The Interaction of Financial Frictions and Labor Market Frictions in a DSGE Model

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1 Introduction

The global financial crisis highlighted the importance of interactions between the real and financial sectors for the transmission of shocks in the macroeconomy. In particular, the crisis emphasised the role of asset price and uncertainty-based channels for the macroeconomy, as well as contagion and feedback mechanisms within the financial system. The financial crisis has created new challenges for research in macroeconomics.

The recent academic literature on DSGE modelling with financial frictions, surveyed below, 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 in at least two ways. First, they add to existing models features that are important in understanding the recent crisis. In particular, they include balance sheet constraints on banks and households, in addition to firms, that enable researchers to assess the effects of leverage on household and bank behavior. Second, they allow specifically for non-linearities, given the fact that crises, in particular, are inherently non-linear events. But, the interaction of financial frictions with frictions in the real economy, such as labour market frictions, has hardly been investigated by the recent academic literature.

In this paper we use a DSGE model calibrated for the US economy, that links financial markets and financial frictions with labour markets and labour market frictions to enhance our understanding of how shocks are transmitted through the real economy and explore the linkages between financial markets and the real economy. More specifically, we start with a standard DSGE model to which we add labour frictions as in Merz and Yashiv (2007) and Yashiv (2016), and financial frictions as in Iacoviello (2015) and 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, employment and hiring), financial market variables (interest rate spreads, volumes of lending and deposits, bank net worth), housing market variables (prices and sales) and labour market variables (wages, employment, unemployment and hiring). We examine technology and monetary policy shocks, as well as credit demand and supply shocks, aiming to determine the consequences of the interactions of labour and financial market frictions. The framework allows us to explore the effects of financial shocks and financial frictions on the transmission mechanism of monetary and macroprudential policies, given that the degree of the various frictions can substantially affect the response of the economy to such policy changes.

We find that investment frictions, by markedly reducing the response of investment to various shocks, can lead to a larger response of consumption to these shocks. Otherwise, as expected, the addition of extra frictions to the model leads to a more muted response of the variables we care about to economic shocks. In terms of the responses of variables to the various shocks in our model, we find, as expected, that monetary policy can be used to lean against a build up of leverage in the banking sector but that monetary policy and macroprudential policy can sometimes be in conflict. In particular, a government spending shock leads to higher inflation, suggesting a need to tighten monetary policy, but to lower bank leverage, suggesting a possible need to loosen macroprudential policy. In the run up to the financial crisis we saw a large increase in Bank leverage; our model suggests that this is exactly what we might expect to see following a positive housing demand shock or a loosening of bank credit standards. And an exogenous fall in bank equity prices – resulting from, say, a re-evaluation of the profitability of banks – will, in our model, result in a recession, though not as bad in terms of lost output as we saw in the Great Recession itself.

The paper proceeds as follows: Section 2 presents the literature. Section 3 discusses the model including the key mechanisms at work in our model that distinguish it from previous models. Section 4 calibrates the model. Section 5 presents the results. Section 6 offers concluding remarks.

2 Literature (to be expanded)

Business cycle research in macroeconomics has been facing new challenges following the 2007-2009 Global Financial Crisis (GFC) crisis; Linde, Smets and Wouters (2016) and Ramey (2016) offer broad discussions. In particular, the important events in financial markets and housing markets, and their substantial effects on the overall economy, were missing from 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. In this context, the current paper focuses on the interactions between real and financial frictions. In what follows we review the key strands in the literature which relate to this anlaysis.

DSGE models. The benchmark DSGE business cycle model is reviewed in Smets and Wouters (2007), Christiano, Trabandt and Walentin (2011) and in Gali (2015). Basically this is a New-Keynesian model with price stickiness modelled following Rotemberg (1982) or Calvo (1983).

labour market and capital market frictions. Papers in the literature, which examine labour and capital frictions, serve to augment the basic DGSE models with real frictions. Labour frictions are at the focus of the search and matching literature, following Diamond, Mortensen and Pissarides (DMP); Pissarides (2000) and Rogerson and Shimer (2011) offer overviews. They have been incorporated in DSGE models by Merz (1995), Andolfatto (1996), den Haan, Ramey and Watson (2000), Gali (2011), and Christiano, Eichenbaum and Trabandt (2016). Aggregate shocks are transmitted to the labour market via the response of job creation and job destruction, and drive cyclical fluctuations in unemployment. Investment frictions have been incorporated in DSGE models by Chirstiano, Eichenbaum and Evans (2005) and Christiano, Eichenbaum and Trabandt (2016).

In this paper labour frictions are modelled as 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 formulation used here. Faccini and Yashiv (2016) show that this way of modelling hiring frictions into the New Keynesian model generates outcomes closer to those of the frictionless, New Classical model, that are the result of a confluence of frictions.

Financial frictions. A fast-growing literature incorporates financial frictions in macroeconomic models; for overviews see Gertler and Kiyotaki (2011), Brunnermeier, Eisenbach and Sannikov (2013), and Gertler, Kiyotaki and Prestipino (2016). Generally, this literature models a financial sector and adds financial frictions shocks to a business cycle model. The intermediation process between firms and households is modelled, banks are added to the list of agents, and phenomena like risk premia are derived. This modelling spells out informational frictions, incentives, moral hazard issues and the like, emphasising the role of the financial sector in the real economy.

In the current paper we draw upon two key papers. One is Iacoviello (2015) which adds the housing market to a DSGE model with financial frictions to capture the role of housing losses in triggering and amplifying the 2007 crisis and the effects to the real economy. His model includes heterogenous households, bankers, which intermediate funds between savers (patient households) and borrowers, who use loans to purchase residential housing (impatient households) and firms (entrepreneurs). In equilibrium both bankers and entrepreneurs are credit constrained and as such, deleveraging by banks, due to a housing market shock, results in a credit crunch, that spills overs to corporate loans, amplifying and propagating the shock to the real economy. The second is Gertler and Kiyotaki (2015), following Gertler and Kiyotaki (2011), who model agency issues in financial intermediation by banks.

3 The Model

In what follows we present the key ingredients of the model and the optimisation problems of the agents. The full derivations are available on request from the authors.

3.1 The Set-Up

The basic set-up is a standard New Keynesian DSGE model. We have two types of households, featuring habit formation, disutility of work, utility from housing, and borrowing *à la* Iacoviello (2015). 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 following Merz and Yashiv (2007). Labour markets are frictional with Nash wage bargaining in the DMP tradition, following Merz (1995). There is a banking sector with frictions following Gertler and Kiyotaki (2015).

Financial activities. To allow for simultaneous lending and borrowing within the household sector we follow Iacoviello (2015) and assume that there are two types of households: patient households, to be denoted with index H – forming a fraction $(1-\sigma)$ of the labour force – who hold deposits with banks and accumulate houses, and impatient households, to be denoted with index S – forming a fraction σ of the labour force – who borrow against their housing wealth. Each household type is of measure 1.

Consumption. Identical households within each sector, each indexed by j or i, will decide on the same consumption so:

$$\begin{aligned} c_{H,t} &= c_{H,j,t} \\ c_{S,t} &= c_{S,i,t} \\ C_t &= (1-\sigma)c_{H,t} + \sigma c_{S,t} \end{aligned} \tag{1}$$

Housing. We assume that the total housing stock is constant and normalised to 1. Identical households within each sector, each indexed by j or i, will decide on the same housing so:

$$\begin{aligned} H_{H,t} &= H_{H,j,t} \\ H_{S,t} &= H_{S,i,t} \\ H_t &= (1-\sigma)H_{H,t} + \sigma H_{S,t} = 1 \forall t \end{aligned} \tag{2}$$

The labour market. The labour market is frictional and workers who are unemployed at the beginning of each period t are denoted by U_t^0. It is assumed that these unemployed workers can start working in the same period if they find a job. Given the same matching technology facing all workers and one pool of unemployment for all households, this happens with probability $f_t = \frac{h_t}{U_t^0}$, where h_t denotes the total number of worker matches. We normalise the labour force to 1.

The stocks are given by:

$$\begin{aligned} 1 &= N_{H,t} + U_{H,t} \\ 1 &= N_{S,t} + U_{S,t} \\ U_t &= (1-\sigma)U_{H,t} + \sigma U_{S,t} \\ N_t &= (1-\sigma)N_{H,t} + \sigma N_{S,t} \end{aligned} \tag{3}$$

The matching probability is:

$$f_t = \frac{h_t}{U_t^0} \tag{4}$$

where

$$U_t^0 = U_{t-1} + (1-\delta_N)\, N_{t-1} \tag{5}$$

The hiring flows are:

$$h_t = (1-\sigma)h_{H,t} + \sigma h_{S,t} \tag{6}$$

So the stocks evolve as follows:

$$U_t = (1-f_t)U_t^0 \tag{7}$$

$$N_{H,t} = (1-\delta_N)N_{H,t-1} + h_{H,t} \tag{8}$$

$$N_{S,t} = (1-\delta_N)N_{S,t-1} + h_{S,t} \tag{9}$$

$$N_t = (1-\delta_N)N_{t-1} + h_t \tag{10}$$

Firms. There is a unit measure of monopolistically-competitive firms indexed by $z \in [0,1]$ and of final goods aggregator firms. Monopolistic competition implies that each firm z faces the demand curve for its own product. 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, hiring frictions and investment frictions, to be elaborated below.

3.2 Patient Households

The problem for patient households is to maximise their utility subject to a budget constraint and the evolution of employment. A typical patient household H , using subscript j, obtains utility from consumption, $c_{H,j,t}$, from housing, $H_{H,j,t}$, and from leisure (ie, obtain disutility from working, $N_{H,j,t}$). They accumulate housing and bank deposits, $D_{H,j,t}$, which pay the (gross) risk-free nominal rate of interest, R_t.

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

Maximise

$$\max_{c_{H,j,t},H_{H,j,t}} E_0 \sum_{t=0}^{\infty} \beta_H^t [(1-\eta)\ln(c_{H,j,t} - \eta C_{H,t-1}) + J A_{H,t} \ln H_{H,j,t} - \frac{\tau}{1+\xi} N_{H,j,t}^{1+\xi}] \tag{11}$$

subject to:

(i) the budget constraint

$$\begin{bmatrix} P_t c_{H,j,t} + D_{H,j,t} \\ +\frac{\phi_D(1-\sigma)}{2}\left(\frac{\left(D_{H,j,t} - D_{H,j,t-1}\right)^2}{D}\right) \\ +P_t q_t (H_{H,j,t} - H_{H,j,t-1}) + T_{H,j,t} \end{bmatrix} = R_{t-1} D_{H,j,t-1} + P_t w_t N_{H,j,t} + \Pi_{H,j,t} \tag{12}$$

(ii) employment evolution is given by:

$$N_{H,j,t} = (1-\delta_N) N_{H,j,t-1} + h_{H,t} \tag{13}$$

where β_H is the discount factor for patient households, A_H is a housing demand shock, q is the real price of housing, w is the real wage, Π denotes the sum of dividend payments received from the firms and the banks less the capital that they put in to newly-created banks, P is the aggregate price level and T denotes lump-sum taxes paid to the government. Notice that we have 'external' habits in consumption. That is, the utility of household H depends on their consumption vis-à-vis the previous period's average consumption of patient households, $C_{H,t-1}$. There are quadratic adjustment costs on deposits (and where D with no time subscript denotes steady state deposits). The constant δ_N is the worker separation rate.

Assuming all patient households are identical with measure 1, the first-order conditions for this problem imply for the aggregate patient household sector:

(i) the inter-temporal Euler equation for consumption:

$$\left[\frac{1}{C_{H,t}-\eta C_{H,t-1}}\right]\left[1+\phi_D\left(\frac{D_t-D_{t-1}}{D}\right)\right]$$
$$=\beta_H E_t\left[\frac{P_t}{P_{t+1}}\frac{1}{C_{H,t+1}-\eta C_{H,t}}\left[R_t+\phi_D\left(\frac{D_{t+1}-D_t}{D}\right)\right]\right] \tag{14}$$

where we have used the fact that total deposits, D_t will be given by:

$$D_t=(1-\sigma)D_{H,j,t} \tag{15}$$

(ii) the housing demand equation:

$$-\frac{JA_{H,t}}{H_{H,t}}+\frac{(1-\eta)}{C_{H,t}-\eta C_{H,t-1}}q_t=\beta_H E_t\left[\frac{(1-\eta)}{C_{H,t+1}-\eta C_{H,t}}q_{t+1}\right] \tag{16}$$

(iii) the value of employment, to be used in wage bargaining

$$\frac{V_t^{N_H}}{1-f_t}=w_t-\tau N_{H,t}^{\xi}\frac{C_{H,t}-\eta C_{H,t-1}}{(1-\eta)}+\beta_H(1-\delta_N)E_t\left[V_{t+1}^{N_H}\frac{C_{H,t}-\eta C_{H,t-1}}{C_{H,t+1}-\eta C_{H,t}}\right] \tag{17}$$

3.3 Impatient Households

Impatient households discount the future more heavily than patient households. If we denote their discount factor as β_S, then we have $\beta_S<\beta_H$. The problem for impatient households is to maximise their utility subject to a budget constraint. As with patient households, a typical impatient household S obtains utility from consumption, c_S, from housing, H_S, and from leisure (ie, obtain disutility from working, N_S). They accumulate housing and borrow from banks (denoted L_M) against their housing wealth. Note that, although we think of this as mortgage borrowing – and call it mortgage borrowing throughout the paper – such borrowing will not be automatically associated with the purchase of new houses. Rather, it represents total household secured borrowing (where the security is provided by the value of their housing wealth). As such, we impose a constraint on this borrowing. Specifically, their borrowing adjusts slowly towards a target loan-to-value ratio (representing the extent to which their borrowing is 'secured'). This target loan-to-value ratio will be given by $m_M A_{M,t}$,where $A_{m,t}$ is a shock to the target. This captures changes in the borrowing capacity of impatient households due to, eg, tighter screening practices by the banks and/or restrictions imposed on this type of lending by the macroprudential regulatory authority. Again, we assume that impatient households have 'external' habits in consumption with their utility today depending on their consumption relative to the previous period's average consumption of impatient households, C_S.

Hence, we can write the problem of the typical impatient household S (with sub-script i the representative household index) as follows.

Maximise

$$\max_{c_{S,i,t},H_{S,i,t}} E_0 \sum_{t=0}^{\infty} \beta_S^t((1-\eta)\ln(c_{S,i,t}-\eta C_{S,t-1}) \\ + JA_{H,t}\ln H_{S,i,t} - \frac{\tau}{1+\xi}N_{S,i,t}^{1+\xi}) \tag{18}$$

subject to:

(i) the budget constraint

$$\left[\begin{array}{c} P_t c_{S,i,t} + P_t q_t (H_{S,i,t} - H_{S,i,t-1}) \\ +R_{L,t-1}L_{M,i,t-1} \\ +\frac{\phi_s \sigma}{2}\left(\frac{(L_{M,i,t}-L_{M,i,t-1})^2}{L_M}\right) + T_{S,i,t} \end{array}\right] = L_{M,i,t} + P_t w_t N_{S,i,t} \tag{19}$$

(ii) the loan constraint

$$L_{M,i,t} = \rho_s L_{M,i,t-1} + (1-\rho_s) m_M A_{M,t} q_t H_{S,i,t} P_t \tag{20}$$

(iii) employment evolution

$$N_{S,i,t} = (1-\delta_N)N_{S,i,t-1} + h_{S,i,t} \tag{21}$$

where $R_{L,t}$ denotes the banks' gross lending rate, $\frac{\phi_S \sigma}{2}\left(\frac{(L_{M,i,t}-L_{M,i,t-1})^2}{L_M}\right)$ represents costs of adjusting mortgage borrowing for impatient household S and L_M denotes the steady-state level of lending to impatient households ('mortgage' lending).

Assuming all impatient households are identical and with a measure 1, the first-order conditions for this problem imply for the aggregate impatient household sector:

(i) the inter-temporal Euler equation for consumption.

$$\frac{1}{(C_{S,t}-\eta C_{S,t-1})}\left[1-\phi_s\frac{(L_{M,t}-L_{M,t-1})}{L_M} - \mu_{SS,t}\right] = \\ \beta_S E_t\left[\frac{1}{C_{S,t+1}-\eta C_{S,t}}\frac{P_t}{P_{t+1}}\left[R_{L,t}-\phi_s\frac{(L_{M,t+1}-L_{M,t})}{L_M} - \mu_{SS,t+1}\rho_s\right]\right] \tag{22}$$

Here we have used:

$$L_{M,t} = \sigma L_{M,i,t} \tag{23}$$

(ii) the housing demand equation:

$$-\frac{JA_{H,t}}{H_{S,t}} + \frac{(1-\eta)}{C_{S,t} - \eta C_{S,t-1}} \left[q_t - \mu_{S,t}(1-\rho s) m_M A_{m,t} q_t\right] = \beta_S E_t \left[\frac{(1-\eta)}{C_{S,t+1} - \eta C_{S,t}} q_{t+1}\right] \tag{24}$$

Notice here the presence of an additional term – $\mu_{S,t}(1-\rho s) m_M A_{m,t} q_t$ – relative to the housing demand equation for patient households. This reflects the fact that the impatient households not only desire housing for its own (utility) sake, but also because an increase in their housing wealth loosens their borrowing constraint. The value to them of such a 'marginal loosening' will be given by μ_S.

(iii) the value of employment, to be used in wage bargaining

$$\frac{V_t^{N_S}}{1-f_t} = w_t - \tau N_{S,t}^{\xi} \frac{C_{S,t} - \eta C_{S,t-1}}{A_{p,t}(1-\eta)} + \beta_S (1-\delta_N) E_t \left[V_{t+1}^{N_S} \frac{A_{p,t+1}}{A_{p,t}} \frac{C_{S,t} - \eta C_{S,t-1}}{C_{S,t+1} - \eta C_{S,t}}\right] \tag{25}$$

3.4 Firms

3.4.1 Final Good Firms

Final good aggregator firms operate in a competitive market and produce y_t using goods y_z as inputs. The price of the final good used for consumption, investment and government purchases is given by $P_{t.}$ Thus aggregate nominal output – aggregate price P_t multiplied by aggregate output y_t – is given by:

$$P_t y_t = \int_0^1 P_{z,t} y_{z,t} dz \tag{26}$$

3.4.2 Intermediate Firms: Monopolistic Competitors

The gross output of a representative firm z at time t is:

$$y_{z,t} = A_{z,t} N_{z,t}^{1-\alpha} k_{z,t-1}^{\alpha} \tag{27}$$

where $A_{z,t}$ is a technology shock.

The firm faces the demand function (derived from the maximisation problem of the final good firms):

$$y_{z,t} = \left(\frac{P_t}{P_{z,t}}\right)^{\epsilon} y_t \tag{28}$$

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

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

$$N_{z,t} = (1-\delta_N)N_{z,t-1} + h_{z,t}, \quad 0 < \delta_N < 1. \tag{29}$$

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

$$g(h_{z,t}, N_t) = \frac{\phi_h}{2}\left(\frac{h_{z,t}}{N_t}\right)^2 \tag{30}$$

In every period t, the existing capital stock depreciates at the rate δ_K and is augmented by new investment subject to investment costs:

$$k_{z,t} = (1-\delta_K)k_{z,t-1} + A_{k,t}I_{z,t}\left[1 - S\left(\frac{I_{z,t}}{I_{z,t-1}}\right)\right], \quad 0 < \delta_K < 1. \tag{31}$$

where $A_{k,t}$ is an investment-specific technology shock, δ_K is the rate of depreciation and, 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.

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 $L_{E,t}$ are given by:

$$L_{E,z,t} = \Omega_1 P_t I_{z,t} + \Omega_2 W_t N_{z,t} + \Omega_3 P_t\left(\frac{\phi_h}{2}\left(\frac{h_{z,t}}{N_{z,t}}\right)^2 y_t\right) \tag{32}$$

where $L_{E,z,t}$ is the stock of loans with gross nominal lending rate $R_{L,t} = 1 + r_{L,t.}$

The maximisation problem for firm z is thus:

$$\max_{h_{z,t}, I_{z,t}, P_{z,t}} E_t \sum_{t=1}^{\infty} \frac{\beta_H^t(1-\eta)}{(C_{H,t} - \eta C_{H,t-1})\, P_t} \begin{pmatrix} P_{z,t}y_{z,t} \\ -P_t I_{z,t} - W_t N_{z,t} \\ +L_{E,z,t} - R_{L,t-1}L_{E,z,t-1} \\ -\left(g(h_{z,t}, N_{z,t}) + \frac{\chi}{2}\left(\frac{P_{z,t}}{P_{z,t-1}} - 1\right)^2\right) P_t y_t \end{pmatrix} \tag{33}$$

s.t. (27), (28), (29), (30), (31), and (32).

We are assuming that the patient households own the firms, so they discount future dividends back at the relevant discount factor.

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

$$\frac{1-\epsilon}{\chi}+\frac{\epsilon rmc_t}{\chi}-\left(\frac{P_t}{P_{t-1}}-1\right)\frac{P_t}{P_{t-1}}+ \\ E_t\left[\frac{\beta_H\left(c_{H,t}-\eta C_{H,t-1}\right)}{\left(c_{H,t+1}-\eta C_{H,t}\right)}\left(\left(\frac{P_{t+1}}{P_t}-1\right)\left(\frac{P_{t+1}}{P_t}\right)^2\frac{y_{t+1}}{y_t}\right)\right]=0 \tag{34}$$

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:

$$\left(\frac{P_t}{P_{t-1}}-1\right)=\pi_t=\beta_H E_t\left[\pi_{t+1}\right]+\frac{(\epsilon-1)\ln\left(\frac{rmc_t}{rmc}\right)}{\chi} \tag{35}$$

(ii) Hiring.

Marginal hiring costs are given by:

$$Q_t^N=(1-\Omega_3)\phi_h\frac{h_t}{N_t}\frac{y_t}{N_t}+\left[R_{L,t}\Omega_3\phi_h\frac{h_t}{N_t}\frac{y_t}{N_t}\right]E_t\left[\frac{\beta_H\left(C_{H,t}-\eta C_{H,t-1}\right)P_t}{\left(C_{H,t+1}-\eta C_{H,t}\right)P_{t+1}}\right] \tag{36}$$

Marginal hiring revenues are given by:

$$Q_t^N=\frac{(1-\alpha)rmc_t y_{z,t}}{N_t}-w_t(1-\Omega_2)+\phi_h\left(\frac{h_t}{N_t}\right)^2\frac{y_t}{N_t}(1-\Omega_3)+ \\ E_t\left[\frac{\beta_H\left(c_{H,t}-\eta C_{H,t-1}\right)}{\left(c_{H,t+1}-\eta C_{H,t}\right)}\left[-R_{L,t}\frac{P_t}{P_{t+1}}\left(\Omega_2 w_t-\Omega_3\phi_h\left(\frac{h_t}{N_t}\right)^2\frac{y_t}{N_t}\right)+ \\ Q_{t+1}^N(1-\delta_N)\right]\right] \tag{37}$$

where rmc_t denotes real marginal cost. We can combine these equations to obtain the following expression for real marginal cost:

$$rmc_t= \\ \frac{w_tN_t(1-\Omega_2)}{y_t(1-\alpha)}+\frac{(1-\Omega_3)\phi_h}{(1-\alpha)}\left(1-\frac{h_t}{N_t}\right)\frac{h_t}{N_t}+\frac{1}{(1-\alpha)}\frac{R_{L,t}}{R_t}\left[\Omega_3\phi_h\left(1-\frac{h_t}{N_t}\right)\frac{h_t}{N_t}+\Omega_2\frac{w_tN_t}{y_t}\right] \\ +\frac{(1-\delta_N)(1-\Omega_3)\phi_h}{(1-\alpha)}\frac{N_t}{y_t}E_t\left[\frac{h_{t+1}}{N_{t+1}}\frac{y_{t+1}}{N_{t+1}}\right]+\frac{1}{(1-\alpha)}\frac{N_t}{y_t}E_t\left[\frac{R_{L,t+1}}{R_{t+1}}\Omega_3\phi_h\frac{h_{t+1}}{N_{t+1}}\frac{y_{t+1}}{N_{t+1}}\right]$$

where, to aid intuition, we have assumed zero deposit adjustment costs.

If we set $\Omega_2 = \Omega_3 = \phi_h = 0$, then we have the familiar expression for real marginal cost – $rmc_t = \frac{w_t N_t (1-\Omega_2)}{y_t(1-\alpha)}$ – 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, ie, 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 additional wages (the first term on the right-hand side of this equation), firms must pay the costs of hiring those 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). Now comparing this with the expression for real marginal cost in the presence of financial frictions suggests the presence of three additional terms that reflect the fact that firms need to borrow to pay wages and to pay these hiring costs (both this period and next). If they could finance these costs out of retained earnings, the cost would be R. But because they are having to borrow the money from banks, they have to pay an interest rate of R_L. Thus, the opportunity cost of this borrowing will be given by the spread of the lending rate over the deposit rate. As we will see later, the frictions within the banking sector determine the spread between lending and deposit rates. And so, we have a channel through which financial frictions, by determining the spread, will affect hiring and real marginal cost, on account of the hiring frictions, and, hence, affect inflation via the New Keynesian Phillips curve.

(iii) Investment.

Marginal investment costs are given by:

$$1 = \Omega_1 + A_{k,t}Q_t^K\left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - \left(\frac{I_t}{I_{t-1}}\right)S'\left(\frac{I_t}{I_{t-1}}\right)\right) + \tag{38}$$
$$E_t\left[\frac{\beta_H\left(c_{H,t} - \eta C_{H,t-1}\right)}{\left(c_{H,t+1} - \eta C_{H,t}\right)}\left[-R_{L,t}\Omega_1\frac{P_t}{P_{t+1}} + A_{k,t+1}Q_{t+1}^K\left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{I_t}\right)\right]\right]$$

Again, we can log-linearise this equation on the assumption of zero deposit adjustment costs to obtain:

$$\widehat{I_t} = \frac{1}{1+\beta_H}\widehat{I_{t-1}} + \frac{\beta_H}{1+\beta_H}\widehat{I_{t+1}} + \frac{1}{\phi_k\left(1+\beta_H\right)}\left(\widehat{Q_t^K} - \Omega_1\left(\widehat{R_{L,t}} - \widehat{R_t}\right)\right) \tag{39}$$

where 'hats' denote the log deviation of a variable from its steady state. Notice that investment depends negatively on the spread; this is intuitive since, again, the firm has to borrow from banks to finance investment and the spread is measuring the opportunity cost of this borrowing. So, here 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.

Finally, marginal investment revenues are given by:

$$Q_t^K = E_t \left[\frac{\beta_H \left(c_{H,t} - \eta C_{H,t-1} \right)}{\left(c_{H,t+1} - \eta C_{H,t} \right)} \left[\frac{\alpha rmc_t y_{z,t+1}}{k_t} + Q_{t+1}^K (1 - \delta_k) \right] \right] = 0 \tag{40}$$

3.5 Wage Determination

We assume that wages are negotiated on behalf of all employed workers by a representative union, without distinction between workers from different households, 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:

$$W_t = \arg\max \left\{ \left(\sigma V_t^{N_S} + (1-\sigma) V_t^{N_H} \right)^{\gamma} \left(Q_t^N \right)^{1-\gamma} \right\}. \tag{41}$$

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

$$(1-\gamma) V_t^N = \gamma Q_t^N \tag{42}$$

where

$$V_t^N = \sigma V_t^{N_S} + (1-\sigma) V_t^{N_H}$$

For incentive compatibility the representative union has to deliver a present discounted value of being employed to a worker that is at least as good as they could obtain on their own:

$$\begin{aligned} V_t^{N_S} &\leq V_t^N \\ V_t^{N_H} &\leq V_t^N \end{aligned} \tag{43}$$

Hence:

$$V_t^N = V_t^{N_S} = V_t^{N_H} \tag{44}$$

We reproduce the relevant expressions:

$$\frac{V_t^{N_H}}{1-f_t} = w_t - \tau N_{H,t}^{\xi} \frac{\left(c_{H,t} - \eta C_{H,t-1} \right)}{(1-\eta)} + \beta_H \left(1 - \delta_N \right) E_t \left[\frac{\left(c_{H,t} - \eta C_{H,t-1} \right)}{\left(c_{H,t+1} - \eta C_{H,t} \right)} V_{t+1}^{N_H} \right] \tag{45}$$

$$\frac{V_t^{N_S}}{1-f_t} = w_t - \tau N_{S,t}^{\xi} \frac{(c_{S,t} - \eta C_{S,t-1})}{(1-\eta)} + \beta_S (1-\delta_N) E_t \left[\frac{(c_{S,t} - \eta C_{S,t-1})}{(c_{S,t+1} - \eta C_{S,t})} V_{t+1}^{N_S} \right] \tag{46}$$

$$Q_t^N = (1-\Omega_3)\phi_h \frac{h_t}{N_t}\frac{y_t}{N_t} + E_t \left[\frac{\beta_H (c_{H,t} - \eta C_{H,t-1}) P_t}{(c_{H,t+1} - \eta C_{H,t}) P_{t+1}} \left[R_{L,t} \Omega_3 \phi_h \frac{h_t}{N_t}\frac{y_t}{N_t} \right] \right] \tag{47}$$

$$\begin{aligned} Q_t^N = {} & \frac{(1-\alpha) rmc_t y_{z,t}}{N_t} - w_t(1-\Omega_2) + \phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t}(1-\Omega_3) + \\ & E_t \left[\frac{\beta_H (c_{H,t} - \eta C_{H,t-1})}{(c_{H,t+1} - \eta C_{H,t})} \left[-R_{L,t} \frac{P_t}{P_{t+1}} \left(\Omega_2 w_t - \Omega_3 \phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t} \right) + \right.\right. \\ & \left.\left. Q_{t+1}^N (1-\delta_N) \right] \right] \end{aligned} \tag{48}$$

Using equations (45) to (48) and the sharing rule (42) to eliminate the terms in Q_{t+1}^N and V_{t+1}^N one gets the following expression for the real wage:

$$w_t = (1-\gamma)\tau N_{H,t}^{\xi} \frac{(c_{H,t} - \eta C_{H,t-1})}{(1-\eta)} + \gamma \left[\phi_h \frac{h_t}{N_t}\frac{y_t}{N_t} \left(\frac{f_t}{1-f_t}\right) + \phi_h \left(\frac{h_t}{N_t}\right)^2 \frac{y_t}{N_t} + \frac{(1-\alpha) rmc_t y_{z,t}}{N_t} \right] \tag{49}$$

That is, wages are a weighted average of the worker's reservation value (ie, the marginal disutility incurred by the household from which the worker is drawn) and the flow value to the firm generated by the worker, which in turn equals their marginal product marked down by real marginal cost plus the hiring costs saved by the firm not having to hire the worker again.

3.6 Banks

Our modelling of the banking sector follows Gertler and Kiyotaki (2015). We assume that banks issue loans to firms and to impatient households (mortgages) 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 (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 patient households.

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

$$n_{b,t} = R_{L,t-1}\left(L_{E,b,t-1} + L_{M,b,t-1}\right) - R_{t-1}D_{b,t-1} \tag{50}$$

where $L_{M,b}$ is the total mortgage lending of bank b, $L_{E,b}$ is the total lending of bank b to firms and D_b are bank b's deposits.

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

$$n_t = \zeta(R_{L,t-1}\left(L_{E,t-1} + L_{M,t-1}\right) - R_{t-1}D_{t-1}) + (1-\zeta)\nu \tag{51}$$

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

$$L_{b,t} = D_{b,t} + n_{b,t} \tag{52}$$

where L_b is total lending (to both mortgages and corporates) of bank b.

Following Gertler and Kiyotaki (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. Specifically, we suppose that they can sell up to a fraction θ 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 $t+1$. So, when deciding whether or not to divert funds, bank b, for example, will compare the franchise value of the bank, $V_{b,t}$, against the gain from diverting funds, $\theta\left(L_{E,b,t} + L_{M,b,t}\right)$. Hence, depositors will ensure that banks satisfy the following incentive constraint:

$$\theta\left(L_{E,b,t} + L_{M,b,t}\right) \leq V_{b,t} \tag{53}$$

So, we can write bank b's problem as choose $L_{E,b}$, $L_{M,b}$, and D_b each period to maximise its franchise value :

$$V_{b,t} = \max_{L_{b,t}} E_t\left[\sum_{j=1}^{\infty}\zeta^{j-1}(1-\zeta)\frac{\beta_H^j(1-\eta)}{\left(c_{H,t+j} - \eta C_{H,t-1+j}\right)P_{t+j}}n_{b,t+j}\right] + \varepsilon_{\psi,t+j}n_{b,t+j}$$

subject to the incentive constraint, 53 and the balance sheet constraints. Here we have assumed that the patient households own the banks and $\varepsilon_{\psi,t}$ is a mean-zero shock to the franchise value of all banks, which could reflect expectations of write-offs or lower profitability in the future. Note that this shock does not reflect anything fundamental in the model but is a short cut way of dealing with shocks to bank equity prices in the data which may or may not reflect shocks to fundamentals.

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

$$V_{b,t} = E_t \left[\frac{\beta_H \left(c_{H,t} - \eta C_{H,t-1}\right) P_t}{\left(c_{H,t+1} - \eta C_{H,t}\right) P_{t+1}} \left[(1-\zeta)\, n_{b,t+1} + \zeta V_{b,t+1} \right] \right] + \varepsilon_{\psi,t} n_{b,t} \quad (54)$$

Now, the balance sheet constraints imply:

$$\begin{aligned} E_t\left(\frac{n_{b,t+1}}{n_{b,t}}\right) &= \frac{R_{L,t}(L_{b,E,t} + L_{b,M,t}) - R_t D_{b,t}}{n_{b,t}} \\ &= R_{L,t}\varphi_{b,t} - R_t \frac{D_{b,t}}{n_{b,t}} \\ &= R_{L,t}\varphi_{b,t} - R_t\left(\frac{L_{b,t}}{n_{b,t}} - 1\right) \\ &= \left(R_{L,t} - R_t\right)\varphi_{b,t} + R_t \end{aligned} \quad (55)$$

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

Assuming that banks set their loan rates higher than the deposit rate, then the expected growth rate of net worth will be an increasing function of the leverage ratio.

Given that both the objective and constraints of the bank are constant returns to scale, we can rewrite the optimisation problem for bank b in terms of choosing the leverage ratio, and the lending split between mortgages and corporate loans, to maximise the ratio of its franchise value to net worth, $\psi_t = \frac{V_t}{n_t}$.

Formally, maximise

$$\psi_{b,t} = \max_{\varphi_{b,t}} E_t \left[\sum_{j=1}^{\infty} \zeta^{j-1}(1-\zeta) \frac{\beta_H^j (1-\eta)}{\left(c_{H,t+j} - \eta C_{H,t-1+j}\right) P_{t+j}} \frac{n_{b,t+j}}{n_{b,t}} \right] + \frac{\varepsilon_{\psi,t+j} n_{b,t+j}}{n_{b,t}}$$

subject to

$$\theta \varphi_{b,t} = \psi_{b,t} \quad (56)$$

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

Given everything is constraint returns to scale, we can aggregate up across all banks to the aggregate Bellman equation:

$$\Psi_t = \max_{\varphi_t} E_t \left\{ \frac{\beta_H \left(c_{H,t} - \eta C_{H,t-1}\right) P_t}{\left(c_{H,t+1} - \eta C_{H,t}\right) P_{t+1}} \left[(1 - \zeta + \zeta \Psi_{t+1}) \left[\left(R_{L,t} - R_t\right) \varphi_t + R_t \right] \right] \right\} + \varepsilon_{\psi,t} \quad (57)$$

subject to:

$$\theta \varphi_t = \Psi_t \tag{58}$$

Now, if we substitute the constraint into the objective function and rearrange (assuming zero deposit adjustment costs to aid intuition) we obtain:

$$\frac{(R_{L,t} - R_t)}{R_t} = \theta E_t \left[\frac{1}{1 - \zeta + \zeta \theta \varphi_{t+1}} \right] - \frac{1}{\varphi_t} - \frac{\varepsilon_{\psi,t}}{\varphi_t R_t} \tag{59}$$

This equation shows that the spread results from the leverage constraint faced by the banks in this model. The spread will be higher the tighter is the constraint (higher θ) and the higher is bank leverage, φ. In addition, a negative shock to bank equity prices, ε_ψ, will lead to a rise in the spread.

3.7 The Government and The Central Bank

The government is assumed to run a balanced budget:

$$P_t G_t = T_t \tag{60}$$

Government spending is assumed to follow the stochastic process:

$$\ln(G_t) = \rho_G \ln(G_{t-1}) + (1 - \rho_G) \ln\left(\overline{G}\right) + \varepsilon_{G,t} \tag{61}$$

where $\overline{G}$ denotes the steady-state level of government spending and ε_G is a white noise shock.

The central bank operates a Taylor Rule of the form:

$$\ln(R_t) = \rho_R \ln(R_{t-1}) + (1 - \rho_R) \ln\left(\frac{1}{\beta^H}\right) + (1 - \rho_R)\left(v_\pi \left(\frac{P_t}{P_{t-1}} - 1\right) + v_y \ln\left(\frac{y_t}{\overline{y}}\right)\right) + \varepsilon_{R,t} \tag{62}$$

where $\overline{y}$ denotes the steady-state level of output and ε_R is a white-noise shock.

3.8 Market Clearing

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

$$y_t = \frac{C_t + I_t + G_t}{1 - \frac{\chi}{2}\left(\frac{P_t}{P_{t-1}} - 1\right)^2 - \frac{\phi_h}{2}\left(\frac{h_t}{N_t}\right)^2} \tag{63}$$

4 Calibration

As we are interested in understanding how the various frictions we have introduced into our model affect the responses of variables within the model to shocks, we use a calibrated version of the model rather than attempt to estimate it. (We plan to estimate the full model on US and UK data in future work.) Our calibration, in general, follows the existing literatures on DSGE models with a housing market and financial frictions.

Table 1A: Parameter Calibration Values
Households

symbol		value
η	habit in utility	0.46
β_H	discounting, patient	0.9925
β_S	discounting, impatient	0.94
J	scale, housing in utility	0.1996
τ	scale, work in utility	0.9002
ξ	inverse Frisch elasticity	1
m_M	target loan-to-value ratio	0.9
σ	share of impatients	0.33
δ_N	worker separation rate	0.126
ϕ_D	scale deposit AC	0.1
ϕ_S	mortgage borrowing AC	0.37
ρ_s	AR1 of mortgage loans	0.7

Table A lists the parameters governing the household sector. For these parameters we follow Iacoviello (2015). Specifically, we set the discount factors for the patient and impatient households, β_H and β_S, to 0.9925 and 0.94, respectively. Iacoviello estimates the degree of habit persistence in consumption, η, to be 0.46 and the proportion of impatient households in the population, σ, to 0.33. We adopt these values in our work. We follow Iacoviello in setting the Frisch elasticity of labour supply, $1/\xi$, to 1 and we set τ to 0.9002, which implies a steady-state employment rate of 94%. We set the utility weight on housing, J, to 0.1996, which implies total housing wealth equal to 3.4 times annual GDP, the same value used by Iacoviello. Iacoviello estimates the scaling parameters for deposit and loan adjustment costs, ϕ_D and ϕ_L, to equal 0.1 and 0.37, respectively. We again adopt these values in our work. Following Iacoviello, we set the loan-to-value ratio for mortgage borrowing, m_m, to 0.9 and use his estimated value of 0.7 for the inertia coefficient in the impatient households' collateral constraint, ρ_S. Finally, for the workers separation rate, δ_N, we follow Faccini and Yashiv (2016) and set this to 0.126.

Table B lists the parameters governing the firms. Here, we follow Faccini and Yashiv (2016). Specifically, we set the depreciation rate for capital, δ_k, equal to 0.024 and the elasticity of output with respect to capital, α, equal to 0.33, implying a labour share of income of about two thirds. We set the price elasticity of demand, ε, equal to 11, implying a steady-state mark-up of 1.1. We set the scale parameter on the price adjustment costs, χ, equal to 129, implying a New Keynesian Phillips curve slope equal to that produced by a model with Calvo price rigidities and an average price duration of one year. Following, Faccini and Yashiv, we set the scale parameter of the hiring costs function, ϕ_h, equal to 1.5. We set workers' bargaining power, γ, to 0, implying competitive wage setting. For the investment adjustment costs, we set the elasticity of these, ϕ_k, equal to 5.74, the value estimated by Smets and Wouters (2007). Finally, we assume that all investment,wages, and hiring costs, have to be financed by bank borrowing (ie, $\Omega_1 = \Omega_2 = \Omega_3 = 1$).

Table 1B: Parameter calibration values
Firms

symbol		value
α	capital share in Cobb Douglas	0.33
ϵ	elasticity of demand	11
Ω_1	investment share in loans	1
Ω_2	wage share in loans	1
Ω_3	adj. costs share in loans	1
δ_K	capital depreciation	0.024
ϕ_h	scale, hiring costs	1.5
$S''(1)$	investment rate of change	5.74
χ	scale, price frictions	129

The remaining parameters are shown in Table C. We calibrate the parameters governing the banks we follow 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). We set the steady-state share of government spending in GDP to 18%, the calibrated value used by Smets and Wouters. 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.

Table 1C: Parameter calibration values
Banks and public sector

symbol		value
ρ_G	govt. expenditure AR1	0.95
ρ_R	Taylor rule AR1	0.81
υ_π	Taylor rule inflation coefficient	1.5
υ_y	Taylor rule output coefficient	0.125
ζ	A bank's probability of staying active	0.95
θ	Seizure rate	0.1939

5 Results

So far, this paper has introduced a very rich model in terms of frictions. On the financial side, credit is constrained in two ways: first, via an exogenous loan-to-value ratio imposed on household borrowing, and second, via an endogenous borrowing constraint on banks giving rise to a wedge between banks funding costs and the lending rate. On the real side, firms face hiring and investment costs. As we have shown before, we link real and financial frictions by requiring entrepreneurs to borrow prior to production. This ensures that financial conditions have a direct effect on firms' production, investment and hiring decisions, with direct consequences to the real economy.

There are two main questions we can investigate using this framework. First, does linking up financial and real economy frictions provide different results than by just analysing frictions in isolation? Second, what can this model tell us about the transmission mechanism of shocks from financial markets to the real economy? We discuss each of these in turn.

5.1 The effects of frictions in our model

In this subsection, we analyse the effects of the various frictions in our model, in particular, concentrating on whether the interaction of these frictions provide different results to what might have been expected examining them in isolation. To do that, we consider the four model configurations shown in Table 2. In particular, we wish to examine the effects of adding financial frictions and labour and investment frictions separately to an otherwise frictionless model – the 'Basic' model – and then to examine what happens when both sets of frictions are added. We do this by comparing the responses of the endogenous variables listed above to the various shocks in our model.

Table 2
Model Configurations

symbol		Basic	L & I Frictions	Financial Frictions	Full
m_M	target loan-to-value ratio	–	–	m_M	m_M
ϕ_D	scale deposit AC	–	–	ϕ_D	ϕ_D
ϕ_S	mortgage borrowing AC	–	–	ϕ_S	ϕ_S
ρ_s	AR1 of mortgage loans	–	–	ρ_s	ρ_s
Ω_1	investment share in loans	–	–	Ω_1	Ω_1
Ω_2	wage share in loans	–	–	Ω_2	Ω_2
Ω_3	adj. costs share in loans	–	–	–	Ω_3
θ	diversion rate	–	–	θ	θ
ϕ_h	scale, hiring costs	–	ϕ_h	–	ϕ_h
γ	bargaining parameter	–	$0, \gamma$	–	$0, \gamma$

We start with a comparison of the frictionless model, the model with only hiring and investment frictions and the model with only financial frictions. Chart 1 compares the responses of GDP, aggregate consumption, C, investment, I, real wages, w, employment, N, the capital stock, k, annual inflation, the deposit rate, R, the lending rate, R_L, and house prices, Pq, to a contractionary monetary policy shock. Specifically, we shock the error in the Taylor rule, $\varepsilon_{R,t}$, by 400 basis points. As can be seen, the investment frictions lead to a 'hump-shaped' response of investment to the shock and, as a result, a much more persistent response of output, wages and employment. The presence of the investment frictions also imply a much smaller initial response of output, investment, wages and employment. Conversely, the response of consumption is much larger and less persistent in the presence of hiring costs and investment adjustment costs. Financial frictions also reduce the impact of the shock on investment wages, employment and the capital stock and increase their persistence, but not by as much as the real frictions. Again, consumption falls by more than in the baseline case initially, though not by as much as in the model with just real frictions. The hiring and investment frictions also increase the persistence of the shock's effect on inflation relative to the other two models. With a larger fall in GDP in the model with just financial frictions relative to the model with just hiring and investment frictions, and an even larger fall in GDP in the model with no frictions, the Taylor rule implies that the same shock to the error in the rule will be associated with the largest increase in rates in the model with only hiring and investment frictions, and the smallest increase in rates in the model with no frictions.

Turning next to a government spending shock, Chart 2 shows that, in this case, although the investment frictions again lead to a smaller and hump-shaped response of investment relative to the response in the frictionless model, the effects on output, consumption, wages, employment, inflation and the deposit rate are actually larger. The intuition is that the shock is crowding out private spending; given that this needs to be split between investment and consumption, and investment does not fall by as much, consumption has to fall by more. Interestingly, the responses of variables to a government spending shock seem unaffected by the presence of financial frictions, except for house prices, which are much more persistently lower. This comes from the fact that the financial frictions will partly work through mortgage lending.

For the case of an investment-specific productivity shock, shown in Chart 3, the responses of variables in the model with hiring and investment frictions are always smaller than in the other models. This should not be a surprise given that the shock is directly affecting investment and the response of investment is exactly what is muted by the investment adjustment costs. Financial frictions, since they also act to reduce investment, lead to a smaller impact of the shock, though they do not bear down as heavily as the investment adjustment costs. After a year, though, the responses in the baseline model and the model with just financial frictions are similar, again with the exception of house prices, whose response is much more persistent.

Chart 4 shows the responses of these variables to a total factor productivity shock. In this case, both models with frictions produce a hump-shaped response to the shock for GDP, consumption and investment. Again, the consumption response is largest, and the investment response most muted, for the model with hiring and investment frictions as the frictions shift expenditure away from investment towards consumption. Employment falls in response to this shock with the fall in employment most muted in the model with financial frictions and most persistent in the model with hiring frictions. The response of inflation is similar in all three models as is that of the deposit rate. Finally, the response of house prices in the model with financial frictions is again much more persistent (and in this case much larger) than in the other two models.

Finally, Chart 5 shows the effect of a housing demand shock in each of the three models. The most obvious thing to note is that such a shock has no effect on anything other than house prices except in the presence of financial frictions (specifically, frictions around mortgage borrowing). The only other point to note is that the response of house prices to such a shock is larger and more persistent in the model with financial frictions than in the other two models. This results from the 'double duty' performed by houses for the impatient households that we noted earlier: impatient households desire housing both for its own sake and because higher housing wealth – which results from the higher house prices resulting from the housing demand shock – slackens the constraint they face on their borrowing.

Of course, none of these results are original. Where our paper adds value is in an examination of the effects of combining the hiring and investment frictions with the financial frictions in the one model. To examine this issue we compare the effects of our shocks in the model with just financial frictions to their effects in the full model with financial frictions and hiring and investment frictions. Chart 6 shows the effect of a contractionary monetary policy shock in these two models. As would be expected, for most variables, the addition of the extra frictions leads to a more muted response to the monetary policy shock. An exception to this is consumption which falls by more in response to the shock in the present of investment and hiring frictions. This is because the 'muting' effect of the investment adjustment costs on investment is stronger than the effect on output. The other noticeable differences are in the banking sector. In the full model, the lending rate and the spread rise in response to the monetary policy shock, as would be expected. The rise in the spread is associated with a rise in net worth (capital) as banks delever. However, in the model with just financial frictions, the lending rate falls and bank capital also falls.

Turning to the effect of an expansionary government spending shock, shown in Chart 7, we can see that the addition of hiring and investment frictions lead to a stronger effect of such a shock on GDP, consumption, employment, inflation and interest rates. Again, the intuition for the different responses of consumption and investment is that, given the shock reduces private spending, a smaller fall in investment must be accompanied by a larger fall in consumption. That said, the effect of the investment frictions on investment outweighs the effect of a larger fall in consumption and so GDP rises by more, ie, the fiscal multiplier is larger in the model with all frictions than in that with just financial frictions. And with GDP rising by more, then employment has to rise by more in order to produce the extra GDP.

Chart 8 compares the responses of variables to a housing demand shock in the full model with those in the model with only financial frictions. The addition of hiring and investment frictions mutes considerably the responses of most variables. One exception is consumption which rises by more in response to a housing demand shock in the full model; this again reflects that the change in response of investment is much larger than the change in response of GDP. Chart 9 paints exactly the same picture for a positive shock to the loan-to-value ratio. This is not surprising given the similar effects of these two shocks.

The effects of a shock to bank equity prices in the two models is shown in Chart 10. Again, the responses in the full model are generally smaller than those in the model with just financial frictions. One exception is the lending rate (and spread) which respond much more in the full model. The other noticeable difference is the positive response of consumption in the model with only financial frictions. This seems counterintuitive, and arises from the fact that the fall in investment in response to the shock is much larger in the model without investment adjustment costs. Given that when investment adjustment costs are added to the model consumption falls in response to this shock, this result suggests the need to include such costs in a model if we are to obtain sensible results for the effect of this sort of shock.

Overall then, the message is that the investment frictions by markedly reducing the response of investment to various shocks can lead to a larger response of consumption to the various shocks. Otherwise, much as we'd expect, the addition of extra frictions to the model leads to a more muted response of the variables we care about to economic shocks.

5.2 The transmission mechanism of financial and real economy shocks in the full model

5.2.1 Monetary policy shock

We first examine the dynamic responses of the variables in our model to a monetary policy that corresponds to a rise in the policy rate – and so rate paid on deposits in our model – of about 250 basis points. The results are shown in Chart 11. This shock makes it much more expensive for banks to raise funds, which leads to a rise in bank lending rates and to a fall in bank lending, with corporates responding more than mortgages to the decreased supply of credit. Spreads initially rise but then fall as leverage falls. The rise in spreads leads to a large fall in hiring (since the cost of hiring depends on the spread) and a fall in investment (which also depends on the spread in our model). In turn, these falls lead to falls of around 1-2% in employment and output. On the household side, consumption falls and housing demand falls in response to the rise in mortgage lending rates. As a result of the fall in housing demand, house prices fall by nearly 4%. As the rise in deposit rates is expected to persist, bank equity prices fall causing the leverage constraint on banks to tighten. As a result, bank leverage falls by almost 5%. Banks respond to the tighter conditions by raising their capital (net worth).

This experiment illustrates an example of policy interaction: a tightening of monetary policy does not only have a negative effect on real economy activity and inflation, but also has a negative effects on financial sector activity (as measured by leverage). Put differently, if bank leverage were considered to be too high, this experiment shows that monetary policy may be able to augment macroprudential policy in leaning against an excessive build-up of financial sector borrowing. This would be consistent with some strands of the literature that argue, under what it is called the 'lean' approach, that in the presence of excessive leverage and asset prices booms, monetary policy should 'lean against the wind' by keeping interest rates higher than necessary for price stability in the short run (Woodford 2012; White 2006). An alternative way of looking at this, though, might be to suggest that a monetary tightening aimed at curbing inflation might need to be associated with a macroprudential loosening in order to avoid the negative consequences for the banking sector.

5.2.2 Government spending shock

We next consider a fiscal expansion, specifically a 1% increase in government spending. The responses of the variables in our model to such a shock are shown in Chart 12. The increase in government spending raises output immediately, though by only about 0.1%. Inflation rises as a result, with the central bank responding by increasing the risk-free rate. As a result, banks adjust their lending rates upwards, reflecting an increase in the cost of borrowing. And these increases in interest rates lead to lower consumption, investment and mortgage lending. This is the standard 'crowding out' story. However, in our model, while mortgage borrowers respond by reducing the demand for credit, lending to corporates increases by almost 0.5%. This results from the need for firms to hire and pay additional workers to meet the increase in demand brought about by the increase in government spending. In our model, this spending has to be met through borrowing from banks. This channel, which is not present in standard models, acts to lower the fiscal multiplier relative to a more standard model in which employment can be costlessly increased and in which wages can be paid out of sales. Real wages and, hence, marginal costs go up for firms, leading to an increase in inflation. Finally, with mortgage borrowing being more expensive, impatient households pull back from housing purchases driving down house prices.

Since the negative effect of the shock on mortgage lending is much more persistent than the positive effect on corporate lending, bank equity prices fall. This tightens their leverage constraint leading to a fall in leverage. Banks achieve this fall through a combination of lower lending and raising their capital. This fall in lending and leverage may suggest the need for a loosening in macroprudential policy. This is in contrast to the need for a tightening in monetary policy and suggests that a potential conflict between fiscal, monetary and macroprudential policy could arise if policymakers are acting in isolation to achieve their individual targets.

5.2.3 Housing demand shock

Chart 13 examines the impact of a 1% increase in the demand for housing. The increase in demand for housing leads to a rise in house prices, as expected. But this rise in house prices loosens the borrowing constraint for impatient households who respond by increasing their mortgage borrowing and consumption. The increase in consumption demand is partially met via an increase in output and partially via a fall in investment. The increase in output is achieved via increased hiring and, since this has to be financed by bank borrowing, corporate borrowing rises. Again, increased hiring leads to an increase in real marginal cost and inflation. As the overall rise in lending is expected to persist, bank equity prices rise, loosening the leverage constraint on banks. This leads to an increased supply of credit that more than matches the increased demand for credit and so the lending rate and the spread both fall initially. This is a surprising result and shows the importance of the particular financial frictions within our model.

5.2.4 Shock to banks' underwriting standards

Similar to Iacoviello (2015), we investigate the effect of a positive 1% shock to the loan-to-value ratio for mortgage lending. This can be thought of as an exogenous increase to the borrowing ability of the household, for example due to looser screening practices of banks, allowing them to supply larger loans for a given amount of collateral. The results are shown in Chart 14. As a result of the shock, the lending rate falls, as does the spread. This incentivises higher borrowing by both households – who would already have increased their borrowing on account of the loosening of their collateral constraints anyway – and corporates. The increase in the value of housing as collateral leads to a rise in house prices. The increase in household borrowing leads to an increase in consumption demand, which leads to an increase in output. This increase in output has to be met by hiring and paying more workers and it is this that leads to the increase in corporate borrowing. But firms do not increase output by enough to cover the increase in consumption demand so investment falls. At the same time the increase in labour demand leads to increases in wages and firms' marginal costs of production. The resulting rise in inflation triggers an increase in the policy rate. Given the persistence of the shock and the resulting increase in mortgage lending, bank equity prices rise. This slackens their leverage constraints and so leverage rises. Again, this rise in leverage is partly achieved via a reduction in capital.

Overall, this experiment shows that a slackening in the lending standards applied by banks will affect the real economy by boosting house prices and demand, at the same time leading to increased leverage in the banking sector. These results – and those of the housing demand shock presented earlier, which works in a similar way – help provide a useful description of what was happening in the United States in the run up to the financial crisis.

5.2.5 Shock to banks' market value

Finally, we examine the effects of a 1% negative shock to the equity value of banks in our model. We can think of this shock as capturing the idea that investors suddenly re-evaluate their view as to the profitability of banks, something that was one of the main causes of the financial crisis, though we do not model why this re-evaluation might have occurred. The responses of the variables in our model to this shock are shown in Chart 15. Lower bank market value tightens the banks' leverage constraint with the result that leverage falls. This fall in leverage is met via both a fall in lending and a rise in capital (net worth). To signal reduced credit availability, banks raise their lending rate which in turn, raise the spread by almost six percentage points initially. This reduces the demand for borrowing from both corporates and households and this, in turn, leads to a fall in hiring, investment and house prices. The fall in hiring and investment leads to a fall in output and a fall in consumption. The fall in output, though, is modest: 0.1%. As real marginal cost has risen, inflation also rises, though the fact that this is small relative to the fall in output leads to a loosening in monetary policy.

6 Conclusions (to be expanded)

In this paper we developed a DSGE model calibrated for the US economy, that links financial markets and financial frictions with labour markets and labour market frictions to enhance our understanding of how shocks are transmitted through the real economy and explore the linkages between financial markets and the real economy. More specifically, we started with a standard DSGE model to which we added investment adjustment costs, hiring costs as in Yashiv (2016), and financial frictions as in Iacoviello (2015) and Gertler and Kiyotaki (2011, 2015). In addition, we imposed that firms had to borrow from banks to finance investment, wages and the hiring costs. As a result, we created a direct link from the banking sector frictions of Gertler and Kiyotaki, through the spread to investment demand and real marginal cost, which were also affected by the investment and hiring frictions, to inflation and real activity. It was this interaction of real and financial frictions that mark out our approach relative to the existing literature.

We found that investment frictions, by markedly reducing the response of investment to various shocks, can lead to a larger response of consumption to these shocks. Otherwise, as expected, the addition of extra frictions to the model leads to a more muted response of the variables we care about to economic shocks. In terms of the responses of variables to the various shocks in our model, we find, as expected, that monetary policy can be used to lean against a build up of leverage in the banking sector but that monetary policy and macroprudential policy can sometimes be in conflict. In particular, a government spending shock leads to higher inflation, suggesting a need to tighten monetary policy, but to lower bank leverage, suggesting a possible need to loosen macroprudential policy. In the run up to the financial crisis we saw a large increase in Bank leverage; our model suggests that this is exactly what we might expect to see following a positive housing demand shock or a loosening of bank credit standards. And an exogenous fall in bank equity prices – resulting from, say, a re-evaluation of the profitability of banks – will, in our model, result in a recession, though not as bad in terms of lost output as we saw in the Great Recession itself.

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Chart 1: The effect of adding either real or financial frictions

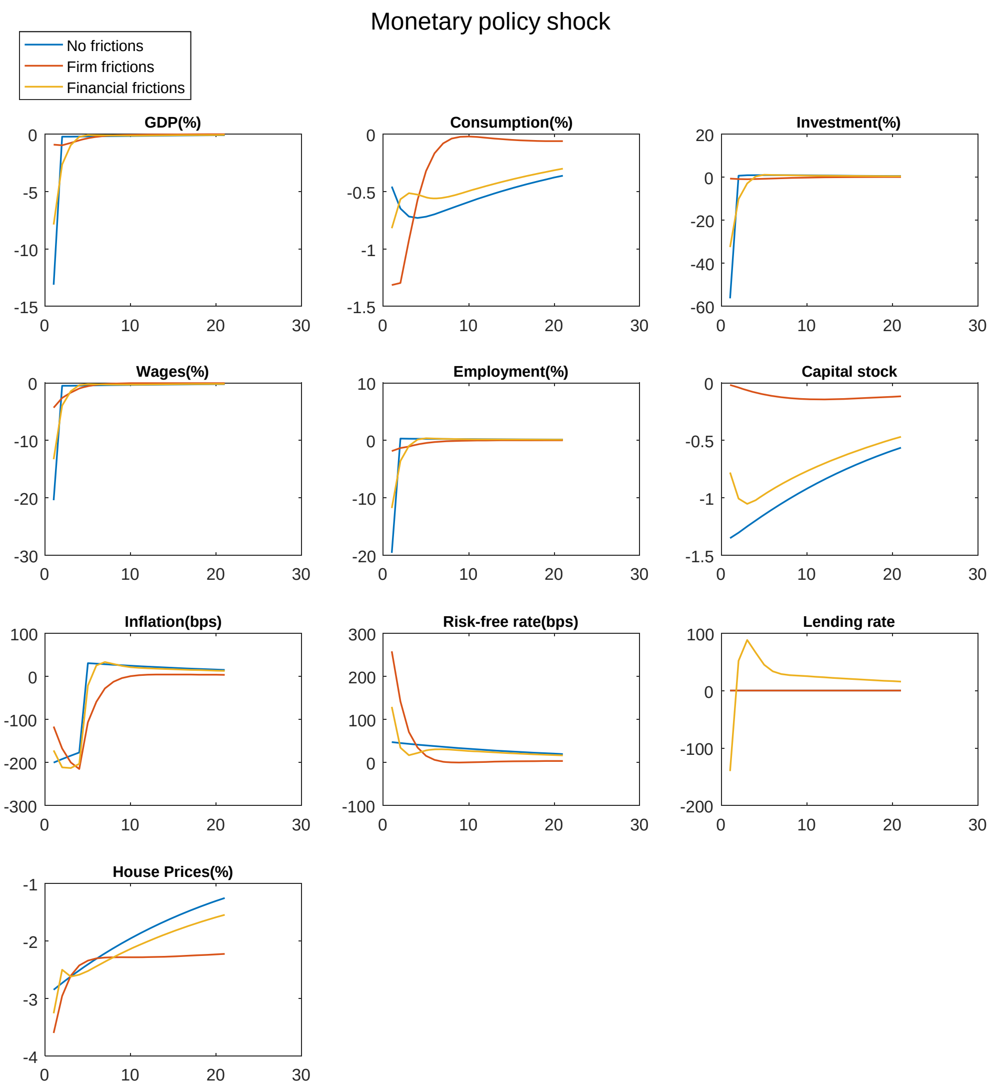
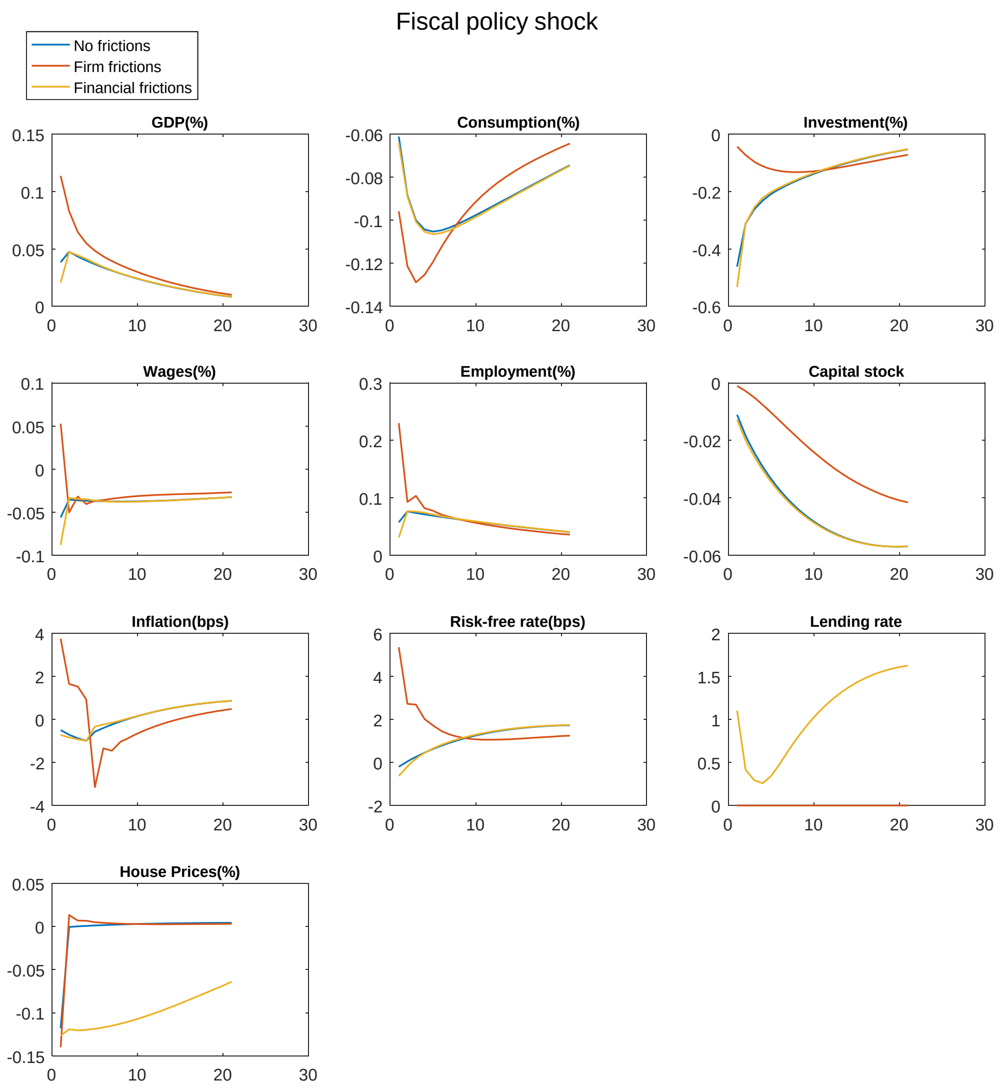


Chart 2: The effect of adding either real or financial frictions



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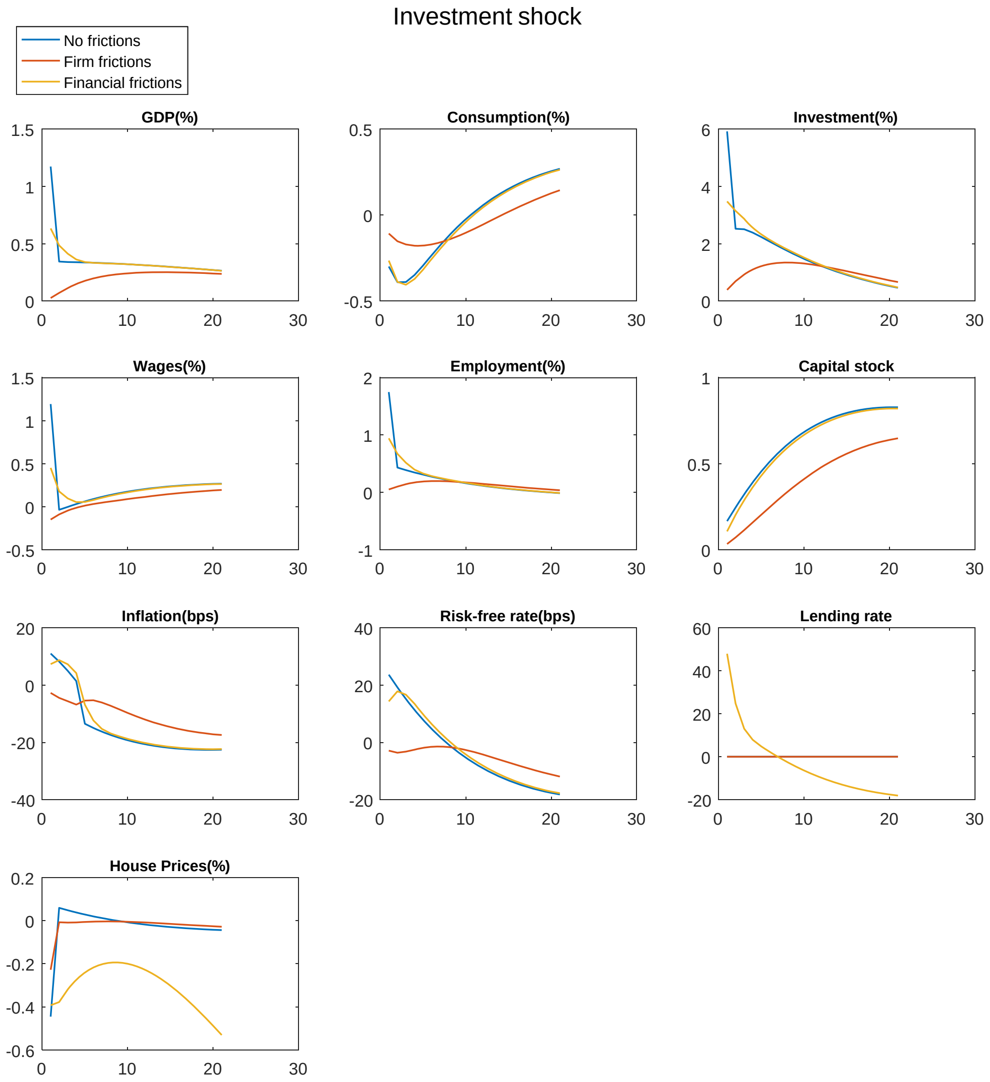

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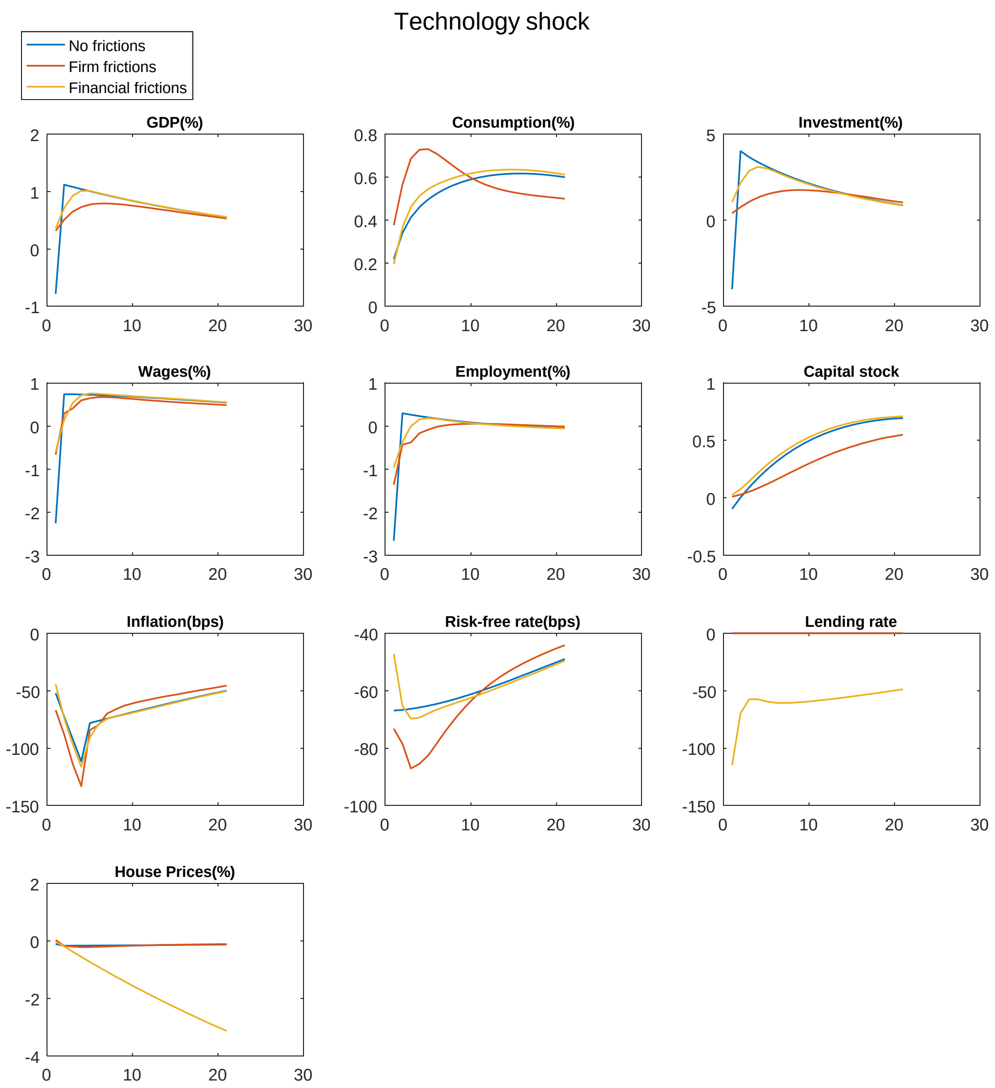

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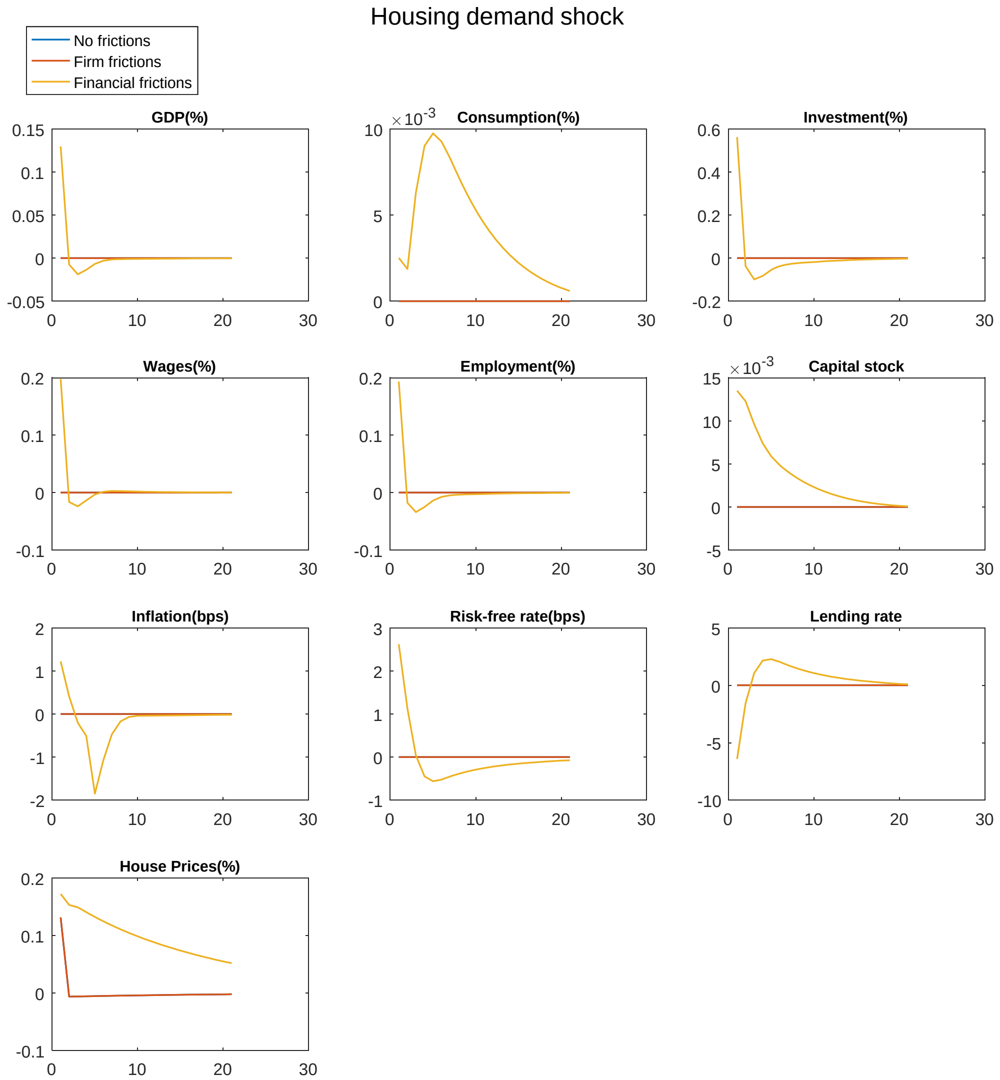

Chart 6: The effect of adding real frictions to the model with financial frictions

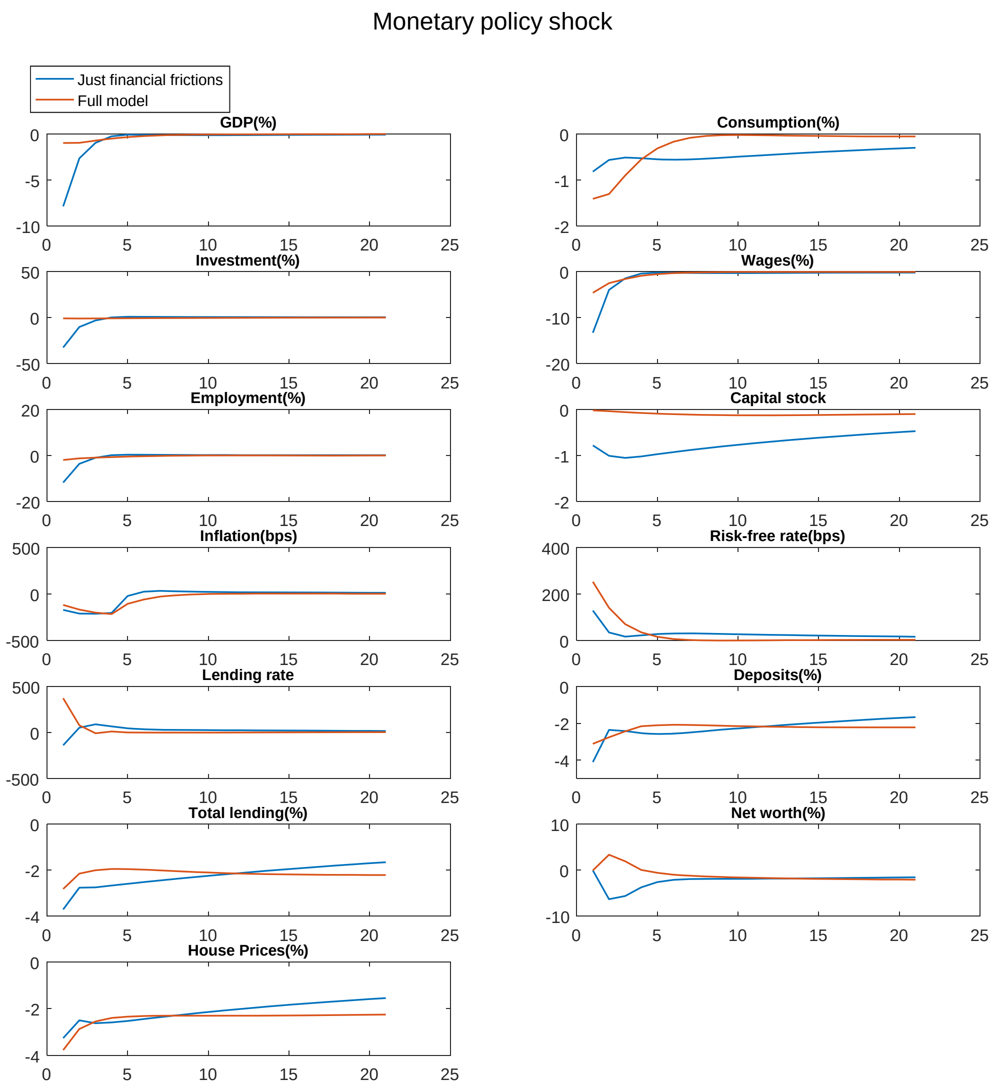

Chart 7: The effect of adding real frictions to the model with financial frictions

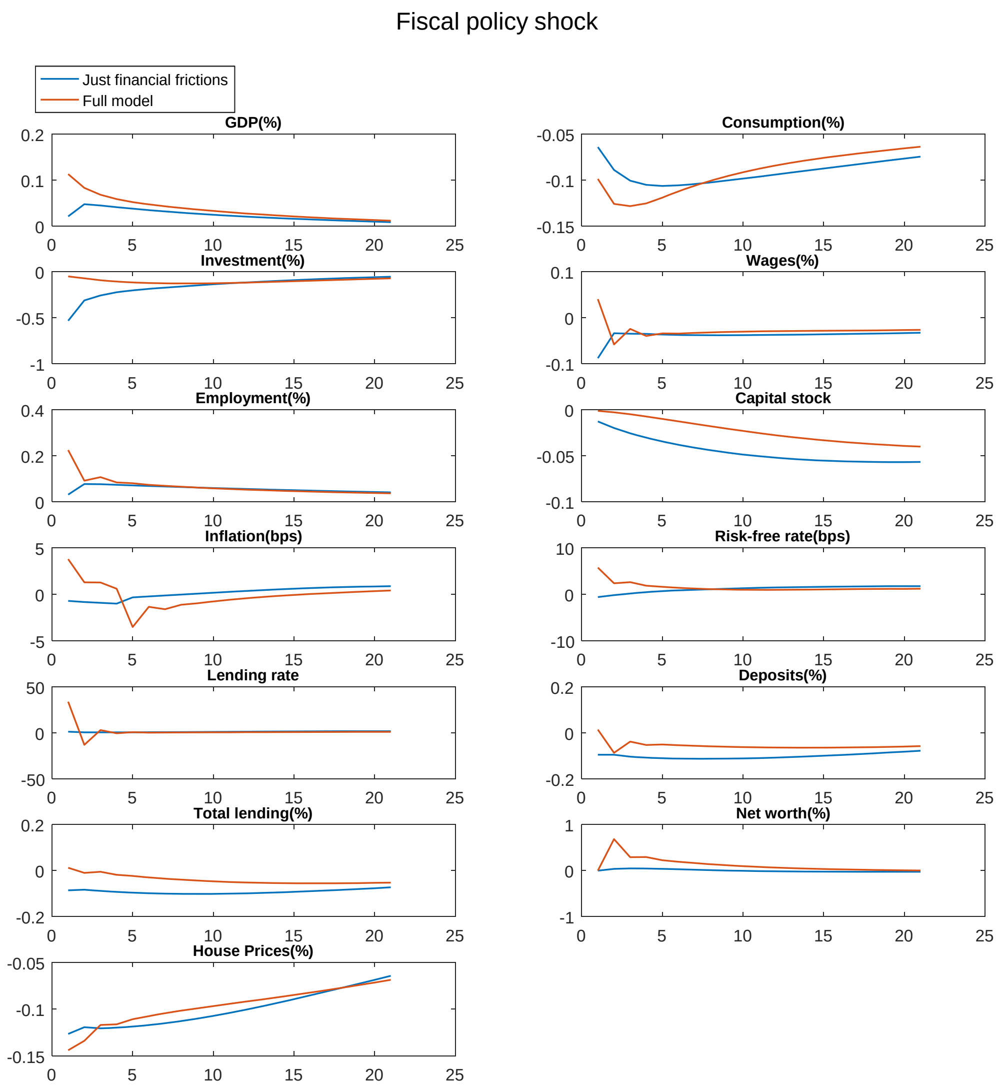

Chart 8: The effect of adding real frictions to the model with financial frictions

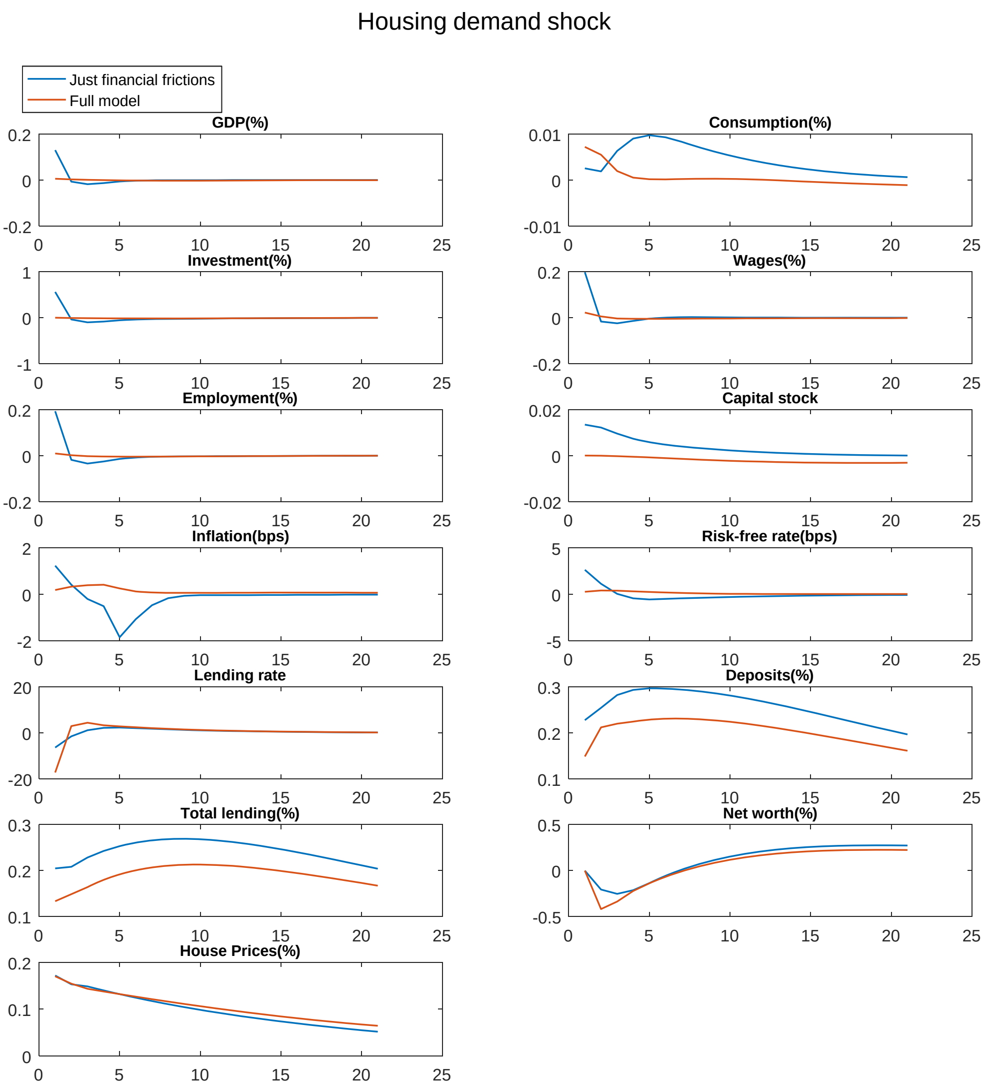

Chart 9: The effect of adding real frictions to the model with financial frictions

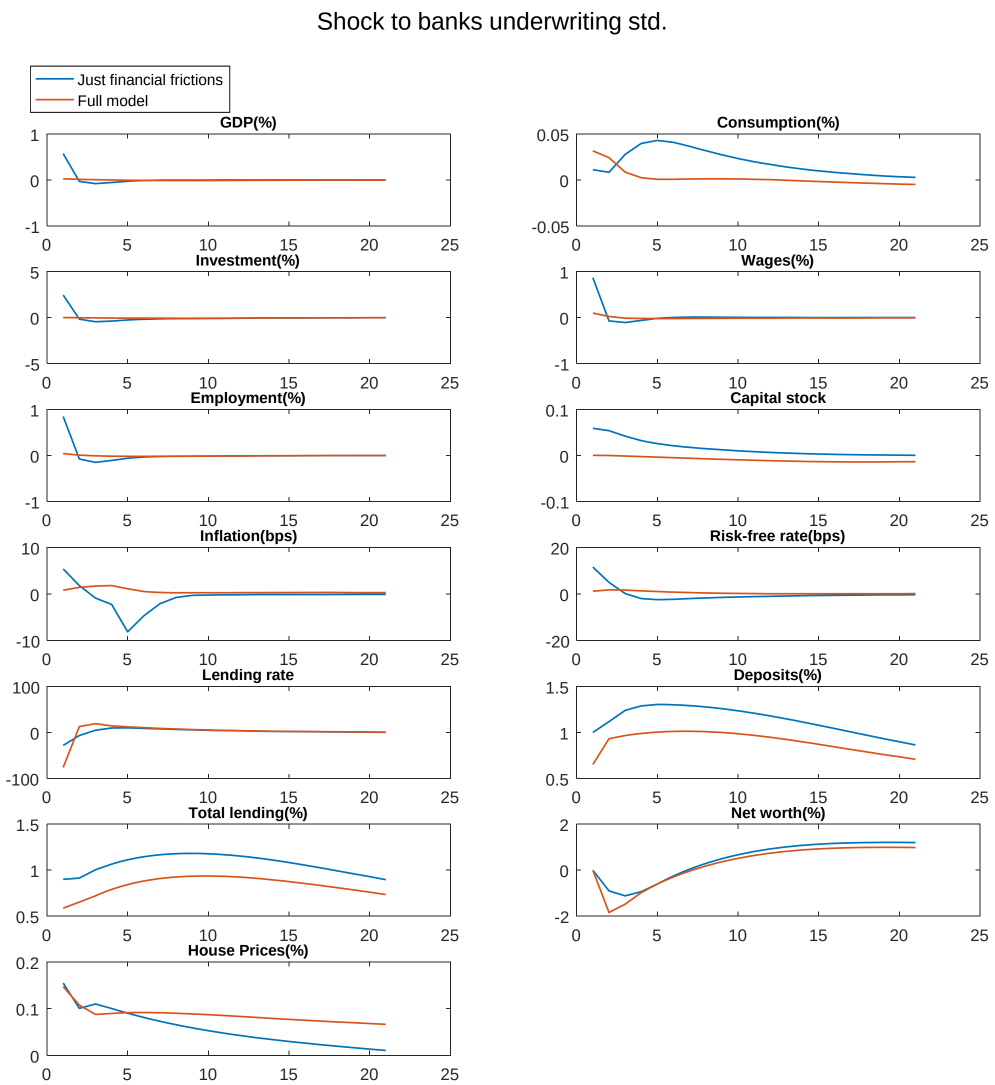

Chart 10: The effect of adding real frictions to the model with financial frictions

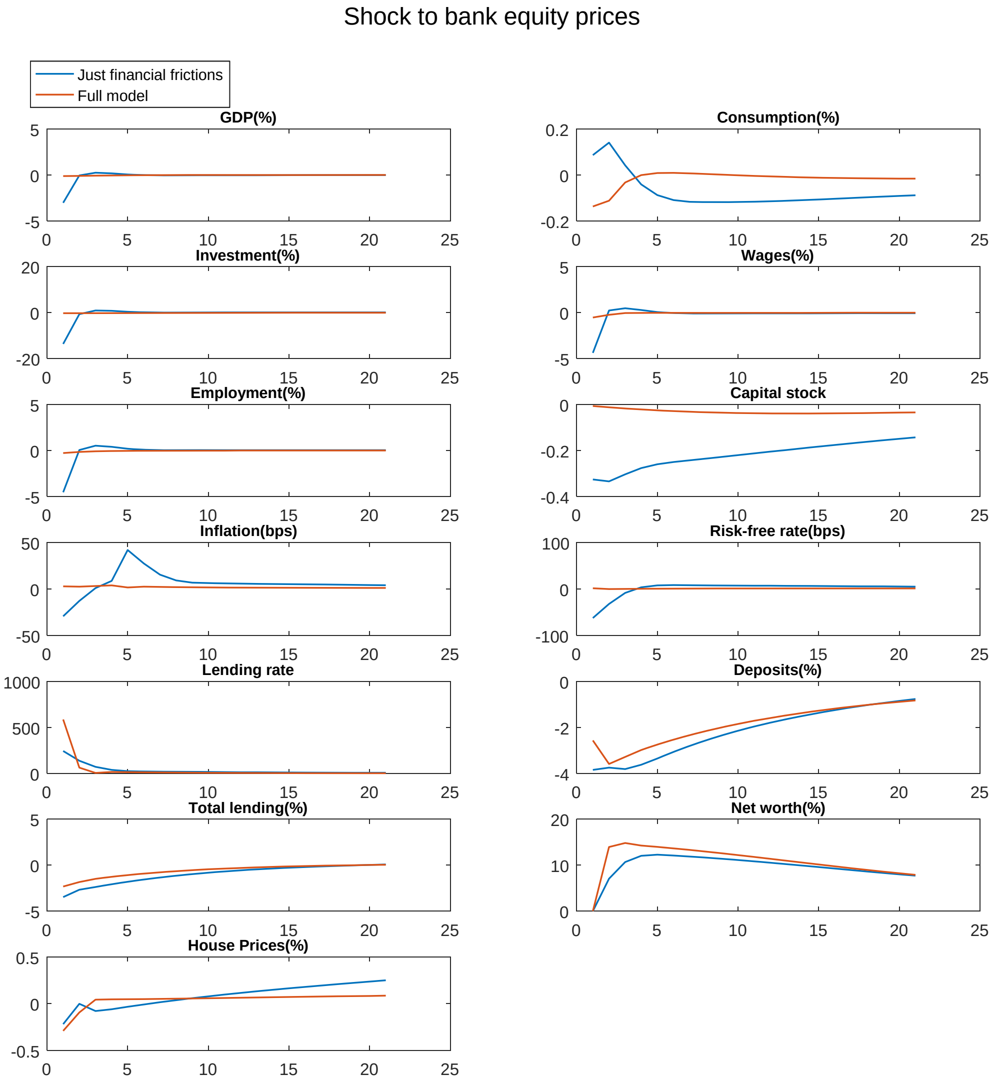

Chart 11: Effect of a monetary policy shock

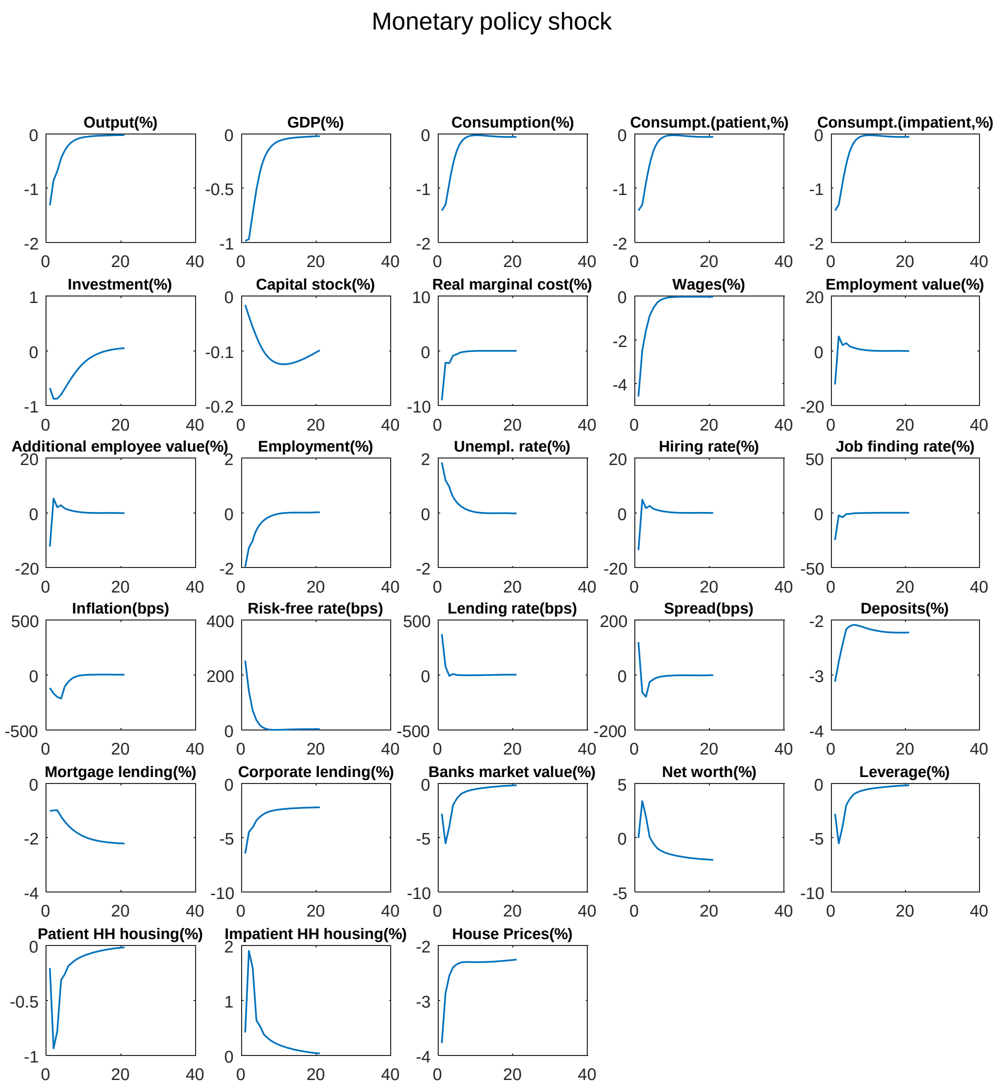

Chart 12: Effect of a government spending shock

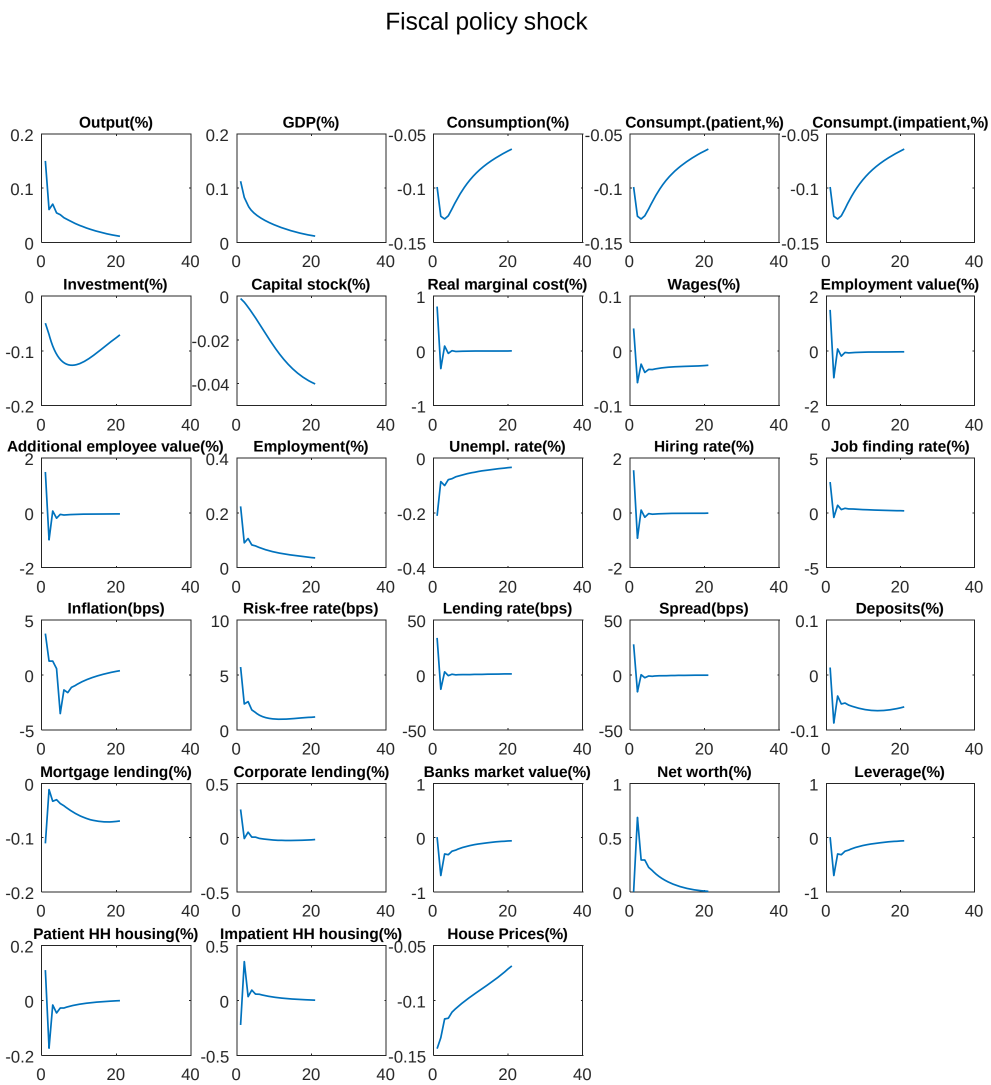

Chart 13: Effect of a housing demand shock

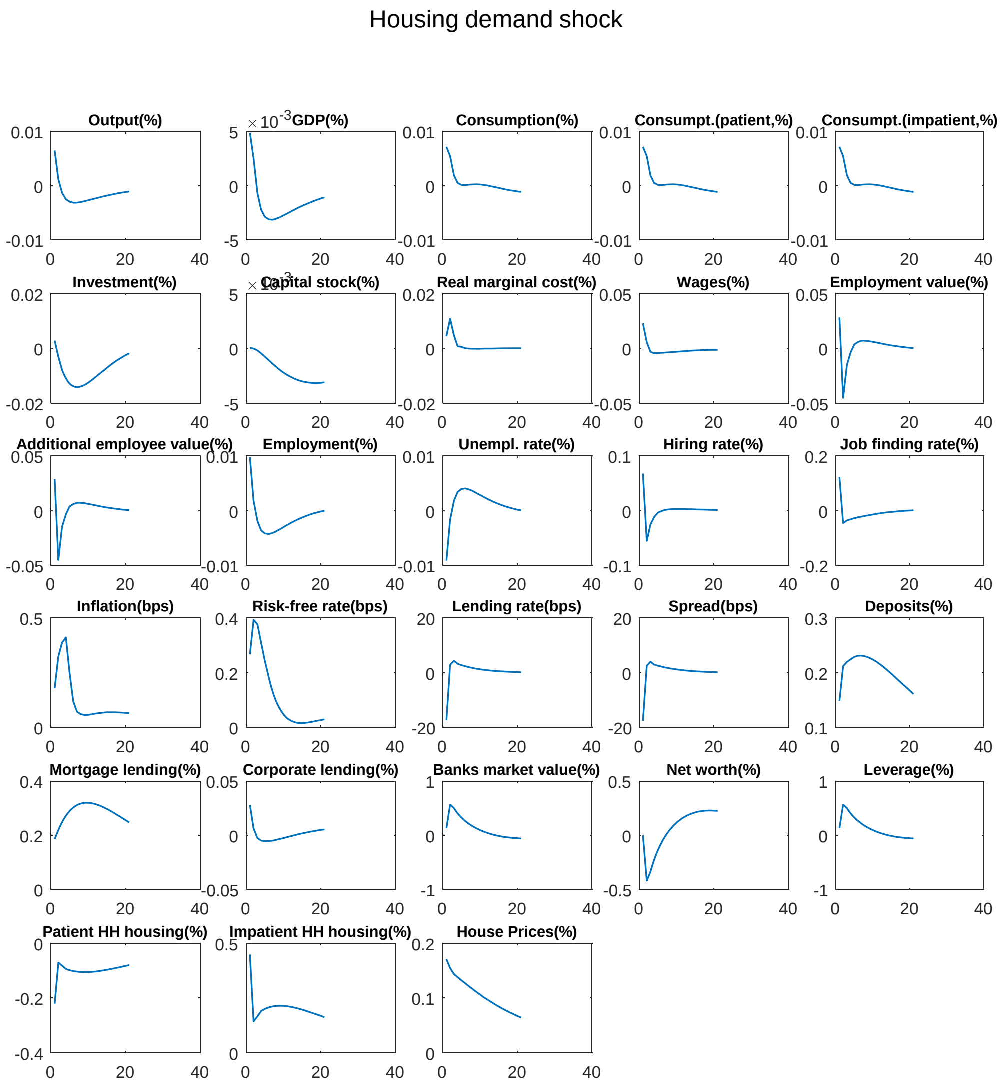

Chart 14: Effect of a shock to banks' underwriting standards (LTV ratio)

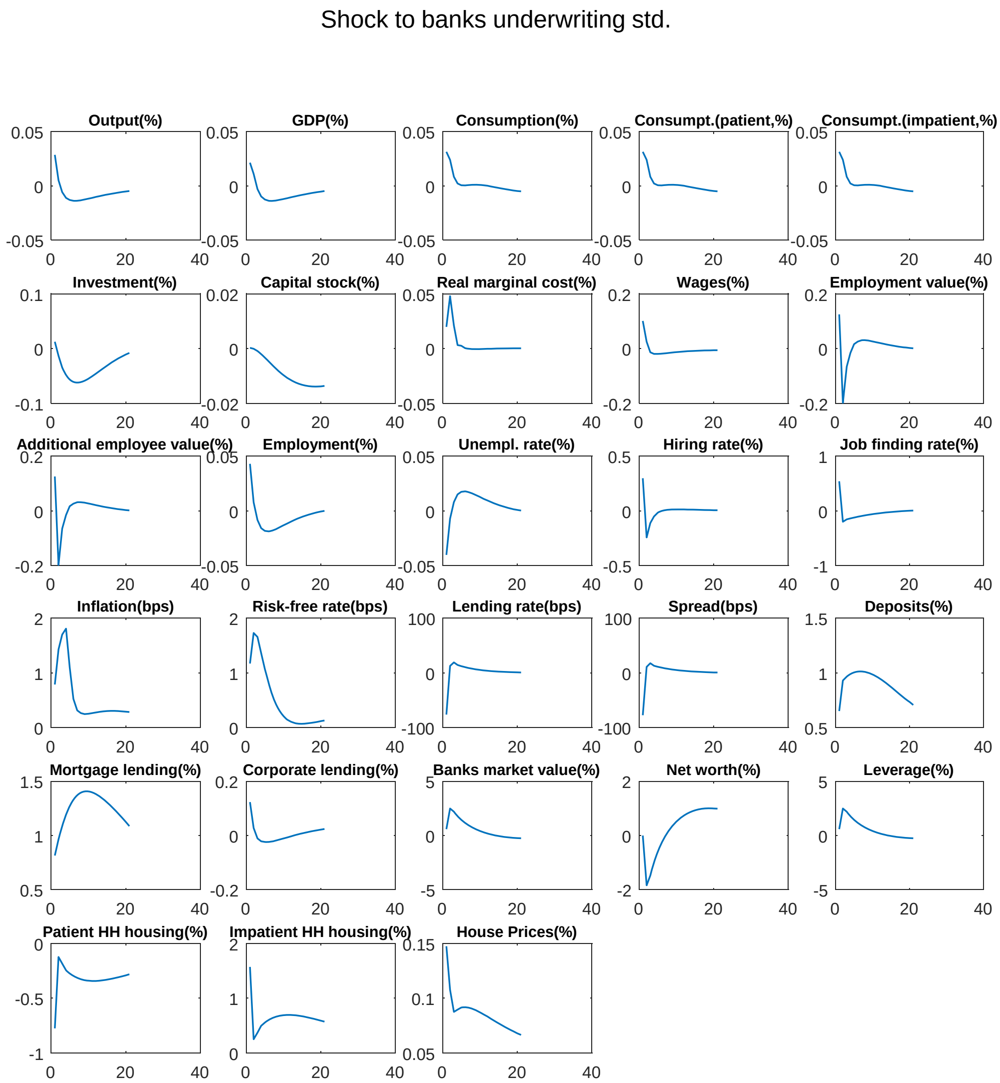

Chart 15: Effect of a shock to bank equity prices