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A Macro-Financial Perspective to Analyse Maturity Mismatch and Default

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Abstract

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.

Keywords: Maturity mismatch, Net Stable Funding Ratio, default, monetary policy, macro-prudential policy, banking

JEL Codes: E44, E51, G18, G21

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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[1] 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.[2] 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 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

[1] 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".

[2] For example, papers by King (2013) and Dietrich et al. (2014) present empirical evidence on this. Section 2 discusses their differences and relevance.

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 implementation 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.

To model the transmission of monetary policy, this paper makes it explicit the issuance of deposits and the reserve market, drawing on insight from the general equilibrium theory of inside money and outside money that dates back at least to Grandmont and Younes (1972, 1973) and Shapley and Shubik (1977). As in Dubey and Geanakoplos

(1992, 2003b, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), Goodhart et al. (2006, 2013), 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, and outside money is the seigniorage profits distributed to the next period to guarantee price-level determinacy along with the policy rate.

Inside money issuance via bank credit is by no means a new concept. As pointed out by Werner (2012), it was much emphasised in older economics literature when the banking sector had just started booming. Many authors such as Macleod (1866), Hahn (1920), Hawtrey (1919), Schumpeter (1954), Keynes (1931), and Tobin (1963) have all produced insightful work on this mechanism. The formalisation of this monetary operation is now finding its way to influence various central banks and policy institutions around the world (see Jakab and Kumhof 2015, 2018).[3] 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), Gu et al. (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 Wang (2019).

Finally, this paper closely connects with the large literature on the role of financial frictions in macroeconomic modelling which follows a rich tradition (Bernanke 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 Martínez and Tsomocos (2018) and Goodhart et al. (2018). However, this paper adds the maturity mismatch and banks' moral hazard of costly monitoring channels to Martínez and Tsomocos (2018) and Goodhart et al. (2018).

3 The Model

3.1 The Environment

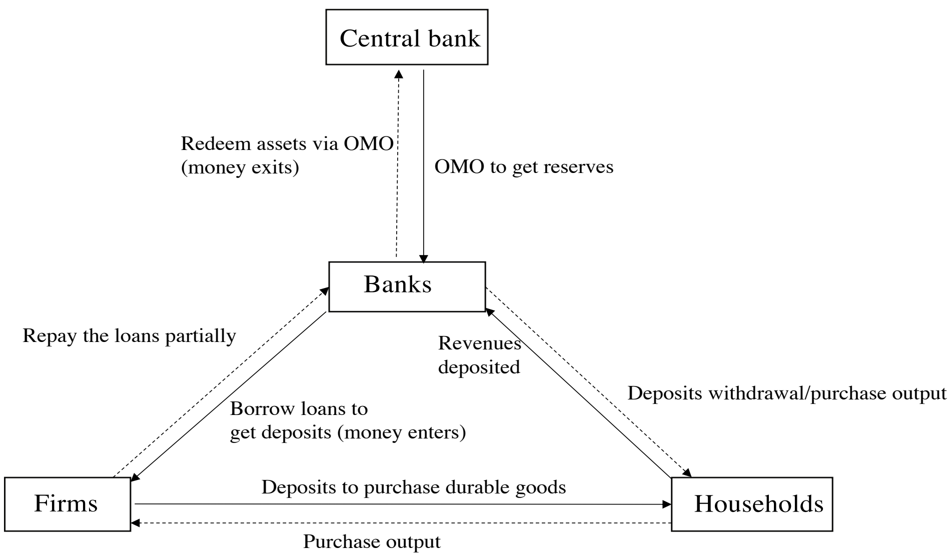
The model is of infinite horizons with three major players: the households, the firms, and the banking sector. At the beginning of every period, the households are endowed with durable goods. The firms have the technology to transform durable goods into capital to produce perishable consumption goods, 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 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

[3] Other examples see Bank of England (McLeay et al. (2014a,b), the Bank for International Settlements (Borio and Disyatat (2015)), the Bundesbank (Bundesbank (2017)), the Central Bank of Ireland (Lozej et al. (2017)), Norges Bank (Kravik and Paulsen (2017)), and People's Bank of China (Sun and He (2018)).

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 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]

$$\begin{aligned}\text{NSFR} &= \frac{\text{Available Amount of Stable Funding (ASF)}}{\text{Required Amount of Stable Funding (RSF)}} \\ &= \frac{\text{Equity} \times 100\% + \text{Stable Funding} \times 80\% + \text{Unstable Funding} \times 20\%}{\text{Liquid Asset} \times 20\% + \text{Iliquid Asset} \times 80\%}.\end{aligned}$$

The numerator is a weighted sum of various types of funding (debt and equity) of the

[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.

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,

$\omega_t^f \equiv$ 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,

[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.

$\delta_t \equiv$ 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

$$\tau P_t^k b_t \leq \mu_t, \tag{1}$$

$$(1 - \tau) P_t^k b_t^{'} = (1 - \delta_t) L_{t-1}, \tag{2}$$

$$k_t = (1 - d) k_{t-1} + \tau b_t + (1 - \tau) b_t^{'}, \tag{3}$$

$$L_t = (1 - \delta_t) L_{t-1} + \mu_t. \tag{4}$$

Eq(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(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(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) 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) 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(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.

$$P_t\omega_t^f = P_t A_t k_t - [(1-\delta_t)L_{t-1}\bar{r}_t^l + (1-\tau)P_t^k b_t^{'} + v_t^f \delta_t L_{t-1}(1+r_t^l)]. \tag{5}$$

Combine eq(2) and eq(5), the firm's profits can be re-expressed as follows,

$$P_t\omega_t^f = P_t A_t k_t - [(1-\delta_t)L_{t-1}(1+\bar{r}_t^l) + v_t^f \delta_t L_{t-1}(1+r_t^l)]. \tag{6}$$

Substitute (3) into (6), the firm chooses $\mu_t, L_t, b_t, \delta_t, v_t^f$ to maximise its utility subject to eqs (1), (2), (4), and (6). Let η_t^f and Λ_t^f be the shadow prices of eqs (6) and (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(7)), the on-the-verge condition of maturity mismatch (eq(8)), and the on-the-verge condition of default (eq(9)).

$$\eta_t^f P_t A_t \tau + \beta^j \eta_{t+j}^f P_{t+j} A_{t+j}(1-\tau) = \beta\eta_{t+1}^f(1+r_t^l)\tau P_t^k + \beta^{j+1}\eta_{t+j+1}^f(1+r_{t+j}^l)(1-\tau)P_{t+j}^k, \tag{7}$$

$$1+\bar{r}_t^l = 1+r_t^l, \tag{8}$$

$$\lambda_t^f \frac{(1-v_t^f)\delta_t L_{t-1}(1+r_t^l)}{P_t} = \Lambda_t. \tag{9}$$

Proof. *Appendix A.1.*

Eq(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(8) states that the marginal cost of maturity mismatch (left-hand side) equates the marginal benefit of maturity mismatch (right-hand side).

Eq(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(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(10) expresses the bank's nomoinal profits,

$$\begin{aligned}\Omega_t^b = {} & (1+r_t^{l'})\int_0^1 (L_{t-1} - M_t(i))di \\ & - [(v_t^b D_{t-1}^b(1+r_t^d) - \int_0^1 Res_t(i)di] \\ & + (1+r_t^{l'})M_t - (1+r_t^p)Res_t.\end{aligned} \tag{10}$$

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(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(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(11),

$$\frac{\chi P_t}{c_t z m_t} = (1 - v_t^f) \delta_t L_{t-1} (1 + r_t^l). \tag{11}$$

Let η_t^b be the shadow price of the on-the-verge condition eq(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(10) and eq(11).

Lemma 2. Banks' optimality conditions.

The bank's optimality conditions are characterised by the pricing of loan rate (eq(12)), the trade-off of exerting monitoring effort (eq(13)),[6] and the supply curve of maturity mismatch (eq(14)).

$$1 + r_t^l = \frac{1 + r_t^p}{1 - \delta_t d_t^f}, \tag{12}$$

$$\gamma z m_t^3 L_{t-1} c_t = \chi P_t - \chi \psi_t (\delta_t^{TR} - \delta_t) \frac{L_{t-1}}{d_t^f (1 + r_t^l)}, \tag{13}$$

$$\psi_t \frac{L_{t-1}}{P_t} (\delta_t^{TR} - \delta_t) \delta_t^{TR} + \frac{\gamma}{2} m_t^2 = r_t^l - r_t^d. \tag{14}$$

Proof. *Appendix A.3.*

Eq(12) is the non-arbitrage condition of the interbank market for reserves and it provides the pricing for the loan rate. Eq(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(14) states the trade-off of the banks' choice of maturity mismatch, which is affected by the NSFR regulation.

[6] As long as the marginal reward of monitoring $\eta_t^b > 0$, the right-hand side of (13) is positive.

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(15), where S_t^m denotes the monetary policy shock.

$$r_t^p = r_{ss}(\frac{P_t}{\bar{P}})^{m_p}(\frac{y_t}{\bar{y}})^{m_y}S_t^m. \tag{15}$$

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:

$$M_t = Res_t.$$

[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.

- 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. □

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(8) and eq(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(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(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(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(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(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(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 A.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(16),

$$q = \frac{\chi e}{(1-\chi)\beta\frac{1+r^p}{d(1-\delta d^f)} + \Theta}. \tag{16}$$

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 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 formally characterise the equilibrium at the Zero Lower Bound. Section 6 provides a discussion on this issue.

Table 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

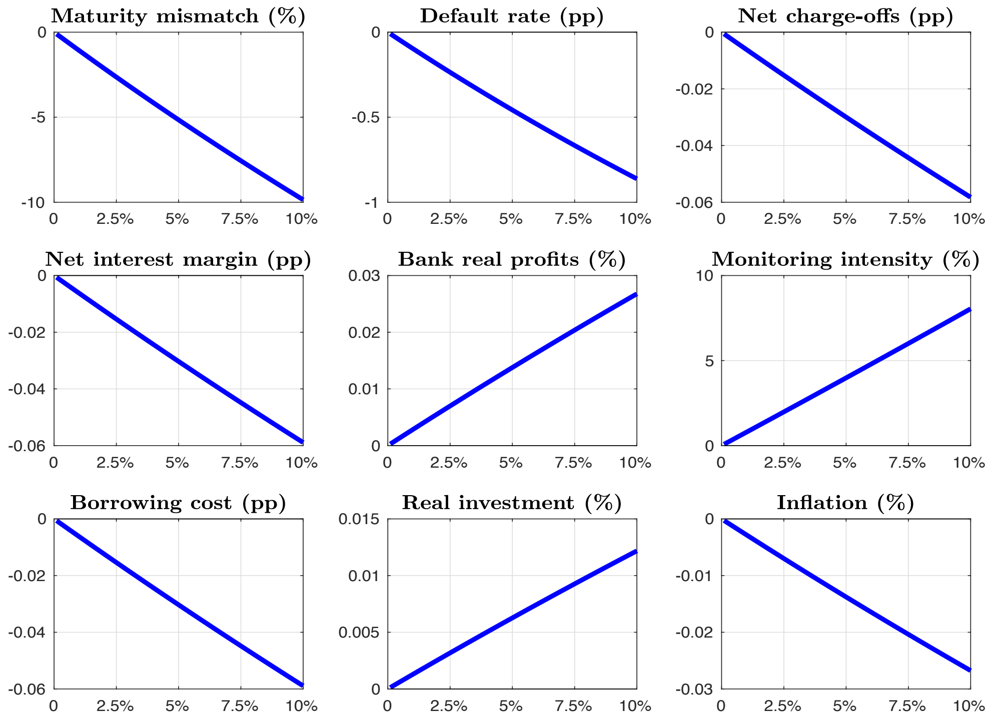
Data source: Board of Governors of the Federal Reserve System and FDIC Call Reports.

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 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 2: NSFR tightening



The simulation illustrated in Figure 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 3: Monetary policy pass-through and the NSFR

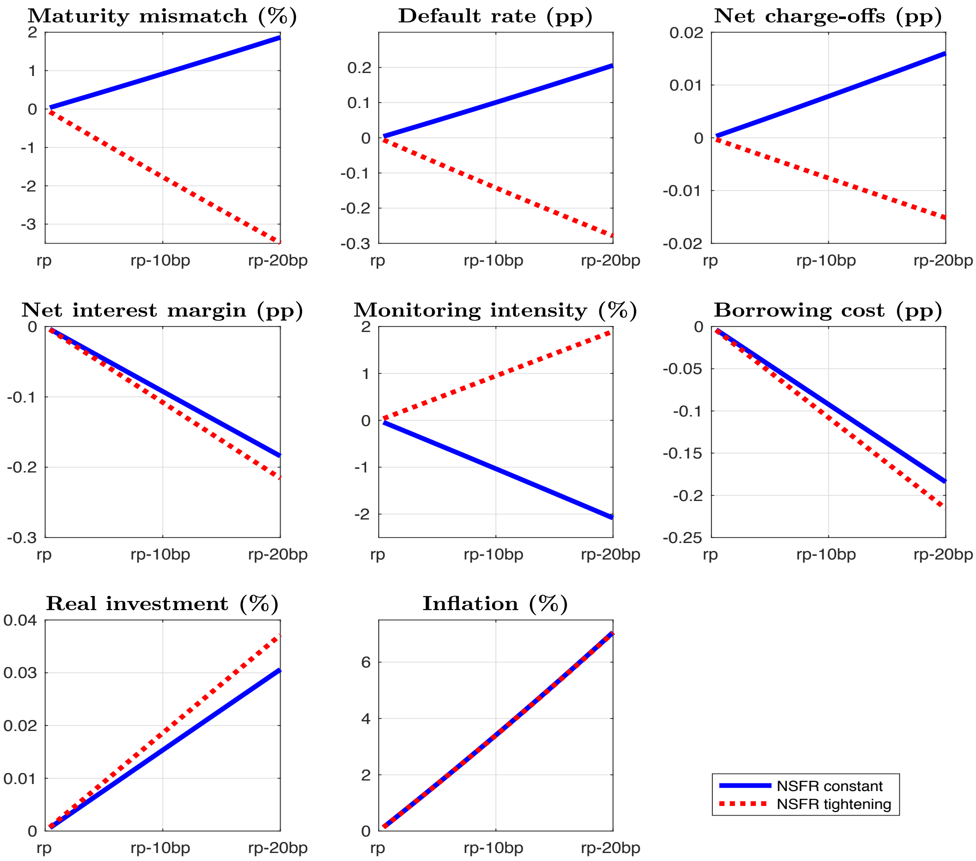
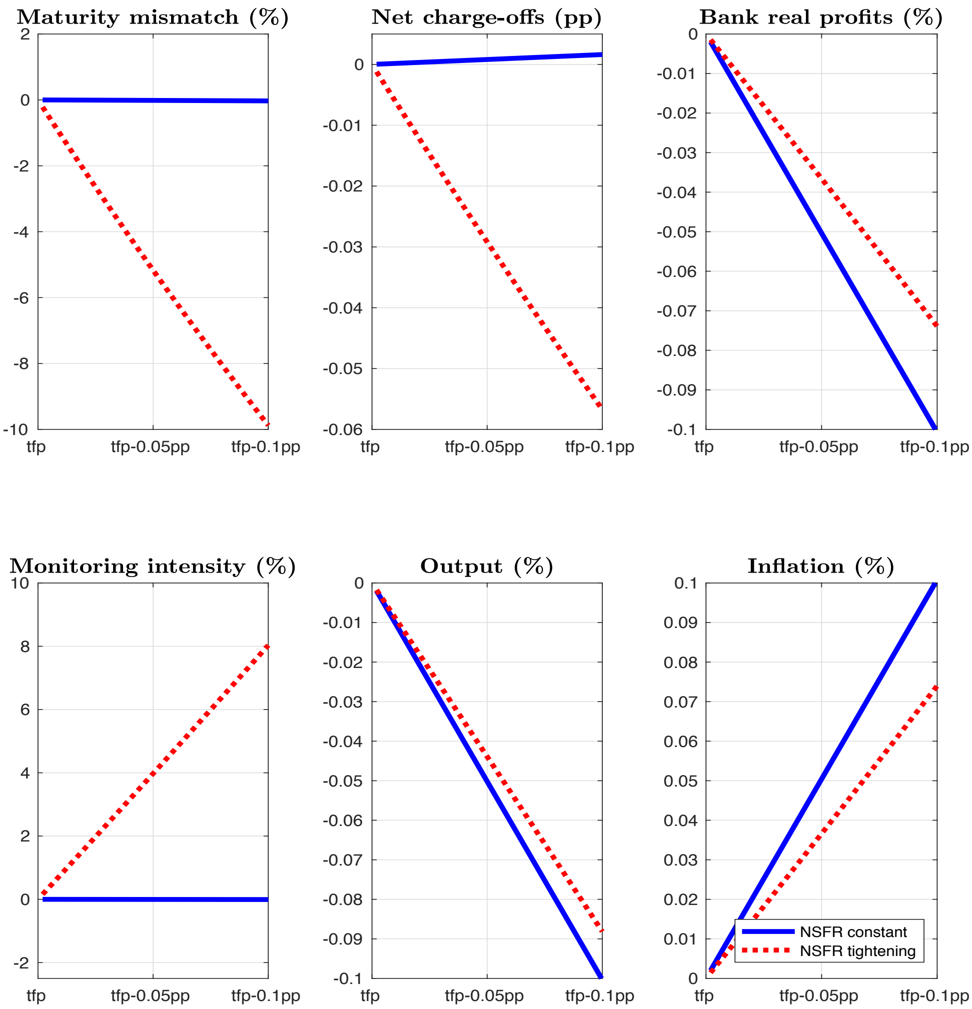


Figure 4 simulates the steady-state equilibrium responding to a negative TFP shock of up to 0.1 pp while varying the stance of the NSFR. It suggests that the NSFR, if appropriately implemented, can reduce the aggregate fluctuation of the economy by dampening the default channel and credit risk premium. 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: 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 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 5: Negative TFP shock

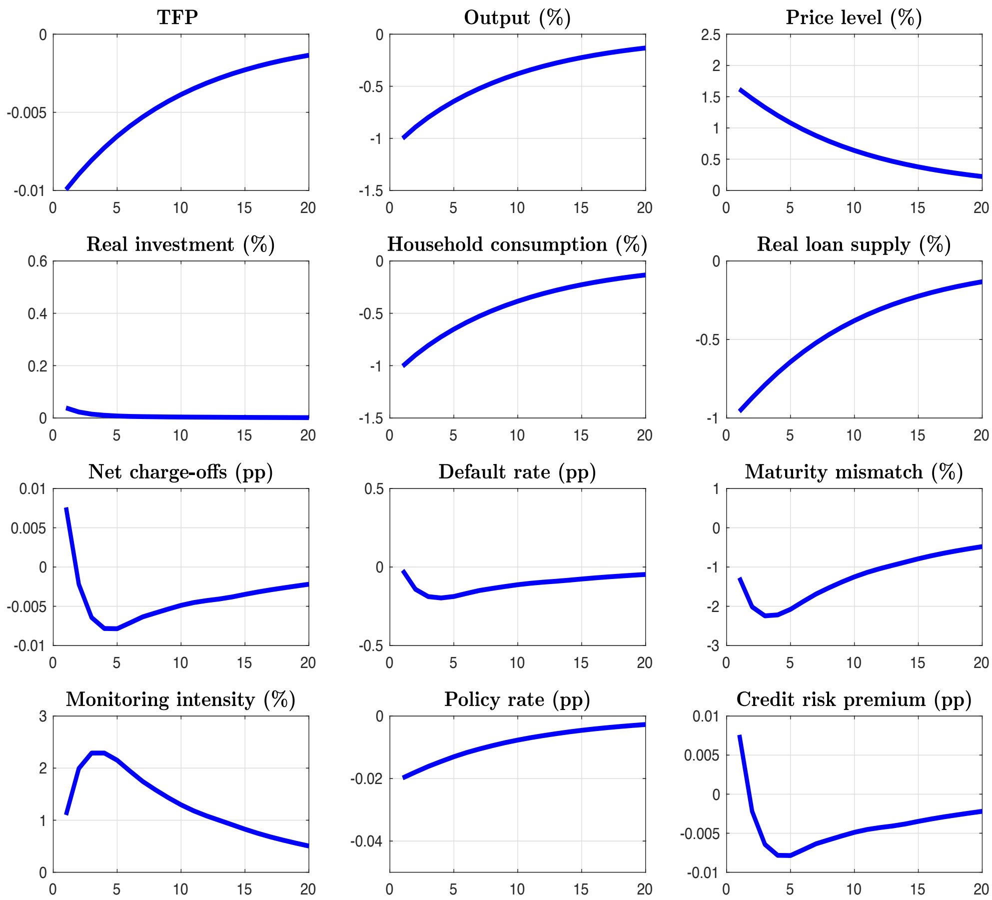
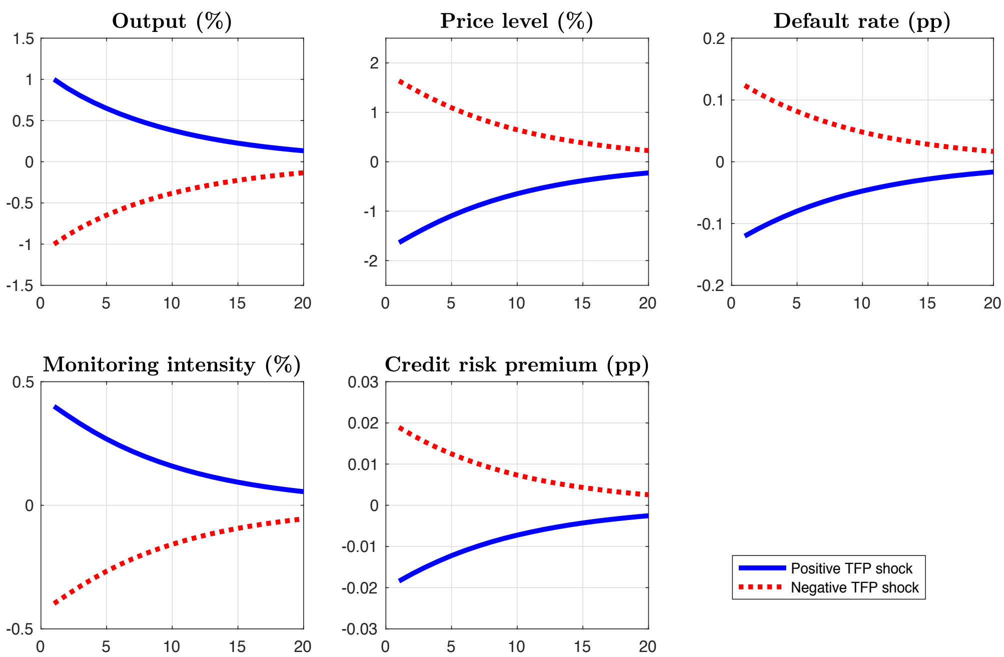


Figure 6: Default and aggregate fluctuations

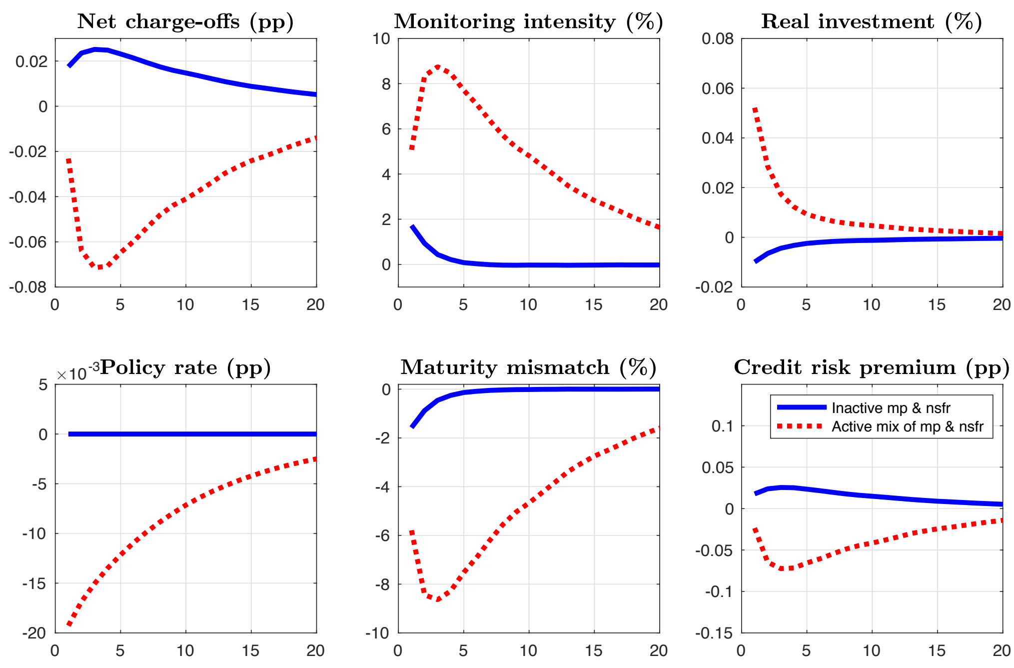


The above analysis suggests that the mix of monetary policy and maturity mismatch can reduce the aggregate fluctuations partly by improving bank credit quality and reducing the moral hazard of banks' private costs of monitoring. To zoom in on this mechanism, Figure 6 demonstrates the default risks and banks' risk-taking during the business cycle fluctuations while shutting down the channel of monetary policy and maturity mismatch, and Figure 7 shows how the combination of monetary policy and the NSFR regulation can dampen the default channel and banks' risk-taking.

In Figure 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 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.

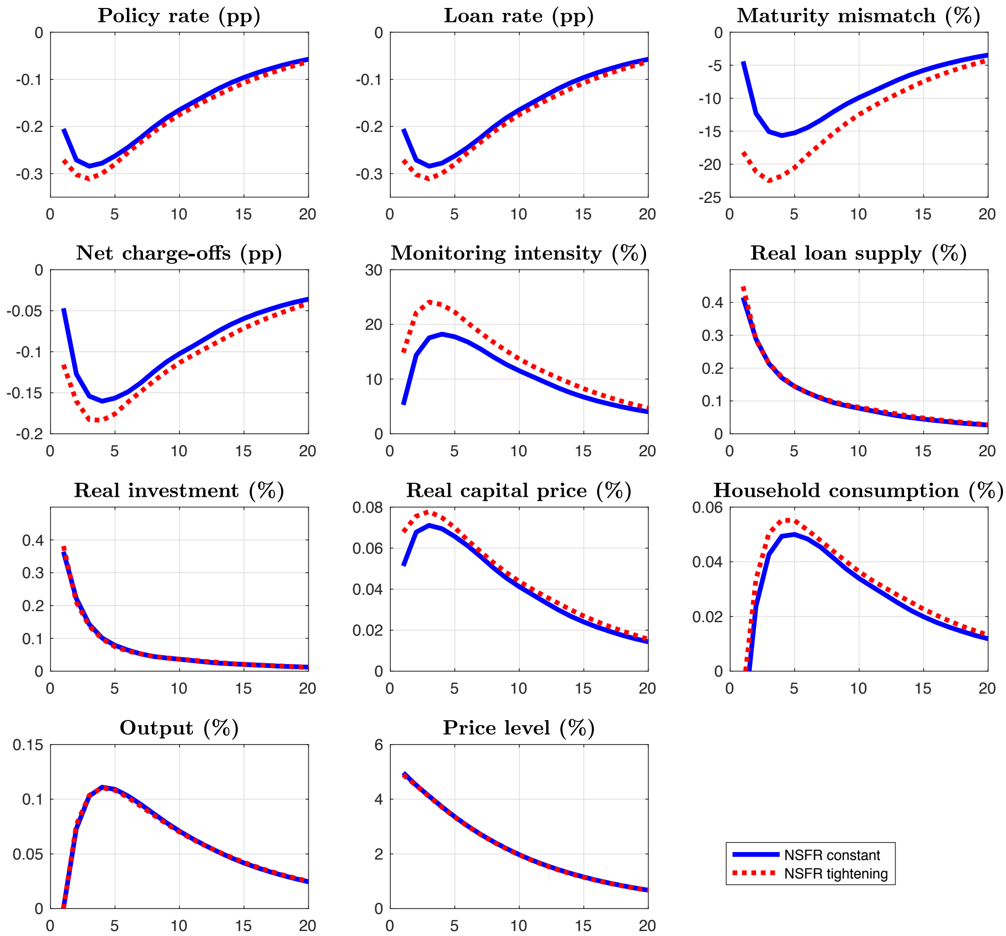
Figure 7: Default and the countercyclical mix of Taylor rule and the NSFR



[9]See White et al. (2004) for a detailed discussion. The author would like to thank an anonymous referee for suggesting this point.

Figure 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 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 (2020), 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

A Optimality Conditions

A.1 Proof of Lemma 1.

Firms' optimality conditions:

Substitute (1) and (2) into (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 $\Lambda = \frac{\chi}{c_t}$. $\square$

A.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,

$$1 + r_{t+1}^d = \frac{\pi_{t+1} c_{t+1}}{\beta c_t},$$

$$\frac{1-\chi}{e_t - q_t} = \frac{P_t^k \chi}{P_t c_t}.$$

A.3 Proof of Lemma 2.

Banks' optimality:

Combine the the market clearing condition of reserves $M_t = Res_t$ and (9) with (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

$$1 + r_t^l = \frac{1 + r_t^p}{1 - \delta_t d_t^f},$$

$$\gamma z m_t^3 L_{t-1} c_t = \chi P_t - \chi \psi_t (\delta_t^{TR} - \delta_t) \frac{L_{t-1}}{d_t^f (1 + r_t^l)},$$

$$\psi_t \frac{L_{t-1}}{P_t} (\delta_t^{TR} - \delta_t) \delta_t^{TR} + \frac{\gamma}{2} m_t^2 = r_t^l - r_t^d.$$

□

A.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.

□

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