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Abstract

We model the interactions of financial frictions and real frictions, using a DSGE model calibrated for the US economy, with households, banks, firms and wage bargaining. The model features labour and investment frictions, in the form of convex costs, and financial frictions, in the form of credit constraints and the risk of banks diverting their funds. In addition, there are price frictions and habits in consumption. We examine technology, monetary policy, and credit shocks. We look at the response to these shocks of real aggregate variables, financial market variables, and labour market variables. We find that the interactions of real frictions and financial frictions have important implications for the effects of financial shocks on the macroeconomy.

Key words: Real frictions, financial frictions, business cycles.

JEL classification: E32, E44.

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1 Introduction

The Global Financial Crisis, its repercussions and ramifications have seen both policymakers and academic researchers become acutely aware of the importance of financial markets, including the shocks and frictions inherent in them, for business cycles. At the same time policymakers keep using labour market indicators, such as wage inflation or the rate of unemployment, as key inputs in their policy decisions. In this paper we consider how labour and financial market frictions and their interaction affect the transmission of real and financial shocks through the economy. In particular, we examine how the presence of financial and labour market frictions affect the transmission of productivity and monetary policy shocks. And we examine a particular channel through which shocks to financial markets, resulting in movements in the spread between loan and deposit rates, interact with hiring frictions, to affect the demand for labour, and hence the economy more generally.

The emerging literature on DSGE modelling with financial frictions since the onset of the crisis either spells out a financial sector or adds financial frictions and/or shocks to the modelling of the firm to determine the intermediation process between firms and households. As suggested by Gertler, Kiyotaki, and Prestipino (2016), these recent models represent an improvement on existing models by adding features that are important in understanding the recent crisis. In this paper we develop a DSGE model that links financial markets and financial frictions with real markets and real frictions. We use this model to enhance our understanding of how shocks are transmitted through the real economy and to explore the linkages between financial markets and the real economy.

We use a DSGE model calibrated to the US economy, with households, banks, firms, and wage bargaining. The model features labour and investment frictions, in the form of convex costs, and financial frictions, in the form of credit constraints and the risk of banks diversion of funds. In addition there are price frictions and habits in consumption. Essentially this a standard DSGE model in the spirit of Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007), to which we add labour frictions as in Merz and Yashiv (2007) and Yashiv (2016), and financial frictions as in Gertler and Kiyotaki (2011, 2015). This approach enables us to obtain a comprehensive model to investigate the behaviour of real aggregate variables (GDP, capital and investment, and consumption), financial market variables (interest rate spreads, volumes of lending and deposits, bank net worth) and labour market variables (wages, employment, unemployment, and hiring). We examine technology and monetary policy shocks, as well as credit shocks, to determine the consequences of the interactions of real and financial frictions.

We focus our analysis on the need for firms to borrow from banks to pay their gross hiring and investment costs and on the leverage and credit spreads that characterise the banking sector. And we attempt to disentangle the relative roles played by the various frictions and shocks in this system.

The paper proceeds as follows: Section 2 presents the literature. Section 3 discusses the model, highlighting the key features in our model that distinguish it from previous models. Section 4 presents the methodology, including the calibration of the model. Section 5 presents the results. Section 6 discusses the results and presents robustness checks. Section 7 offers concluding remarks.

2 Literature

Business cycle research in Macroeconomics has been facing new challenges following the 2007-2009 Global Financial Crisis; see Linde, Smets and Wouters (2016) and Ramey (2016) for broad discussions. Prior to the crisis, macroeconomic researchers and policymakers relied on the benchmark DSGE model, as formulated in Christiano, Eichenbaum, and Evans (2005) and in Smets and Wouters (2007) and as described in detail in the Gali (2015) textbook. But the important events in financial markets and housing markets, and their substantial effects on the overall economy, were missing from these standard models. Much of the ensuing work has been an attempt to embed various concepts of frictions, and in particular financial frictions, in existing business cycle DSGE models to account for such developments.

The literature, emerging over the past decade, incorporating financial frictions in macroeconomic models is already voluminous. Surveys and discussions may be found in Gertler and Kiyotaki (2011), Brunnermeier, Eisenbach, and Sannikov (2013), Ramey (2016), and Gertler, Kiyotaki and Prestipino (2016). In what follows we discuss the specific papers relevant for our work.

In terms of DSGE modelling we draw upon Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007). For investment frictions we follow the approach used by Christiano, Eichenbaum and Evans (2005) and Christiano, Eichenbaum and Trabandt (2016). For labour frictions we postulate gross hiring costs, following Merz and Yashiv (2007) and Yashiv (2016), which use an approach akin to the one used for investment costs by Lucas and Prescott (1971) and by Tobin (1969) and Hayashi (1982). More recently, King and Thomas (2006), Khan and Thomas (2008), Alexopoulos (2011), and Alexopoulos and Tombe (2012) provide justifications for the hiring costs formulation used here.

For financial shocks and frictions we draw upon papers that study the banking sector, an important source of shocks within the economy as demonstrated vividly by the Global Financial Crisis. In particular, we adopt the approach of Gertler and Kiyotaki (2011, 2015), who model agency issues in financial intermediation by banks. These agency issues lead to the emergence of a spread between banks' lending and funding rates. Because agents in the economy need to borrow from banks, movements in the spread – caused by shocks within the banking sector – will have real effects. Gertler and Karadi (2011) have implemented the Gertler and Kiyotaki (2011) model in a DSGE framework. Gersbach and Rochet (2017) have discussed this framework in the context of an analysis of credit cycle stabilization and counter-cyclical capital requirements on banks. Important related contributions have been made by Jermann and Quadrini (2012) and by Curdia and Woodford (2016).

3 The Model

3.1 The Set-Up

The basic set-up is a standard New Keynesian DSGE model. There is a unit continuum of identical 'large' households, featuring habit formation and disutility of work. There are two types of firms, with the monopolistically-competitive firms facing Rotemberg (1982) price fictions, investment adjustment costs as in Christiano, Eichenbaum and Evans (2005), and hiring costs as in Merz and Yashiv (2007). Labour markets are frictional with Nash wage bargaining in the DMP tradition; see, for example, Merz (1995). There is a banking sector with frictions following Gertler and Kiyotaki (2011, 2015).

Firms produce output using labour and capital. We assume that frictions exist such that firms are unable to fund all of their investment out of retained earnings; rather, they have to borrow from banks to finance a fraction of their investment. In addition, we assume that they have to borrow 'working capital' from banks. This working capital is used to pay a fraction of their wage bill as well as a fraction of the costs associated with hiring new workers.

Finally, banks channel funds from the households (depositors) through to firms. As in Gertler and Kiyotaki (2011, 2015), they face an endogenous leverage constraint arising out of the friction that they can divert a fraction of their assets should that be more profitable than continuing as an ongoing entity. In addition, there is turnover in the banking sector with dying banks' net worth returning to the households (as the owners of the banks), who also set up new banks by supplying some initial net worth.

Figure 1 shows graphically the agents in the model and the transactions between them.

3.2 The Labour Market

The labour market is frictional in the sense that there will be unemployed workers searching for a job who will not be able to immediately find work. We assume the following timing within the labour market. At the beginning of each period t, U_t^0 workers are unemployed. Given the same matching technology facing all workers and one pool of unemployment for all households, unemployed workers are matched to jobs with probability $f_t = \frac{h_t}{U_t^0}$, where h_t denotes the total number of worker matches. Once matched, workers immediately start producing. That is, we assume the matching process happens ahead of production. At the end of the period, we assume that an exogenous proportion of workers, δ_N, separate from employment. They join the existing pool of unemployed workers, U_t, to form the pool of unemployed workers that look for jobs at the beginning of the following period, U_{t+1}^0.

We normalise the labour force to 1. This implies that the stocks of employed workers, N, and unemployed workers, U, are given by:

$$1 = N_t + U_t \tag{1}$$

The matching probability is:

$$f_t = \frac{h_t}{U_t^0} \tag{2}$$

where

$$U_t^0 = U_{t-1} + \delta_N N_{t-1} \tag{3}$$

$$U_t = U_t^0 - h_t \tag{4}$$

This implies the following relations:

$$h_t = f_t U_t^0 = \frac{f_t}{1 - f_t} U_t = \frac{f_t}{1 - f_t}(1 - N_t) \tag{5}$$

So the stocks evolve as follows:

$$U_t = (1 - f_t)U_t^0 \tag{6}$$
$$N_t = (1 - \delta_N)N_{t-1} + h_t$$

3.3 Households

The problem for households is to maximise their utility subject to a budget constraint and the evolution of employment. We assume that households are 'large' in the sense that the unemployment rate in the economy as a whole will equal the proportion of members of an individual household who are unemployed. A typical household j, obtains utility from consumption, $c_{j,t}$ and disutility from those members of the household who work, $N_{j,t}$. We assume perfect insurance within the household; that is, consumption within the household is spread across household members in such a way as to ensure that individual utility is the same and equal to household utility. Households accumulate bank deposits, $D_{j,t}$, which pay the (gross) risk-free nominal rate of interest, R_t. We also assume that they own the firms and the banks, receive profits from the firms, and get net transfers from the banks; we denote these by $\Pi_{j,t}$.

Hence, we can write the problem for household j as follows:

Maximise

$$\max_{c_{j,t}} E_0 \sum_{t=0}^{\infty} \beta^t [(1-\eta)\ln(c_{j,t} - \eta C_{t-1}) - \frac{\tau}{1+\xi} N_{j,t}^{1+\xi}] \tag{7}$$

subject to:

(i) the budget constraint in nominal terms is given by:

$$P_t c_{j,t} + D_{j,t} = R_{t-1} D_{j,t-1} + P_t w_t N_{j,t} + \Pi_{j,t} \tag{8}$$

(ii) employment evolution is given by (using (5) for this type of household):

$$\begin{aligned} N_{j,t} &= (1-\delta_N)N_{j,t-1} + h_{j,t} \\ &= (1-\delta_N)N_{j,t-1} + \frac{f_t}{1-f_t}(1 - N_{j,t}) \end{aligned} \tag{9}$$

where τ is the relative weight of leisure in the utility function, β is the discount factor, ξ is the inverse of the Frisch elasticity of labour supply, w_t is the real wage, $\Pi_{,j,t}$ denotes the sum of dividend payments received from the firms and the banks less the capital that they put in to newly-created banks and P_t is the aggregate price level. Notice that we have 'external' habits in consumption. That is, the utility of household j depends on their consumption vis-à-vis the previous period's average household consumption, C_{t-1}.

Assuming all households are identical with unit measure, the first-order conditions for this problem for the aggregate household sector are given by:

(i) the intertemporal Euler equation for consumption:

$$\frac{1}{C_t - \eta C_{t-1}} = \beta R_t E_t \left[\frac{P_t}{P_{t+1}} \frac{1}{C_{t+1} - \eta C_t} \right] \tag{10}$$

(ii) the value of employment $V_{N,t}$:

$$\frac{V_t^N}{1 - f_t} = w_t - \tau N_t^{\xi} \frac{C_t - \eta C_{t-1}}{(1-\eta)} + \beta(1-\delta_N) E_t \left[V_{t+1}^N \frac{C_t - \eta C_{t-1}}{C_{t+1} - \eta C_t} \right] \tag{11}$$

where f_t is the job-finding rate and we can note that since there are a unit continuum of households, aggregate employment N will equal the number of workers employed in each household. $V_{N,t}$ represents the value of a marginal job to the household sector, and this, in turn, will be the value of the marginal job from the point of view of the labour union that negotiates wages on behalf of the household sector. This negotiation process is described later in this section of the paper.

3.4 Firms

There is a unit measure of monopolistically-competitive firms indexed by $l \in [0, 1]$ and of perfectly-competitive final goods aggregator firms. We assume price stickiness *à la* Rotemberg (1982), meaning firms maximise the present discounted value of current and expected future profits subject to quadratic price adjustment costs, and hiring and investment frictions, to be elaborated below. In what follows we present the optimisation problem for the two types of firms.

3.4.1 Final Goods Firms

Final goods firms operate in a perfectly-competitive market and produce y_t using goods $y_{l,t}$ as inputs. The price of the final good used for consumption and investment is given by P_t. Final goods firms maximise

$$\max P_t y_t - \int_0^1 P_{l,t} y_{l,t} dl$$

subject to

$$Y_t = \left(\int_0^1 {y_{l,t}}^{(\epsilon-1)/\epsilon} dl \right)^{\epsilon/(\epsilon-1)}.$$

where $\epsilon > 0$ is the elasticity of demand for an individual firm's good.

Taking first order conditions with respect to y_t and $y_{l,t}$ and merging we solve for the demand function

$$y_{l,t} = \left(\frac{P_t}{P_{l,t}} \right)^{\epsilon} y_t \tag{12}$$

3.4.2 Intermediate Goods Firms

Intermediate goods firms produce output using capital, k, and labour, N. We assume they can vary the extent to which they utilise their capital and denote this by z. The gross output of a representative firm l at time t is:

$$y_{l,t} = A_t N_{l,t}^{1-\alpha} \left(z_{l,t} k_{l,t-1} \right)^{\alpha} \tag{13}$$

where A_t is an aggregate technology shock. The firm faces the demand function derived above (12).

In order to produce this output, the firm has to hire $h_{l,t}$ workers:

$$N_{l,t} = (1 - \delta_N) N_{l,t-1} + h_{l,t}, \quad 0 < \delta_N < 1. \tag{14}$$

In order to hire these workers, the firm has to pay a hiring cost given by:

$$g(h_{l,t}, N_{l,t}) = \frac{\phi_h}{2} \left(\frac{h_{l,t}}{N_{l,t}} \right)^2 P_t y_t \tag{15}$$

We interpret hiring costs as training costs and other costs that are related to the hiring rate. The modelling of these costs follows previous work by Merz and Yashiv (2007) and Yashiv (2016), whereby the cost function is quadratic in the hiring rate,where ϕ_h is a positive parameter governing the degree of hiring frictions.

In every period t, the existing capital stock depreciates at the rate $\delta_{K,l,t}$ and is augmented by new investment subject to investment costs:

$$k_{l,t} = (1 - \delta_{K,l,t})k_{l,t-1} + I_{l,t}\left[1 - S\left(\frac{I_{l,t}}{I_{l,t-1}}\right)\right] \tag{16}$$

where, following Christiano, Eichenbaum and Evans (2005), we assume that the cost function S satisfies $S(1) = S'(1) = 0$ and $S''(1)$ is a positive constant. We assume that the greater the extent to which capital is utilised, the faster it depreciates:

$$\delta_{K,l,t} = \delta_K + r_k\left(\omega\frac{z_{l,t}^2}{2} + (1-\omega)\,z_{l,t} + \frac{\omega}{2} - 1\right) \tag{17}$$

where ω is a technological parameter, δ_K is the steady-state capital depreciation rate, r_k is the steady-state return on capital and steady-state capital utilisation is assumed to equal 1.

The firm borrows from banks in order to pay a fraction $0 \leq \Omega_1 \leq 1$ of their investment costs, a fraction $0 \leq \Omega_2 \leq 1$ of their wage bill, and a fraction $0 \leq \Omega_3 \leq 1$ of their hiring costs. Thus firm loans to firm l, $L_{l,t}$, are given by:

$$L_{l,t} = \Omega_1 P_t I_{l,t} + \Omega_2 W_t N_{l,t} + \Omega_3 P_t\left(\frac{\phi_h}{2}\left(\frac{h_{l,t}}{N_{l,t}}\right)^2 y_t\right) \tag{18}$$

where these loans have a gross nominal lending rate $R_{L,t} = 1 + r_{L,t.}$ attached to them. The idea of this friction is both to pick up the various real-world frictions that mean that some firms are unable to finance all their investment from internal funds and so have to borrow from banks at a premium over the cost of internal funds (R in this model since the households own the firms), and the fact that firms typically borrow from banks to finance their 'working capital', ie, those payments that need to be made (for production to take place) ahead of the firm generating revenue. See Barth and Ramey (2002) for a discussion of these issues and the effects of adding a 'working capital' or 'cost' channel on the monetary transmission mechanism. Unfortunately, there is minimal evidence on what are the appropriate values of Ω_1, Ω_2 and Ω_3, should be. But, as our interest in this paper is on understanding channels of transmission and the effects of adding various frictions, the precise values of these parameters are not important for our purposes. In what follows, we consider only the effects of switching these channels off and on by using values of 0 and 1 for each of the Ωs.

We also assume that firms always pay these loans back to the banks, ie, there is no default risk. While the effects of firm default, and potential firm default, are both interesting and can be used to understand why firms pay a premium to borrow from banks over the cost of using their internal funds (as in eg, Bernanke, Gertler and Gilchrist (1999)), adding firm default (following, eg, Clerc *et al.* (2015)) would severely complicate the model without adding any additional channels linking financial and labour market frictions, the key interaction that this paper seeks to examine.

We assume that the intermediate firms are owned by the households. So, they will maximise the present discounted value of the current and future expected streams of profits they send to their owners where the stochastic discount factor will be that given by the households' problem. Following Rotemberg (1982), we assume that firms face quadratic costs of adjusting their prices. The maximisation problem for firm l is thus:

$$\max_{h_{l,t},I_{l,t},P_{l,t}} E_t \sum_{t=1}^{\infty} \frac{\beta^t (1-\eta)}{(C_t - \eta C_{t-1}) P_t} \left(\begin{array}{c} P_{l,t} y_{l,t} \\ -P_t I_{l,t} - W_t N_{l,t} \\ +L_{l,t} - R_{L,t-1} L_{l,t-1} \\ -\left(\frac{\phi_h}{2} \left(\frac{h_{l,t}}{N_{l,t}} \right)^2 + \frac{\chi}{2} \left(\frac{P_{l,t}}{P_{l,t-1}} - 1 \right)^2 \right) P_t y_t \end{array} \right) \tag{19}$$

subject to (12), (13),(14), (16), (17) and (18).

Assuming all firms are symmetric and so set the same price, hiring rates and investment, the first-order conditions for this problem imply the following, where Q_t^N and Q_t^K are the real values of an additional employee and an additional unit of the capital good, respectively.

(i) Prices.

$$\begin{array}{l} \frac{1-\epsilon}{\chi} + \frac{\epsilon rmc_t}{\chi} - \left(\frac{P_t}{P_{t-1}} - 1 \right) \frac{P_t}{P_{t-1}} + \\ E_t \left[\frac{\beta (C_t - \eta C_{t-1})}{(C_{t+1} - \eta C_t)} \left(\left(\frac{P_{t+1}}{P_t} - 1 \right) \left(\frac{P_{t+1}}{P_t} \right)^2 \frac{y_{t+1}}{y_t} \right) \right] = 0 \end{array} \tag{20}$$

where rmc_t is the Lagrange multiplier on (13) and is spelled out below.

Log-linearising this equation around a zero-inflation steady state produces the familiar New Keynesian Phillips curve linking inflation this period with expected inflation next period and real marginal cost:

$$\left(\frac{P_t}{P_{t-1}} - 1 \right) = \pi_t = \beta E_t [\pi_{t+1}] + \frac{(\epsilon - 1) \ln \left(\frac{rmc_t}{rmc} \right)}{\chi} \tag{21}$$

(ii) Hiring.

Marginal hiring costs are given by:

$$Q_t^N = \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) \phi_h \frac{h_t}{N_t} \frac{y_t}{N_t} \tag{22}$$

Notice that if we assume the firm pays these costs out of internal funds, ie, $\Omega_3 = 0$, then the cost is $\phi_h \frac{h_t}{N_t} \frac{y_t}{N_t}$. However, if the firm has to finance these costs entirely by borrowing from the banks, ie, $\Omega_3 = 1$, then the hiring cost will equal $\frac{R_{L,t}}{R_t} \phi_h \frac{h_t}{N_t} \frac{y_t}{N_t}$. That is, the hiring cost will be higher, the higher is the spread of bank lending rate over the deposit rate, $\frac{R_{L,t}}{R_t}$. This spread represents the opportunity cost of firm borrowing and, as we will show below, the frictions within the banking sector will determine this spread. So, financial frictions, by determining the spread, will affect the cost of hiring resulting from hiring frictions.

Marginal hiring revenues are given by:

$$\begin{aligned} Q_t^N &= \frac{(1-\alpha) rmc_t y_t}{N_t} - w_t \left(1 - \Omega_2 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) + \phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t} \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) \\ &\quad + (1 - \delta_N) E_t \frac{\beta \left(C_t - \eta C_{t-1}\right)}{\left(C_{t+1} - \eta C_t\right)} Q_{t+1}^N \end{aligned} \tag{23}$$

The value of a hired worker will equal his real marginal product, $\frac{(1-\alpha) rmc_t y_t}{N_t}$, less the wage paid by the firm, $w_t \left(1 - \Omega_2 \left(1 - \frac{R_{L,t}}{R_t}\right)\right)$, plus the savings in hiring costs (as the worker has already been hired), $\phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t} \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right)$, plus the expected present discounted value of the worker still being at the firm next period, $E_t \frac{\beta \left(C_t - \eta C_{t-1}\right)}{\left(C_{t+1} - \eta C_t\right)} Q_{t+1}^N$, times the probability that this is the case, $(1 - \delta_N)$. As long as the firm has to borrow some portion of their wage and hiring costs from banks, a rise in the spread will raise the cost of wage payments but also raise the savings in hiring costs resulting from the worker already being in place at the firm. However, this rise in the savings in hiring costs – $\phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t} \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right)$ – is lower than the rise in initial hiring costs resulting from a rise in the spread – $\left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) \phi_h \frac{h_t}{N_t} \frac{y_t}{N_t}$ – and so a rise in the spread will unambiguously lead to a fall in hiring. Again, this is equivalent to stating that a worsening of financial frictions will lead to a fall in hiring and this effect is stronger the larger are the hiring frictions, ie, ϕ_h. Notice, however, that the financial frictions will not affect the discount rate applied to the 'continuation' value, Q^N_{t+1}. This results from our assumption that households own the firms. If, on the other hand, we assumed that the banks own the firms (as in Gertler and Kiyotaki (2015) for instance) then we would have an additional channel whereby a worsening of financial frictions would lead to an increase in the discount rate applied to this continuation value and so would lead to an even larger fall in hiring. This channel was emphasised in Hall (2017).

Now we can combine these equations to obtain the following expression for real marginal cost:

$$rmc_t = \frac{w_t N_t(1-\Omega_2)}{y_t(1-\alpha)} + \frac{(1-\Omega_3)\phi_h}{(1-\alpha)}\left(1-\frac{h_t}{N_t}\right)\frac{h_t}{N_t} + \frac{1}{(1-\alpha)}\frac{R_{L,t}}{R_t}\left[\Omega_3\phi_h\left(1-\frac{h_t}{N_t}\right)\frac{h_t}{N_t} + \Omega_2\frac{w_t N_t}{y_t}\right] \tag{24}$$

$$+\frac{(1-\delta_N)(1-\Omega_3)\phi_h}{(1-\alpha)}\frac{N_t}{y_t}E_t\left[\frac{h_{t+1}}{N_{t+1}}\frac{y_{t+1}}{N_{t+1}}\right] + \frac{1}{(1-\alpha)}\frac{N_t}{y_t}E_t\left[\frac{R_{L,t+1}}{R_{t+1}}\Omega_3\phi_h\frac{h_{t+1}}{N_{t+1}}\frac{y_{t+1}}{N_{t+1}}\right]$$

If we set $\Omega_2 = \Omega_3 = \phi_h = 0$, then real marginal costs are given by the familiar expression

$$rmc_t = \frac{w_t}{(1-\alpha)\frac{y_t}{N_t}} = \frac{w_t N_t}{y_t(1-\alpha)}$$

which underlies the use of the labour share in empirical estimates of the New Keynesian Phillips curve, eg, Gali, Gertler, and Lopez-Salido (2005). The introduction of hiring frictions, i.e., setting $\phi_h > 0$, changes the expression for real marginal cost to

$$rmc_t = \frac{w_t N_t}{y_t(1-\alpha)} + \frac{\phi_h}{(1-\alpha)}\left(1-\frac{h_t}{N_t}\right)\frac{h_t}{N_t} + \frac{(1-\delta_N)\phi_h}{(1-\alpha)}\frac{N_t}{y_t}E_t\left[\frac{h_{t+1}}{N_{t+1}}\frac{y_{t+1}}{N_{t+1}}\right]$$

The intuition here is that to increase output, in addition to paying wages (the first term on the right-hand side of this equation), firms must pay the costs of hiring additional workers (the second term on the right-hand side of this equation) and, next period, will have to pay the costs of hiring workers to replace those who became unemployed at the end of this period (the third term on the right-hand side of this equation).

Comparing this with the expression for real marginal cost in the presence of financial frictions, i.e., with $\Omega_2 \neq 0, \Omega_3 \neq 0$, one sees three additional terms that reflect the fact that firms need to borrow to pay wages and to pay hiring costs (both this period and the next). If firms could finance these costs out of retained earnings, the cost would be R. But because they are having to borrow from banks, they have to pay an interest rate of R_L. So, financial frictions, by determining the spread, will affect real marginal costs, both directly – through the effect of rises in spreads on wage costs – and indirectly through the hiring frictions. Hence they will affect inflation via the New Keynesian Phillips curve.

(iii) Investment.

Marginal investment costs are given by:

$$1 - \Omega_1 \left(1 - \frac{R_{L,t}}{R_t}\right) = Q_t^K \left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - \left(\frac{I_t}{I_{t-1}}\right) S'\left(\frac{I_t}{I_{t-1}}\right)\right) \tag{25}$$
$$+\beta E_t \left[\frac{(C_t - \eta C_{t-1})}{(C_{t+1} - \eta C_t)} Q_{t+1}^K \left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{I_t}\right)\right]$$

For $\Omega_1 > 0$, this equation implies that investment depends negatively on the spread, $\frac{R_{L,t}}{R_t}$, as the firm has to borrow from banks to finance investment, and the spread measures the opportunity cost of this borrowing. This is another channel through which a worsening of financial frictions, leading to a rise in the spread, will have a negative effect on the real economy.

Marginal investment revenues are given by:

$$Q_t^K = E_t \left[\frac{\beta (C_t - \eta C_{t-1})}{(C_{t+1} - \eta C_t)} \left[\frac{\alpha \cdot rmc_{t+1} y_{t+1}}{k_t} + Q_{t+1}^K (1 - \delta_{k,t})\right]\right] \tag{26}$$

Firms set the marginal cost of investing in capital today, Q_t^K, equal to the discounted value of the expected benefit accruing to them tomorrow. This benefit, in turn, has two parts: the marginal product of capital, $\frac{\alpha \cdot rmc_t y_{z,t+1}}{k_t}$, and the value of the undepreciated capital left in the firm at the end of the period, $Q_{t+1}^K (1 - \delta_{k,t})$.

Finally, optimization of capacity utilization equates the marginal benefit from more capacity with the marginal cost (see equation (17)).

$$\frac{\alpha \cdot rmc_t y_t}{k_{t-1}} = Q_t^K r_k z_t \left(\omega z_t + 1 - \omega\right) \tag{27}$$

Hence the marginal product of capital depends on the extent to which it is utilised.

3.5 Wage Determination

We assume that wages are negotiated on behalf of all employed workers by a representative union and that the solution is the Nash solution.

Wages are assumed to maximise a geometric average of the household's and the firm's surplus weighted by the parameter γ, which denotes the bargaining power of the households:

$$W_t = \arg\max \left\{ \left(V_t^N\right)^{\gamma} \left(Q_t^N\right)^{1-\gamma} \right\}. \tag{28}$$

The first order condition to this problem leads to the Nash sharing rule:

$$(1-\gamma)V_t^N = \gamma Q_t^N \tag{29}$$

We reproduce the relevant expressions:

$$\frac{V_t^N}{1-f_t} = w_t - \tau N_t^{\xi} \frac{(C_t - \eta C_{t-1})}{(1-\eta)} + \beta(1-\delta_N) E_t \left[\frac{(C_t - \eta C_{t-1})}{(C_{t+1} - \eta C_t)} V_{t+1}^N \right] \tag{30}$$

$$Q_t^N = \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) \phi_h \frac{h_t}{N_t} \frac{y_t}{N_t} \tag{31}$$

$$\begin{aligned} Q_t^N \quad = \quad & \frac{(1-\alpha) rmc_t y_t}{N_t} - w_t \left(1 - \Omega_2 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) + \phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t} \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) \\ & + (1-\delta_N) E_t \frac{\beta (C_t - \eta C_{t-1})}{(C_{t+1} - \eta C_t)} Q_{t+1}^N \end{aligned} \tag{32}$$

Using equations (30) to (32) and the sharing rule (29) to eliminate the terms in Q_{t+1}^N and V_{t+1}^N one gets the following expression for the real wage:

$$w_t = \frac{1}{1 - \Omega_2 \gamma \left(1 - \frac{R_{L,t}}{R_t}\right)} \left[\begin{array}{c} (1-\gamma)\, \tau N_t^{\xi} \frac{(C_t - \eta C_{t-1})}{(1-\eta)} \\ +\gamma \left[\begin{array}{c} \phi_h \frac{h_t}{N_t} \frac{y_t}{N_t} \left(1 - \Omega_3 \left(1 - \frac{R_{L,t}}{R_t}\right)\right) \left(\frac{f_t}{1-f_t} + \frac{h_t}{N_t}\right) \\ + \frac{rmc_t \cdot (1-\alpha) y_t}{N_t} \end{array} \right] \end{array} \right] \tag{33}$$

To obtain some intuition for this equation, note that with zero hiring costs ($\phi_h = 0$) and no financial frictions ($\Omega_2 = \Omega_3 = 0$), it becomes:

$$w_t = (1-\gamma)\, \tau N_t^{\xi} \frac{(C_t - \eta C_{t-1})}{(1-\eta)} + \gamma \cdot rmc_t (1-\alpha) \frac{y_t}{N_t} \tag{34}$$

Wages are a weighted average of: (i) the worker's reservation value, which takes into account utility from consumption and disutility from work; and (ii) the flow of value to the firm generated by the worker, which equals their marginal product.

If we now add hiring costs, then wages will be higher, as the firm has to partly compensate the worker for the hiring cost savings generated by a match having been formed:

$$w_t = (1-\gamma)\,\tau N_t^{\xi} \frac{(C_t - \eta C_{t-1})}{(1-\eta)} + \gamma \left[\phi_h \frac{h_t}{N_t} \frac{y_t}{N_t} \left(\frac{f_t}{1-f_t} + \frac{h_t}{N_t} \right) + rmc_t (1-\alpha) \frac{y_t}{N_t} \right] \quad (35)$$

Comparing this with equation (33), we can see that the effect of financial frictions is to lower the wage, as the need for firms to borrow to pay wages and/or hiring costs will lower the surplus value of any job match.

Equation (33) enables us to examine the effect of a rise in the spread on wages. Since firms have to borrow to pay wages, a rise in the spread will lead to a fall in wages. This can be seen in the denominator of equation (33). Against this, however, the rise in the spread will lead to a rise in hiring costs – since firms have to borrow to pay the hiring costs – and, in turn, this will lead to a rise in the surplus of an existing match and, hence, wages. This works through the numerator of equation (33). The net effect of the financial shock will depend on the extent to which firms have to borrow to pay hiring costs relative to wages. This is the key channel through which financial shocks, leading to movements in the spread, will affect real variables, operating through the real frictions in the economy.

3.6 Banks

Our modelling of the banking sector follows Gertler and Kiyotaki (2011, 2015) with an endogenously-generated interest rate spread and leverage ratio.

We assume that banks issue loans to firms and finance these out of household deposits and their own net worth, n. As a result of financial market frictions, banks are constrained in their ability to raise deposits from households. Given this, they would attempt to save their way out of these constraints by accumulating retained earnings in order to move towards 100% equity finance. Following Gertler and Kiyotaki (2011, 2015), we limit this possibility by assuming that each period banks have an iid probability $1-\zeta$ of exiting. Hence, the expected lifetime of a bank is $\frac{1}{1-\zeta}$. When banks exit, their accumulated net worth is distributed as dividends to the households.

Each period, exiting banks are replaced with an equal number of new banks which initially start with a net worth ν, provided by the households. A bank that survived from the previous period – bank b, say – will have net worth, n_b, given by:

$$n_{b,t} = (R_{L,t-1}A_{L,t}L_{b,t-1} - R_{t-1}D_{b,t-1}) \tag{36}$$

where L_b is the total lending of bank b to firms and D_b are bank b's deposits. Here A_L is a shock to the 'quality of the banks' loan books' and can be thought of as a proxy for 'bad loans'. It is analogous to the 'capital quality' shock in Gertler *et al.* (2017). In their model, the banks' assets consist of equity shares in capital; so a shock to the quality of capital is equivalent to a shock to the quality of the banks' assets, in our case the banks' loan books.

So, total net worth, n, of the banking sector will be given by:

$$n_t = \zeta(R_{L,t-1}A_{L,t}L_{t-1} - R_{t-1}D_{t-1}) + (1-\zeta)\nu \tag{37}$$

Each period banks (whether new or existing) finance their loan book with newly issued deposits and net worth:

$$L_{b,t} = D_{b,t} + n_{b,t} \tag{38}$$

Following Gertler and Kiyotaki (2011, 2015), we introduce the following friction into the banks' ability to issue deposits. After accepting deposits and issuing loans, banks have the ability to divert some of their assets for the personal use of their owners.[1] Specifically, they can sell up to a fraction θ_t of their loans in period t and spend the proceeds during period t. But, if they do, their depositors will force them into bankruptcy at the beginning of period $t+1$. We model this as a parameter $\overline{\theta}$ with a multiplicative AR1 shock to the ease of diversion, as follows:[2]

$$\begin{aligned} \theta_t &= \overline{\theta}^{1-\rho_\theta}\theta_{t-1}^{\rho_\theta}e^{\varepsilon_{\theta,t}} \\ \ln\theta_t - \ln\overline{\theta} &= \rho_\theta(\ln\theta_{t-1} - \ln\overline{\theta}) + \varepsilon_{\theta,t} \end{aligned}$$

When deciding whether or not to divert funds, bank b, will compare the franchise value of the bank, $V_{b,t}$, against the gain from diverting funds, $\theta_t L_{b,t}$. Hence, depositors

[1]Although the households are both the owners of the banks and the depositors in the model, we assume that each household is 'large' enough that we could imagine the banks owners and depositors being separate individuals, in particular with the owners prepared to divert assets towards their own personal use.

[2]Gersbach and Rochet (2017, p. 121) show how similar results w.r.t. leverage can emerge from alternative forms of financial frictions, including moral hazard, the Inalienability of human capital, and haircuts and limits to arbitrage.

will ensure that banks satisfy the following incentive constraint:

$$\theta_t L_{b,t} \leq V_{b,t} \tag{39}$$

We can write bank b's problem as the choice of L_b, and D_b each period to maximise its franchise value:

$$V_{b,t} = \max_{L_{b,t}} E_t \left[\sum_{j=1}^{\infty} \zeta^{j-1}(1-\zeta) \frac{\beta^j (1-\eta)}{\left(C_{t+j} - \eta C_{t-1+j}\right) P_{t+j}} n_{b,t+j} \right] \tag{40}$$

subject to the incentive constraint (39) and the balance sheet constraints. Here we have assumed that the patient households own the banks.

The Bellman equation for bank b's franchise value will be given by:

$$V_{b,t} = \beta E_t \left[\frac{\left(C_t - \eta C_{t-1}\right) P_t}{\left(C_{t+1} - \eta C_t\right) P_{t+1}} \left[(1-\zeta)\, n_{b,t+1} + \zeta V_{b,t+1} \right] \right] \tag{41}$$

The balance sheet constraints imply:

$$\begin{aligned} E_t \left(\frac{n_{b,t+1}}{n_{b,t}} \right) &= E_t \frac{R_{L,t} A_{L,t+1} L_{b,t} - R_t D_{b,t}}{n_{b,t}} \\ &= R_{L,t} \frac{L_{b,t}}{n_{b,t}} E_t A_{L,t+1} - R_t \frac{L_{b,t} - n_{b,t}}{n_{b,t}} \\ &= \left(R_{L,t} E_t A_{L,t+1} - R_t \right) \varphi_{b,t} + R_t \end{aligned} \tag{42}$$

where $\varphi_{b,t} = \frac{L_{b,t}}{n_{b,t}}$ is bank b's leverage ratio, i.e., the ratio of assets to net worth.

As the banks set their loan rates higher than the deposit rate, the expected growth rate of net worth will be an increasing function of the leverage ratio. Both the objective and constraints of the bank are constant returns to scale. As a result, we can rewrite the optimisation problem for bank b in terms of choosing the leverage ratio to maximise the ratio of its franchise value to net worth, $\psi_t = \frac{V_t}{n_t}$.

Formally, maximise

$$\psi_{b,t} = \max_{\varphi_{b,t}} E_t \left[\sum_{j=1}^{\infty} \zeta^{j-1}(1-\zeta) \frac{\beta^j (1-\eta)}{\left(C_{t+j} - \eta C_{t-1+j}\right) P_{t+j}} \frac{n_{b,t+j}}{n_{b,t}} \right] \tag{43}$$

subject to

$$\theta_t \varphi_{b,t} = \psi_{b,t} \tag{44}$$

where we have assumed parameter values such that the constraint binds in equilibrium.

Given constant returns to scale, we can aggregate up across all banks to the aggregate Bellman equation with franchise value Ψ_t:

$$\Psi_t = \max_{\varphi_t} E_t \left\{ \frac{\beta \left(C_t - \eta C_{t-1}\right) P_t}{\left(C_{t+1} - \eta C_t\right) P_{t+1}} \left[\left(1 - \zeta + \zeta \Psi_{t+1}\right) \left[\left(R_{L,t} A_{L,t+1} - R_t\right) \varphi_t + R_t \right] \right] \right\} \quad (45)$$

subject to:

$$\theta_t \varphi_t = \Psi_t \quad (46)$$

The solution implies:

$$\theta_t \varphi_t = \beta E_t \left[\frac{\left(C_t - \eta C_{t-1}\right) P_t}{\left(C_{t+1} - \eta C_t\right) P_{t+1}} \left(1 - \zeta + \zeta \theta_{t+1} \varphi_{t+1}\right) \left(\left(R_{L,t} A_{L,t+1} - R_t\right) \varphi_t + R_t \right) \right] \quad (47)$$

Log-linearising and noting that $E_t \left[\frac{\beta \left(C_t - \eta C_{t-1}\right) P_t}{\left(C_{t+1} - \eta C_t\right) P_{t+1}} \right] = \frac{1}{R_t}$ means we can rewrite this equation as:

$$\left(\widehat{R_{L,t}} - \widehat{R}_t\right) = \frac{1}{\varphi \beta R_L} \widehat{\varphi}_t + \frac{\varphi \left(\beta R_L - 1\right) + 1}{\varphi \beta R_L} \widehat{\theta}_t - \frac{\zeta \theta \left(\varphi \left(\beta R_L - 1\right) + 1\right)}{\beta R_L \left(1 - \zeta + \zeta \theta \varphi\right)} E_t \left(\widehat{\theta_{t+1}} + \widehat{\varphi_{t+1}}\right) - E_t \widehat{A_{L,t+1}} \quad (48)$$

Equation (48) suggests that, *ceteris paribus*, a worsening of the financial frictions (ie, an increase in θ_t) will be associated with an increase in the spread (ie, an increase in $\widehat{R_{L,t}} - \widehat{R}_t$). Similarly, a fall in the quality of banks' loan books that is expected to persist (ie, a fall in $E_t \widehat{A_{L,t+1}}$) will also be associated with an increase in the spread. To reiterate, due to financial frictions in the banking sector (ie, banks' ability to divert funds), financial shocks (ie, shocks to θ_t and/or $A_{L,t}$) lead to movements in the spread. And, as a result of the financial frictions faced by firms (ie, the need for firms to borrow for both investment and working capital purposes), any movement in spreads will then interact with the real frictions faced by firms (hiring and investment adjustment costs). This interaction will result in movements in key macroeconomic variables (ie, hiring, employment, investment, output, consumption, real marginal cost and inflation).

3.7 Monetary Policy

The central bank operates a Taylor Rule of the form:

$$\ln(R_t) = \rho_R \ln(R_{t-1}) + (1-\rho_R)\ln\left(\frac{1}{\beta}\right) + (1-\rho_R)\left(v_\pi\left(\frac{P_t}{P_{t-1}} - 1\right) + v_y \ln\left(\frac{y_t}{\overline{y}}\right)\right) + \varepsilon_{R,t} \tag{49}$$

where $\overline{y}$ denotes the steady-state level of output and ε_R is a white-noise shock. In line with most of the empirical and theoretical literature, eg, Altig et al. (2011) and Christiano et al. (2011), we assume that households and firms are unable to respond within period to the monetary policy shock. But we allow the banks to adjust their lending rates in response to the shock.

3.8 Market Clearing

Aggregating the budget constraints for each sector implies the goods market clearing condition:

$$y_t = \frac{C_t + I_t + G_t}{1 - \frac{\chi}{2}\left(\frac{P_t}{P_{t-1}} - 1\right)^2 - \frac{\phi_h}{2}\left(\frac{h_t}{N_t}\right)^2} \tag{50}$$

4 Empirical Implementation

So far, we have examined how the interaction of labour market and financial frictions affects the wage-setting process and inflation determination, through the effects on real marginal cost. In the following section we examine Impulse Response Functions (IRF) generated by the model in order to evaluate the extent to which these interactions might affect the way the economy responds to standard shocks – specifically productivity and monetary policy – and how these interactions enable the transmission of financial shocks through the real economy. We first briefly present the empirical methodology we follow.

4.1 Rationale and Format

The key aim is to see and understand the interactions of hiring and financial frictions, working through the channels we highlighted earlier in the paper. To do so we examine the effects of real, financial, and policy shocks under different model configurations. We shut down key elements pertaining to real and financial frictions in order to determine the relative role played by different parts of the model.

The model embeds the following shocks. First, we look at the more standard shocks – technology A_t and monetary policy $\varepsilon_{R,t}$. Then we look at the shock related to the financial markets, ie, a shock to the ease with which bankers can divert their funds, θ_t.

We consider five different configurations, which appear in the figures in different colors as shown in Table 1.

The idea behind this set up is to shut down or open up two key dimensions of the real-financial interaction: one is the existence of hiring frictions, manifested in the hiring costs scale parameter ϕ_h; the other is the existence of links between firms and banks via borrowing to finance investment, wages and hiring costs, parameterized by $\Omega_1, \Omega_2, \Omega_3$. In addition, we also consider more specifically the interaction between hiring costs and financial frictions by comparing the two cases where these are financed by bank borrowing and where they are not, while leaving wages and investment financed by bank borrowing. Model 1 (blue lines in the figures below) shuts down the interaction completely, while model 4 (red) has the interactions in full. Model 3 (green) has no hiring frictions, but firms still need to borrow from banks for investment and wage costs. Model 2 (black) features hiring frictions but no banking sector since firms are able to finance their costs out of internal funds. Model 5 (magenta) is a hybrid of Models 2 and 3 where firms face hiring frictions but do not need to borrow from banks to finance them, while at the same time firms do need to borrow from banks to finance investment and wages. The comparison between Models 4 and 5 allows us to consider explicitly the effect of the hiring costs/financial frictions interaction, holding all other things equal.

To be clear, we do not believe that firms finance the entirety of their investment, wage and hiring costs out of bank borrowing, nor that bank borrowing is not used at all to finance these costs. The likelihood is that firms finance a (possibly different) proportion of each of these costs out of bank borrowing, though unfortunately, we have not found any empirical evidence allowing us to precisely calibrate these parameters. The point is that we are interested in how important this channel might be for the transmission of real and financial shocks and how this channel interacts with hiring frictions. We can best answer these questions using the approach we have adopted, though we must bear in mind that the model with $\Omega_1 = \Omega_2 = \Omega_3 = 1$ provides an upper bound as to the effects of these frictions and it is likely the effect would be much smaller in reality.

We present the results in three panels for each shock. Each panel contains five lines according to the configurations of Table 1. Panel a in each case shows the response of real variables: GDP, consumption, investment, employment, the hiring rate, and real wages. Panel b in each case shows the financial variables – the rates (the interest rate, the lending rate, and the spread) and the volumes (deposits, lending, and net worth). Panel c in each case shows inflation and real marginal cost.

Table 1
Set Up of Model Permutations

		no borrowing		**borrowing**		**partly borrowing**
		$\Omega_1 = \Omega_2 = \Omega_3 = 0$		$\Omega_1 = \Omega_2 = \Omega_3 = 1$		$\Omega_1 = \Omega_2 = 1, \Omega_3 = 0$
no hiring frictions		1		3		
$\phi_h = 0$		blue		green		
hiring frictions		2		4		5
$\phi_h > 0$		black		red		magenta

4.2 Calibration

We calibrate and simulate the model. Our calibration, in general, follows the existing literatures on DSGE models with real and financial frictions.

Table 2A: Parameter Calibration Values
Households

symbol		**value**
η	habit in utility	0.71
β	discounting	0.9925
τ	scale, work in utility	0.6616
ξ	inverse Frisch elasticity	1.83
δ_N	worker separation rate	0.126
f	steady-state job finding rate	0.6638

Table 2A lists the parameters governing the household sector. We set the discount factor, β, to 0.9925, which implies a steady-state risk-free interest rate of around 3%. We set the inverse Frisch elasticity of labour supply to 1.83 and the consumption habits parameter to 0.71, the mean values for these parameters estimated by Smets and Wouters (2007). We set the scale parameter on leisure in the utility function, τ, to 0.6964, which together with our assumed value for the steady-state job finding rate, f, of 0.66 implies a steady-state unemployment rate of 6%. Finally, our values for the steady-state job finding rate and the steady-state unemployment rate imply a value of 0.126 for the exogenous rate of job destruction, δ_N.

Table 2B lists the parameters governing the firms. We use standard values for (i) the capital share, α; (ii) the capital depreciation rate, δ_K; and (iii) the elasticity of demand for individual goods, ϵ. We set the scaling parameter for the price adjustment costs, χ, equal to 117. Together with our calibration for the elasticity of demand, this implies a 0.085 slope of the New Keynesian Phillips curve, the same that would be obtained with Calvo (1983) price frictions with an average duration for prices of 4 quarters. The scaling parameter on the investment adjustment costs is set equal to the value estimated by Smets and Wouters (2007) for the US economy and the scaling parameter on the hiring costs is set equal to the value used by Faccini and Yashiv (2018). In the baseline we assume that firms have to finance their entire investment and wage bills by bank borrowing as well as all hiring costs. That is, we set $\Omega_1 = \Omega_2 = \Omega_3 = 1$. When studying the effects of financial frictions we set these parameters to 0. Again, we do not believe that firms finance the entirety of their investment, wage and hiring costs out of bank borrowing, nor that bank borrowing is not used at all to finance these costs. But, given the lack of evidence as to the actual proportion of these costs financed by bank borrowing, we think it is instructive to consider the extreme cases. Finally, we set the workers' bargaining power γ to 0.29.

Table 2B: Parameter Calibration Values

Firms

symbol		**value**
α	capital share in Cobb Douglas	0.33
ϵ	elasticity of demand	11
Ω_1	proportion of investment financed by borrowing	1
Ω_2	proportion of wage bill financed by borrowing	1
Ω_3	proportion of hiring costs financed by borrowing	1
δ_K	capital depreciation	0.025
ϕ_h	scaling parameter, hiring costs	1.5
$S''(1)$	scaling parameter, investment adjustment costs	5.74
χ	scaling parameter, price frictions	117
γ	worker bargaining parameter	0.29

Finally, Table 2C lists the parameters governing the financial sector and the central bank. We calibrate the parameters governing the banks following Gertler and Kiyotaki

(2015). Specifically, we set the survival rate for banks, ζ, to 0.95, implying an average bank life expectancy of five years, and the proportion of bank assets that can be diverted, θ, to 0.1939, implying an annualised steady-state spread of loan rates over deposit rates of one percentage point. The coefficients on the Taylor rule take the standard values of 1.5 on inflation and 0.125 on quarterly output. We set the inertia coefficient, ρ, to 0.81, the value estimated by Smets and Wouters (2007).

Table 2C: Parameter Calibration Values
Banks and the Public Sector

symbol		value
ρ_R	Taylor rule AR1	0.81
v_π	Taylor rule inflation coefficient	1.5
v_y	Taylor rule output coefficient	0.125
ζ	A bank's probability of staying active	0.95
θ	Diversion rate	0.1939

Finally, all of our shocks – with the exception of the monetary policy shock, assumed to be white noise – are assumed to follow AR(1) processes with an autocorrelation coefficient of 0.95.

5 Real-Financial Interactions in the Effects of Shocks

A key question for our paper is how financial frictions and frictions in the real economy, such as labour market frictions, interact in the presence of shocks and what does this mean for the responses of variables to shocks? In this section, we report the IRFs for four shocks: shocks to aggregate technology (TFP), monetary policy, the ability of banks to divert their funds (proxying for a shock to the 'degree of financial frictions' or 'credit supply') and the quality of banks' assets, analogous to the 'capital quality' shock in Gertler *et al.* (2017). The idea is to evaluate both the extent to which these interactions might affect the way the economy responds to standard shocks – specifically productivity and monetary policy – and how these interactions enable the transmission of financial shocks through the real economy. We first show the IRFs graphs and offer an explanation of the patterns seen. We then present in a table the differences across the five model configurations and discuss them.

5.1 Technology Shocks

Figure 2 shows the IRFs of a 1% reduction in A_t namely a negative technology shock.

Upon impact, output, consumption and investment (panel a) decline followed by a gradual return to steady state. Employment, the hiring rate and wages rise initially; given sticky prices, output is initially demand-determined and, with higher productivity, fewer workers are needed to produce this level of output. (See Gali (2015).) In the models with hiring frictions, employment and hiring adjust gradually back to their steady states; with no hiring frictions in place, employment and the hiring rate jump below their steady states before rising back to their steady state. In addition, and as expected, employment and hiring respond much more in the models with no hiring costs whereas wages respond much more in the model with hiring costs. The introduction of financial frictions makes little difference to the responses of output, investment and consumption. As expected, given that the financial frictions increases the cost of hiring and employing workers, hiring, employment and wages do not increase as much in the presence of financial frictions as in the full model; however, the differences are small.

In terms of the financial variables (panel b), and inflation and real marginal cost (panel c), the responses across the four models are similar and involve all variables rising on impact, before reverting back to their steady states. For all these variables it takes more than the 20 quarters depicted in the graphs for a return to steady state.

These results can be explained as follows: the contractionary productivity shock raises real marginal costs and hence inflation; the nominal rate R_t responds with an increase via the Taylor rule. As labour costs rise, the demand for lending increases leading to greater lending and a rise in the spread. And as lending rises and consumption contracts, deposits rise as well. After the first period, the continuing contraction in output and investment – together with the return of hiring, employment and wages towards their steady-state values – means that total lending and deposits have to fall to below their steady-state values, as does the spread.

Table 3 summarizes the results across models. Note that the results for Model 4 (baseline with $\Omega_1 = \Omega_2 = \Omega_3 = 1$) and Model 5 ($\Omega_1 = \Omega_2 = 1$, $\Omega_3 = 0$) were more or less identical and so are considered together.

Table 3

The Effects of a Negative Technology Shock

	no borrowing	*borrowing*	*differences*
	$\Omega_1 = \Omega_2 = \Omega_3 = 0$	$\Omega_1 = \Omega_2 = 1$	
no hiring frictions	*blue*	*green*	similar
$\phi_h = 0$	$y, I, c \downarrow; n, \frac{h}{n}, w \uparrow$	$y, I, c \downarrow; n, \frac{h}{n}, w \uparrow$	blue responds more
	$R \uparrow$	R, R_L,spread $\uparrow$	for wages and
		$D, L \downarrow$ $n \uparrow$	employment
	$\pi, rmc \uparrow$	$\pi, rmc \uparrow$	
hiring frictions	*black*	*red/magenta*	similar
$\phi_h > 0$	$y, i, c \downarrow; n, \frac{h}{n}, w \uparrow$	$y, i, c \downarrow; n, \frac{h}{n}, w \uparrow$	black responds more
	$R \uparrow$	R, R_L,spread $\uparrow$	for wages and
		$D, L \downarrow$ $n \uparrow$	employment
	$\pi, rmc \uparrow$	$\pi, rmc \uparrow$	
differences	substantial,	substantial	
	especially for real variables	for real variables	
	blue responds more	green responds more	

The table shows five sets of differences. First, we see relatively big differences between the blue and the red/magenta lines, i.e., with no firm borrowing and hiring frictions and with both. Hence these features of the economy are of importance. Second, shutting down hiring frictions, we see only small differences between the blue and the green lines, i.e., without and with firm borrowing. The same is true if we compare the black and the red/magenta lines. Thus, the introduction of financial frictions in the form of firm borrowing makes only a small difference to the response of variables to a productivity shock within this model. Finally, we see substantial differences in the case of no firm borrowing: most variables respond more in the blue lines, when there are no hiring frictions, than in the black lines, when they are present. Overall, it appears that hiring frictions play the dominant role in affecting how the economy responds to a productivity shock.

5.2 Monetary Policy Shocks

Figure 3 shows the IRFs of a contractionary monetary policy shock $\varepsilon_{R,t}$ of 25 basis points.

Upon impact, the rise in R leads to a rise in R_L. As is standard in these models, consumption and investment fall in response to the rise in real interest rates, implying a fall in output and inflation. Given the fall in demand, firms reduce their employment and hiring. In terms of wage bargaining, the fall in marginal product, together with the rise in the interest rate, lowers the value of the match surplus and so wages fall. With investment, employment and wages falling, the demand for loans falls; hence, lending and the spread fall.

As interest rates fall back to steady state levels, the above processes are reversed. Interestingly, in the model with hiring frictions, the fall in the spread persists whereas without hiring frictions the spread is highly volatile. This reflects the higher volatility of hiring and employment in the model without hiring frictions: the spread needs to respond more so that total lending to firms – and so bank leverage – can move smoothly, as required by the friction on bank lending.

Table 4 summarizes the results across models. Again, since the results for Model 4 (baseline with $\Omega_1 = \Omega_2 = \Omega_3 = 1$) and Model 5 ($\Omega_1 = \Omega_2 = 1$, $\Omega_3 = 0$) were more or less identical, these are considered together.

Table 4

The Effects of a Contractionary Monetary Policy Shock

	no borrowing	*borrowing*	*differences*
	$\Omega_1 = \Omega_2 = \Omega_3 = 0$	$\Omega_1 = \Omega_2 = \Omega_3 = 1$	
no hiring frictions	*blue*	*green*	similar but
$\phi_h = 0$	$y, c, I, n, \frac{h}{n}, w \downarrow$	$y, c, I, n, \frac{h}{n}, w \downarrow$	blue responds more
			for investment
	$R \uparrow$	R , $R_L \uparrow$spread $\downarrow$	and employment
		$D, L \downarrow n \uparrow$ initially	
	$\pi, rmc \downarrow$	$\pi, rmc \downarrow$	
hiring frictions	*black*	*red/magenta*	similar but
$\phi_h > 0$	$y, i, n, \frac{h}{n}, w \downarrow$	$y, i, n, \frac{h}{n}, w \downarrow$	black responds more
	$c \downarrow$		for investment
	$R \uparrow$	R , $R_L \uparrow$spread $\downarrow$	and employment
		$D, L \downarrow n \uparrow$ initially	
	$\pi, rmc \downarrow$	$\pi, rmc \downarrow$	
differences	substantial	substantial,	
	blue responds more for real	green responds more for	
	and less for inflation	real and less for inflation	

Table 4 suggests that the red, magenta and black models, when hiring frictions are present, exhibit similar behaviour, though investment and employment fall by more in the cases where there are no financial frictions. The same is true of the blue and green models. This suggests that the presence of financial frictions reduces the volatility in investment and employment. It does this because the friction within the banking sector implies a smooth path for lending; firms have to smooth investment and their wage bill, since they are borrowing to finance these. As we said earlier, the spread becomes more volatile in order to equate the demand for, and supply of, lending. In the case of no firm borrowing there are lower responses of real variables in the presence of hiring frictions (black) than without them (blue), but bigger responses for real wages, real marginal cost and inflation. This is, as would be expected: hiring frictions lead to less volatility in employment and hiring but more volatility in real wages (a key determinant of real marginal cost and, hence, inflation). The same results hold when comparing the models with financial frictions and hiring frictions (red/magenta) against the model with financial frictions and no hiring frictions (green).

Overall, financial frictions in the form of firm borrowing takes the economy in the same direction as real frictions, i.e., mitigates responses to shocks. But the hiring frictions are dominant. In particular, the interaction of financial and hiring frictions does not add quantitatively to our understanding of the effects of monetary policy and productivity shocks on the economy relative to a model in which hiring frictions are already present. However, introducing a financial sector does enable us to consider the effects of these shocks on a wider set of variables.

5.3 Credit Supply Shocks

One key aim of this paper is to assess the impact of linking financial and real frictions. The constraint on firms, whereby they have to borrow to finance the costs associated with investment, the wage bill, and hiring costs, introduces a direct relationship between financial frictions and firms' output. As shown in equation (24), the opportunity cost of firms borrowing from banks to finance this working capital is the spread of the lending rate over the deposit rate. Movements in the spread, as a result of financial shocks, affect the real marginal cost of firms, and in turn, influence firms' decisions on hiring, investment, and prices. This channel is missing when firms do this finance out of retained earnings instead of bank credit. In other words, for frictions within the banking sector itself to affect the real economy, we need the additional financial frictions forcing firms to borrow from the banking sector.

In this subsection, we consider two types of financial shock. The first is an exogenous tightening of the frictions facing the banks, ie, an increase in the ability of the banks to divert their assets, which leads depositors to insist on the banks maintaining a lower leverage ratio. The second is an exogenous shock to the quality of the banks' assets, analogous to the 'capital quality' shock in Gertler *et al.* (2017).

5.3.1 Ease of diversion of funds shock

In this subsubsection we look at a shock to the ability of banks to divert their assets; we think of this as proxying a shock to the frictions within the banking sector that affects credit supply. Figure 4 shows the IRFs of a rise in θ_t, namely an increase in the ease of diversion by the banks.

Starting from panel b we see that banks cut back on lending, as required by depositors, given the greater risk of banks diverting their funds. This leads to a rise in the lending rate and the spread. Since firms have to borrow to finance investment, hiring and wages, the rise in the spread causes them to cut back on investment, employment and hiring. In addition, they cut wages, although the rise in spreads means that real marginal cost overall rises. In turn, this causes inflation to rise, causing the central bank to raise the (deposit) interest rate. Output falls. The effect on consumption depends on whether or not there are hiring costs in the model. In the presence of hiring costs, the falls in employment, hiring and output are smaller and consumption actually rises on impact. But these effects are all really small: in the model with both financial and hiring frictions, a rise in the spread of 100 basis points is associated with a fall in GDP of only 0.01%. To put this in perspective, the Gilchrist and Zakrajsek (2012) measure of the credit spread – arguably the nearest analogue in the US data to the spread in our model – rose by about 600 basis points over the course of the Great Recession. At the same time, GDP fell by just over 4%, while our model would have predicted a fall in GDP of only 0.06%, absent other shocks.

To understand why the effects of this shock are small, consider the log-linearised version of Equation (25):

$$\widehat{I_t} = \frac{1}{1+\beta}\widehat{I_{t-1}} + \frac{\beta}{1+\beta}E_t\widehat{I_{t+1}} + \frac{1}{\phi_k\left(1+\beta\right)}\left(\widehat{Q_{k,t}} - \left(\widehat{R_{L,t}} - \widehat{R_t}\right)\right) \tag{51}$$

The elasticity of investment with respect to the spread is equal to $\frac{1}{\phi_k(1+\beta)}$ which, given our calibration, will equal 0.0874. So, a 100 basis point rise in the spread between the annualised lending and deposit rates would lower investment by 0.02% (ignoring any effect coming through expected future investment or the current value of installed capital, Q_k). Since investment in our calibration is 23% of GDP, other things equal, a 0.02% fall in investment would imply a direct effect on GDP coming through investment of only 0.005%. And, with consumption rising, the direct effect on output would be even smaller. In practice, however, the shock reduces future investment, leading to a larger effect on current investment and, hence, output; but the total effect is still small.

Table 5 compares the results in the two models: the full model with hiring frictions and the model without hiring frictions. Aside from the difference in consumption, explained above, we note that in the models with hiring frictions (red and magenta), employment and the hiring rate respond less than in the model with no hiring frictions (green) whereas wages respond more. This is to be expected. A rise in the spread makes employing labour more expensive for a given wage. As a result, firms want to cut back on their employment. But they will be less inclined to do this if it is more costly to hire this labour back into the firm in the future, ie, if hiring costs are positive. The more employment firms shed, the smaller will be the fall in wages, and the larger will be the rise in real marginal cost. This larger rise in real marginal cost is also reflected in a larger rise in inflation. The central bank reacts to this by raising the deposit rate by more in the model without hiring costs than the models with hiring costs. As expected, the responses of output are in line the responses of employment: output responds by more in the model without hiring costs than in the models with hiring costs.

When thinking specifically about the interaction of hiring frictions and financial frictions, it is instructive to compare the models with hiring frictions but with and without firms needing to borrow to pay the hiring costs. In the case where firms have to borrow to pay the hiring costs (red), the increase in the spread will increase real marginal cost relative to the case where they did not have to borrow to pay these costs (magenta). This results in a smaller response of inflation in the model with $\Omega_3 = 0$ than in the model with $\Omega_3 = 1$. This smaller response of inflation, implies a looser monetary policy response. In fact, interest rates actually fall, as the negative response to the fall in output outweighs the positive response to the rise in inflation. In turn, this leads to a smaller response of output and employment than in the model where firms have to borrow to pay their hiring costs. The smaller response of output is mirrored by a more positive response of consumption.

Table 5

The Effects of a Rise in the Diversion Rate

	firm borrowing	*borrowing, but not for hiring*
	$\Omega_1 = \Omega_2 = \Omega_3 = 1$	$\Omega_1 = \Omega_2 = 1, \Omega_3 = 0$
no hiring frictions	*green*	*green*
$\phi_h = 0$	$y, c, I, N, \frac{h}{N}, w \downarrow$	$y, c, I, N, \frac{h}{N}, w \downarrow$
	R , R_L, *spread* $\uparrow$	R , R_L, *spread* $\uparrow$
	$D, L \downarrow n \uparrow$	$D, L \downarrow n \uparrow$
	$\pi, rmc \uparrow$	$\pi, rmc \uparrow$
hiring frictions	*red*	*magenta*
$\phi_h > 0$	$y, I, N, \frac{h}{N}, w \downarrow c \uparrow$	$y, I, N, \frac{h}{N}, w \downarrow$ <red, $c \uparrow$ >red
	R , R_L, *spread* $\uparrow$	R , R_L, *spread* $\uparrow$
	$D, L \downarrow n \uparrow$	$D, L \downarrow n \uparrow$
	$\pi, rmc \uparrow$	$\pi, rmc \uparrow$ <red
differences	small apart from	
	$c, N, \frac{h}{N}, w, R, \pi$ and *rmc*	

5.3.2 Shock to the quality of bank loans

In this subsubsection we look at a shock to the quality of bank loans. We think of this as proxying a shock to the amount of bad loans on banks' balance sheets, which will affect credit supply. Figure 5 shows the IRFs of a fall in $A_{L,t}$.

Starting from panel b we see that the shock reduces net worth of banks. This means that the banks have to cut back on lending so as to restore the leverage ratio required by depositors, given the risk of banks diverting their funds. This leads to a rise in the lending rate and the spread. Since firms have to borrow to finance investment, hiring and wages, the rise in the spread causes them to cut back on investment, employment and hiring. In addition, they cut wages, although the rise in spreads means that real marginal cost rises overall. In turn, this causes inflation to rise, with the result that the central bank raises the (deposit) interest rate. Output falls. In response to this shock, though, consumption rises on impact as the effect on investment of the reduction in loan supply is so much greater than the effect on output, given that this only comes through indirectly via employment. The effects of this shock are larger than that of a shock to the diversion friction while still being fairly small: in the model with both financial and hiring frictions, a rise in the spread of 100 basis points is associated with a fall in GDP of only 0.07%.

Table 6 compares the results in the three models: the full model with hiring frictions where firms have to borrow to pay hiring costs, the full model with hiring frictions but where firms do not have to borrow to pay hiring costs, and the model without hiring frictions. The key difference between the models with and the model without hiring frictions is that in the models with hiring frictions, employment and the hiring rate respond less while the real wage responds more. This is to be expected. As a result of the larger decline in wages in the models with hiring frictions, together with the presence of falling hiring costs within real marginal cost, the rise in real marginal cost will be lower in these models for a given rise in the spread. This again implies that the rise in inflation in these models will also be lower than in the model without hiring frictions and this, in turn, means that the rise in the deposit rate will be lower. Because the fall in employment is smaller in the models with hiring frictions, the fall in output will also be smaller, in turn resulting in a smaller fall in investment and a larger rise in consumption.

Table 6

The effects of a fall in the quality of bank loans

	firm borrowing	*borrowing, but not for hiring*
	$\Omega_1= \Omega_2= \Omega_3= 1$	$\Omega_1= \Omega_2= 1, \Omega_3= 0$
no hiring frictions	*green*	*green*
$\phi_h= 0$	$y, I, N, \frac{h}{N}, w \downarrow c \uparrow$	$y, I, N, \frac{h}{N}, w \downarrow c \uparrow$
	R , $R_L, spread \uparrow$	R , $R_L, spread \uparrow$
	$D, L \downarrow n \uparrow$	$D, L \downarrow n \uparrow$
	$\pi, rmc \uparrow$	$\pi, rmc \uparrow$
hiring frictions	*red*	*magenta*
$\phi_h > 0$	$y, I, N, \frac{h}{N}, w \downarrow c \uparrow$	$y, I, N, \frac{h}{N}, w \downarrow <$red, $c \uparrow >$red
	R , $R_L, spread \uparrow$	R , $R_L, spread \uparrow$
	$D, L, n \downarrow$	$D, L, n \downarrow <$red
	$\pi, rmc \uparrow <$green	$\pi, rmc \uparrow <$red
differences	substantial	

Again, it is instructive to compare the models with hiring frictions but with and without firms needing to borrow to pay the hiring costs, though the story is similar to the case of the 'diversion' shock. In the case where firms have to borrow to pay the hiring costs (red), the increase in the spread will increase real marginal cost relative to the case where they did not have to borrow to pay these costs (magenta). This results in a smaller response of inflation in the model with $\Omega_3 = 0$ than in the model with $\Omega_3 = 1$. This smaller response of inflation, implies a smaller rise in the policy (deposit) rate. In turn, this leads to a smaller response of output and employment than in the model where firms have to borrow to pay their hiring costs. The smaller response of output is mirrored by a more positive response of consumption.

6 Conclusions

In this paper we examined the connections between financial market frictions and labour market frictions. In particular we asked how labour market frictions and shocks relate to financial frictions and shocks over the business cycle, seeking to identify channels of effect running from financial markets to labour markets and vice versa. We used a DSGE model calibrated to the US economy, with households, banks, firms, and wage bargaining. The model featured labour and investment frictions, in the form of convex costs, and financial frictions, in the form of credit constraints and the risk of banks diversion of funds. In addition there were price frictions and habits in consumption. This approach enabled us to obtain a comprehensive model to investigate the behaviour of real aggregate variables (GDP, capital and investment, and consumption), financial market variables (interest rate spreads, volumes of lending and deposits, bank net worth) and labour market variables (wages, employment, unemployment, and hiring). We examined technology and monetary policy shocks, as well as credit shocks, to determine the consequences of the interactions of real and financial frictions.

At the heart of our analysis is firm borrowing from banks and the leverage and credit spreads characterizing the banking system. We linked these to gross hiring costs and gross investment costs in the model by ensuring that firms had to borrow for investment and to pay their wage and hiring costs. We used the model to examine the effect of a rise in the spread on wages. Since firms have to borrow to pay wages, a rise in the spread will lead to a fall in wages. Against this, however, the rise in the spread will lead to a rise in hiring costs – since firms have to borrow to pay the hiring costs – and, in turn, this will lead to a rise in the surplus of an existing match and, hence, wages. The net effect of the financial shock will depend on the extent to which firms have to borrow to pay hiring costs relative to wages. This is the key channel through which financial shocks, leading to movements in the spread, will affect real variables, operating through the real frictions in the economy.

We then attempted to disentangle empirically the relative roles played by the various frictions and shocks in this system by examining the responses of variables within our model to productivity, monetary policy and financial shocks under various assumptions about labour market and financial frictions. We found that, across all shocks, there are big differences between the model with no borrowing and real frictions and with both. That is, the interaction of labour market and financial frictions matters for the behaviour of variables within the model. That said, we found that the hiring frictions were much more important for the effects of the productivity and monetary policy shocks than the financial frictions: adding financial frictions to our model does not add quantitatively to our understanding of the effects of monetary policy and productivity shocks on the economy relative to a model in which hiring frictions are already present. But, introducing a financial sector does enable us to consider the effects of these shocks on a wider set of variables, viz. those relating to the financial sector itself.

We also found that financial shocks and frictions have implications for the real economy. In particular, movements in the spread, as a result of financial shocks, affect the real marginal cost of firms, and in turn, influence firms' decisions on hiring, investment, and prices. This channel is missing when firms do this finance out of retained earnings instead of bank credit.

Hiring frictions were important: switching off the hiring frictions led to greater responses of employment and hiring, as well as investment, output, real marginal cost and inflation. At the same time, wages responded less and consumption rose by less in response to a 'bank asset quality' shock while actually falling in response to an 'ease of diversion' shock. This all suggests that the interaction of financial and hiring frictions really matters for how the economy response to financial shocks.

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7 Figures

Figure 1: Set Up

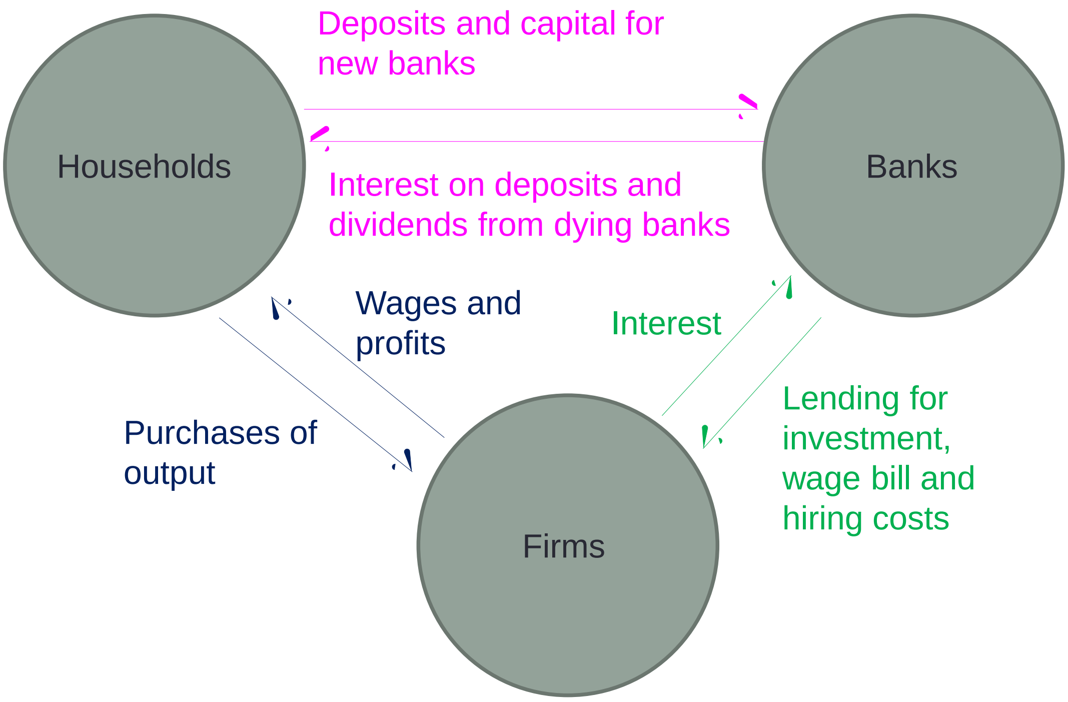
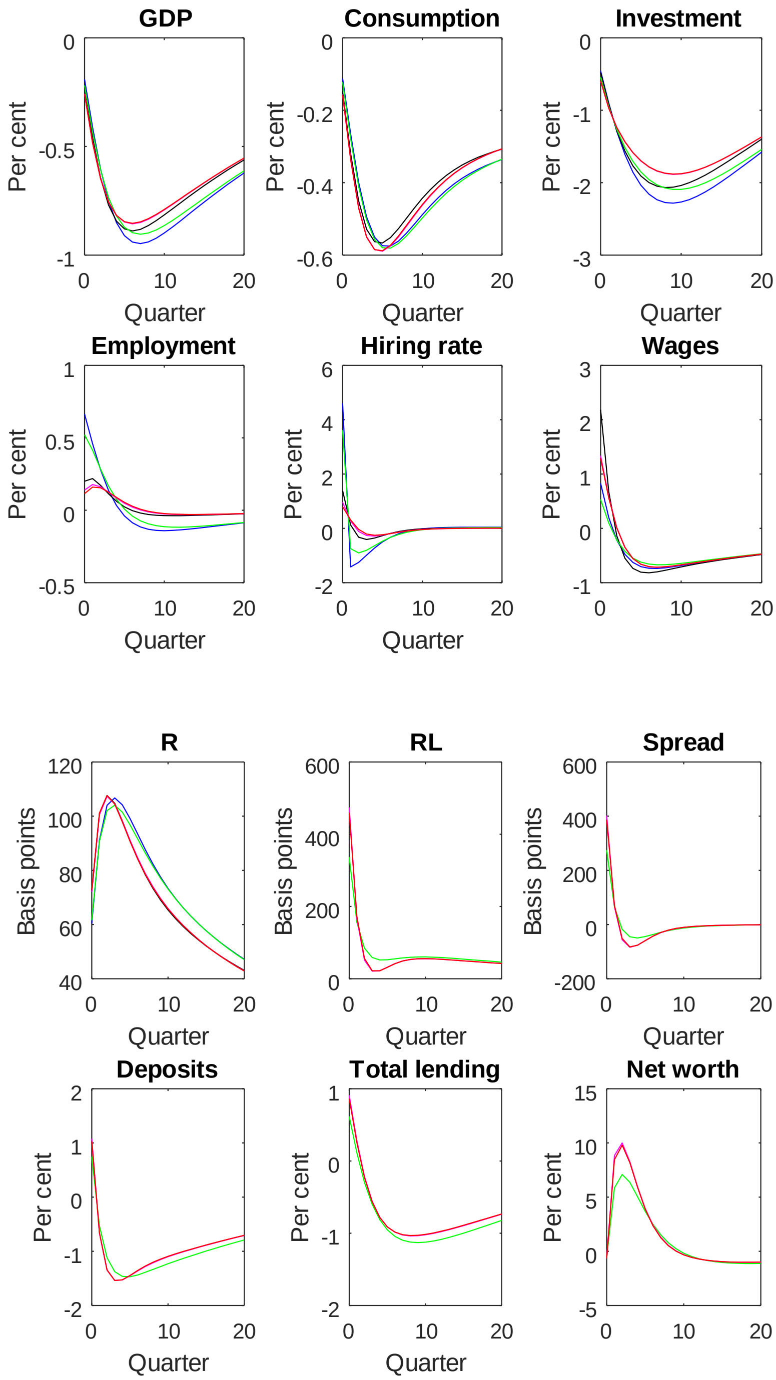
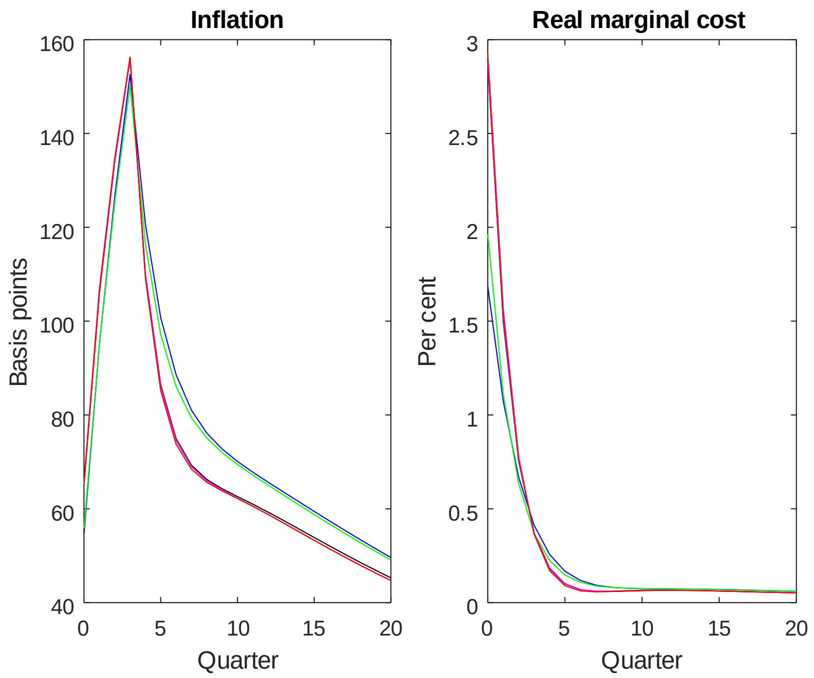


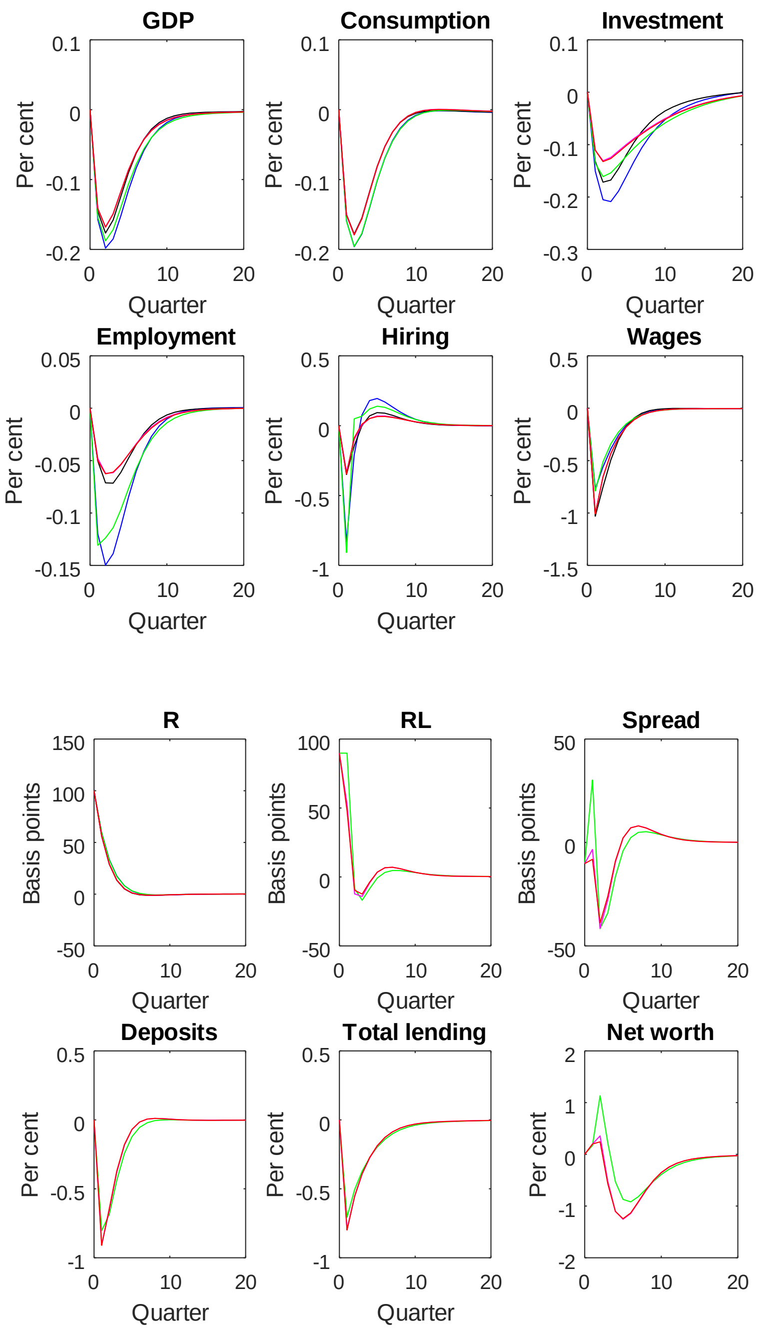
Figure 2: Negative Technology Shock A_t (1%)

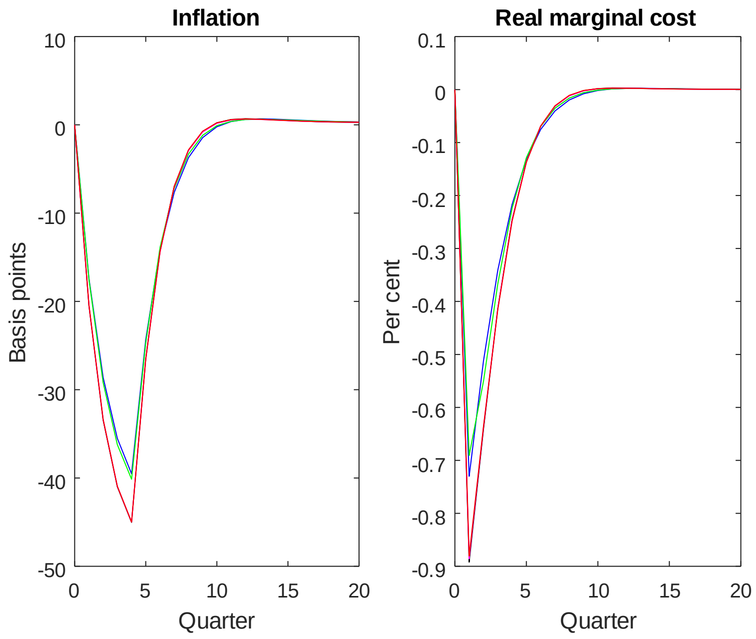




Notes: Line colors follow Table 1 in the text.

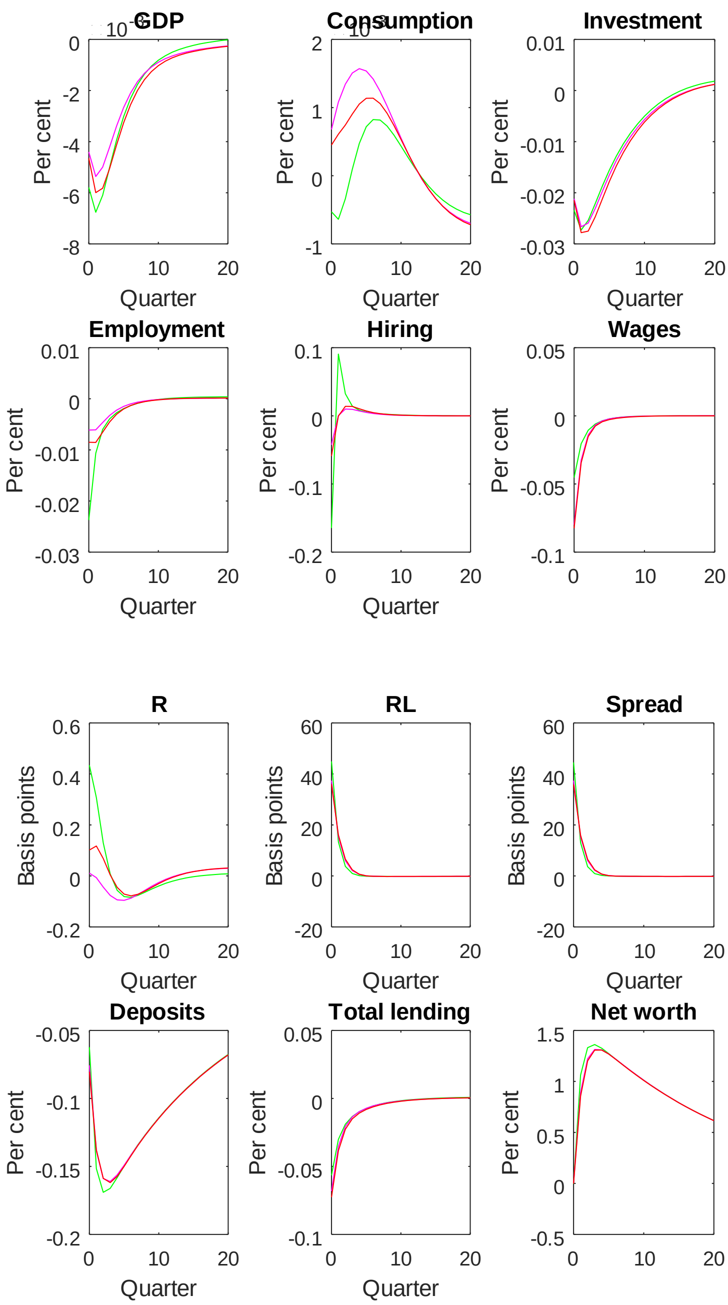
Figure 3: Contractionary Monetary Shock $\varepsilon_{R,t}$(25 bp)

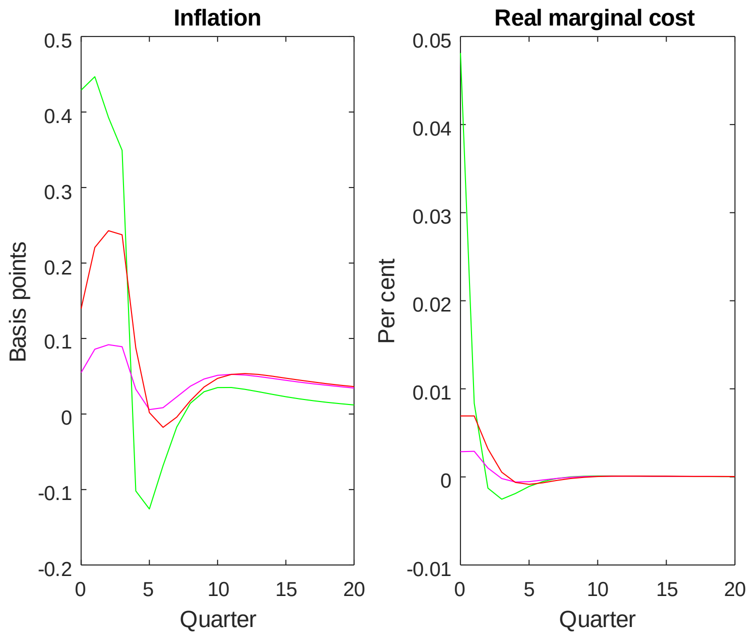




Notes: Line colors follow Table 1 in the text.

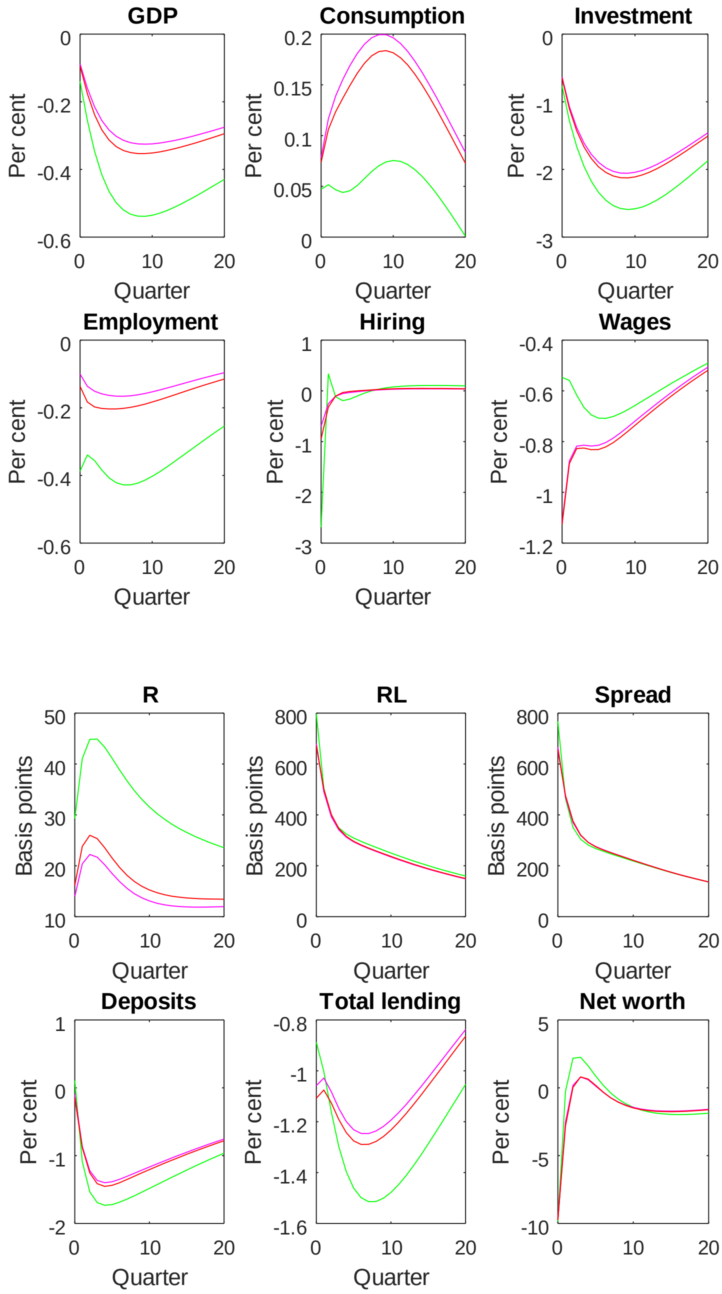
Figure 4: Higher Diversion Fraction θ_t Shock

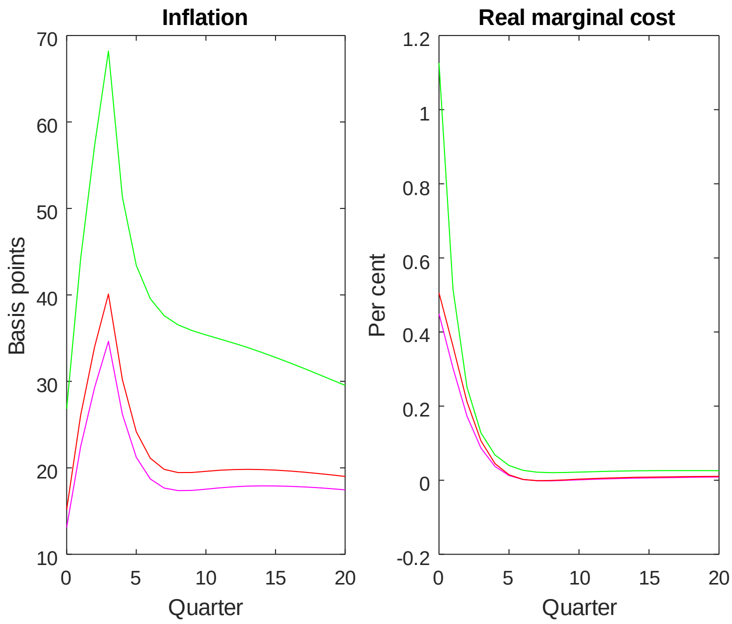




Notes: Line colors follow Table 1 in the text.

Figure 5: Shock to the quality of bank capital





Notes: Line colors follow Table 1 in the text.