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Bank credit, inflation, and default risks over an infinite horizon[☆]

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ABSTRACT

The financial intermediation wedge of the banking sector used to co-move positively with the federal funds rate, but the post-GFC era saw a disconnect between them. We develop a flexible price dynamic general equilibrium with banks' liquidity creation to offer an explanation. In a corridor system, the financial wedge and policy rate are shown to co-move, and the pass-through of monetary policy onto both inflation and output obtains. However, the post-GFC floor system obviates the need for the financial wedge to cover the cost of obtaining reserves, so the wedge and the policy rate indeed disconnect in equilibrium; furthermore, we show that the disconnect obstructs monetary expansions from generating inflation. In this environment, tightening bank capital requirement leads to disinflationary pressure. Money-financed fiscal expansions that subsidise non-bank sectors' borrowing costs improve output and reduce default risks but increase inflation. The model uses banks' liquidity creation via credit extension to provide a rationale for both the pre-pandemic disinflation and the post-pandemic inflation. The results hold both on the dynamic paths and in the steady state, and the role of money enlarges the Taylor rule determinacy region.

1. Introduction

Before the Global Financial Crisis (GFC), the federal funds rate and the financial intermediation wedge (defined as the spread between loan and deposit rates, hereafter 'financial wedge') used to co-move in the US. However, these two series disconnected after the GFC, when the central bank increased its balance sheet while issuing massive reserves to the wider financial institutions and paying interest rates on reserves. Against this backdrop, the authority relied on macro-prudential policies to discipline the banking sector, for example, via the bank capital requirement.[1] Fig. 1 documents these two stylised facts of the federal funds rate and the financial wedge. As can be seen, from 1997 to late 2008, an increase in the federal funds rate is associated with an increase in the financial wedge and vice versa. However, between late 2008 to 2015, this relationship broke down.[2]

To understand whether the post-GFC's ample reserve environment with interest on reserves has any bearing on this disconnect, we develop a tractable dynamic general equilibrium model with money and banks to offer an explanation. Interestingly, by investigating this disconnect, we uncover a mechanism that can jointly explain the missing inflation puzzle in the post-GFC period and the burst of high inflation we are currently facing in the post-pandemic era (see Reis, 2022). This mechanism traces its root to Shubik and Wilson (1977) and Dubey

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[1] In the paper, we focus on macro-prudential capital policies, which are aggregate requirements, different from particular minimum requirements or micro-prudential ones for each institution. They aim to address the externalities that each institution can exert on the rest of the system. One example is the Basel III countercyclical capital buffer.

[2] This disconnect is also reflected in the estimation of Wang (2020) where the author shows that the pass-through of the monetary policy rate to the loan and deposit rates is much less complete in the post-GFC low interest rate environment. Fig. 1 uses the loan rate of commercial and industrial loans because the paper focuses on loans to firms; however, the weighted average loan rate of commercial and industrial loans was discontinued in 2017. To capture the recent trend, we use the loan rate for all loans from 1997 to 2022 plotted in Fig. 9 in Appendix A. We can also observe the disconnect between late 2008 and 2015, but when the central bank implemented monetary contractions, the positive relationship seemed to be revived (during the taper tantrum and the recent monetary contractions post-Covid). Another confounding factor during the disconnect period is the zero lower bound on deposit rates, as typically, banks are reluctant to set negative deposit rates for private sectors. As the central bank lowers the policy rate further, the loan rate decreases but the deposit rate is bound by zero from falling further, and so banks' financial wedge would ceteris paribus decrease further, up until even the loan rate starts to resist further decreases, which would be another mechanism to generate the disconnect. The zero lower bound on deposit rates has been studied in Kumhof and Wang (2021) featuring sticky prices.

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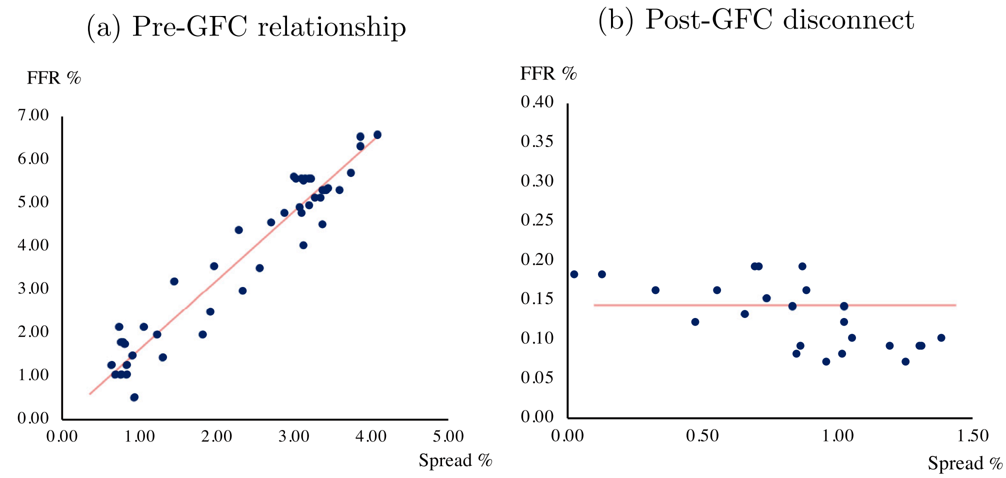


Fig. 1. Federal funds rate and the financial wedge in the US. X-axis is the spread between the commercial and industrial loan rate and deposit rate, net of smoothed charge-offs for loan losses. *Y*-axis is the federal funds rate. The left graph plots the relationship from Q4 1997 to Q4 2008, and the right graph plots the relationship from Q4 2008 to Q4 2015 the low-rate period. After Q4 2015 the federal funds rate started to increase up until the pandemic. Because the weighted-average effective loan rate for commercial and industrial loans was discontinued in 2017, Appendix A provides the plots using the series of loan rates for all loans from 1997 to 2022.
Source: Board of Governors of the Federal Reserve System, FDIC, Kumhof and Wang (2021), and authors' calculation.

et al. (2005), and it relies on (1) the banks' role in creating liquidity as inside money by extending credit to the non-bank sectors and (2) the bankruptcy code that enforces the (partial) repayment of the credit to retire the bank money and reserves from the macroeconomy. We choose to remove the usual sticky price assumption by featuring flexible prices to exclusively assess the financing role of money and determine the price level in equilibrium. We also allow firm credit risks and bank risks to emerge endogenously in equilibrium, depending on the default penalty and states of nature. This is because ever since the GFC, if not before, it has become clear that money and financial frictions are as important as price/wage stickiness in explaining the manifold deviations of our economies from a perfectly flexible real business cycle. Empirically money and financial forces affect the real economy in the long run (see evidence in Brunnermeier et al., 2021), and our model proves money non-neutrality with flexible prices in the steady state, which we interpret as the long run.

In the model commercial banks issue deposit contracts during loan extensions to finance firm's purchase of production factors, which bears the flavour of working capital financing-in-advance constraint in Christiano et al. (2005), Ravenna and Walsh (2006), Goodhart et al. (2021).[3] The key feature of our model is that the deposit contract plays a dual role of the stipulated means of exchange and a portfolio asset with interest payments. New deposit balances are issued against bank credit and are nominal. This is when inside money enters the economy. When the household receives the payment from the firms by selling the production factors, she can choose to deposit it into the banks or invest in government bonds. After production, firms sell output, receive revenues in deposits, and use deposits plus interest payments to repay the loans they borrowed prior to production. This is when money exits the economy. Moreover, commercial banks are subject to a Capital Adequacy Ratio (CAR) as bank capital regulation, which may or may not bind.

At any point in time, when there is deposit reshuffling within the banking system or deposit withdrawals, commercial banks need reserves to meet such liquidity demand. To model this, we consider two cases: (1) when reserves are provided on demand subject to interest cost, and (2) when there are excess reserves in the banking system and the central bank pays interest on reserves. The first case corresponds to the pre-GFC corridor system whereby there is a significant spread between the interbank market rate and the interest rate on reserves (hence, a 'corridor'), and there are not many excess reserves. In this case, the liquidity constraint for reserves is tight, which rules out arbitrage in the interbank market. To obtain reserves, the commercial banks sell assets in the interbank market to obtain reserves (ultimately from the central bank) at the interbank market rate, taken as the short-term monetary policy rate. In the second case, there are large quantities of excess reserves on the commercial banks' balance sheet and the central bank operates a floor system whereby the seigniorage is used to pay interest on reserves, and the interest rate on reserves is (almost) equal to the short-term policy rate (and hence, the 'floor'). In this case the liquidity constraint for reserves is not tight.

We show both analytically and numerically that when the liquidity constraint for reserves is tight, the financial wedge picks up the variations of the policy rate, and these two series are positively connected, much resembling the pre-GFC relationship we observe in Fig. 1. This also holds when we remove the credit risk premium from the financial wedge. The reason is that in the corridor system, the commercial banks' financial wedge in effect covers their cost of obtaining reserves. In this case, we show a decrease in policy rate leads to a reduction in the financial wedge, an increase in output and an increase in the price level both in the steady state and on the dynamic paths. Moreover, the monetary expansion reduces the overall non-performing loans and bank credit risks. Calibrating the parsimonious model with the US model, we find that in the steady state, when the policy rate decreases by 0.25 pp per annum, quarterly output increases by around 0.14%, and the steady state price level increases from 1 to 1.5 permanently. Quantitatively, in this environment, the price movement is much larger than the output movement after monetary expansions. This is partly because we do not add sticky prices. By incorporating the usual sticky price friction, the price movement would decrease, and the output movement would increase due to the New Keynesian aggregate demand externality channel.

On the dynamic paths, when the expansionary monetary policy shock propels the policy rate to fall by 1 pp per annum, the financial wedge falls by around 0.7 pp, and output increases by 0.6% per annum on impact and gradually goes back to the steady state. Moreover, we show that the Taylor rule determinacy region is enlarged in our environment. We set the Taylor rule inflation coefficients to a wide range, such as 1.5 or −3, the Blanchard–Kahn condition is satisfied, and even when we remove the endogenous components of the Taylor rule by modelling the policy rate as an exogenous shock, the determinacy

[3] See the empirical evidence of bank liquidity creation via loan extension, or 'loans creating deposits' in Berger and Bouwman (2009) and more recently (Thakor and Yu, 2022).

still obtains. This is because the price level is determined in the steady state equilibrium, as we demonstrate in our steady state analysis.

In the second case where there are excess reserves, the liquidity constraint for reserves is not tight.[4] We show both analytically and numerically that policy rate changes do not pass through to the financial wedge (with or without credit risk premium), much resembling the post-GFC relationship we observe in Fig. 1. In this case, the fall in the monetary policy rate has little nominal or real effects, suggesting that in the post-GFC period, the floor system and excess reserves in the financial system may have obstructed further monetary expansions from increasing output and creating inflation significantly. Then we further tighten the CAR requirement in this case. We show that it leads to an increase in the financial wedge, which increases the overall transaction cost of liquidity and reduces gains from trade, and thus, output falls. This is broadly consistent with the existing literature on the real effect of tightening the bank capital requirement. We contribute to the literature by also analysing its nominal effect on inflation, which has not received much attention in the literature. We show that tightening the bank capital requirement is highly deflationary. This is because it constrains the banks' ability to increase nominal loans and so the endogenous money supply decreases. During the pandemic crisis, some countries relaxed the bank capital requirement to encourage liquidity creation and credit extension of the banks. Based on our result, this would be inflationary, which echoes a concern raised in Gersbach (2021).

We then extend our model to consider a money-financed fiscal stimulus. During the pandemic crisis, the government increased its debt while the QE operation by the central bank helped to monetise the government debt. We model the treasury issuing a perpetuity during the crisis which is held by the central bank as assets while creating reserves as the liability. The government uses the newly-issued liquidity to subsidise the firms' borrowing costs from the banks (see Bergant and Forbes, 2022 for the details of government support programmes). We show analytically that such fiscal stimulus reduces the loan rate and the newly created high-powered money flows to the banking system and increases bank capital, simply a result of the Walras's law application with money and banks. Numerically, we demonstrate that this money-financed stimulus improves output and causes sizeable inflation, while reducing corporate loan default risks. Our model extension complements (Galí, 2020) where the author studies a money-financed fiscal stimulus in a canonical New Keynesian model. Galí (2020) shows that the increase in inflation is mild whereas our results suggest the movement in inflation could be over 15 times as much as the movement in output. The key difference between (Galí, 2020) and our framework is that the former considers sticky prices and no role of banks or credit risks, whereas we allow prices to fully adjust and explicitly model the role of banks in issuing liabilities as means of payments and circulating money; therefore, the nominal effects in our model are larger. In our framework, the key to quantifying the magnitudes of inflation would be calibrating seigniorage transfers, rather than choosing the fraction of firms not adjusting prices.

In all our numerical simulations, credit risks fluctuate on the dynamic paths and also in the steady state. 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. We utilise the approach developed by Shubik and Wilson (1977) and Dubey et al. (2005) to replace the discontinuity of bankruptcy by the decision of the amount to repay, which can be treated as a continuous variable. Thus, the default risks emerge as a general equilibrium outcome and we show they exert real and pecuniary effects. We show when the loan quality deteriorates such that the NPL rate increases by 3% per annum in the steady state, quarterly output drops by 0.5% permanently, and price level jumps to a higher level. On the dynamic paths, a temporary increase in corporate default risks also decreases output and increases inflation temporarily. In the steady state, the amplification effects due to default decrease after monetary expansions with no excess reserves. When bank risk increases by 2 pp temporarily, the price level increases by around 0.4% on impact, and output falls by around 0.3% on impact. Moreover, corporate loan default risks and bank risks fluctuate when the economy is hit by fundamental shocks such as technology shocks. That the corporate loan default risks and bank risk fluctuate alongside the business cycle is consistent with empirical facts, reflecting the strength of modelling default as a general equilibrium outcome with the associated price effects.

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 provides calibration details. Section 6 shows the steady state real and nominal outcomes. Section 7 conducts dynamic numerical analysis and policy experiments. Section 8 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, Cúrdia and Woodford (2010, 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 by differing bargaining powers of agents with brokers with whom they have to transact and model money as exogenous endowments. Drechsler et al. (2017) model this spread via the market power of the deposit markets and model the liquidity service of money via money-in-utility. Our model complements these works because we model the entire circulation of money, which is issued endogenously against bank credit, and the endogenous partial repayment of credit feeds back to financial stability. In the model, the financial spread, the lending to deposit rate spread, emerges in equilibrium due to endogenous default and monetary stance. Thus, this paper contributes to the literature by removing the dichotomy between money and financial frictions in a dynamic setting.

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, 2020). Most of these papers, to our knowledge, model money separately from financial frictions. In these works, the real effect of money is achieved via price stickiness either in the goods markets or in the labour markets. Our model differs from these papers because the non-neutrality of money in our environment does not need to appeal to price stickiness of the non-financial sectors, but rather, it stems from the financing role of money and its credit nature. And it holds in the long run as well, as in Wang (2021). Therefore, the model generates real effects of money due to financial forces alone. Relatedly, Jermann and Quadrini (2012), Bianchi (2016), Bianchi and Mendoza (2018) model firm financial flows and working capital in advance financing constraint, but they

[4] The model takes a parsimonious approach; for example, we do not model the Overnight Reverse Repo Facility (ONRRP), which would involve collaterals and an additional interest rate (ONRRP rate). In practice, this interest rate of ONRRP is the true floor rather than the interest rate on reserves (IROR). Hence, the result here is stark in that the liquidity constraint does not bind at all. Nevertheless, the theoretic result, we believe, is a reasonable first-order approximation of reality. In practice, the constraint may still bind due to the subtlety between IROR and ONRRP, but not to the same degree as the corridor system. For a detailed explanation of the reserve management system and the floor system in the US, please see Lopez-Salido and Vissing-Jorgensen (2022).

assume there is zero interest on the working capital loan. This means the monetary policy rate does not pass through to the borrowing cost through the cost channel. Whereas in our paper, we model the working capital in advance financing constraint while considering the cost channel and non-Ricardian seigniorage transfer; therefore, our model obtains the value for money and non-neutrality of monetary policy with flexible prices in equilibrium. The model can therefore produce the endogenous supply side effects due to monetary policy shocks (see empirical evidence in Drechsler et al. (2022)). Wang (2020) show that the pass-through of monetary policy rate to the financial wedge is less complete in a low interest rate environment, and the frictions the author considers include banks' market power and the zero lower bound. Our model achieves the disconnect between the financial wedge and the policy rate via excess reserves, but not via banks' market power or the bound on interest rates. Moreover, Wang (2020) features sticky prices to study the New Keynesian money non-neutrality channel, whereas our model removes the sticky price assumption and proves money non-neutrality via only the financing role of money and credit. This way of modelling money via bank credit shares a similar spirit to bank liquidity provision emphasised in the finance and banking literature (see Gorton and Pennacchi, 1990; Stein, 2012) and safe assets (see J Caballero and Farhi, 2017). We see our paper as a bridge between the finance banking literature and the monetary literature.

Moreover, our model reflects the insight of the fiscal theory of the price level (FTPL) (Buiter, 1999; Sims, 1994; Cochrane, 2001). The fiscal dividends in the FTPL resemble the seigniorage transfer in our model and help to pin down the price level in equilibrium. Thus, we are able to evaluate the nominal and 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 (2020) examines the nexus between money financing and fiscal stimulus by modelling the government bond purchase via money issuance. Thus, our work is also related to Galí (2020), but our model differs in that we achieve non-neutrality of money via the cost of liquidity and default in the steady state and on the dynamic paths, whereas Galí (2020) obtains money non-neutrality on the dynamic paths by appealing to price stickiness in non-financial sectors.

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 issuance of fiat money via bank credit was extensively written about by earlier economists. Classic works by Macleod (1866), Wicksell (1906), Hahn (1920), Hawtrey (1923), Keynes (1931), Schumpeter (1954), Tobin (1963) and Minsky (1977) have all provided insight into this mechanism and its macro-financial implications. The early formalisation of this mechanism is found in the general equilibrium theory of money. In this segment of the 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), Shapley and Shubik (1977), Lucas and Stokey (1987). Inside money enters the economy against an offsetting debt 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 Dubey and Geanakoplos (1992, 2003b, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), and Goodhart et al. (2006, 2013). This group of literature establishes generic money non-neutrality with flexible prices in general equilibrium with uncertainty. The cash-in-advance constraint in this literature uses the term 'cash' in the figurative sense because 'cash' in these models includes inside money (liquidity creation) issued against bank credit, and it should not be taken literally as the physical 'cash' in circulation. In our model, we make an operational distinction between cash, reserves, and deposits, so the 'liquidity' in our liquidity-in-advance constraint can be either cash in the literal sense or deposit balances depending on whether agents withdraw deposits from the commercial banking system.

After the Global Financial Crisis, with a renewed interest in banks' balance sheet transformation for credit extension and liquidity provision and the associated macro-financial outcomes, 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), Piazzesi and Schneider (2018), Martinez and Tsomocos (2018), McMahon et al. (2018), Kiyotaki and Moore (2018, 2019), Wang (2019), Kumhof and Wang (2021), and Bianchi and Bigio (2022). Our work complements this body of literature by focusing on the interaction between the financial wedge and monetary and fiscal policies.

Many 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., 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 model default as an out of equilibrium, never really occurring in equilibrium, phenomenon as in Gertler and Kiyotaki (2010) and Alvarez and Jermann (2000). However, empirically corporate loan default rates are highly volatile in the business cycle. In contrast, as Candian and Mikhail, 2020 show that state-of-the-art models with a costly-state-verification financial accelerator mechanism à la Bernanke et al. (1999) produce debt recovery rates that are flat over the cycle. We model default as a general equilibrium outcome following Shubik and Wilson (1977) and Dubey et al. (2005). Therefore, default fluctuates alongside the business cycle with its associated pecuniary effects, as we show in our subsequent analysis. In this sense, our work complements the group of literature on the financial stability implications of default (see e.g., Clerc et al., 2015; Begenau and Landvoigt, 2022, non-exhaustive).

3. A dynamic model

3.1. Model description and timeline

The model has infinite periods. 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 choose their investment portfolios, pay taxes, and consume the final output. The treasury sets the inter-period government bond supply and provides treasury bills on demand, and the central bank issues reserves via open market operations to commercial banks while setting the short-term policy rate and the CAR requirement. The model allows the households to access inter-period government bonds as an inter-temporal nominal saving device and intra-period treasury bills to compete with intra-period deposits.

The key model feature is the function of the deposit contract, which plays a dual role of the stipulated means of exchange and a portfolio asset that brings interest payment. New deposit balances D_t^f are issued against bank credit L_t to meet agents' liquidity demand. This is banks' liquidity creation via loan extension. Each period has two sub-periods such that we have both the intra-period rates and inter-period rates,

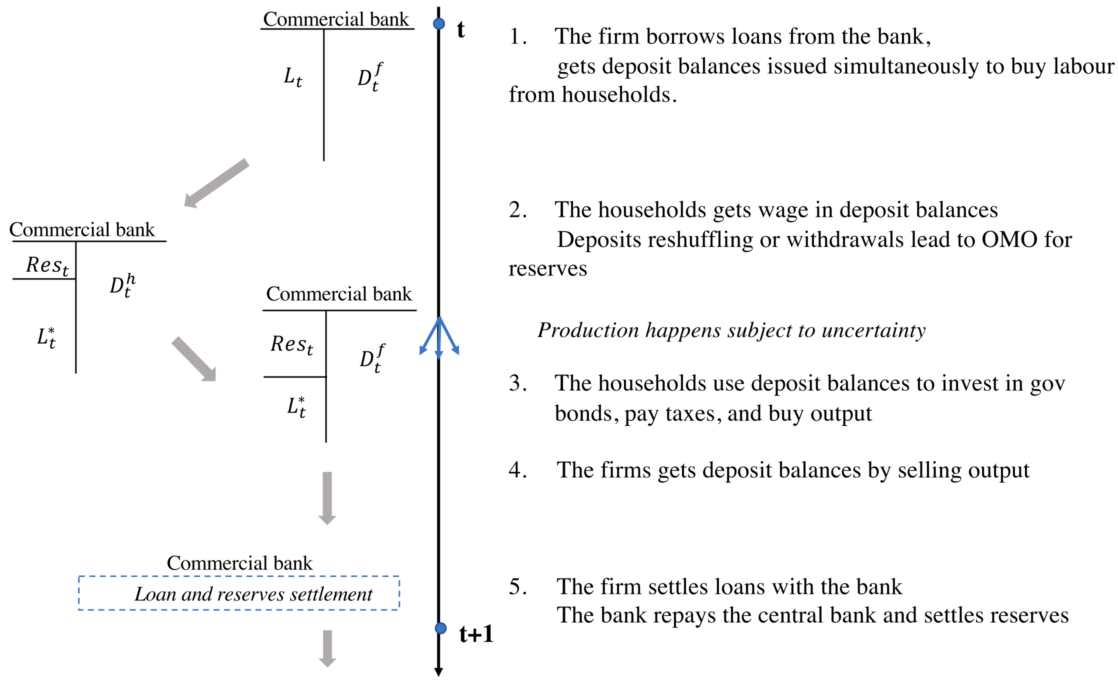


Fig. 2. Timeline of the dynamic model.

capturing the term structure of interest rates. 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 D_t^h. Meanwhile, households use their deposit balances from wage payments to invest in intra-period deposits or treasury bills, and at this time point, there is a deposit reshuffling amongst household members. To facilitate deposit reshuffling within the banking sector, commercial banks sell assets to obtain central bank reserves Res_t at the cost of short-term policy rate as the discount rate. After production, households use the deposit balances at hand as well as proceeds from inter-period government bonds to buy output from the firm, pay taxes to the government, and invest in the next period's inter-period government bonds. 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 banker pays dividends to the households and repays the central bank.

Fig. 2 illustrates the timeline along with the main balance sheet changes, and the sequence of events in each sub-period.[5]

3.2. Firm

Entrepreneurs managing the firms are assumed to be designated actors on behalf of households. The entrepreneur chooses labour demand h_t, loan demand L_t and loan repayment rate v_t^f to maximise the real value of the firm's profits in terms of the marginal utility of households, subject to a non-pecuniary default penalty cost in case of default. The default penalty in practice takes a myriad of forms. It can range from the harshness of the terms of debt restructuring, market exclusions, 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, it does not matter at the core the specific form of default punishment as long as it affects the marginal rate of substitution of consumptions. Therefore, although the non-pecuniary default penalty in our setup is a simplified representation of various forms of default punishment in reality, this modelling approach is comprehensive enough and has the advantage of analytic convenience, as the repayment of debt shall turn out a continuous decision variable. Formally, the firm's preference is given as follows:

$$max \quad E_t\left\{ \Lambda_t \omega_t^f - \lambda_t^f [\mathbb{I}_t^f]^+ \right\},$$

where Λ_t is the marginal utility of consumption of the household, ω_t^f denotes the real profits of the firm. Let $\frac{L_t}{P_t}$ be the real value of the loan and $1 - v_t^f$ be the non-performing loan rate. We define $\lambda_t^f [\mathbb{I}_t^f]^+$ as the non-pecuniary penalty cost if the firm fails to fully repay the loan, and specifically,

$$[\mathbb{I}_t^f]^+ = \begin{Bmatrix} [\frac{(1-v_t^f)L_t}{P_t}]^2 & \text{if } 1 - v_t^f > 0 \\ 0 & \text{if } 1 - v_t^f = 0 \end{Bmatrix}. \tag{1}$$

We interpret λ_t^f as a non-bank sector credit quality shock and it indicates the severity of firm's default punishment. 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.

The firm is subject to the following flow of funds constraints:

$$\underbrace{W_t h_t}_{\text{to pay wages}} \leq \underbrace{\frac{L_t}{1 + r_t^l}}_{\text{apply for bank loan to get new deposit balances } D_t^f}, \tag{2}$$

$$\underbrace{P_t \omega_t^f}_{\text{nominal profits}} = \underbrace{P_t y_t}_{\text{sales revenue}} + \Delta_t(2) - \underbrace{v_t^f L_t}_{\text{partially repay bank loan and interest}}, \tag{3}$$

Condition (2) is the firm's liquidity-in-advance constraint to finance its working capital. At the start of date t, the firm borrows money from the banking sector by entering a loan contract with the nominal face value of L_t at the loan rate r_t^l, and simultaneously banks credit the firm with deposit balances D_t^f that equals the amount $\frac{L_t}{1+r_t^l}$, which is the key step of liquidity creation. The firm uses the newly created deposit balances to pay labour h_t and pay nominal wages W_t before production

[5] Fig. 2 is only for illustrative purposes and does not include any changes in bank equity, profits or dividends paid, in order to simplify. But such changes are taken into account precisely in the model.

is complete. And any unused deposit balances from the flow of funds constraint (2) is denoted as $\Delta_t(2)$.

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 $y_t = A_t h_t$. Then the firm sells output and gets revenue in deposit balances. The sales revenue and any unused deposit balances from Condition (2) constitute firm's total deposit balances at the interim stage. Condition (3) says the firm uses its sales revenue plus any unused deposit balances from Condition (2) 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.

3.3. Banking sector

The banker maximises the real value of 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; otherwise, the deposit withdrawal pressure could induce a liquidity crisis for the banking sector. Moreover, as part of macro-prudential regulation, the bank faces the capital requirement Capital Adequacy Ratio (CAR). We explore both cases when the CAR binds and when the CAR is non-binding.

No excess reserves - reserves provided on demand

First we analyse the case where there are no excess reserves whereby the central bank operates a corridor system. At the start of date t, the banker underwrites loans to the borrowers, and against the loans deposits are issued to the borrowers for their liquidity needs. Meanwhile, following Wang (2022), depositors move around some quantity of deposit balances within the banking sector, which propels the banks to borrow from the interbank market to obtain reserves Res_t to meet the liquidity needs from the deposit reshuffle, at the cost of central bank policy rate r_t. We assume the gross amount of deposit reshuffle is νD_t and the parameter ν is to be internally calibrated, as well as estimated. In the interim, banks set the contractual deposit rates r_t^d and choose the repayment rate υ_t^b on the deposit balances plus interest when the shock hits. At the end of date t, the banker needs to repay the central bank.

Formally, the banker's preference is represented by

$$max \quad E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \Lambda_t^h Div_t - \lambda_t^b [\mathbb{I}_t^\lambda]^+ \right\},$$

where Div_t is bank's dividends, Λ_t^h is the households' shadow price of their budget constraint, and $\lambda_t^b [\mathbb{I}_t^\lambda]^+$ is the non-pecuniary default penalty should the banker fail to fully repay deposit balances plus interest, and

$$[\mathbb{I}_t^\lambda]^+ = \left\{ \begin{array}{ll} (\frac{(1-\upsilon_t^b)D_t(1+r_t^d)}{P_t})^2 & \text{if } 1-\upsilon_t^b > 0 \\ 0 & \text{if } 1-\upsilon_t^b = 0 \end{array} \right\}.$$

The banking sector's nominal profits Ω_t^b at the end of date t is thus

$$\Omega_t^b = \upsilon_t^f L_t - \upsilon_t^b D_t(1+r_t^d) + Res_t - Res_t(r_t+1). \tag{4}$$

Eq. (4) says the banks' nominal profits consist of money inflows from loan repayments and outflows from repaying deposits plus interest and the cost of obtaining reserves.

Banks then pay dividends to households out of their retained equity e_{t-1} from $t-1$ and the nominal profits, and the rest becomes their retained equity at t., i.e.,

$$e_t = e_{t-1} + \Omega_t^b - Div_t. \tag{5}$$

We assume the CAR requirement is captured by the following simple condition (6), which says at the start of t, the ratio of the book value of the retained equity from $t-1$ to present value of loan extension is bounded by the CAR requirement ι_t, where the present value of loans $L'_t = \frac{L_t}{1+r_t^l}$.

$$\iota_t \leq \frac{e_{t-1}}{L'_t}. \tag{6}$$

Let the shadow price of the CAR requirement be ϕ_t, in the equilibrium analysis, we analyse both the binding CAR case ($\phi_t > 0$) and the non-binding CAR case ($\phi = 0$), and identify the condition in which the CAR is more likely to bind.

With excess reserves and interest rate on reserves

Now we tweak the banks' problem to consider excess reserves and the central bank operates a floor system. With the floor system, the central bank pays an interest rate on excess reserves using its seigniorage profits, and the banking sector would have more than enough reserves to meet the deposit reshuffling pressure. This means the banking sector's end-period flow of funds becomes

$$\Omega_t^b = \upsilon_t^f L_t - \upsilon_t^b D_t(1+r_t^d) + Res_t(r'_t+1) - Res_t(r_t+1). \tag{7}$$

where r'_t is the interest rate on reserves, and we assume $r'_t = r_t - \epsilon$. The interest rate on reserves in practice is close to the policy rate as is the Fed's floor system, and in the analytic parts of the model we take it as $-\epsilon$ smaller than the policy rate to rule out commercial banks arbitraging on the central bank.[6] The rest of the banks' flow of funds and regulatory constraints remain unchanged.

3.4. Household

The household is endowed with leisure of n_t and derives utility from consumption and leisure. The household chooses the labour supply and consumption, as well as their investment portfolio among deposits D_t, treasury bills B_t with interest rate r_t and long-term (inter-period) government bonds $\bar{B}_t$ with interest rate $\bar{r}_t$.

Formally, let γ_t^h be the preference parameter of consumption, and $\gamma^h \in (0,1)$. The household's preference is given as follows:

$$max \quad E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \gamma_t^h log(c_t) + (1-\gamma_t^h) log(n_t - h_t) \right\}.$$

At the start of date t, the household receives the wage payment of $W_t h_t$ as deposit balances. Due to idiosyncratic liquidity needs amongst measure one of household members, it leads to a deposit reshuffle amongst household members. For each member, the net deposit reshuffle is denoted as $\Delta m_t(i)$. In the aggregate, because deposit reshuffles happen amongst household members, it follows $\int \Delta m_t(i) di = 0$. During the deposit reshuffle, the banking sector needs to borrow from the central bank to obtain reserves to facilitate these liquidity transactions, and the total amount of reserves on demand is only a fraction ν of the total deposit balances in the banking system, as explained in the banks' section.

The household chooses to allocate her wage payment adjusted by deposit reshuffling into short-term (intra-period) deposit contracts or treasury bills. In the case of equal risk-adjusted interest rates on short-term deposits and treasury bills, she prefers deposits because deposit balances can be withdrawn as cash if needed during any point in time. This flow of funds constraint at the start of t is summarised in (8) as follows

$$D_t + B_t = W_t h_t - \int \Delta m_t(i) di, \tag{8}$$

and the flow of funds at the end of t is

$$\bar{B}_t + T_t + P_t c_t = R_t^b D_t(1+r_t^d) + B_t(1+r_t) + \bar{B}_{t-1}(1+\bar{r}_{t-1}) + \mathbb{O}_t, \tag{9}$$

where R_t^b is her expected repayment rate of the banking sector on the deposits plus interest repayment. And Eq. (9) says at the end of

[6] In the numerical analysis we take them to be the same for simplicity.

t, the household receives interest payments on her portfolio as well as transfers $\mathbb{O}_t$ consisting of firm profits and bank dividends. She uses her proceeds to buy consumption goods, pay taxes, and invest in the long-term (inter-period) government bonds,

3.5. The treasury and the central bank

The Treasury sets a total supply of inter-period government bond $\bar{B}_t$ and supplies short-term treasury bills in the market on demand. It collects taxes from households, and respects the government budget constraint. It also obtains the previous period's seigniorage profits S_{t-1}, if any, from the central bank.

$$\bar{B}_{t-1}(1+\bar{r}_{t-1}) + B_t(1+r_t) = \bar{B}_t + B_t + S_{t-1} + T_t. \quad (10)$$

The central bank buys assets from the banking sector and in turn supplies reserves Res_t on demand at the policy rate of r_t. The central bank sets its policy rate r_t according to the Taylor principle. Let $\bar{P}$ be the steady-state price level, and let $\bar{y}$ be the steady-state output. Eq. (11) states the monetary policy rule, and S_t^m is a monetary policy shock that follows an AR(1) process.[7]

$$r_t = r(\frac{P_t}{\bar{P}})^{m_p}(\frac{y_t}{\bar{y}})^{m_y} S_t^m. \quad (11)$$

Moreover, the central bank can also set the CAR requirement ι_t.

4. Equilibrium

Equilibrium definition: Following Tsomocos (2003) and Goodhart et al. (2006), given the exogenous shocks, this dynamic stochastic general equilibrium is a sequence of quantities (c_t, y_t, h_t, L_t, D_t, Res_t, T_t, ω_t^f, Div_t, ω_t^b, e_t) and prices (P_t, W_t, r_t^l, r_t^d, $\bar{r}_t$, υ_t^f, υ_t^b), given policy instruments (r_t, ι_t), government action ($\bar{B}_t$) and initial seigniorage transfer S_{-1} and initial bank equity e_{-1}, agents maximise subjects to liquidity-in-advance constraints and budget sets; and the goods market, labour market, loan market, deposit market, reserve money market, and government bond market clear, and expectations are rational.

4.1. Equilibrium characterisation

Lemma 1. *Deposits-in-advance constraint binds and no idle money balances in the portfolio. If $r_t^l > 0$, then $\Delta_t(2) = 0$.*

Lemma 1 makes sure the flow of funds are tight. As long as the borrowing cost is larger than zero, the firms do not borrow more money than needed. Through the flow of funds, the seigniorage from the previous period is used to pay for the cost of obtaining reserves, i.e., $S_{t-1} = r_t Res_t$, and it follows that the seigniorage profits for the central bank at date t S_t is equal to S_{t-1}. Therefore, the seigniorage transfer is always equal to the initial level S_{-1}. Given $S_t = S_{-1}$ and Lemma 1 hold, we now combine the flow of funds constraints of the household the firm, the bank, and the treasury, while substituting in the law of motion of bank capital, it follows that

$$P_t c_t = P_t y_t + e_{t-1} - e_t. \quad (12)$$

In order for the goods market to clear $y_t = c_t$, it follows that $e_t = e_{t-1} = \cdots e_{-1}$, which suggests no fluctuations of bank equity on the dynamic paths with shocks. This result is simply an application of the Walras's law with money and banks. We summarise this result in Lemma 2.

Lemma 2 (*Slow-moving Bank Capital*)**.** *In the corridor system, when the seigniorage transfer is used to pay for the cost of obtaining reserves, in equilibrium, $S_t = S_{-1}$ and $e_t = e_{-1}$*

[7] 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.

The above analysis only relies on the flow of funds constraints and the general equilibrium concepts and it does not need the optimality conditions of the agents in the economy. Proposition 1 considers agents' optimality conditions in conjunction with the analysis above and show that in our environment money is non-neutral even with flexible prices.

Proposition 1 (*Money Non-Neutrality with Flexible Prices*)**.** *In equilibrium, with the corridor system and non-binding CAR, the equilibrium production factor h_t is solved as a function of exogenous parameters, the policy rate r_t and credit risks υ_t^f and υ_t^b. Given credit risks, a change in the policy rate changes equilibrium production factor, consumption and real output, even in the steady state.*

$$\frac{\gamma^h}{h_t}\frac{(1+r_t)\upsilon_t^f}{\nu r_t + \frac{1+r_t}{\upsilon_t^b}} = \frac{1-\gamma_t^h}{n_t - h_t}. \quad (13)$$

Proof. Appendix C.

Proposition 1 says in the case of no excess reserves and non-binding CAR, a change in the monetary policy rate leads to a change in real allocations, given credit risks. As we cannot obtain closed-form solutions with endogenous credit risks, we shortly use numerical solutions to show money is non-neutral in the general equilibrium on the dynamic paths as well as in the steady state.

To see Eq. (13) more clearly, let us simplify the model by setting the default penalties to $+\infty$ to rule out credit risks, it follows that

$$\frac{\gamma^h}{h_t}\frac{(1+r_t)}{\nu r_t + 1 + r_t} = \frac{1-\gamma_t^h}{n_t - h_t}. \quad (14)$$

Total differentiate the above equation, we find $\partial h_t/\partial r_t < 0$, and so $\partial y_t/\partial r_t < 0$. This means a rise in the monetary policy rate with the corridor system and non-binding CAR is contractionary, and vice versa.

Proposition 2 (*Financial Wedge and Policy Rate (Dis)connect*)**.** *Controlling for credit risks and the shadow prices of the household's budget constraint and of the CAR, with the corridor system, an increase in the monetary policy rate increases the financial wedge; with the floor system, the monetary policy rate does not pass through to the financial wedge.*

Proof. Appendix D.

In our numerical analysis, we demonstrate that the (dis)connect results hold in the general equilibrium. In particular, with excess reserves, the monetary policy rate does not change the financial wedge because the banks incur no cost in obtaining reserves to meet their liquidity demands. This means monetary expansion bears no real or nominal consequences in this environment.[8] The disconnect between the policy rate and the financial wedge therefore weakens the role of monetary expansion in generating inflation. Moreover, in the case of a binding CAR, the financial wedge is well connected with the CAR, as we shortly formalise their steady state relations in the proposition below, and we use the *overline* symbol to denote steady state variables.

Proposition 3 (*Bank Capital Requirement*)**.** *In the steady state equilibrium with the floor system and a binding CAR, we have*

$$(1+\bar{r}^l)\bar{\upsilon}^f - \frac{1+\bar{r}}{\bar{\upsilon}^b} = \iota\frac{1-\beta}{\beta}. \quad (15)$$

Thus, given credit risks and monetary policy rate, an increase in ι increases loan rate, and an increase in β decreases loan rate.

Proof. Appendix E.

[8] We acknowledge that by introducing sticky prices, it would have the usual New Keynesian non-neutral effects, although only on the dynamic paths, not in the steady state.

Proposition 3 says a tightening in the CAR increases the borrowing cost for the firms, but if the bankers become more patient, the borrowing cost for the non-bank sector decreases. The takeaway from Propositions 2 and 3 is that when there are excess reserves and a binding CAR, lowering the monetary policy rate may not be effective in supporting the economy and generating inflation. If the central bank further tightens CAR, the economy could contract due to a rise in the borrowing costs for the non-bank sector. In this environment, would unconventional monetary–fiscal policy such as money-financed fiscal stimulus be effective in supporting the economy and generating inflation? Below we extend the model to consider money-financed fiscal stimulus and characterise the equilibrium. In the quantitative section, we provide numerical answers.

4.2. Money-financed fiscal stimulus

During the pandemic crisis, the government increased its debt while the QE operation by the central bank helped to monetise the government debt. Using the liquidity aided by the central bank's reserve creation, the government implemented various support programmes to subsidise firm's borrowing costs from the banking sector. We extend the model with the floor system and a binding CAR to assess the effects such a money-financed fiscal stimulus. We model the treasury issuing a perpetuity during the crisis which is held by the central bank as assets while creating reserves as the liability. The government uses the newly-issued liquidity to subsidise the firms' borrowing cost from the banks. The assumption of a perpetuity is based on the fact that the debt the government issued during the pandemic crisis would only be repaid in a much longer horizon than what this model considers and it also renders model considerably more tractable. In theory, as long as the debt maturity via the money-financed fiscal expansion is longer than the maturity of the inter-period government bond considered in the benchmark model, it will have both nominal and real consequences, because the way we model money (inside and outside money) is inherently non-Ricardian.

We model the subsidy $(1+\delta_t)$ proportional to the credit the banks extend to the firms. The nominal value of the perpetuity is thus $L_t\delta_t$. The government chooses the nominal value of the perpetuity or sets the subsidy δ_t. The banks' end-period flow of funds constraint thus becomes

$$\Omega_t^b = \upsilon_t^f L_t(1+\delta_t) - \upsilon_t^b D_t(1+r_t^d) + Res_t(r_t'+1) - Res_t(r_t+1). \tag{16}$$

The optimality condition of the banks is

$$\Lambda_t^h\left(\upsilon_t^f(1+\delta_t)(1+r_t^l) - (1+r_t^d)\right) = \frac{(\Lambda_{t-1}^h - \beta\Lambda_t^h)}{\beta}\iota_t, \tag{17}$$

and from the above optimality condition, *ceteris paribus* an increase in the subsidy leads to a decrease in the loan rate. We shall shortly see in our numerical results that this effect holds in the general equilibrium.

Moreover, the money-financed fiscal expansion means liquidity injection to the banking sector and we should expect the nominal value of banks' capital to increase. To formally see this, let us focus on the steady state with *overline* indicating steady state, assuming $\bar{r}' = \bar{r}$.

Combining the budget constraints of the treasury, the firm, and the household and the goods market clearing condition, we obtain

$$\bar{Div} = \bar{\upsilon}^f \bar{L} - \bar{\upsilon}^b \frac{\bar{L}}{1+\bar{r}^l}(1+\bar{r}^d). \tag{18}$$

Note that in the steady state, Eq. (16) becomes

$$\bar{\Omega}^b = \bar{\upsilon}^f \bar{L} - \bar{\upsilon}^b \frac{\bar{L}}{1+\bar{r}^l}(1+\bar{r}^d) + \bar{\upsilon}^f \bar{L}\bar{\delta}. \tag{19}$$

According to the law of motion of bank capital, the bank capital after money-financed fiscal expansion at the steady state $\bar{e}'$ becomes $\bar{e}' = \bar{e} + \bar{\upsilon}^f \bar{L}\bar{\delta}$. The proposition below summarises the above analysis, and the subsequent numerical solutions assess how such a stimulus affects output, credit risks, and inflation in the general equilibrium.

Proposition 4 (*Money-financed Fiscal Stimulus*). *Money-financed fiscal stimulus that subsidises banks' credit extension puts downward pressure on the loan rate. In equilibrium, this money-fiscal operation increases banks' capital level in the steady state.*

5. Calibration

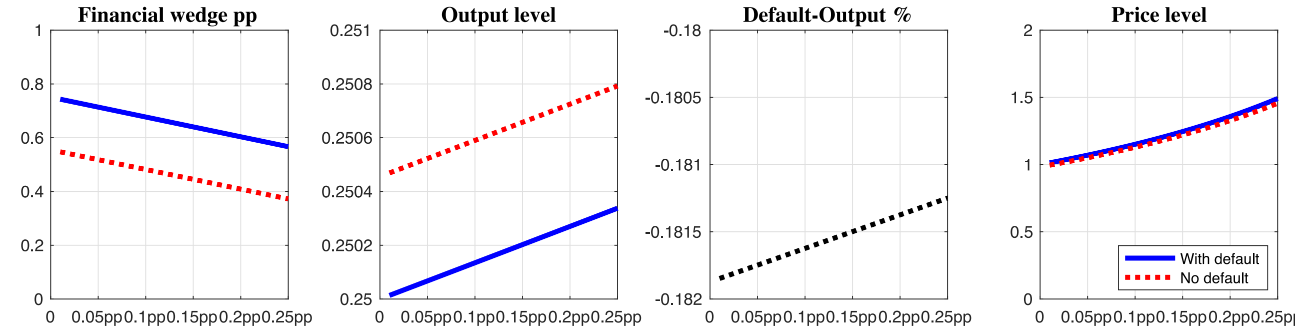
The model period is one quarter. We set the pre-GFC discount factor β to 0.9925, close to the value in Ottonello and Winberry (2020), and we set the post-GFC discount factor to 0.9975. We calibrate the pre-GFC steady state policy rate to be 3% per annum as in Christiano et al. (2005), and we set the post-GFC steady state policy rate as 0.12%, close to the average in the ZLB period. As we show in the equilibrium analysis, the parameter ν controls the positive correlation between the financial wedge f_t and the policy rate, i.e., $f_t = \nu r_t$. A simple OLS regression using the data for f_t and r_t from 1997 to 2008 suggests that the estimated value of ν is 0.73 and is statistically significant. This produces the financial wedge as 2.2 percentage points per annum, which is close to the steady state credit spread of 2 percentage points in Cúrdia and Woodford (2010). Similarly, we can take the 2 percentage points figure in Cúrdia and Woodford (2010) to internally calibrate ν to be 0.67, which is close enough to our estimation result.

The CAR regulation ι is internally calibrated as 0.06–0.08, by using the post-GFC financial wedge and the post-GFC policy rate. Even though our model's main purpose is to illustrate the key mechanism of the theory, rather than developing a large scale dynamic model for a quantification exercise, the internally calibrated ι is it is broadly in line with the general requirement for banks under the Basel III regulatory framework (see Basel (2016)), which gives us confidence of the internal calibration method. Regarding the monetary policy rule, the response to inflation is set to 1.5, similar to Gomes et al. (2016) and in line with the literature. Following Christiano et al. (2010), we set the output coefficient to 0.2. The persistence of first-order autoregressive monetary shock is set as 0.9, and that of the productivity shock is set as 0.7. The government bond supply in the steady state is calibrated as 100% of GDP. Following Wang (2022) we set the steady state price level to one to calibrate the seigniorage transfer in the steady state. Alternatively, one can estimate the seigniorage transfer to obtain price level endogenously.

To calibrate the default penalty λ^f (price of default) for loans to the firms, we use the empirical counterparts of the net steady state charge-offs of US commercial and industrial loans. The charge-off rates are retrieved from Call Reports of FDIC. Then I use the smoothing method developed à la (Hood, 2013) to estimate the average of the smoothed charge-off rates from 1999 to 2010 to be 0.78%. To calibrate the default penalty or bankruptcy cost λ_t^b for banks, we use the deposit rate to policy rate spread in the stable zero-lower-bound period. This is because the zero lower bound on retail deposit rates during this period can help us isolate the bank market power's confounding effect on deposit rate: had it not been this bound, banks would have used its market power to lower the retail deposit rate significantly into negative territory. Hence, the spread between the deposit rate and the policy rate during this period indicates the credit risk premium that markets anticipate on bank deposits. As could be expected, this credit risk premium is extremely small (0.2 pp during the stable period). In all of the ensuing numerical analysis, we refer to

(1) the benchmark case to mean the pre-GFC scenario where there are no excess reserves (reserves are provided on demand) and the CAR is non-binding; and

(2) the CAR binding case to mean the post-GFC scenario where there are excess reserves and the CAR is binding (see Table 1).



X-axis is reduction of nominal policy rate in percentage points; further to the right, the lower the rates. 'Default-output%' refers to the percentage change of the output with default risks from the output without default risks. The further to the right, the less the amplification due to default risks.

Fig. 3. Money non-neutrality in the steady state.

Table 1
Model calibration.
Data source: Board of Governors of the Federal Reserve System and FDIC Call Reports.

Description	Target	Parameter	Value
Policy rate pre-GFC (p.a.)		r	3%
Policy rate post-GFC (p.a.)		r	0.12%
Discount factor pre-GFC		β	0.9925
Discount factor post-GFC		β	0.9975
Frisch elasticity	3	γ^h	0.2515
Deposits reshuffle	Estimated	ν	0.73
Policy rate&wedge post-GFC		ι	0.06–0.08
Government debt/GDP	100%	$\bar{B}$	0.25
Price Level	1	ξ	0.0013
Leisure endowment		n	1
Net charge-offs (p.a.)	0.78%	λ^f	1.006×10^3
Deposit-policy rate spread post-GFC	0.2 pp	λ^b	4.05×10^3
Policy rate inflation feedback		m_p	1.5
Policy rate output feedback		m_y	0.2
Shock persistence S^m		ρ_m	0.9
TFP Shock persistence A		ρ_a	0.7

6. Steady states real and nominal effects

Fig. 3 displays the benchmark model steady state solutions while varying the monetary policy rate. We compare two sets of steady state equilibria: one with default risks (solid line), and the other ruling out default in equilibrium (dotted line). The horizontal axis is the reduction of percentage points in the policy rate. The further to the right, the more expansionary monetary policy is. As the monetary policy rate decreases, the financial wedge of the banking system decreases, and we see both the output level and price level increase in the steady state. In the case with default risks, as the policy rate decreases by 0.25 percentage points per annum permanently, quarterly output increases by around 0.14%, the financial wedge decreases by 0.2 percentage points per annum, and inflation is extremely responsive since the price level increases from 1 to 1.5.[9] This suggests a permanent shift in the policy rate can change the price level permanently. Moving to the case ruling out all default risks, the output level is higher than the case with default risks, and the financial wedge and the price level are lower. Nevertheless, as monetary policy loosens, the financial wedge also decreases, output and inflation both increase. The third subplot shows the percentage change of the output with default risks from the output without default risks. Not surprisingly it is negative, but the magnitude of the negative amplification due to default risks becomes less as monetary policy further loosens.

This numerical result supports Proposition 1 that money is non-neutral in the long run, and even with credit risks endogenously determined in the general equilibrium the result still holds. This is because the decrease in the policy rate passes through effectively to the loan rate in the benchmark model, which explains the reduction in the financial wedge. Loan rate reductions mean the borrowing cost of the non-bank sector decreases, which encourages the growth of output. The price level increases in the steady state because the loosening of monetary stance increases the banks' capacity to extend nominal loans which endogenously increases broad money supply.

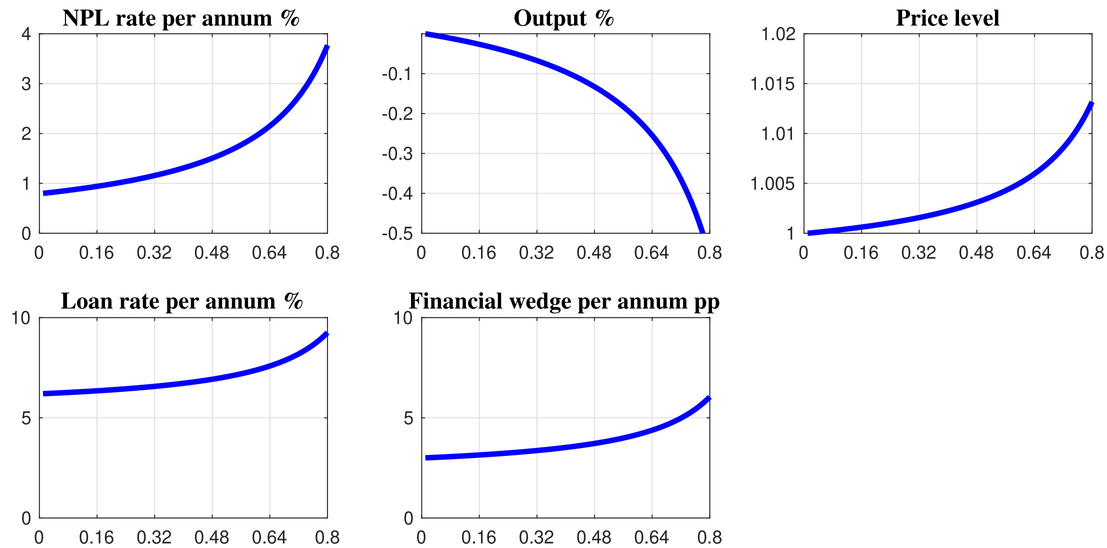
In the equilibrium characterisation, we are not able to solve for the endogenous credit risks analytically, so now we display their steady state solutions numerically. Fig. 4 shows the real and nominal effects of rising corporate credit risks by reducing the corporate loan default penalty while keeping the monetary policy rate unchanged. As we can see, as corporate credit risks, or the non-performing loan (NPL) rate increases by around 3% per annual, quarterly output drops by 0.5% in the steady state and price level increases mildly. As the corporate credit risks command a risk premium, the loan rate increases by around 3% per annum and the financial wedge increases by a similar magnitude, which increases the overall transaction cost of the economy reducing gains from trade. The interesting observation here is that reducing the corporate loan default penalty is inflationary, which is reminiscent of a result in Shubik and Tsomocos (1992). Shubik and Tsomocos (1992) show that when a low penalty creates the possibility of strategic default and there is no uncertainty, it is possible for inflation to occur.[10]

7. Dynamic responses

In this section, we simulate the dynamic responses to different shocks and study the dynamic properties of this model. In particular, we show numerically the (dis)connect between the policy rate and the financial wedge and examine the resulting real and nominal consequences. We also study the real and nominal effects when the bank risks increase or the central bank tightens the CAR requirement. Lastly, we simulate the model extension to demonstrate the role of money-financed fiscal stimulus that resembles some of the Covid-related support policies implemented during the pandemic crisis. In the appendix, we also include the dynamic responses to fundamental shocks and demonstrate the enlargement of the Taylor rule determinacy region.

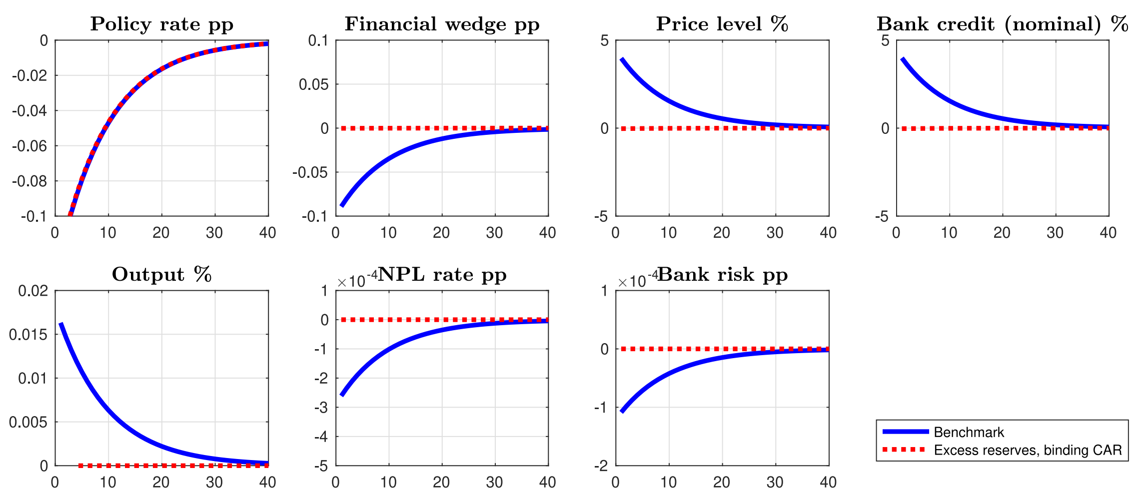
[9] In reality, the pass through of monetary policy to inflation is weaker than this due to obstructing factors such as price stickiness, maturity mismatch of banks' balance sheets, and banks' market power.

[10] Empirically, Acharya et al. (2020) show that the low inflation in Europe after the GFC is related to the zombie-lending that leads to few defaults. Galli (2020) shows that sovereign default and inflation are positively correlated.



X-axis is the softening degree of loan default penalty λ^f; further to the right, the smaller the penalty.

Fig. 4. Corporate credit risks non-neutrality in the steady state.



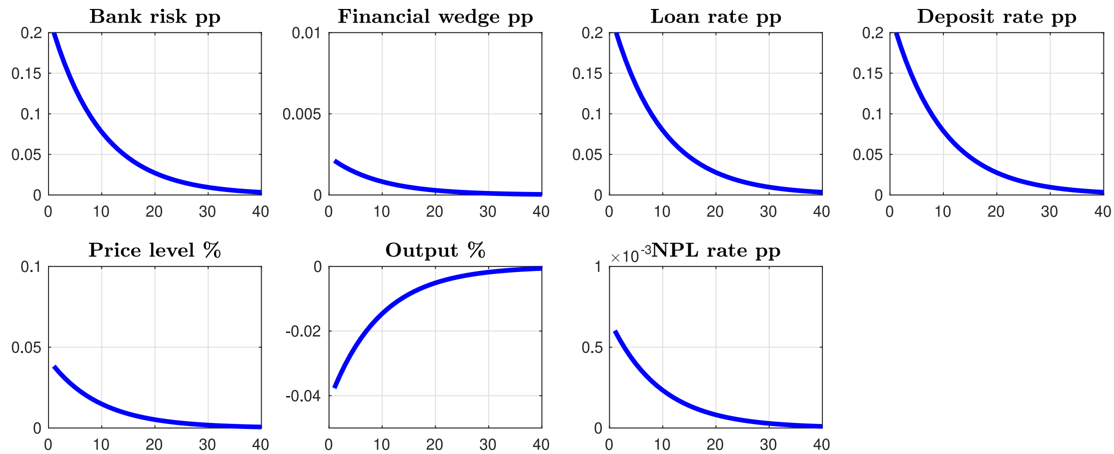
Dynamic responses to an expansionary monetary policy shock. X-axis is in quarters. Policy rate, financial wedge, NPL. rate, and bank risk are annualised.

Fig. 5. Monetary expansion and (dis)connect with financial wedge.

7.1. Disconnect between policy rate and financial wedge

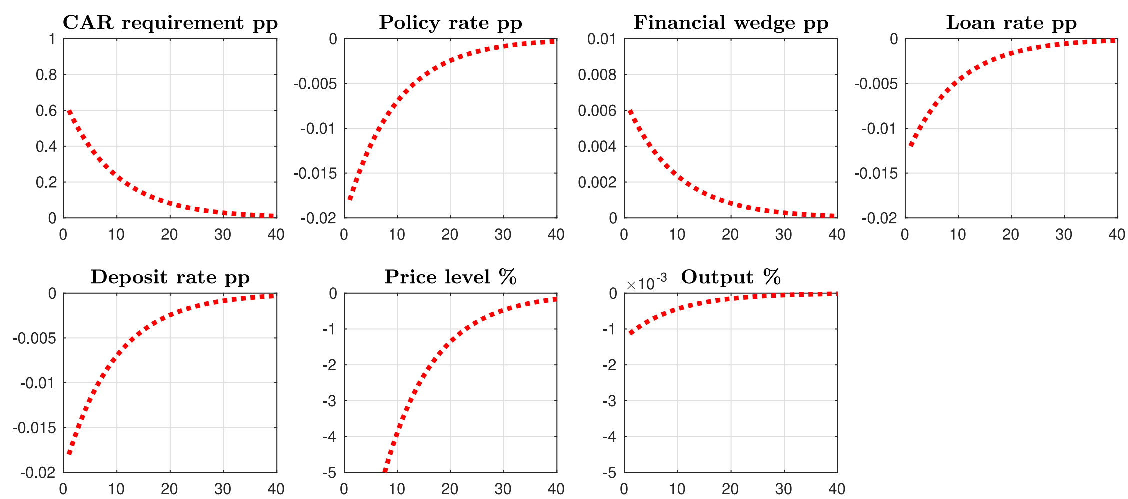
Fig. 5 displays the impulse responses to an expansionary monetary policy shock whereby the policy rate falls by around 0.1 pp per annum. For the benchmark model where the reserve liquidity constraint is tight, the financial wedge falls in response by around 0.07 pp. The policy rate and the financial wedge are well connected. The nominal and real effects are pronounced: the price level increases by 5% on impact and gradually go back to the steady state, and the real output increases by over 0.015% on impact and then gradually returns to the steady state. In particular, the credit risks are mildly reduced in this loose monetary environment.

In the binding CAR case with excess reserves, the financial wedge barely responds to the fall in the policy rate, which is consistent with the stylised fact we have documented: the financial wedge and the monetary policy rate disconnected after the GFC. In this environment, the fall in the monetary policy rate has little nominal and real effect, seen in the dotted impulse response functions. This result suggests that in the post GFC period, the floor system and excess reserves in the financial system may obstruct further monetary expansions from increasing output and creating inflation. Of course, this is a stark result because we assume away sticky prices and the role of lowering long-run yield.



Dynamic responses to a penalty softening shock to bank repayment in the benchmark model. X-axis is in quarters. Interest rates, financial wedge, NPL. rate, and bank risk are annualised.

Fig. 6. Credit risk of the banking system.



Dynamic responses to a tightening shock to the CAR requirement in the case when CAR is binding. X-axis is in quarters. Interest rates and financial wedge are annualised.

Fig. 7. Tightening of bank capital requirement.

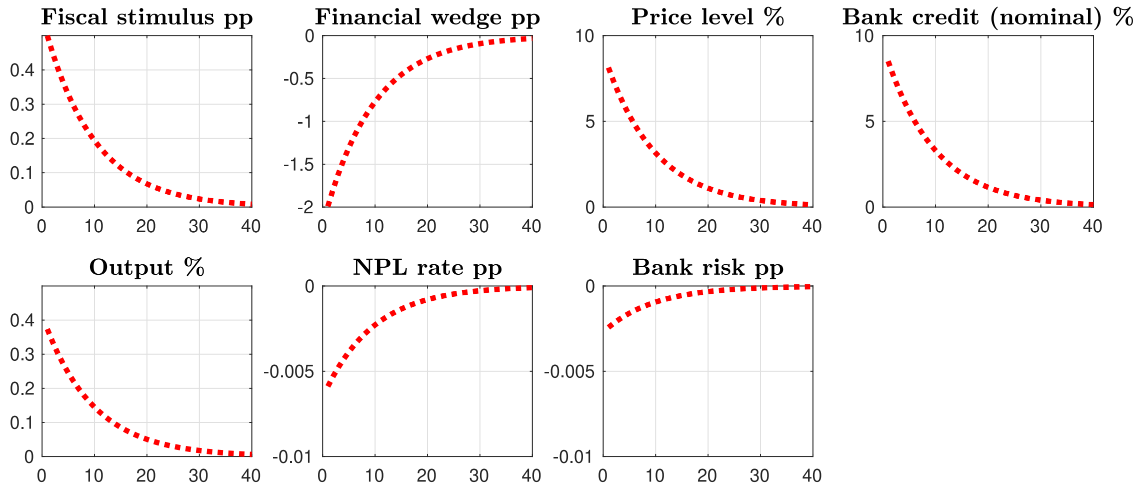
7.2. Real and nominal effects of bank risks

Then we investigate the real and nominal effects by allowing bank deposits to carry more credit risks. We do so by softening the bank default penalty so that the bank risk, or the credit risk on deposits, increases by 0.2 pp per annum on impact. We can see from Fig. 6 that this translates to an increase in the corporate default risk, which reflects the domino effects of default in the general equilibrium, accompanied by inflation. The financial wedge, the loan rate, and the deposit rate all go up, and so the overall cost of liquidity goes up in the economy reducing gains from trade. Consequently, quarterly output goes down by almost 0.04% and price level increases by just under 0.05%.

7.3. Disinflationary effects of tightening CAR

The post-GFC period is characterised by the strengthening of macroprudential policy. The existing literature has already investigated the real effect of tightening the bank capital requirement, which we affirm here in Fig. 7: with binding CAR and ample reserves, the rise in the CAR increases the financial wedge and is contractionary for the output. However, the existing literature has not focused much on its nominal effect, which is what we also consider in this experiment. We can see in Fig. 7 the price level falls by more than 5% in response to a 0.6 pp in the CAR requirement. This disinflationary effect occurs despite the monetary policy rate reacting endogenously to counter the fall in prices and output. This is because even though the fall in the monetary policy rate propels the loan rate and the deposit rate to go down, the financial wedge increases due to the increase in CAR. The increase in the financial wedge causes output to fall, and the tightening of CAR constrains the banks from issuing nominal loans even more, which leads to a reduction in the endogenous broad money supply.

The policy experiments considered in Figs. 5 and 7 provide one explanation to the post-GFC missing inflation puzzle. Despite the unconventional monetary policy injecting massive amount of reserves into



Dynamic responses to a 0.5 pp increase in the fiscal stimulus shock.

Fig. 8. Expansionary shock to money-financed fiscal stimulus.

the financial system, with interest rate on reserves and a tight bank regulatory environment, the overall nominal effect is still disinflationary.

7.4. Money-financed fiscal expansion

Now we conduct the following experiment to analyse the model extension on money-financed fiscal expansions. We assume the government's subsidy via money-financing to banks' credit extension is 0.2 pp (annualised) so that the borrowing cost to the firms is reduced by 0.2 pp per annum. In the steady state, quarterly output increases by 0.04%, inflation increases by 0.75% and corporate default risks decrease by 0.08 pp. This is because the subsidy decreases the financial wedge which encourages the gains from trade and improves output growth. The increase in output reduces the marginal utility of consumption of the borrowers, which decreases their marginal benefits of defaulting. Therefore, overall credit risks decrease. Since we have proven in Proposition 4, the quantity of money-financed fiscal stimulus increases bank capital in the steady state, this relaxes the banks' CAR constraint and in turn, banks issue more nominal loans and endogenous money supply increases, producing sizeable inflation in the steady state. Because we have removed the usual sticky price assumption to exclusively focus on the financing role of money in generating money non-neutrality, the movements in prices and inflation are much larger quantitatively than output movements.

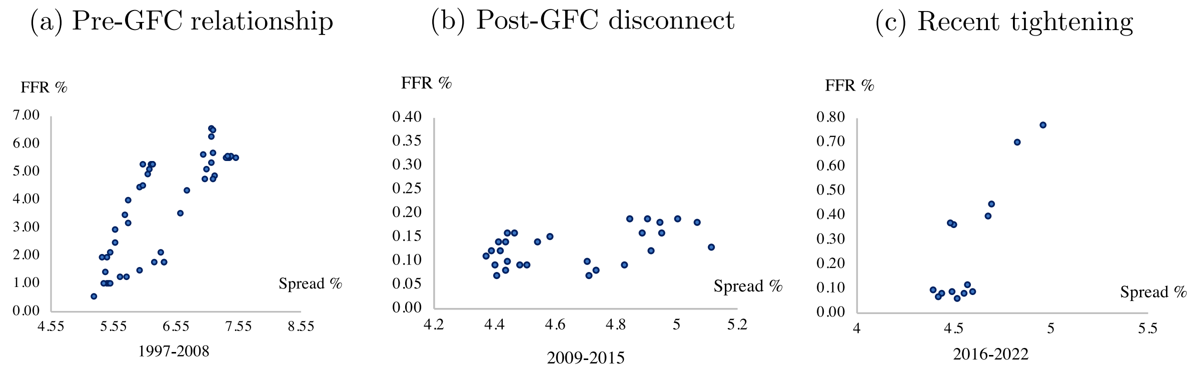
On the dynamic path, the results also hold. We simulate in Fig. 8 the dynamic responses to a 0.5 pp increase in the fiscal stimulus shock δ. In response, the financial wedge goes down by 2 pp per annum, and both the corporate loan default risk and the bank risk decrease on impact. Quarterly output increases by close to 0.4%, and noticeably price level increases by around 7%. The inflationary pressure is high, and it is because the money-financed fiscal stimulus eventually flows to build up the bank equity, as Proposition 4 proves. This relaxes the CAR constraint and encourages banks to extend more nominal loans and create liquidity to the firms. Overall the endogenous money supply increases responsively, which is broadly consistent with the empirical observation that with the government's stimulus policy, banks used credit lines to help firms during the pandemic crisis and that the deposits of the banking system also suddenly went up.

7.5. Fundamental shocks and determinacy space

Lastly, we investigate the dynamic properties of the model in response to technology shocks, and we also explore the determinacy region of the Taylor rule in our environment. As Fig. 10 in Appendix F shows, in the case with default, as a negative technology shock forces the output to decrease by around 1%, price level increases by 0.5%. In response to inflation, the policy rate goes up. On credit risks, corporate default rate increases by over 0.015 pp and bank risk also rises mildly. This suggests an advantage of modelling corporate loan default as an general equilibrium outcome: the pecuniary effects of endogenous default cause the corporate default rate on loans to fluctuate as the business cycle is hit by fundamental shocks, which is consistent with empirical facts that default recovery rates in the US are highly volatile, whereas in state-of-the-art models with a costly-state-verification financial accelerator mechanism à la Bernanke et al. (1999), the recovery rates are flat over the cycle (see Candian and Mikhail, 2020). However, for fundamental shocks, the amplification effects of default risks are very small, as we can see from the case ruling out default. This is not just because the low charge-off rate and credit risks we calibrated in the steady state, but also because the shock is within period and we have not introduced firm heterogeneity as in Ottonello and Winberry (2020). It would be interesting to introduce firm heterogeneity in the future to study the possible amplification effects of default on allocations and inflation.[11]

As we show in our steady state analysis, price level is endogenously determined. This implies that the usual Taylor rule determinacy space in our environment might be much larger than models that do not model money and credit. Indeed, as we see in Fig. 11 in Appendix F, we simulate the dynamic responses to an expansionary monetary policy shock while varying the Taylor rule inflation coefficients. When we set the Taylor rule inflation coefficient to 1.5 and −3, the Blanchard–Kahn conditions are both satisfied, but for standard New Keynesian models the Taylor rule inflation coefficient has to be larger than 1. Moreover,

[11] The model captures both strategic default and default due to ill fortune, both of which account for reasons for failing to meet financial commitments. According to Shubik and Wilson (1977), even when resources are available, if the marginal utility of not paying equals the default penalty, then the debts are not repaid; thus, strategic default harbours different motivations to stop paying debts compared to the reasons for bad luck.



X-axis is the spread between loan rate and deposit rate, net of smoothed charge-offs for loan losses. Y-axis is the effective federal funds rate. The left graph plots the relationship from Q4 1997 to Q4 2008, and the middle graph plots the relationship from Q1 2009 to Q4 2015 the low-rate period, and the right graph plots the relationship between Q1 2016-Q3 2022. The loan rate is calculated as loan interest income divided by total loans, and it is consistent with the Figure 1 where the loan rate of commercial and industrial loans is used. In particular, the right graph shows the reconnect recently, suggesting that as the central bank raises interest rates and lifts off from the zero lower bound, the loan rate increases but the increase of deposit rates is sticky. Source: Board of Governors of the Federal Reserve System, FDIC, and authors' calculation

Fig. 9. Federal funds rate and the financial wedge in the US.

we also remove the endogenous components of the Taylor rule and simply let the policy rate equate the exogenous shock, the model is also determinate. In our robustness checks, we set a broad range for the coefficients, and the Blanchard–Kahn condition holds.

8. Conclusion

In this paper, we have proposed a tractable dynamic stochastic general equilibrium model to remove the dichotomy between money and financial frictions and to address the interaction between the financial wedge and the monetary policy rate. The interaction between the financial intermediate wedge and monetary policy is quantitatively important. 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 the dual role of the stipulated means of exchange and a portfolio asset with interest payments and credit risks. The deposit contracts are issued and circulated via the banks' balance sheets. They mobilise physical resources to facilitate production and trade, with endogenous default in both the banking and non-bank sectors being the key financial friction.

With fully flexible prices, we show money non-neutrality obtains in the short run and in the long run. The model can generate a feedback loop between the value of money and endogenous default and examine the effectiveness of money-financed fiscal expansions. We show that the official policy rate and the financial intermediation wedge, namely the spread between loan and deposit rates, are the key variables for the analysis of the interaction between price stability and credit risks. The model allows us to understand the disconnect between the monetary policy rate and the financial wedge in the post-GFC period and shed light on both the missing inflation puzzle post-GFC and the burst of inflation post-pandemic. Nevertheless, because we only focus on liquidity and default as the key friction and have not introduced other relevant frictions (such as sticky prices to get a more realistic relative fluctuations between output and prices, and habit formation to generate hump-shaped consumption responses), we do not aim for a comprehensive quantitative assessment of business cycle fluctuations in this paper.

Furthermore, the most recent developments have seen the tentative reconnect between policy rate hikes and the financial wedge (see Appendix A). This suggests that as the central bank raises interest rates and lifts off from the zero lower bound, the loan rate increases but the deposit rate only increases slowly. Future work includes endogenising sticky deposit rates (possibly via banks' market power in the deposit market à la Drechsler et al., 2017) and assessing its impact on monetary transmission and corporate credit risks.

A broader role of this paper is to put liquidity creation 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 meaningful scope for policy that addresses price stability and financial stability simultaneously. Future directions include combining the specific features of the pandemic support policies with the mechanism of the model to understand the amplifying factors of inflation and investigate the mix of monetary and fiscal policies to control inflation. With rising interest rates, higher default becomes a possibility, it would also be of interest to assess the nominal and real effects in an environment where rising debt servicing costs lead to a larger scale of bankruptcies.

Data availability

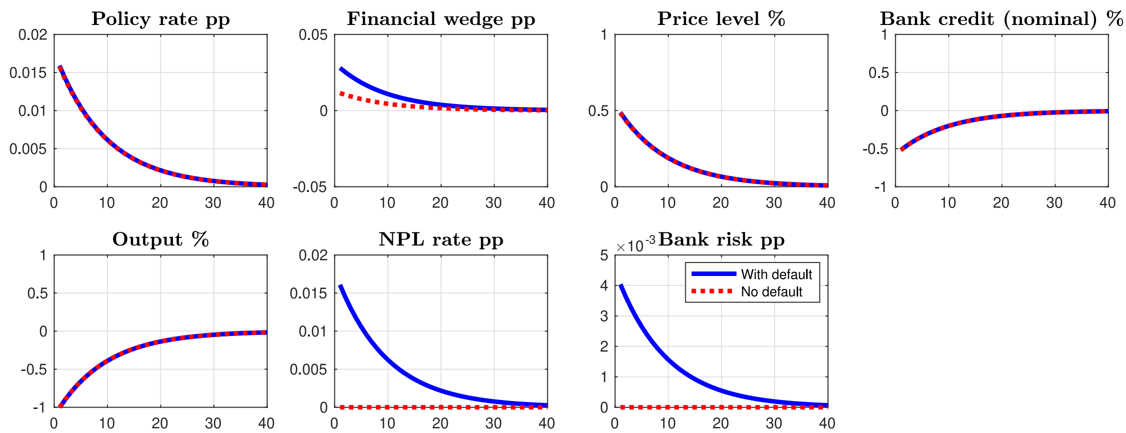
Data will be made available on request

Appendix A. Stylised facts

See Fig. 9.

Appendix B. Proof of Lemma 1

Suppose $\Delta_t(2) > 0$, then the firm can borrow ϵ less loan without violating (2). This leads to a reduction of deposit balances by $\epsilon/(1+r_t^l)$



Dynamic responses to a negative technology shock in the benchmark model. X-axis is in quarters. Interest rates and financial wedge are annualised.

Fig. 10. Technology shock.

flowing to constraint (9). The loan repayment decreases by ϵ. Thus, there is an extra deposit balance of $r_t^l\epsilon/(1+r_t^l)$ in (9). This either leads to an increase in firm's profits or repayment rate, both of which improve firm's utility. This is a contradiction; hence, $\Delta_t(2) = 0$. □

Appendix C. Proof of Proposition 1

Suppose the CAR being non-binding and no excess reserves, combining the firms' FOCs for L_t, h_t and υ_t^f, it follows that

$$\frac{W_t}{(1+r_t^l)} = P_t A_t \sigma h_t^{\sigma-1}, \tag{20}$$

multiply the above equations with h_t, it follows that

$$W_t h_t (1+r_t^l) = \sigma P_t y_t. \tag{21}$$

From the households' optimality condition for h_t and c_t, we have

$$\frac{1-\gamma^h}{n_t-h_t} = W_t/P_t \frac{\gamma^h}{c_t}\upsilon_t^b(1+r_t^d). \tag{22}$$

Combining (21) and (22) and the market clearing condition $c_t = y_t$, it follows that

$$\frac{1-\gamma^h}{n_t-h_t} = \left(\frac{h_t(1+r_t^l)}{\sigma y_t}\right)^{-1}\frac{\gamma^h}{c_t}\upsilon_t^b(1+r_t^d), \tag{23}$$

equivalent to

$$\frac{\gamma^h}{h_t}\frac{\upsilon_t^b(1+r_t^d)}{1+r_t^l} = \frac{1-\gamma_t^h}{n_t-h_t}. \tag{24}$$

Now we use the FOCs of the banks' choices of L_t, Div_t, and υ_t^b, we obtain

$$(1+r_t^l)\upsilon_t^f - (1+r_t^d) - \nu r_t = 0. \tag{25}$$

From the household's optimality condition for her portfolio, we obtain

$$\upsilon_t^b(1+r_t^d) = 1+r_t. \tag{26}$$

Combine (24), (25), and (26), we have

$$\frac{\gamma^h}{h_t}\frac{(1+r_t)\upsilon_t^f}{\nu r_t + \frac{1+r_t}{\upsilon_t^b}} = \frac{1-\gamma_t^h}{n_t-h_t}. \tag{27}$$

Given credit risks, since γ^h, n_t are exogenous, a change in r_t changes h_t, and hence c_t and y_t in equilibrium. □

Appendix D. Proof of Proposition 2

With no excess reserves, banks' FOCs give the following relationship for interest rates:

$$\Lambda_t^h\left(\upsilon_t^f - \frac{1+r_t^d}{1+r_t^l} - \frac{\nu r_t}{1+r_t^l}\right) - \phi_t\frac{\iota}{1+r_t^l} = 0, \tag{28}$$

where ϕ_t is the shadow price of the CAR. Controlling for Λ_t^h, ϕ_t and credit risks, an increase in r_t causes an increase in the financial wedge, the loan-deposit-rate spread.

With excess reserves, the above equation becomes

$$\Lambda_t^h\left(\upsilon_t^f - \frac{1+r_t^d}{1+r_t^l}\right) - \phi_t\frac{\iota}{1+r_t^l} = 0, \tag{29}$$

Controlling for Λ_t^h, ϕ_t and credit risks, the monetary policy rate does not matter for the financial wedge. □

Appendix E. Proof of Proposition 3

When the CAR is non-binding and there are excess reserves, and suppose we are in the steady state, from the above proof, we have

$$(1+\bar{r}^l)\bar{\upsilon}^f - (1+\bar{r}^d) = \iota\frac{1-\beta}{\beta}, \tag{30}$$

and from household's portfolio decision, we know $1+\bar{r}^d = \frac{1+\bar{r}}{\bar{\upsilon}^b}$, so it follows that

$$(1+\bar{r}^l)\bar{\upsilon}^f - \frac{1+\bar{r}}{\bar{\upsilon}^b} = \iota\frac{1-\beta}{\beta}. \tag{31}$$

From the above equation, given credit risks and monetary policy rate, an increase in ι increases loan rate, and an increase in β decreases loan rate. □

Appendix F. Other experiments

See Figs. 10 and 11.

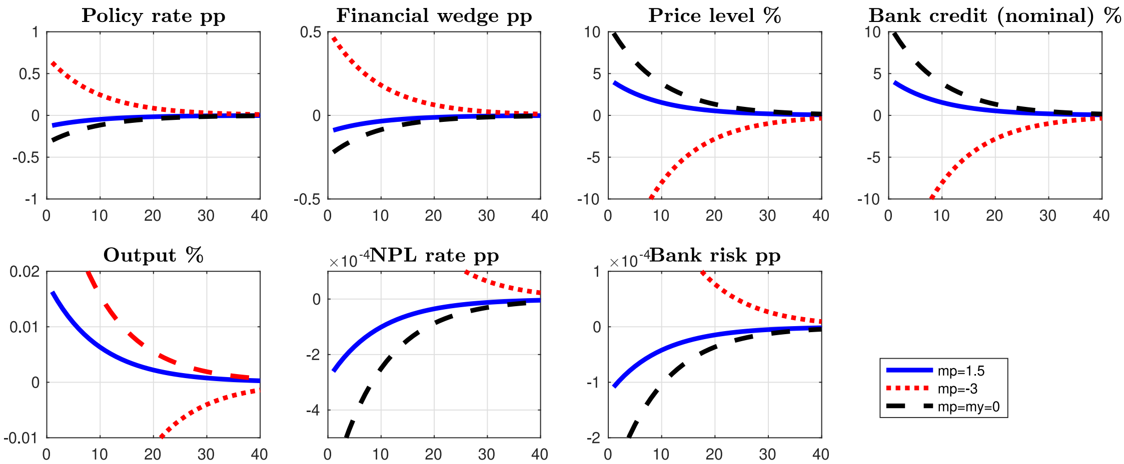


Fig. 11. Monetary policy shocks and determinacy space. Dynamic responses to an expansionary monetary policy shock in the benchmark model varying Taylor rule inflation coefficients. X-axis is in quarters. Interest rates and financial wedge are annualised.

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