flattening of the Phillips curve. Chapter 2 sheds light on the critical debate on the viability of a currency union. In this chapter, I design the bankruptcy code of the cross-border capital markets union as an alternative to a fiscal union in improving risk sharing of a currency union. I show when domestic credit risks are present, a lenient union-wide bankruptcy code that allows for default in the cross-border capital markets union removes the pecuniary externality of banking insolvency; therefore, it leads to a Pareto improvement within the currency union. The model provides the welfare and financial stability implications of bankruptcy within a capital markets union in the Eurozone. Chapter 3 studies the structural relationship between monetary policy and the aggregate financial wedge of the economy, with various policy implications provided. Chapter 4 develops a dynamic stochastic general equilibrium featuring endogenous default and banks' costly monitoring to assess the new Basel III liquidity tool the Net Stable Funding Ratio and its real and financial effects on the banks' credit quality, real investment, and the pass-through of monetary policy.

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