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The anatomy of standard DSGE models with financial frictions

Michał Brzoza-Brzezina[a,b], Marcin Kolasa[a,b], Krzysztof Makarski[a,b,*]

[a] National Bank of Poland, Świętokrzyska 11/21, 00-919 Warszawa, Poland
[b] Warsaw School of Economics, Al. Niepodległości 162, 02-554 Warszawa, Poland

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ABSTRACT

We compare two standard extensions to the New Keynesian framework that feature financial frictions. The first model, originating from Kiyotaki and Moore (1997), is based on collateral constraints. The second, developed by Carlstrom and Fuerst (1997) and Bernanke et al. (1999), accentuates the role of external finance premia. We tweak the models and calibrate them in a way that allows for both qualitative and quantitative comparisons. Next, we thoroughly analyze the two variants using moment matching, impulse response analysis and business cycle accounting. Overall, we find that the business cycle properties of the external finance premium framework are more in line with empirical evidence. In particular, the collateral constraint model fails to produce hump-shaped impulse responses and generates volatilities of the price of capital and rate of return on capital that are inconsistent with the data by a large margin.

1. Introduction

The 2007–2010 financial crisis has shown how deep an impact financial markets can have on macroeconomic developments. Shocks originating from the American subprime mortgage market spread worldwide, affecting interbank and property markets in developed and developing economies. Financial institutions transmitted these shocks further, restricting lending and raising the cost of borrowing. As a result, consumers reduced consumption, enterprises cut investment and the world economy witnessed the first recession since WWII.

One of the important lessons from the crisis was that financial markets matter for the economy and should be taken into account when constructing macromodels. This resulted in a surge of interest in theoretical frameworks incorporating financial frictions. Models with imperfect financial markets were used to study important topical issues, like (i) the impact of financial frictions on monetary transmission (Calza et al., 2012; Gerali et al., 2010; Christiano et al., 2010), (ii) optimal monetary policy in the presence of financial frictions (Cúrdia and Woodford, 2009; De Fiore and Tristani, 2009; Carlstrom et al., 2010; Kolasa and Lombardo, 2011), (iii) the impact of financial shocks on the economy (Christiano et al., 2003; Iacoviello and Neri, 2010; Brzoza-Brzezina and Makarski, 2011) or (iv) capital regulations and macroprudential policies (Angelini et al., 2010; Angeloni and Faia, 2009; Meh and Moran, 2010; Jeanne and Korinek, 2010). Finally, it should be mentioned that financial frictions have recently been added to models used for policy purposes at several central banks.[1]

* Corresponding author. Economic Institute, National Bank of Poland, Świętokrzyska 11/21, 00-919 Warszawa, Poland. Tel.: +48 22 653 2118; fax: +48 22 826 9935.
E-mail address: krzysztof.makarski@nbp.pl (K. Makarski).

[1] See Jonsson et al. (2010) for an extensive review.

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This includes the Riksbank's model RAMSES (Christiano et al., 2011) and the European Central Bank's NAWM (Lombardo and McAdam, 2012).

Studying the enumerated problems requires a modeling framework that is able to account for macrofinancial linkages observed in the data. There exists a strong and two-sided link between the business cycle and systemic risk. Debt usually increases during upturns, while deleveraging observed during recessions makes them more severe (Borio, 2003). Hence, understanding how financial market imperfections affect the macro economy is very important for the design of effective stabilization policies.

The financial frictions literature is mostly based on two alternative approaches developed long before the crisis. One important direction was introduced by the seminal paper of Kiyotaki and Moore (1997) and extended by Iacoviello (2005). This line of research introduces financial frictions via collateral constraints. Agents are heterogeneous in terms of their rate of time preference, which divides them into lenders and borrowers. The financial sector intermediates between these groups and introduces frictions by requiring that borrowers provide collateral for their loans. Hence, this approach introduces frictions that affect directly the quantity of loans.

The second stream of research originates from the seminal paper of Bernanke and Gertler (1989), where financial frictions have been incorporated into a general equilibrium model. This approach was further developed by Carlstrom and Fuerst (1997) and merged with the New Keynesian framework by Bernanke et al. (1999), becoming the workhorse financial accelerator model in the 2000s. In this model, frictions arise because monitoring a loan applicant is costly, which drives an endogenous wedge between the lending rate and the risk free rate. This means that financial frictions affect the economy via prices of loans rather than via quantities as in models based on collateral constraints.

Our contribution is a thorough comparison of the consequences of introducing collateral constraints (referred to as CC) and external finance premia (EFP) into a standard medium-sized New Keynesian (NK) DSGE model. Since we are interested in comparing the business cycle properties of two different types of financial frictions, we keep the CC and EFP versions identical in all aspects but the financial sector. We explain analytically the differences between the two modeling approaches and examine them quantitatively using moment comparison, impulse response analysis and business cycle accounting (BCA).

We find that both models with financial frictions improve some of the NK model's business cycle properties. First, they do a better job when matching the volatilities of some key variables (output, investment, consumption). Second, consistently with the data, but in contrast to the NK framework, they give a significant role to the investment wedge in the BCA exercise. However, contrary to popular belief, there are important differences between the two modeling alternatives. In particular, the CC setup shows several features that spoil its business cycle properties and might make its usage in policy analysis problematic. More specifically

- it generates volatilities of some variables (e.g. the price of capital, the return on capital) that are inconsistent with empirical evidence by a large margin,
- it has a weak internal propagation mechanism. For instance, reactions of several variables (e.g. output, investment) to monetary policy shocks are sharp and short-lived, with the strongest response occurring on impact. This is inconsistent with the existing VAR evidence, which shows hump-shaped reaction patterns,
- these features generate several further undesirable effects. For instance, after a positive productivity shock, a sharp decline in the price of capital results in falling output on impact. Furthermore, the debt deflation effect after a monetary policy shock is so strong that it overrides the smoothing effects of adjustment costs on investment.

The rest of the paper is structured as follows. Section 2 sketches the baseline NK model, Section 3 presents and compares analytically the two versions of financial frictions. Section 4 discusses the calibration, Section 5 presents the impulse response analysis and Section 6 presents the results of business cycle accounting. Section 7 concludes.

2. The benchmark NK model

Our baseline NK specification is a standard medium-sized closed economy DSGE model with sticky prices and a range of other frictions that have been found crucial for ensuring a reasonable empirical fit (see Christiano et al., 2005; Smets and Wouters, 2003). The model economy is populated by households, producers, as well as fiscal and monetary authorities. Households consume, accumulate capital stock and work. Output is produced in several steps, including a monopolistically competitive sector with producers facing price rigidities. Fiscal authorities use taxes to finance exogenously given government expenditure and the monetary authority conducts monetary policy according to a Taylor rule.

2.1. Households

The economy is populated by households of measure one. Each household h chooses consumption c_t, labor supply n_t and capital holdings for the next period k_t to maximize the expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(c_t(h) - \xi c_{t-1})^{1-\sigma_c}}{1-\sigma_c} - \frac{n_t(h)^{1+\sigma_n}}{1+\sigma_n} \right] \tag{1}$$

where ξ denotes the degree of external habit formation. Households use labor income $W_t n_t$, capital income $R_{k,t}k_{t-1}$, dividends[2] Π_t and undepreciated capital holdings from the previous period $(1-\delta)k_{t-1}$ to finance their expenditures and lump sum taxes T_t. Each household faces the following budget constraint:

$$P_t c_t(h)+Q_t k_t(h)+E_t\{\Upsilon_{t+1}B_t(h)\} \le W_t n_t(h)+(R_{k,t}+Q_t(1-\delta))k_{t-1}(h)-P_t T_t(h)+\Pi_t(h)+B_{t-1}(h) \tag{2}$$

where P_t and Q_t denote, respectively, the price of a consumption good and capital. As in Chari et al. (2002), we assume that agents have access to state contingent bonds B_t, traded at price $\Upsilon_{t,t+1}$, which allows them to insure against idiosyncratic risk. The expected gross rate of return $[E_t\{\Upsilon_{t+1}\}]^{-1}$ is equal to the risk-free interest rate R_t, fully controlled by the monetary authority.

2.1.1. Labor supply

We assume that each household has a unique labor type h. Labor services are sold to perfectly competitive aggregators, who pool all labor types into one undifferentiated labor service with the following function:

$$n_t = \left(\int_0^1 n_t(h)^{1/\phi_w}\, dh\right)^{\phi_w} \tag{3}$$

The static profit maximization problem of the aggregator gives the following demand for labor of type h:

$$n_t(h) = \left(\frac{W_t(h)}{W_t}\right)^{-\phi_w/(\phi_w-1)} n_t \tag{4}$$

where

$$W_t = \left(\int_0^1 W_t(h)^{-1/(\phi_w-1)}\, dh\right)^{-(\phi_w-1)} \tag{5}$$

is the aggregate wage in the economy.

Households set their wage rate according to the standard Calvo scheme, i.e. with probability $(1-\theta_w)$ they receive a signal to reoptimize and then set their wage to maximize their utility subject to the demand for their labor services. With probability θ_w they do not receive the signal and index their wage according to the following rule:

$$W_t(h) = ((1-\zeta_w)\overline{\pi}+\zeta_w \pi_{t-1})W_{t-1}(h) \tag{6}$$

where $\pi_t \equiv P_t/P_{t-1}$, $\overline{\pi}$ is the steady state inflation rate and $\zeta_w \in [0,1]$ is the degree of wage indexation.

2.2. Producers

There are several stages of production in the economy. Intermediate goods firms produce differentiated goods and sell them to aggregators. Aggregators combine differentiated goods into a homogeneous final good. The final good can be used for consumption or sold to capital good producers.

2.2.1. Capital good producers

Capital good producers act in a perfectly competitive environment. In each period a representative capital good producer buys i_t of final goods and old undepreciated capital $(1-\delta)k_{t-1}$. Next, she transforms old undepreciated capital one-to-one into new capital, while transformation of the final good is subject to an adjustment cost $S(i_t/i_{t-1})$. We adopt the specification of Christiano et al. (2005) and assume that $S(1)=S'(1)=0$ and $S''(1)=\kappa>0$. Thus, the technology to produce new capital is given by

$$k_t = (1-\delta)k_{t-1} + \left(1-S\left(\frac{i_t}{i_{t-1}}\right)\right)i_t \tag{7}$$

The new capital is then sold in a perfectly competitive market to households and can be used in the next period production process. The real price of capital is denoted as $q_t \equiv Q_t/P_t$.

2.2.2. Final good producers

Final good producers play the role of aggregators. They buy differentiated products from intermediate goods producers $y(j)$ and aggregate them into a single final good, which they sell in a perfectly competitive market. The final good is produced according to the following technology:

$$y_t = \left(\int_0^1 y_t(j)^{1/\phi}\, dj\right)^{\phi} \tag{8}$$

[2] Households own all firms in this economy.

The static profit maximization problem of the aggregator gives the following demand functions for differentiated goods:

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\phi/(\phi-1)} y_t \tag{9}$$

where

$$P_t = \left(\int_0^1 P_t(j)^{-1/(\phi-1)}\, dj\right)^{-(\phi-1)} \tag{10}$$

2.2.3. Intermediate goods producers

There is a continuum of intermediate goods producers of measure one denoted by j. They rent capital and labor from households and use the following production technology:

$$y_t(j) = A_t k_t(j)^{\alpha} n_t(j)^{1-\alpha} \tag{11}$$

where A_t is the total factor productivity, the log of which follows an exogenous $AR(1)$ process.[3]

Intermediate goods firms act in a monopolistically competitive environment and set their prices according to the standard Calvo scheme. In each period each producer receives with probability $(1-\theta)$ a signal to reoptimize and then sets her price to maximize the expected profits, subject to demand schedules given by (9). Those who are not allowed to reoptimize index their prices according to the following rule:

$$P_t(j) = P_{t-1}(j)((1-\zeta)\overline{\pi}+\zeta\pi_{t-1}) \tag{12}$$

where $\zeta \in [0,1]$ is the degree of price indexation.

2.3. Government

The government uses lump sum taxes to finance its expenditure. Since Ricardian equivalence holds, we assume that its budget is balanced each period so that

$$g_t = T_t \tag{13}$$

where g_t denotes exogenous government expenditure.[4]

2.4. Central bank

As it is common in the New Keynesian literature, we assume that monetary policy is conducted according to a Taylor rule that responds to deviations of inflation and output from the deterministic steady state, allowing additionally for interest rate smoothing

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\gamma_R} \left(\left(\frac{\pi_t}{\overline{\pi}}\right)^{\gamma_\pi} \left(\frac{y_t}{\overline{y}}\right)^{\gamma_y}\right)^{1-\gamma_R} e^{\varphi_t} \tag{14}$$

where a bar over a variable denotes its steady state value and φ_t are i.i.d. innovations (the standard deviation is σ_R).

2.5. Market clearing

To close the model, we need the market clearing condition for the final goods market

$$c_t + i_t + g_t = y_t \tag{15}$$

Finally, the factor markets need to clear as well

$$k_{t-1} = \int_0^1 k_t(j)\, dj \tag{16}$$

$$n_t = \int_0^1 n_t(j)\, dj \tag{17}$$

[3] The autoregressive coefficient is ρ_A and the standard deviation is σ_A.

[4] The log of g_t follows an AR(1) process, with autoregressive coefficient ρ_g, standard deviation of innovations σ_g, and mean $\ln \mu_g$.

3. Financial frictions

In the NK model presented above, financial markets do not generate any distortions. In particular, households can trade in state contingent claims, available at any quantity and paying the expected rate of return equal to the risk-free rate R_t. This will no longer be the case in the extensions discussed in this section.

Implementing any credit imperfections requires distinguishing between borrowers and lenders. As in both EFP and CC versions financial frictions emerge at the level of capital management, its ownership needs to be separated from the households. Therefore, one introduces a new type of agents, named entrepreneurs, who specialize in capital management.[5] Entrepreneurs finance their operations, i.e. renting capital services to firms, by taking loans from the banking sector, which refinances them by accepting deposits from households. This financial intermediation is subject to frictions, which manifest themselves in interest rate spreads or quantity constraints.

3.1. External finance premium version (EFP)

In the EFP version, financial frictions arise because management of capital is risky. Individual entrepreneurs are subject to idiosyncratic shocks, which are observed by them for free, while the lenders can learn about the shocks' realizations only after paying monitoring costs. This costly state verification problem (Townsend, 1979) results in a financial contract featuring an endogenous premium between the lending rate and the risk-free rate. Since the banking sector is perfectly competitive and owned by risk-averse households while entrepreneurs are risk-neutral, banks pay interest on household deposits equal to the risk-free rate and break even every period.

3.1.1. Entrepreneurs

There is a continuum of risk-neutral entrepreneurs, indexed by $\imath$. At the end of period t, each entrepreneur purchases installed capital $k_t(\imath)$ from capital producers, partly using her own financial wealth $V_t(\imath)$ and financing the remainder with a bank loan $L_t(\imath)$

$$L_t(\imath) = Q_t k_t(\imath) - V_t(\imath) \geq 0 \tag{18}$$

After the purchase, each entrepreneur experiences an idiosyncratic productivity shock, which converts her capital to $a_{E,t}(\imath)k_t(\imath)$, where $a_{E,t}(\imath)$ is a random variable, distributed independently over time and across entrepreneurs, with a cumulative density function F_t and a unit mean. Following Christiano et al. (2003), we assume that this distribution is log normal, with a time-varying standard deviation of log $a_{E,t}$ equal to $\varepsilon_{E,t}$.[6]

Next, each entrepreneur rents out capital services, treating the rental rate $R_{k,t+1}$ as given. Since the mean of an idiosyncratic shock is equal to one, the average rate of return on capital earned by entrepreneurs is

$$R_{E,t+1} \equiv \frac{R_{k,t+1} + (1-\delta)Q_{t+1}}{Q_t} \tag{19}$$

and the rate of return earned by an individual entrepreneur is $a_{E,t}(\imath)R_{E,t+1}$.

Since lenders can observe the return earned by borrowers only at a cost, the optimal contract between these two parties specifies the size of the loan $L_t(\imath)$ and the gross non-default interest rate $R_{L,t+1}(\imath)$. The solvency criterion can also be defined in terms of a cutoff value of idiosyncratic productivity, denoted as $\tilde{a}_{E,t+1}(\imath)$, such that the entrepreneur has just enough resources to repay the loan[7]

$$\tilde{a}_{E,t+1} R_{E,t+1} Q_t k_t(\imath) = R_{L,t+1} L_t(\imath) \tag{20}$$

Entrepreneurs with $a_{E,t}$ below the threshold level go bankrupt. All their resources are taken over by the banks, after they pay a proportional monitoring cost μ.

3.1.2. Banks

Banks finance their loans by issuing time deposits to households at the risk-free interest rate R_t. The banking sector is assumed to be perfectly competitive and owned by risk-averse households. This, together with risk-neutrality of entrepreneurs implies that an optimal financial contract insulates the lender from any aggregate risk.[8] Hence, interest paid by entrepreneurs is state contingent and guarantees that banks break even in every period. As a result, the lending rate $R_{L,t+1}$ is implicitly defined by the aggregate zero profit condition for the banking sector

$$(1-F_{1,t+1})R_{L,t+1}L_t + (1-\mu)F_{2,t+1}R_{E,t+1}Q_t k_t = R_t L_t \tag{21}$$

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[5] This means in particular that terms related to capital management drop out from households' budget constraint (2).

[6] The log of $\varepsilon_{E,t}$ follows an AR(1) process, with autoregressive coefficient ρ_E, standard deviation of innovations σ_E, and mean ln σ_{a_E}.

[7] In order to save on notation, in what follows we use the result established later on, according to which the cutoff productivity $\tilde{a}_E(\imath)$ and the non-default interest paid on a bank loan $R_{B,t+1}(\imath)$ is identical across entrepreneurs.

[8] Given the infinite number of entrepreneurs, the risk arising from idiosyncratic shocks is fully diversifiable.

which can be equivalently written as (using (20))

$$R_{E,t+1}\varrho_t[\tilde{a}_{E,t+1}(1-F_{1,t+1})+(1-\mu)F_{2,t+1}]=(\varrho_t-1)R_t \tag{22}$$

where the leverage ratio is

$$\varrho_t \equiv \frac{Q_t k_t}{V_t} \tag{23}$$

and

$$F_{1,t} \equiv \int_0^{\tilde{a}_{E,t}} dF(a_{E,t}) \tag{24}$$

$$F_{2,t} \equiv \int_0^{\tilde{a}_{E,t}} a_{E,t}\, dF(a_{E,t}) \tag{25}$$

3.1.3. Optimal contract

The equilibrium debt contract maximizes welfare of each individual entrepreneur. It is defined in terms of expected end-of-contract net worth relative to the risk-free alternative, which is holding a domestic bond

$$E_t\left\{\frac{\int_{\tilde{a}_{E,t}}^{\infty}(R_{E,t+1}Q_t k_t(\imath)a_E(\imath)-R_{L,t+1}L_t(\imath))\, dF(a_E(\imath))}{R_t V_t(\imath)}\right\} \tag{26}$$

or equivalently (using (20), (23)–(25))

$$E_t\left\{\frac{R_{E,t+1}}{R_t}\varrho_t(\imath)(1-F_{2,t+1}(\imath)-\tilde{a}_{E,t+1}(\imath)[1-F_{1,t+1}(\imath)])\right\} \tag{27}$$

The optimization problem is to choose the leverage ratio ϱ_t such that (27) is maximized, subject to banks' zero profit condition (22). The first-order condition can be written as

$$E_t\left\{\frac{R_{E,t+1}}{R_t}[1-\tilde{a}_{E,t+1}(1-F_{1,t+1})-F_{2,t+1}]+\frac{(1-F_{1,t+1})\left(\frac{R_{E,t+1}}{R_t}[\tilde{a}_{E,t+1}(1-F_{1,t+1})+(1-\mu)F_{2,t+1}]-1\right)}{1-F_{1,t+1}-\mu\tilde{a}_{E,t+1}F'_{1,t+1}}\right\}=0 \tag{28}$$

Eq. (28), together with the bank zero profit condition (22), defines the optimal debt contract in terms of the cutoff value of the idiosyncratic shock $\tilde{a}_{E,t+1}$ and the leverage ratio ϱ_t. It is easy to verify that these two contract parameters are identical across entrepreneurs. Similarly, the rate of interest paid to the bank is the same for each non-defaulting entrepreneur

$$R_{L,t+1}=\frac{\tilde{a}_{E,t+1}R_{E,t+1}\varrho_t}{\varrho_t-1} \tag{29}$$

We refer to the ratio of this rate to the risk-free rate R_t as the credit spread.

3.1.4. Net worth evolution and resource constraint

Proceeds from selling capital, net of interest paid to the banks, constitute end of period net worth. To capture the phenomenon of ongoing entries and exits of firms and to ensure that entrepreneurs do not accumulate enough wealth to become fully self-financing, it is assumed that each period a randomly selected and time-varying fraction $(1-\varepsilon_{v,t})$[9] of them go out of business, in which case all their financial wealth is rebated to the households. At the same time, an equal number of new entrepreneurs enters so that their total number is constant. Those who survive or enter receive a fixed transfer T_E from households. This ensures that entrants have at least a small but positive amount of wealth, without which they would not be able to buy any capital.

Aggregating across all entrepreneurs and using (22) yields the following law of motion for net worth in the economy:

$$V_t=\varepsilon_{v,t}\left[R_{E,t}Q_{t-1}k_{t-1}-\left(R_{t-1}+\frac{\mu F_{2,t}R_{E,t}Q_{t-1}k_{t-1}}{L_{t-1}}\right)L_{t-1}\right]+T_E \tag{30}$$

The term in the square brackets represents the total revenue from renting and selling capital net of interest paid on bank loans, averaged over both bankrupt and non-bankrupt entrepreneurs.

Finally, as monitoring costs are real, the aggregate resource constraint from the NK model (15) needs to be modified

$$c_t+i_t+g_t+\mu F_{2,t}R_{E,t}q_{t-1}k_{t-1}=y_t \tag{31}$$

[9] The log of $\varepsilon_{v,t}$ follows and AR(1) process, with autoregressive coefficient ρ_v, standard deviation σ_v, and mean ln v.

3.2. Collateral constraint version (CC)

The key financial friction in the CC version is introduced by assuming that entrepreneurs need collateral to take a loan. The restrictiveness of this constraint is perturbed stochastically in the form of a shock to the required loan-to-value (LTV) ratio. Additionally, to ensure comparability with the EFP version, we assume that the interest rate on loans differs from the risk-free rate. The difference is due to monopolistic competition in the banking sector and is subject to exogenous shocks.

In order to introduce monopolistic competition, banking activity is divided into two steps. First, banks collect deposits from households and use them to offer differentiated loans to financial intermediaries. Financial intermediaries aggregate all differentiated loans into a homogeneous loan that is offered to entrepreneurs.

3.2.1. Entrepreneurs and resource constraint

There is a continuum of entrepreneurs, indexed by $\imath$. They draw utility only from their consumption c_t^E

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \frac{(c_t^E(\imath) - \xi c_{t-1}^E)^{1-\sigma_c}}{1-\sigma_c} \tag{32}$$

Entrepreneurs cover their consumption and capital expenditures with revenues from renting capital services to intermediate goods producers, financing the remainder by bank loans L_t, on which the interest to pay is $R_{L,t}$[10]

$$P_t c_t^E(\imath) + Q_t k_t(\imath) + R_{L,t-1} L_{t-1}(\imath) + \tilde{T}_E = (R_{k,t} + Q_t(1-\delta)) k_{t-1}(\imath) + L_t(\imath) \tag{33}$$

where $\tilde{T}_E$ denotes transfers between households and entrepreneurs.[11] Loans taken by the entrepreneurs are subject to the following collateral constraint:

$$R_{L,t} L_t(\imath) \le m_t E_t \{Q_{t+1}(1-\delta) k_t(\imath)\} \tag{34}$$

where m_t is the loan-to-value ratio, the log of which follows an $AR(1)$ process.[12] This states that the loan to repay cannot exceed the expected future value of collateral multiplied by the LTV ratio. As in Kiyotaki and Moore (1997), the constraint is assumed to bind eternally.

The first order condition obtained after taking the derivative with respect to k_t takes the following form:

$$1 = \beta_E E_t \left\{ \frac{u_{c,t+1}^E}{u_{c,t}^E} \frac{R_{E,t+1}}{\pi_{t+1}} \right\} + \Theta_t m_t (1-\delta) E_t \left\{ \frac{Q_{t+1}}{Q_t} \right\} \tag{35}$$

where $(\beta_E^t u_{c,t}^E / P_t) \Theta_t$ denotes the Lagrange multiplier on (34) and $u_{c,t}^E$ is the derivative of entrepreneurs' instantaneous utility function with respect to c_t^E. Similarly, by taking the derivative with respect to L_t, we get

$$1 = \beta_E E_t \left\{ \frac{u_{c,t+1}^E}{u_{c,t}^E} \frac{R_{L,t}}{\pi_{t+1}} \right\} + \Theta_t R_{L,t} \tag{36}$$

Finally, since entrepreneurs consume, the modified aggregate resource constraint is

$$c_t + i_t + g_t + c_t^E = y_t \tag{37}$$

3.2.2. The financial system

The financial system consists of monopolistically competitive banks and financial intermediaries operating under perfect competition. This two-stage structure is necessary to introduce time-varying interest rate spreads.

Financial intermediaries take differentiated loans from banks $L_t(i)$ at the interest rate $R_{L,t}$ and aggregate them into one undifferentiated loan L_t that is offered to entrepreneurs at the rate $R_{L,t}(i)$. The technology for aggregation is

$$L_t = \left[\int_0^1 L_t(i)^{1/\phi_{L,t}} \, di \right]^{\phi_{L,t}} \tag{38}$$

where $\phi_{L,t}$ is a measure of substitutability between loan varieties, the log of which follows an exogenous $AR(1)$ process.[13] Financial intermediaries operate in a competitive market, thus they take the interest rates as given and maximize their profits subject to (38).

By solving the problem defined above we obtain the demand for banks' loans

$$L_t(i) = \left(\frac{R_{L,t}(i)}{R_{L,t}} \right)^{-\phi_{L,t}/(\phi_{L,t}-1)} L_t \tag{39}$$

[10] In contrast to the EFP framework, the nominal interest rate on loans is not state contingent, i.e. it is determined while taking the loan.

[11] These transfers are introduced to insure comparability in calibration of the two frameworks (see Section 4).

[12] The autoregressive coefficient is ρ_m, the standard deviation is σ_m, and the mean is $\ln m$.

[13] The autoregressive coefficient is ρ_{ϕ_L}, the standard deviation is σ_{ϕ_L}, and the mean is $\ln \phi_L$.

and the interest rate on loans to entrepreneurs

$$R_{L,t} = \left(\int_0^1 R_{L,t}(i)^{-1/(\phi_{L,t}-1)} \, di \right)^{-(\phi_{L,t}-1)} \tag{40}$$

Each bank i collects deposits $D_t(i)$ from households at the risk-free rate R_t, and uses them for lending to financial intermediaries $L_t(i)$ at the interest rate $R_{L,t}(i)$. Banks set their interest rates to maximize profits subject to the demand for loans (39). The solution to this problem yields the following relationship between the lending rate and the policy rate:

$$R_{L,t} = \phi_{L,t} R_t \tag{41}$$

Note that $\phi_{L,t}$ introduces a time-varying credit spread. We refer to its innovations as spread shocks.

3.3. *The essence of financial frictions*

To provide more insight into the workings of financial frictions, we focus on each model's key equilibrium condition determining the investment decisions.

In the baseline NK model described in Section 2, households choose capital purchases to maximize their expected lifetime utility (1), subject to the budget constraint (2). The associated first-order condition, using definition (19) and ignoring aggregate uncertainty to facilitate exposition, implies equalization between the rate of return on capital and the risk-free rate

$$R_{E,t+1} = R_t \tag{42}$$

In the EFP version, the counterpart of Eq. (42) is equilibrium condition (28), which can be rewritten, after dropping the expectations operator, as

$$R_{E,t+1} = (1+\chi^{EFP}(\tilde{a}_{E,t+1}))R_t \tag{43}$$

It is easy to verify that if $\mu = 0$, i.e. monitoring by banks is free, then $\chi^{EFP} = 0$, Eq. (43) simplifies to (42) and financial markets work without frictions. Otherwise, asymmetric information results in an endogenous wedge between the rate of return on capital and the risk-free rate. As shown by Bernanke et al. (1999), for any $\tilde{a}_{E,t+1}$ that can be an equilibrium, $\chi' > 0$ and there is a positive relationship between $\tilde{a}_{E,t+1}$ and ϱ_t. This implies that the external finance premium increases with leverage.

In the CC version, from (35), (36), and (41) we get the following equation replacing (42):

$$R_{E,t+1} = (1+\Theta_t \chi^{CC}(m_t, Q_{t+1}, Q_t, R_{k,t+1}))\phi_{L,t} R_t \tag{44}$$

where $\chi^{CC} > 0$. This shows how the collateral constraint and monopolistic competition in the banking industry drive a wedge between the return on capital and the (risk-free) policy rate. If the collateral constraint is not binding ($\Theta_t = 0$) and the banking industry is perfectly competitive ($\phi_{L,t} = 1$), then financial frictions disappear. When the constraint tightens (Θ_t goes up) or monopoly power increases ($\phi_{L,t}$ goes up), the excess return on capital becomes larger.

4. Calibration

The main goal of our calibration is to achieve the highest possible comparability between the EFP and CC specifications. This task is not trivial since both versions have different forms of financial frictions. Nevertheless, we are able to succeed by applying a precise calibration procedure, the details of which are presented in Tables 1–3.

We start with the structural parameters unrelated to the financial sector and so common across the NK, EFP and CC versions. We take their values directly from the literature, relying mainly on Smets and Wouters (2007), or set them to match the key steady state proportions of the US data.

In each of our extensions to the NK setup, the financial sector is governed by four parameters,[14] which we use to pin down four steady state proportions: investment share in output, interest rate spread, capital-to-debt ratio and the output share of monitoring costs (EFP)/entrepreneurs' consumption (CC).[15] The first three have their natural empirical counterparts, which we match exactly. The target value for the last share is consistent with Christiano et al. (2011) and identical in both extensions. As a result, our calibration implies that in the steady-state the rates of return on capital, and hence the excess return on capital defined by Eqs. (43) and (44), are the same in the EFP and CC versions.

We apply a similar procedure to calibration of stochastic processes. We first calibrate the shocks that are common for the NK, EFP and CC models. The properties of technology shocks are taken from Cooley and Prescott (1995) and the volatility of monetary shocks comes from Smets and Wouters (2007). For government expenditures, we set the autoregressive coefficient at 0.95, which is standard in the literature, and calibrate the standard deviation to match it with the data on real government spending. Next, we calibrate the financial shocks in the EFP and CC models. In the

[14] These parameters are μ, ν, σ_{a_E}, T_E (EFP model) and β_E, ϕ_L, m, $\tilde{T}_E$ (CC model).

[15] Entrepreneurs' consumption is treated in a similar way as monitoring costs, i.e. as a part of government spending, in all simulations, as well as in the business cycle accounting exercise presented in Section 6.

Table 1
Structural parameters.

Parameter	Values	Description
Households		
β	0.995	Discount rate
σ_c	2.0	Inverse of intertemporal elasticity of substitution
σ_n	2.0	Inverse of Frisch elasticity of labor supply
ξ	0.6	Degree of external habit formation
ϕ_w	1.2	Labor markup
θ_w	0.7	Calvo probability for wages
ζ_w	0.58	Indexation parameter for wages
Producers		
α	0.33	Product elasticity with respect to capital
ϕ	1.1	Product markup
δ	0.025	Depreciation rate
κ	5.74	Investment adjustment cost
θ	0.66	Calvo probability for prices
ζ	0.24	Indexation parameter for prices
Taylor rule		
γ_R	0.8	Interest rate smoothing
γ_π	1.5	Response to inflation
γ_y	0.5	Response to output
Financial sector—EFP		
μ	0.10	Monitoring costs
ν	0.977	Survival rate for entrepreneurs
σ_{a_E}	0.29	Steady state st. deviations of idiosyncratic productivity
T_E	0.029	Transfers to entrepreneurs (relative to steady state output)
Financial sector—CC		
β_E	0.985	Entrepreneurs discount factor
ϕ_L	1.002	Loan markup
m	0.52	Steady state LTV
$\tilde{T}_E$	0.002	Transfers to entrepreneurs (relative to steady state output)

Table 2
Stochastic processes.

Parameter	Values	Description
Common shocks—same in both models		
ρ_A	0.95	Productivity shock
σ_A	0.007	Productivity shock
ρ_G	0.95	Government spending shock
σ_G	0.012	Government spending shock
σ_R	0.001	Monetary policy shock
Financial sector shocks—EFP		
ρ_ν	0.84	Net worth shock
σ_ν	0.006	Net worth shock
ρ_E	0.83	Entrepreneur riskiness shock
σ_E	0.012	Entrepreneur riskiness shock
Financial sector shocks—CC		
ρ_m	0.96	LTV shock
σ_m	0.016	LTV shock
ρ_{ϕ_L}	0.85	Spread shock
σ_{ϕ_L}	0.002	Spread shock

former, we have net worth and entrepreneur riskiness shocks, while in the latter we have LTV and bank markup shocks.[16] These shocks are different but they govern the behavior of two financial variables appearing in both models: spreads and

[16] While these financial shocks are standard in the literature using the CC and EFP frameworks, we also experimented with using alternative sets of shocks to match the moments for spreads and loans. These included shocks to the remaining parameters describing the financial sector, i.e. monitoring costs in the EFP model, entrepreneurs' preferences in the CC model and transfers to entrepreneurs in both versions (compare Table 1). These experiments failed as either it was impossible to match the moments of the two financial variables with shocks of a reasonable volatility, or the matching came at the expense of spoiling the rest of calibration (e.g. by moving the standard deviation of key macroaggregates far away from the data).

Table 3
Steady state ratios.

Variable	Values
Consumption share in output	0.63
Government expenditure share in output	0.16
Investment share in output	0.21
Steady state inflation rate	1.006
Spread	0.002
Capital-to-debt ratio	2.0
Monitoring costs (EFP)/entrepreneurs cons. (CC) share in output	0.005

Table 4
Variance decomposition.

Variable	Product.	Gov.	Mon.	Net worth/LTV	Riskiness/spread
NK version					
Output	98.5	0.9	0.5	–	–
Labor	95.6	3.4	1.0	–	–
Consumption	88.8	10.6	0.6	–	–
Investment	93.7	5.9	0.3	–	–
Inflation	99.8	0.2	0.0	–	–
Interest rate	99.0	0.5	0.6	–	–
Real price of capital	78.6	7.5	13.9	–	–
Real ret. on capital	91.3	1.1	7.6	–	–
EFP version					
Output	46.1	0.9	0.8	49.0	3.3
Labor	70.0	2.8	0.8	21.5	5.0
Consumption	47.8	5.8	0.3	42.2	3.8
Investment	0.9	0.8	0.6	80.7	17.0
Loans	26.4	0.5	0.4	56.9	15.8
Inflation	63.6	0.0	0.2	35.7	0.5
Interest rate	65.0	0.1	0.9	33.7	0.3
Spread	3.3	0.0	0.2	17.0	79.5
Real price of capital	7.9	0.9	2.4	13.5	75.3
Real ret. on capital	31.7	0.6	3.1	4.8	59.9
CC version					
Output	59.1	0.7	1.4	31.5	7.4
Labor	77.0	1.6	1.4	15.6	4.3
Consumption	70.0	8.3	0.3	11.7	9.6
Investment	23.6	1.3	1.5	50.1	23.5
Inflation	5.0	0.4	0.1	91.1	3.5
Interest rate	74.7	0.1	0.1	22.2	3.0
Real price of capital	72.8	0.2	0.4	24.8	1.8
Real ret. on capital	0.0	0.0	0.0	0.0	100.0

loans to firms. While calibrating these shocks, we simulate both models with the three standard shocks (already calibrated) and the two financial sector shocks. We set the parameters of the latter to match autocorrelations and standard deviations of spreads and loans observed in the data. This procedure anchors the magnitude and inertia of financial sector shocks, thus enabling us to calibrate models with different financial sector structures in a coherent way.[17]

To show what our calibration strategy implies for the role played by different shocks in each model version, in Table 4, we present the results of the variance decomposition. In the NK variant, virtually all volatility of the main macroaggregates can be attributed to productivity shocks. This is no longer the case once we add financial frictions. It is worth noting that in both versions of our models with imperfect financial markets, financial shocks are very important, which is consistent with recent findings of Jermann and Quadrini (2012). The overall picture is very similar for the EFP and CC models. The highest share of variance in standard macroeconomic variables is driven by productivity and net worth/LTV shocks. One notable difference is the relatively low importance of non-financial shocks for investment in the EFP version. As regards financial variables (i.e. loans, spreads, the price of and the return on capital), financial shocks are even more important, accounting

[17] An interesting alternative would be to use the external finance premia defined in Eqs. (43) and (44) as model counterparts of credit spreads observed in the data (Carlstrom et al., 2010). However, following this line turned out to be impossible in practice due to the dynamics of the CC model. In particular, it generates the volatility of the external finance premium that significantly exceeds the volatility of spreads observed in the data even if we do not include financial shocks.

Table 5
Moments of the model generated variables against the data.

Variables	St. deviations				Autocorrelations				Corr. with output			
	Data	NK	EFP	CC	Data	NK	EFP	CC	Data	NK	EFP	CC
Output	2.30	1.79	1.87	1.90	0.93	0.99	0.98	0.92	1.00	1.00	1.00	1.00
Labor	2.41	1.84	2.15	2.59	0.96	0.82	0.86	0.75	0.69	−0.61	−0.40	−0.04
Cons.	2.34	1.48	2.13	1.80	0.96	0.99	0.99	0.99	0.86	0.89	0.54	0.57
Invest.	9.26	4.21	9.59	6.92	0.97	0.99	0.99	0.88	0.79	0.93	0.61	0.81
Loans	7.80	–	7.80	7.80	0.99	–	0.99	0.99	0.41	–	0.07	−0.05
Inflation	0.80	1.70	1.68	1.73	0.74	0.94	0.95	0.94	0.23	−0.86	−0.88	−0.69
Int. rate	0.81	1.50	1.45	1.64	0.95	0.99	0.99	0.98	0.04	−0.96	−0.93	−0.77
Spread	0.42	–	0.42	0.42	0.85	–	0.85	0.85	−0.45	–	−0.17	−0.23
Real price of capital	4.28	0.86	2.74	22.3	0.98	0.61	0.74	−0.02	−0.24	0.35	0.08	0.32
Real ret. on capital	1.25	0.52	0.92	22.9	0.92	0.51	0.73	0.00	0.47	−0.11	−0.11	−0.32

Sample for the US data: 1q1970–4q2008. Loans are defined as credit market instruments liabilities of nonfarm nonfinancial businesses (source: FRB) deflated with the GDP deflator. Inflation is the consumer price index. Interest rate is the federal funds rate. Spread is the difference between the industrial BBB corporate bond yield, backcasted using BAA corporate bond yields (source: Bloomberg), and the federal funds rate. Real price of capital is calculated as price of nonresidential fixed capital (source: BEA) deflated with the GDP deflator. Real return on capital is based on estimates provided by Mulligan and Threinen (2010).

for at least two-thirds of fluctuations. By construct, the spread in the CC model is entirely driven by spread shocks, but this variable is hardly affected by non-financial shocks also in the EFP version. An important difference across the two financial sector specifications concerns the role of productivity shocks for fluctuations of loans (negligible in the CC model) and the price of capital (relatively small in the EFP variant).

Given our method of calibration, we can compare the performance of the models along the dimensions that were not used in the calibration process. Table 5 documents several important business cycle features of the models. First, both financial frictions extensions improve upon the NK baseline in terms of matching the volatilities of output, consumption, investment and labor, though the EFP framework does a somewhat better job here. Second, all three models clearly overestimate the volatility of inflation and the interest rate. Finally, in contrast to EFP, the CC model generates fluctuations in the price of and return on capital that exceed those observed in the data by an order of magnitude.

There are further differences between the models when one looks at autocorrelations. The most notable one is very high autocorrelation of output, labor, consumption and investment in the EFP and NK models (in most cases higher than in the data) and substantially lower autocorrelation of these variables in the CC model (usually lower than in the data). Moreover, while the real price of and return on capital are moderately autocorrelated in the NK and EFP models (as in the data), they are close to white noise in the CC model.

Important differences between the models and the data also concern correlations of the main macrovariables with output. It is well known that a standard NK model with a dominant role of productivity shocks implies countercyclicality of labor, which is clearly at odds with the data. Both versions of financial frictions improve upon it in this respect, but none gets the sign right. A similar picture emerges with respect to inflation and the return on capital, which are procyclical in the data, but countercyclical in all three models. Furthermore, both financial frictions models clearly underestimate the procyclicality of consumption and, interestingly, neither of them is able to reproduce the procyclicality of loans. All in all, in terms of correlations of the main macrovariables with output, the financial frictions models do not substantially improve upon the NK model.

To sum up, adding financial market imperfections improves the NK framework in terms of matching standard deviations of the main macroaggregates. However, the CC setup raises the volatilities of some variables substantially too much. As regards autocorrelations, the EFP model generally increases the persistence of the NK framework, while the CC version brings it much below what is observed empirically. Finally, in terms of correlations with output, all three models look alike and show several features inconsistent with the data.

5. Impulse response analysis

A natural way to explain the results reported in the previous section is to compare the responses of the analyzed models to shocks. Such an analysis highlights and helps to understand the key differences in the propagation mechanisms embedded in various setups. We begin with the standard macroeconomic shocks (productivity and monetary policy), common to all model versions. We next move to shocks specific to the financial frictions literature (net worth, LTV, riskiness and spreads). As we have already mentioned, financial shocks differ in our two model variants by construction and so are not fully comparable. However, there is some conceptual analogy between the net worth shock in the EFP model and the LTV shock from the CC version. Similarly, a natural counterpart of the riskiness shock (EFP) is the spread shock (CC). Therefore, we present the impulse response analysis for the financial shocks by grouping them into these two pairs.

In Figs. 1, 2, 4, and 5, the impulse response functions for the EFP model are denoted with the solid line, for the CC model with the dashed line and for the standard NK model with the dotted line. Since there are no financial frictions in the NK model, we only present its impulse response functions to productivity and monetary shocks.

5.1. Productivity shock

Fig. 1 shows the reactions to a positive productivity shock. In all models, the shock lowers the marginal cost and drives inflation down. This process has a non-standard impact on the CC model. Lower inflation raises the real value of debt and forces the constrained agents to decumulate capital. Demand for capital falls, bringing down investment and the real price of capital. This in turn results in a further tightening of the collateral constraint, decreasing investment and output even more. As a result, the initial reactions of the real variables are non-standard, only in later periods the usual positive effects of higher productivity prevail.

In the EFP model, lower inflation also raises the real value of debt, thus increasing leverage. This results in higher spreads between the lending rate and the risk free rate. However, entrepreneurs do not face direct collateral constraints, so the effect of higher productivity on output prevails. Still, as tighter lending standards do not die out quickly, the expansion in investment is significantly weaker than in the standard NK model and in the medium run it also falls short of that in the CC version.

Overall, since debt in both models with financial frictions is nominal, an unexpected decrease in inflation resulting from a positive productivity shock leads to a debt deflation (Fisher) effect, which dampens the response of investment and output compared to the NK model. The dampening impact of the CC setup is mostly pronounced in the short run, while that of the EFP is spread over time.

5.2. Monetary policy shock

Fig. 2 presents the impulse responses to a monetary policy shock. Following the shock, nominal and real interest rates rise and, as in the standard NK model, aggregate demand declines. Lower demand for capital pushes its price down, which has an amplifying effect in models with financial frictions. In the CC version, lower value of collateral forces the constrained agents to save on investment. This drives the price of capital further down, tightening the lending constraint even more. As a result, investment and output sharply decline on impact, but then recover relatively quickly following the rise in the price of capital.

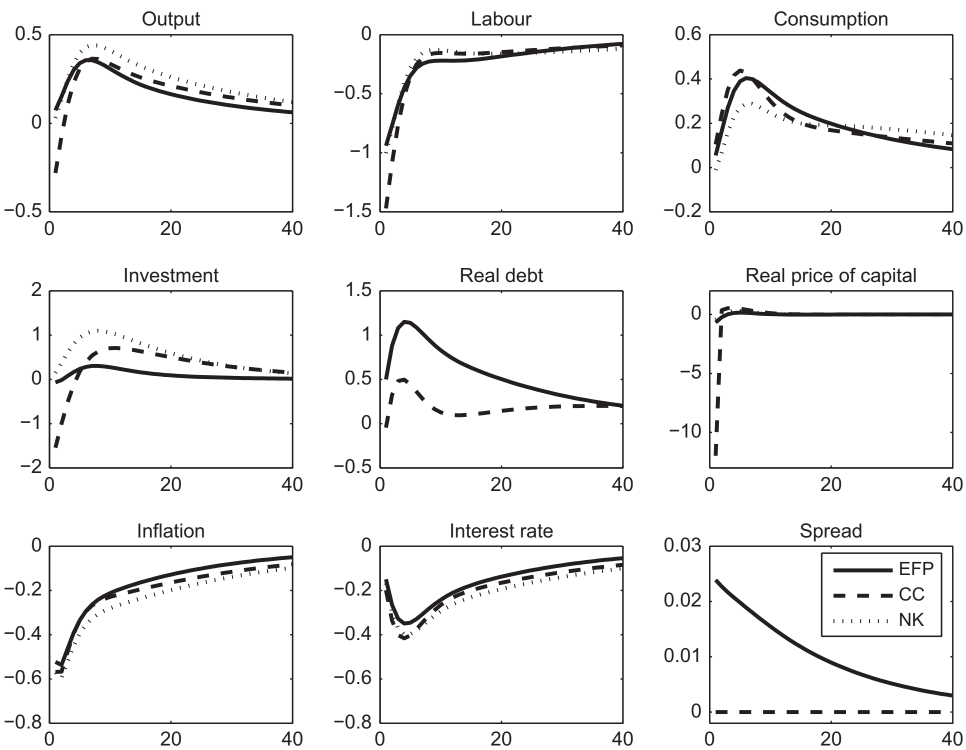

Fig. 1. Productivity shock IRFs.

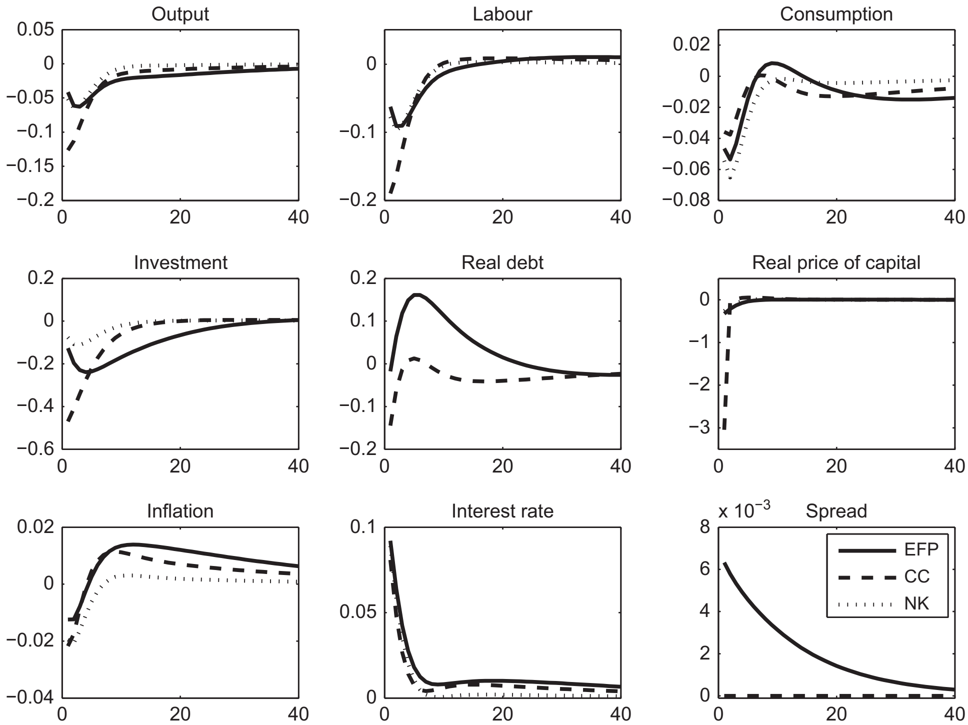

Fig. 2. Monetary shock IRFs.

In the EFP model, the fall in the price of capital subtracts from entrepreneurs' net worth, which, together with a rising real value of their debt, translates into a higher spread between the lending and the risk free rate. This mechanism amplifies the initial impact of the monetary tightening on investment, though by substantially less than the direct collateral effect in the CC model. On the other hand, as entrepreneurs' balance sheets (and so lending conditions) improve only gradually, the speed of reversion to the steady state is much lower than in the CC variant.

There exists a large body of literature that documents the dynamic effects of monetary policy shocks. This allows us to provide an empirical benchmark to the monetary impulse response functions discussed above. To this end, we construct a VAR model based on standard macroaggregates and the two financial variables used in calibration.[18] The impulse responses to a monetary policy shock are presented in Fig. 3. As is commonly found in the literature, a positive innovation to the central bank interest rate reduces output, investment and consumption relatively quickly. The impact on inflation is substantially slower, but also negative. This is consistent with the responses in the analyzed models, where output, consumption, investment and inflation fall. However, it should be noted that reactions from the VAR exhibit substantial inertia and are hump-shaped. This result contrasts in particular with the effects generated by the CC model, where the strongest reaction occurs on impact, while it comes closer to the impulses obtained from the EFP version.

5.3. Net worth and loan-to-value ratio shock

In Fig. 4 we compare the impact of a shock to net worth (implemented as an increase in the survival rate of entrepreneurs) on the EFP model to the impact of an LTV shock on the CC model. The shock definitions are not fully equivalent. Nevertheless, there are some similarities between them. First of all, both shocks have an expansionary impact on the economy. A higher LTV ratio allows entrepreneurs to demand more loans and increase investment. Higher net worth increases entrepreneurs' stake in financing capital expenditures and so allows them to borrow at a lower premium over the risk free rate. It is also worth noting that the two shocks are important sources of fluctuations of standard macro-variables in both models.

The transmission of an LTV shock in the CC model is fairly intuitive. Entrepreneurs increase borrowing and use the proceeds to invest more, which raises output. Higher demand for capital sharply increases its price, relaxing the collateral

[18] The VAR consists of the following time series: enterprise loans, inflation, output, consumption, investment, the federal funds rate and the interest rate spread (for sample and definitions see note to Table 5). The VAR lag was set using the LR and AIC criteria to six quarters. Monetary policy shocks were identified using the Cholesky decomposition with variables ordered as above. Apart from standard assumptions regarding the ordering of inflation, national account variables and the interest rate (e.g. Christiano et al., 1999), this implies that loans respond with a one period lag (loan applications usually take time), while the spread is affected immediately (this is a quickly reacting financial variable). Changing the ordering of the two financial variables does not affect the results substantially.

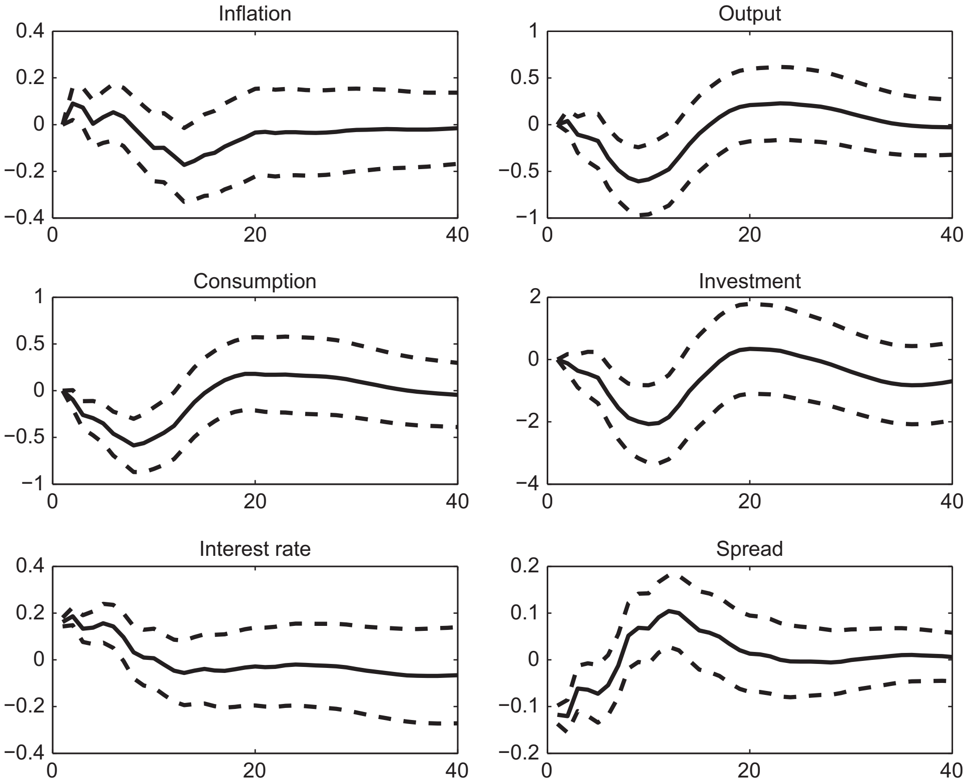

Fig. 3. Monetary policy shock IRFs from a VAR. *Note*: The figure shows the impulse response functions (solid line) together with ± 2 standard error bounds (dashed lines).

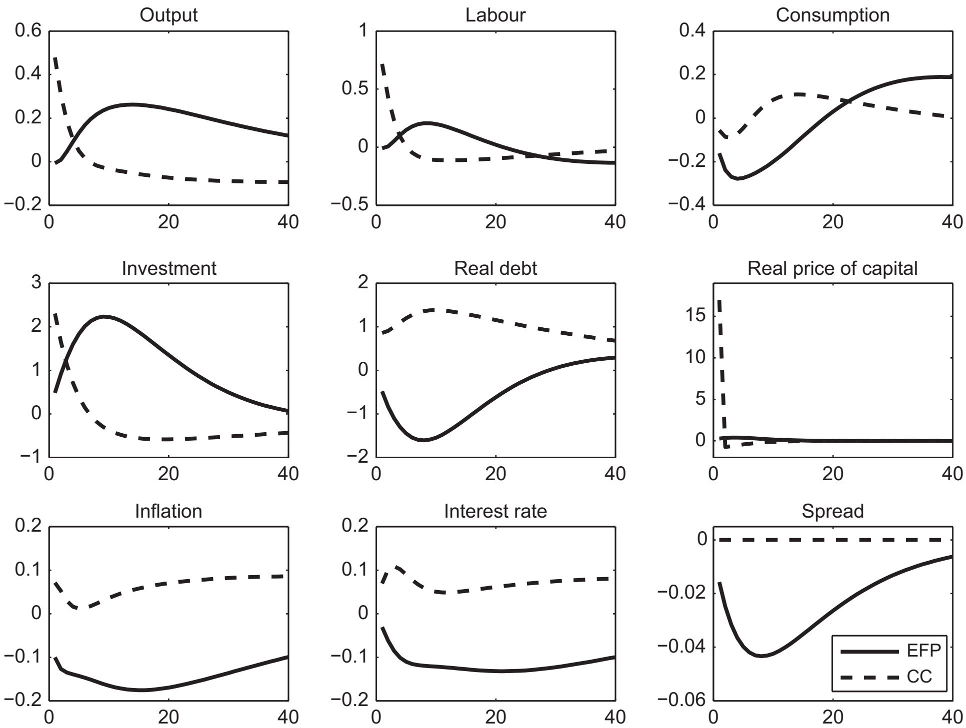

Fig. 4. Net worth (EFP) and LTV (CC) shock IRFs.

constraint further. The boom translates into an increase in inflation. The reactions are very fast but short-lived, with output and private demand components peaking in the first quarter.

The story behind the reaction of the EFP model to a net worth shock differs in several vital respects. As in the case of an LTV shock, the responses of investment and output are positive, but exhibit a hump-shaped pattern, gaining momentum and dying out very slowly. The second striking difference across the models concerns the reactions of consumption and debt. Since a positive net worth shock is defined in the EFP version as a decrease in the number of exiting entrepreneurs, it implies lower wealth transfers to households. As a result, households cut consumption and savings, the latter bringing about a fall in debt. Finally, in contrast to an increase in the LTV ratio, a boost to net worth leads to a fall in inflation, indicating that the two shocks imply a different balance of supply and demand effects.

5.4. Riskiness and spread shock

While net worth and LTV shocks affect primarily the available quantity of loans, entrepreneur riskiness (EFP) and spread (CC) shocks directly affect their cost. As can be seen from the response of spreads in both models (see Fig. 5), the degree of comparability between these two shocks is very high. Therefore, even though they contribute relatively less to the variance of non-financial variables, their inspection is useful in highlighting the differences between the two financial sector variants considered in this paper.

In the CC model, higher spreads tighten the collateral constraint, affecting negatively loans and investment. As a result, output and labor input fall as well. As the demand for capital decreases, its price goes down. The story in the EFP model is similar. Higher riskiness of projects run by entrepreneurs makes banks demand a higher premium on loans to entrepreneurs, which discourages the latter from investing. As a result, credit, output and the price of capital decrease. In both models, shocks affecting spreads act like cost-push shocks, driving output and inflation in opposite directions.

Again, the main difference between the two alternative specifications concerns how the responses are spread over time. In the CC variant, all real variables are most strongly affected on impact. In the EFP version, consumption, investment and debt display an inverted hump-shaped pattern.

5.5. Can financial frictions replace real rigidities?

Our final point in this section is related to the role of real rigidities and their possible substitutability with financial frictions. Real rigidities (e.g. habit formation, investment adjustment cost) are introduced into DSGE models in order to allow for hump-shaped reactions of some variables (e.g. consumption, investment) to shocks. However, their microfoundations

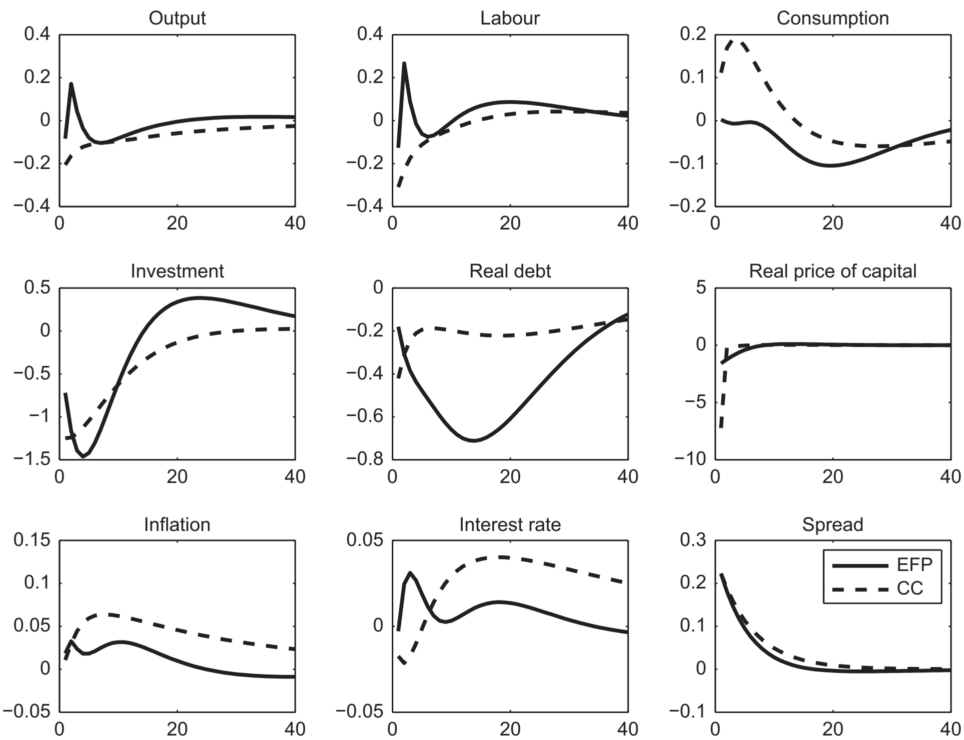

Fig. 5. Entrepreneur riskiness (EFP) and spread (CC) shock IRFs.

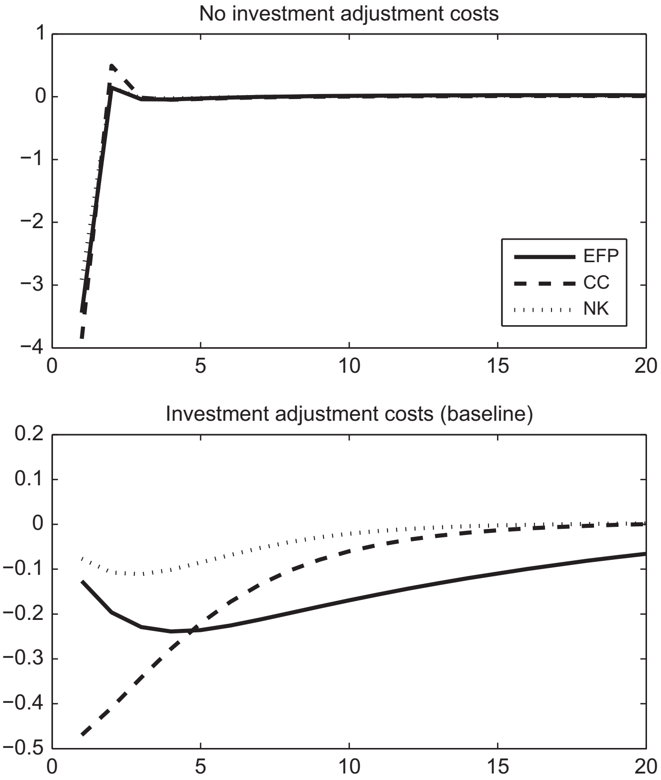

Fig. 6. Monetary policy shock IRF for investment.

are relatively weak and hence they are often treated as necessary, though disliked additions to the models. Thus, one possible benefit from introducing financial frictions could be their ability to introduce persistence without resorting to somewhat ad hoc real rigidities. The prototype models analyzed give the opportunity to study this issue. Since in our frameworks financial frictions affect capital accumulation, we check whether they can replace adjustment costs in generating persistence of investment.

The first panel of Fig. 6 presents the impulse response functions of investment to a contractionary monetary policy shock under the assumption that investment adjustment costs are zero. As can be expected, in the NK model the strongest reaction comes on impact. However, this also happens in both models with financial frictions, except that the initial decline is deeper. It is clear that, absent adjustment costs, neither of the two extensions can generate a hump-shaped response of investment.

Going back to our baseline, replicated in the second panel of Fig. 6 for convenience, reveals an interesting interaction between financial frictions and the costs of adjusting investment as now the responses differ substantially between the three models. To see why, it is important to note that adjustment costs permit a variable price of capital. Since changes in the price of capital directly affect the collateral value in the CC version, a monetary contraction leads to a strong fall in investment. This amplification mechanism is so strong that it overrides the effect of adjustment costs and hence the strongest response occurs on impact. In the EFP model, a decrease in the price of capital affects negatively entrepreneurs' profits and hence their ability to finance capital purchases. Since net worth takes time to rebuild, the contraction in investment is relatively persistent.

Summing up, financial frictions cannot replace real rigidities. However, once these are built in, the EFP model amplifies while the CC model overrides the persistence they generate.

5.6. Summary

Several general observations can be drawn from the analysis of impulse response functions presented above. First, in all cases the reaction of the CC model is much faster than that of the EFP setup. In particular, the CC variant usually generates reaction functions with the deepest impact occurring in the first quarter of the shock. This seems inconsistent with VAR evidence on monetary transmission, where the reactions are usually hump-shaped, more like in the EFP model. Unfortunately, there is much less agreement on how to measure the effects of productivity and financial shocks that we analyze in this paper. However, the most recent empirical evidence suggests that the responses of the main macroaggregates to spread and credit shocks exhibit substantial inertia, which again speaks in favor of the EFP variant.[19]

Second, in the CC model all shocks exercise a very strong influence on the price of capital, driving it down or up by as much as 10–20% after a standard shock. This is inconsistent with empirical estimates of the price of capital behavior discussed before and also translates into excessive fluctuations in the rate of return on capital. Finally, the CC model generates several further undesirable effects. One striking example is the initial decline of output after a positive productivity shock.

6. Business cycle accounting

To shed more light on the differences between the EFP and CC setups, we filter the artificial data generated from these two model versions through the business cycle accounting procedure developed by Chari et al. (2007). In a nutshell, this approach considers a standard real business cycle model with time-varying wedges that resemble productivity, labor and investment taxes, and government spending. The wedges are assumed to follow a first-order vector autoregressive process. The original idea of the Chari et al. (2007) paper was to take this prototype economy to the observed data and examine the role of each wedge in accounting for fluctuations in the main macrovariables. The outcomes could then be used to judge which frictions are quantitatively important for business cycle fluctuations. We do the same exercise on simulated data, with the purpose to highlight the main differences between the business cycle properties of our alternative models and evaluate their consistency with actual data.

6.1. Setup

We design our prototype economy in a similar way as in Chari et al. (2007). The only difference is incorporation of habits and capital adjustment costs, which we define consistently with our baseline model structure presented in Section 2.

The problem of household h is to maximize discounted lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(c_t(h) - \xi c_{t-1})^{1-\sigma_c}}{1-\sigma_c} - \frac{n_t(h)^{1+\sigma_n}}{1+\sigma_n} \right] \tag{45}$$

subject to the budget constraint

$$c_t(h) + (1+\tau_{i,t}) i_t(h) = r_{k,t} k_{t-1}(h) + (1-\tau_{l,t}) w_t n_t(h) - T_t(h) \tag{46}$$

and capital accumulation

$$k_t(h) = (1-\delta) k_{t-1}(h) + \left(1 - S\left(\frac{i_t(h)}{i_{t-1}(h)}\right)\right) i_t(h) \tag{47}$$

Firms are perfectly competitive and maximize profits subject to the production function

$$y_t = A_t k_{t-1}^{\alpha} n_t^{1-\alpha} \tag{48}$$

The aggregate resource constraint is

$$y_t = c_t + i_t + g_t \tag{49}$$

All variables are defined as in our baseline setup, except that factor prices are now expressed in real terms and so denoted by lower case letters. The four wedges are A_t, $\tau_{l,t}$, $\tau_{i,t}$ and g_t. We will refer to them as efficiency, labor, investment and government wedges, respectively.

6.2. Mapping financial frictions into wedges

In this section we explain how financial frictions from the CC and EFP models map into the wedges in the BCA framework. First, financial market imperfections affect the intertemporal choice and hence show up in the investment wedge. To demonstrate it in a transparent fashion, we abstract from capital adjustment costs and uncertainty. Under these assumptions the intertemporal equilibrium condition of our prototype economy becomes

$$\frac{u_{c,t}}{\beta u_{c,t+1}} = \frac{\alpha A_{t+1} k_t^{\alpha-1} n_{t+1}^{1-\alpha} + (1-\delta)(1+\tau_{i,t+1})}{1+\tau_{i,t}} \tag{50}$$

where $u_{c,t}$ denotes the derivative of the instantaneous utility function with respect to c_t.

[19] For example, Assenmacher-Wesche and Gerlach (2008) present hump-shaped impulse responses to credit shocks (without identifying whether they originate from demand or supply) from a VAR. Kose et al. (2010) identified credit supply shocks in a FAVAR framework and obtain hump-shaped impulse responses. Gilchrist and Zakrajsek (2012) use a VAR to extract shocks to the excess bond premium, and find hump-shaped reactions of standard macrovariables.

For the EFP economy, combining Eqs. (19) and (43) (both expressed in real terms), the equilibrium condition linking the rental rate of capital to its marginal product[20] and the household's intertemporal equilibrium condition yields

$$\frac{u_{c,t}}{\beta u_{c,t+1}} = \frac{mc_{t+1}\alpha A_{t+1}k_t^{\alpha-1}n_{t+1}^{1-\alpha}+1-\delta}{1+\chi^{EFP}(\cdot)} \tag{51}$$

where mc_t is the real marginal cost of intermediate goods producers.

Proceeding similarly with the CC economy gives

$$\frac{u_{c,t}}{\beta u_{c,t+1}} = \frac{mc_{t+1}\alpha A_{t+1}k_t^{\alpha-1}n_{t+1}^{1-\alpha}+1-\delta}{(1+\Theta_t\chi^{CC}(\cdot))\phi_{L,t}} \tag{52}$$

Comparing Eqs. (51) and (52) with equilibrium condition (50) reveals that the wedge between the rate of return on capital and the risk-free rate created by financial frictions in the CC and EFP economies maps into the investment wedge of the prototype economy. As demonstrated by Sustek (2011), this wedge also captures frictions due to monopolistic competition and price stickiness, reflected in the mc_t term in Eqs. (51) and (52). Since in our calibration both the steady-state excess return on capital and product market markup are the same in the EFP and CC variants (see Section 4), so is the steady-state investment wedge.

Second, as it becomes clear after comparing Eqs. (31) and (37) with (49), financial frictions affect the aggregate resource constraint. Therefore, since we treat monitoring costs (EFP)/entrepreneurs' consumption (CC) as a part of government spending, they show up in the government wedge of the prototype economy. Again, as our calibration implies that these terms are identical in the steady state, the steady-state government wedge in both models with financial frictions is also the same.

6.3. Results

We calibrate the structural parameters of the prototype economy as in Section 4 and estimate the stochastic process for wedges using 25 000 observations simulated from each model, as well as actual data for the US economy, covering the period 1970q1–2008q4. As in the original business cycle accounting procedure, the observable variables are output, labor, investment and government spending. As mentioned above, we treat monitoring costs (EFP)/entrepreneurs' consumption (CC) as a part of government spending. This, together with incorporation of habits and investment adjustment costs into our prototype economy, ensures that (to first order): the efficiency wedge in all three models coincides with total factor productivity, fluctuations in the labor wedge are only due to wage and price stickiness,[21] movements in the investment wedge are only due to financial frictions and price stickiness. The estimation method is maximum likelihood.

To compare the role of wedges between our models, we present their moments (standard deviations, autocorrelations and correlations with output) and the impact of each single wedge on output volatility (Table 6). The last part is obtained by running the estimated business cycle accounting models with each wedge at a time.

All three models generate identical and excessive volatility of the efficiency wedge while underestimating the role of the labor wedge.[22] The impact of the government wedge is very small in all three models and in the data. Important differences concern the investment wedge. In the NK model, its role is marginal and results only from price stickiness. On the contrary, in the data and in both financial frictions models, fluctuations of this wedge account for a substantial part of output volatility (see the last row of Table 6). However, while the EFP model comes close to the data, the CC model implies a standard deviation of this wedge that is much too high.

As regards autocorrelations, the differences between the NK and EFP models are very small. Both feature too much inertia of the efficiency wedge and too little inertia of the labor wedge. The latter shortcoming is even more pronounced in the CC variant. Furthermore, consistently with the earlier findings, this model dramatically underestimates the autocorrelation of the investment wedge.

The analyzed models have similar implications for correlations of the wedges with output. Productivity shocks account for virtually all output fluctuations in the NK model, so it should come as no surprise that the efficiency wedge is highly correlated with output. Both financial friction models underestimate somewhat the procyclical behavior of this wedge. Moving to the labor wedge, it is procyclical in the NK model. This is consistent with the negative correlation of labor and output reported earlier, but clearly at odds with the data. Neither of the financial friction models is able to fix this problem. Finally, the NK model shows a strongly procyclical behavior of the investment wedge. This is again at odds with the data and with intuition—charging a tax on investment should result in lower output. Both financial sector models turn the correlation negative, clearly improving fit to the data.

Summing up, the BCA exercise shows that financial frictions improve some of the business cycle properties of the NK framework. Moreover, it demonstrates that financial distortions embedded in the EFP and CC models show up in the

[20] This comes from minimizing the intermediate goods producers' costs, subject to the production function (11). It yields $r_{k,t} = mc_t\alpha A_t k_{t-1}^{\alpha-1}n_t^{1-\alpha}$, where mc_t is the Lagrange multiplier on the constraint (i.e. the real marginal cost).

[21] Sustek (2011) demonstrates that price stickiness shows up as fluctuations in both labor and investment wedge.

[22] Total factor productivity is described by the same stochastic process in the NK, EFP and CC models, hence the first-order properties of the efficiency wedge also do not differ. On the other hand, even though the degree of wage stickiness (i.e. the Calvo probability and indexation) is identical in all three model variants, their shock propagation mechanisms are not the same, which makes the labor wedge evolve differently.

Table 6
Results of the business cycle accounting exercise.

	Data	NK	EFP	CC
Wedges				
St. deviations				
Efficiency	1.36	2.27	2.27	2.27
Labor	8.11	4.52	4.39	5.30
Government	3.76	3.94	6.15	3.71
Investment	8.02	0.31	6.02	22.11
Autocorrelations				
Efficiency	0.88	0.95	0.95	0.95
Labor	0.96	0.72	0.73	0.66
Government	0.97	0.95	0.91	0.95
Investment	0.69	0.99	0.92	0.14
Correlations with output				
Efficiency	0.86	0.89	0.65	0.59
Labor	−0.60	0.48	0.47	0.08
Government	0.11	0.06	−0.10	0.10
Investment	−0.30	0.89	−0.18	−0.41
Output components				
St. deviations				
All wedges	2.32	1.81	1.87	1.90
Efficiency	1.21	2.62	2.62	2.62
Labor	1.72	0.89	0.91	0.97
Government	0.26	0.21	0.37	0.19
Investment	1.16	0.11	1.74	1.26

investment wedge and are quantitatively important for output fluctuations. However, while the EFP variant provides a relatively good data fit, the CC model achieves this at the cost of a dramatically high volatility accompanied by almost zero autocorrelation of the wedge.

7. Conclusions

Models with financial frictions have recently become very popular in academia and at central banks. In particular, they form the basis for construction of frameworks that explain bilateral linkages between financial stress and the business cycle. These are in turn expected to provide policy advice regarding macroeconomic and regulatory policies. In this paper we make a thorough comparison of the business cycle properties of two standard ways of introducing financial frictions into the New Keynesian model – the EFP and the CC extensions. To make this task possible, we tweak the models to make them comparable in all aspects but the financial sector setup. We next analyze the differences between the two alternative approaches with the following tools: moment comparison, impulse response analysis and business cycle accounting.

Both types of frictions improve upon the standard NK framework in bringing the moments of several macrovariables closer to the data. However, the CC model also shows a number of features inconsistent with empirical observations. In particular, its internal propagation is weaker and the volatilities of some variables are substantially higher than observed in the data.

The impulse response analysis reveals important differences in the propagation mechanisms between the CC and EFP variants. The former usually generates reaction functions with the deepest impact occurring in the first quarter, while those obtained from the latter are usually hump-shaped, which is consistent with VAR evidence.

Finally, business cycle accounting confirms the superior performance of both models with financial frictions over the simple NK framework. In particular, in accordance with the data but in contrast to the NK model, both financial frictions setups give a significant role to the investment wedge. We show analytically that this wedge indeed reflects the presence of financial frictions. However, while the behavior of the investment wedge is consistent with the data in the EFP model, it is not the case in the CC framework.

Overall, we conclude that while both financial frictions models improve in some aspects the NK framework, several properties of the CC model seem undesirable. Notwithstanding the role of collateral constraints in the real world, their introduction through sharply binding constraints generates strong overreactions. We believe that this paper will support the process of developing macro-financial models that match the data and economic intuition. This should benefit both academic and policy-oriented research.

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