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Output Gap, Monetary Policy Trade-offs and Financial Frictions*

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Abstract

This paper investigates how the presence of pervasive financial frictions and large financial shocks changes the optimal monetary policy prescriptions and the estimated dynamics in a New Keynesian model. We find that financial factors affect the optimal policy only to some extent. A policy of nominal stabilization (with a particular focus on targeting wage inflation) is still the optimal policy, although the central bank is now unable to fully stabilize economic activity around its potential level. In contrast, the presence of financial frictions and financial shocks crucially changes the size and the shape of the estimated output gap and the relative importance of different shocks in driving economic fluctuations, with financial shocks absorbing explanatory power from labor supply shocks.

Keywords: Financial frictions; output gap; monetary policy.

JEL codes: E32, C51, C52

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1 Introduction

During the last 30 years, the evolution of inflation and to some extent of measures of real economic activity has been more and more disconnected from financial variables. On the one hand, Christiano, Ilut, Motto, and Rostagno (2010) document that inflation is always relatively low during stock market booms (which in turn are often associated with credit booms). On the other hand, financial variables like stock prices and various measures of credit have experienced large boom-and-bust cycles with an average duration much longer than the one of standard business cycles. In addition, Jermann and Quadrini (2008) and Fuentes-Albero (2018) document that the volatility of financial variables at business cycle frequencies has increased substantially since the mid-1980s, while the volatility of inflation and real economic activity measures has diminished markedly. At the same time, a series of influential papers finds that shocks originating in the financial sector may play an important role in driving these dynamics, cf. Christiano, Motto, and Rostagno (henceforth CMR) (2014), Gilchrist and Zakrajsek (2011) and Jermann and Quadrini (2012).

From a policy perspective, many prominent observers, such as the Bank for International Settlements (BIS), have questioned the desirability of monetary policies pursuing price stability in a world in which inflation and real economic activity measures are more and more disconnected from financial variables. According to this view, the boom-and-bust cycle ending with the Great Recession is an iconic example of how the pursuit of price stability may not be sufficient to achieve real economic activity stability in presence of financial disturbances. In this paper we reevaluate this view and investigate whether the presence of pervasive financial frictions and large financial shocks is, in and of itself, a reason for central banks to abandon their focus on price stability which they have pursued over the last twenty years. In addition, and related to the previous point, we investigate also whether the presence of financial frictions and financial shocks has an impact on the measurement of real economic activity indicators such as the output gap. This question is interesting because, as shown by Borio, Disyatat, and Juselius (2017), traditional measures of the output gap computed by several policy institutions were in negative territory in the pre-Great Recession period, arguably a period of financial exuberance for the US economy.

To investigate our questions, we need an estimated macroeconomic model in which financial frictions and financial shocks play an important role to interpret the data. We largely rely on CMR (2014), a state-of-the-art model with financial frictions featuring a financial accelerator mechanism along the lines of Bernanke, Gertler and Gilchrist (1999) and an important role for

financial shocks. Those disturbances are modeled as shocks to the net worth of firms, which directly affect the availability of credit for the production sector, and as shocks to the volatility of the cross-sectional idiosyncratic uncertainty (risk shocks), which reflect possible tensions in financial markets (or fluctuations in uncertainty) and include news components. We use the model to compute the optimal equilibrium and evaluate the trade-offs for the monetary policy authority. Such an exercise has not been done in the context of an estimated model with financial frictions and extends the analysis by Justiniano, Primiceri, and Tambalotti (2013), henceforth JPT, in the context of the standard New Keynesian model. Our research question is admittedly complex and we acknowledge already here that our framework does not capture important elements like frictions in the household and banking sectors, and important nonlinearities such as bank runs and sudden stops in credit flows. Nevertheless, the financial accelerator model seems to be a useful and well-known starting point to investigate optimal monetary policy in a quantitative set-up with financial frictions.

Our main result is that nominal stabilization remains a very useful intermediate objective for central banks to pursue on the way to optimal policy, even in a model in which financial frictions are pervasive and financial shocks are dominant. In fact, in our model the optimal monetary policy achieves an almost full stabilization of wage inflation and price inflation, as in the absence of financial frictions and financial shocks. Achieving nominal stabilization, however, does not guarantee a full stabilization of real economic activity around its potential level. Some fluctuations in the output gap are unavoidable and actually desirable (conditional on being the interest rate the only policy instrument available). The magnitude of those fluctuations is far from negligible but still relatively small, at least when compared to historical fluctuations in the output gap obtained under the estimated monetary policy rule. This result relies on the fact that financial shocks do not seem to pose particular challenges to the monetary policy authority: in the end they behave like standard demand shocks and do not generate adverse trade-offs between nominal and real stabilization.

While the presence of financial frictions and financial shocks affects the policy prescriptions only to some extent, it has a large effect on the measurement of the stance in real economic activity. In fact, the output gap derived from our baseline model is more persistent and volatile than the output gap derived by JPT (2013) in the absence of financial frictions, which constitutes our reference for comparison. In particular, we estimate a long cycle for the output gap that was positive from the mid-1990s until the Great Recession, thus over a period characterized by asset

price boom-and-bust cycles. A standard New Keynesian model implies instead a negative output gap in the pre-Great Recession period. The main reason for such a different shape for the output gap in the model with financial frictions is that financial shocks absorb explanatory power from labor supply shocks. In fact, neither of the financial shocks propagates in the potential economy, thus behaving like monetary policy shocks. Potential output in the model with financial frictions is therefore substantially different from its counterpart in the standard New Keynesian model.

This paper contributes to the literature on optimal monetary policy in models with financial frictions. Carlstrom, Fuerst, and Paustian (2010), De Fiore and Tristani (2013), Nisticó (2016) and Ravenna and Walsh (2006) evaluate optimal monetary policy in simple small-scale models with financial frictions, where they are able to derive analytical expressions for the model-consistent welfare functions. In a similar set-up, Faia and Monacelli (2007) and Cúrdia and Woodford (2010) study optimal monetary policy rules. De Fiore, Teles and Tristani (2011) analyze optimal monetary policy in a model in which firms' financial positions are denominated in nominal terms and debt contracts are not state-contingent. Fendoglu (2014) computes the Ramsey monetary policy in a calibrated financial accelerator model. We contribute to this literature by conducting our analysis in an estimated (rather than calibrated) model driven by several disturbances, including two financial shocks.

Since we use an estimated model, we can evaluate the trade-offs faced by the central bank from a quantitative point of view. We can thus extend to the framework with financial frictions a discussion which has so far been confined within the standard New Keynesian model (cf. Blanchard and Galí, 2007). Most central banks perceive a trade-off between stabilizing inflation and a measure of capacity utilization. However, in medium scale DSGE models the importance of this trade-off largely depends on whether the low frequency fluctuations in hours worked are attributed to labor supply shocks (JPT, 2013) or to wage mark-up shocks (Debortoli, Kim, Lindé, and Nunes, 2019). In the former case, trade-offs between real and nominal stabilization exist but are fairly weak, thus leading to a sort of *"Trinity"* in which the monetary policy authority is able to stabilize price inflation, wage inflation and the output gap almost completely.[1] In the latter case, trade-offs are substantially larger and the weight on the output gap should be equal to or larger than that of annualized inflation when designing a loss function for the central bank. Our contribution is to measure the policy trade-offs in an environment where frictions are

[1] Eusepi, Giannoni, and Preston (2019) show that these trade-offs may become larger once agents have imperfect knowledge about the long-run, reflecting uncertainty about the mean of inflation and the equilibrium real interest rate.

more pervasive. Moreover, our results do not depend on which labor market shock is driving the low-frequency fluctuations in hours since the labor market shock loses almost all its explanatory power in favor of financial shocks.

We contribute also to the literature on the behavior of the output gap in structural macroeconomic models. Earlier contributions include Levin, Onatski, Williams, and Williams (2005), Galí, Gertler and Lopez-Salido (2007), Edge, Kiley and Laforte (2008), Christiano, Trabandt, and Walentin (2011) and Galí, Smets, and Wouters (2011). As far as we know, our paper is the first that derives the output gap from an estimated model with financial frictions driven by a large set of shocks.[2] The importance of considering financial factors in the computation of the output gap is stressed in Borio, Disyatat, and Juselius (2017) in a reduced-form set-up. Our paper considers the same issues in a structural model.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 summarizes the details of the Bayesian estimation and the main properties of the estimated model. Section 4 discusses the optimal monetary policy exercise. In Section 5 we investigate further the model-based measure of the output gap and its properties. Finally, we conclude in Section 6.

2 The Model

Our baseline model of the US economy combines the standard New Keynesian model (cf. Christiano, Eichenbaum, and Evans, 2005, and Smets and Wouters, 2007) together with the workhorse model with financial frictions (cf. Bernanke, Gertler and Gilchrist, 1999) following the contributions of CMR (2014) and Del Negro and Schorfheide (2013). The model nests JPT (2013) and thus replicates exactly their results when we shut down financial frictions. In this section we present the model in non-stationary form, while in Online Appendixes A and B we report the full set of equilibrium conditions in their stationary form.

Final good producers. A representative, competitive final good producer combines a continuum of intermediate goods $Y_t(i)$, indexed with $i \in [0,1]$, according to a Dixit-Stiglitz

[2]The concept of the output gap in the presence of financial frictions is briefly discussed in Carlstrom, Fuerst, and Paustian (2010), Cúrdia and Woodford (2010), De Fiore and Tristani (2013) and Davis and Huang (2013) in calibrated models driven by a few shocks. However, these papers do not provide an estimated series for the output gap.

technology to produce the homogeneous good Y_t

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{1}{1+\Lambda_{p,t}}} di \right]^{1+\Lambda_{p,t}},$$

where $\Lambda_{p,t}$ is related to the degree of substitutability across different intermediates. It is a measure of competitiveness in the intermediate goods markets and its exogenous movements are one of the forces driving the economy away from its efficient frontier. $\Lambda_{p,t}$ varies exogenously over time in response to its independently and identically distributed $N(0, \sigma_p)$ innovation $\varepsilon_{p,t}$ (referred to as price markup shock) according to

$$\log(1 + \Lambda_{p,t}) \equiv \lambda_{p,t} = (1 - \rho_p)\lambda_p + \rho_p \lambda_{p,t-1} + \varepsilon_{p,t}.$$

The associated price index P_t obtained from profit maximization is an aggregate of the intermediate goods prices $P_t(i)$

$$P_t = \left[\int_0^1 P_t(i)^{-\frac{1}{\Lambda_{p,t}}} di \right]^{-\Lambda_{p,t}},$$

whereas the demand function for each intermediate good i is given by

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\frac{1+\Lambda_{p,t}}{\Lambda_{p,t}}} Y_t.$$

Intermediate goods producers. The intermediate goods are produced by monopolistically competitive firms using the following production function

$$Y_t(i) = A_t^{1-\alpha} K_t(i)^{\alpha} L_t(i)^{1-\alpha} - A_t F,$$

where $K_t(i)$ and $L_t(i)$ represent the services of effective capital and labor used by firm i in the production sector. F is a fixed cost of production (indexed to technology) which is set such that profits are zero in steady state. A_t is the Solow residual of the production function. Its growth rate z_t ($z_t = \Delta \log A_t$) is stationary and varies exogenously over time in response to independently and identically distributed $N(0, \sigma_z)$ technology shocks $\varepsilon_{z,t}$, as follows

$$z_t = (1 - \rho_z)\gamma + \rho_z z_{t-1} + \varepsilon_{z,t},$$

where γ represents the growth rate of the economy along a balanced growth path. Each producer chooses its price subject to a Calvo (1983) mechanism. Every period a fraction ξ_p does not choose prices optimally but simply indexes their current price according to the rule

$$P_t(i) = P_{t-1}(i)\,\pi_{t-1}^{\iota_p}\pi^{1-\iota_p},$$

where π_t is the gross inflation rate and π represents its steady state value. This indexation scheme has the desirable property that the level of steady state inflation does not affect welfare and the level of output in steady state.

Remaining firms set their price $\widetilde{P}_t(i)$ by maximizing profits intertemporally

$$E_t\sum_{s=0}^{\infty}\xi_p^s\frac{\beta^s\lambda_{t+s}}{\lambda_t}\left\{\left[\widetilde{P}_t(i)\left(\prod_{j=0}^{s}\pi_{t-1+j}^{\iota_p}\pi^{1-\iota_p}\right)\right]Y_{t+s}(i) - \left[W_tL_t(i) + P_tr_t^kK_t(i)\right]\right\},$$

where $\frac{\beta^s\lambda_{t+s}}{\lambda_t}$ represents the household's discount factor, λ_t being the marginal utility of consumption, whereas W_t and r_t^k indicate the nominal wage and the real rental rate of capital, respectively.

Employment agencies. A representative competitive employment agency combines differentiated labor services, indexed by $j \in [0,1]$, into homogeneous labor using the following technology

$$L_t = \left[\int_0^1 L_t(j)^{\frac{1}{1+\Lambda_{w,t}}}\,dj\right]^{1+\Lambda_{w,t}},$$

where $\Lambda_{w,t}$ is the elasticity of substitution across different labor varieties. $\log(1+\Lambda_{w,t}) = \lambda_{w,t}$ is an independently and identically distributed $N\left(0,\sigma_w^2\right)$ wage mark-up shock. As in the goods market, the demand function for labor of type j is given by

$$L_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-\frac{1+\Lambda_{w,t}}{\Lambda_{w,t}}}L_t,$$

whereas the wage index is

$$W_t = \left[\int_0^1 W_t(j)^{-\frac{1}{\Lambda_{w,t}}}\,dj\right]^{-\Lambda_{w,t}}.$$

For each labor type, we assume the existence of a union representing all workers of that type.

Wages are set subject to Calvo lotteries. Every period, a fraction ξ_w of unions index the wage according to the rule

$$W_t(j) = W_{t-1}(j)\left(\pi_{t-1}e^{z_{t-1}}\right)^{\iota_w}\left(\pi e^{\gamma}\right)^{1-\iota_w}.$$

This indexation scheme implies that output is independent of the steady state value of wage inflation. The remaining unions choose the wage optimally by maximizing the utility of their members subject to labor demand.

Households. The household sector is composed of a large number of identical households, each composed of a continuum of family members indexed by j. All labor types are represented in each household and family members pool wage income and share the same amount of consumption. After goods production in period t, the representative household constructs raw capital by combining investment goods I_t and undepreciated capital $\overline{K}_{t-1}$ according to the following technology[3]

$$\overline{K}_t = (1-\delta)\overline{K}_{t-1} + \mu_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right]I_t,$$

where δ is the depreciation rate, and the function $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\zeta}{2}\left(\frac{I_t}{I_{t-1}} - e^{\gamma}\right)^2$ captures investment adjustment costs, as in Christiano, Eichenbaum, and Evans (2005). In steady state $S(\cdot) = S'(\cdot) = 0$ and $S''(\cdot) = \zeta$. μ_t varies exogenously over time in response to independently and identically distributed $N\left(0, \sigma_\mu^2\right)$ investment specific shocks $\varepsilon_{\mu,t}$, as follows

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu,t}.$$

The representative household takes the price of capital Q_t, the price of investment (and consumption) goods P_t and labor income as given. It maximizes the utility function

$$E_t\left\{\sum_{s=0}^{\infty}\beta^s b_{t+s}\left[\log\left(C_{t+s} - hC_{t+s-1}\right) - \varphi_t\int_0^1 \frac{L_{t+s}(j)^{1+\nu}}{1+\nu}dj\right]\right\},$$

where C_t stands for consumption, h for the degree of habit formation, ν for the inverse of labor supply elasticity. b_t varies exogenously over time in response to independently and

[3]The timing convention for the state variables reflects their end-of-period value. The stock of raw capital is produced within the household. Alternatively, this task could be assigned to competitive capital producers.

identically distributed $N\left(0,\sigma_b^2\right)$ intertemporal preference shocks $\varepsilon_{b,t}$, as follows

$$\log b_t = \rho_b \log b_{t-1} + \varepsilon_{b,t},$$

as does φ_t in response to independently and identically distributed $N\left(0,\sigma_\varphi^2\right)$ intratemporal labor supply shocks $\varepsilon_{\varphi,t}$

$$\log \varphi_t = (1-\rho_\varphi)\,\varphi + \rho_\varphi \log \varphi_{t-1} + \varepsilon_{\varphi,t}.$$

The representative household maximizes utility subject to the budget constraint

$$P_t C_t + P_t I_t + T_t + Q_t\left(1-\delta\right)\overline{K}_{t-1} + B_t = \int_0^1 W_t\left(j\right) L_t\left(j\right) dj + R_t B_{t-1} + Q_t \overline{K}_t + O_t + H_t.$$

Funds are used to buy consumption and investment goods, to pay lump sum taxes (T_t), to buy undepreciated capital from entrepreneurs and to save in a one period bond B_t that pays a gross nominal return R_t in each state of nature. This bond is the source of external funds for entrepreneurs and plays a crucial role in the financial accelerator mechanism. Expenses are financed with labor income, revenues from previous period savings and from selling capital to entrepreneurs, profits from ownership of firms in the intermediate good sectors O_t and net transfers from entrepreneurs H_t.

Entrepreneurs. There is a continuum of entrepreneurs indexed by l. Each entrepreneur uses its own net worth $N_{t-1}\left(l\right)$ and borrows $B_{t-1}^e\left(l\right)$ from a financial intermediary (that channels households' savings to entrepreneurs) to purchase $\overline{K}_{t-1}\left(l\right)$ units of raw capital from households at the end of period $t-1$ according to

$$B_{t-1}^e\left(l\right) = Q_{t-1}\overline{K}_{t-1}\left(l\right) - N_{t-1}\left(l\right).$$

After purchasing capital, at the beginning of period t, each entrepreneur is subject to an idiosyncratic productivity shock (ω) that transforms raw capital into effective capital $\omega_t\left(l\right)\overline{K}_{t-1}\left(l\right)$. This shock is assumed to be independently drawn across time and across entrepreneurs and log-normally distributed with mean 1 and standard deviation σ_t. The latter is the so-called risk shock, modeled exactly as in CMR (2014). In particular

$$\log \sigma_t = (1-\rho_\sigma)\,\sigma + \rho_\sigma \log \sigma_{t-1} + \overbrace{\xi_{0,t} + \xi_{1,t-1} + ... + \xi_{8,t-8}}^{=\varepsilon_{\sigma,t}},$$

where $\varepsilon_{\sigma,t}$ is a sum of independently and identically distributed mean zero random variables. It is assumed that in period t agents observe $\xi_{j,t}$, $j = 0, 1, ..., 8$ and that $\xi_{0,t}$ is defined as the unanticipated component of $\varepsilon_{\sigma,t}$ and $\xi_{j,t}$ as anticipated, or news, components. It is further assumed that $\xi_{j,t}$s follow a correlation structure such that for this shock there are four free parameters to be estimated: ρ_σ, σ_σ, $\sigma_{\sigma,n}$, and $\rho_{\sigma,n}$. They are respectively the autoregressive coefficient of the risk shock, the standard deviation of the unanticipated shock, the standard deviation of the anticipated shock, and the correlations between news, namely

$$\rho_{\sigma,n}^{|i-j|} = \frac{E\xi_{i,t}\xi_{j,t}}{\sqrt{\left(E\xi_{i,t}^2\right)\left(E\xi_{j,t}^2\right)}} \qquad i, j = 0, 1, ..., 8,$$

with the extra assumption that $E\xi_{0,t}^2 = \sigma_\sigma^2$, $E\xi_{1,t}^2 = E\xi_{2,t}^2 = ...E\xi_{8,t}^2 = \sigma_{\sigma,n}^2$.

After observing the idiosyncratic shock, each entrepreneur chooses the utilization rate u_t of its effective capital and rents an amount of capital services $K_t(l) = u_t(l)\,\omega_t(l)\,\overline{K}_{t-1}(l)$ to intermediate goods-producing firms at the competitive real rental rate r_t^k. At the end of the period, each entrepreneur is left with $(1-\delta)\,\overline{K}_{t-1}(l)$ units of capital that are sold to households at price Q_t. The overall gross nominal rate of return $R_t^{n,k}$ enjoyed by the entrepreneur in period t is

$$R_t^{n,k} = \frac{P_t r_t^k u_t - P_t a(u_t) + (1-\delta) Q_t}{Q_{t-1}},$$

where $a(u_t)$ represents the cost of changing capital utilization and where we omit the index l, as we take advantage of the fact that the capital utilization decision is common across entrepreneurs. As in Levin, Onatski, Williams, and Williams (2005), $a(u_t) = \rho\frac{u_t^{1+\chi}-1}{1+\chi}$ and in steady state $u = 1$, $a(1) = 0$ and $\chi \equiv \frac{a''(1)}{a'(1)}$.

To cope with the asymmetric information about entrepreneurs idiosyncratic productivity, financial intermediaries enter into a financial contract with entrepreneurs. There is a cutoff value $\overline{\omega}_t(l)$ such that entrepreneurs whose $\omega_t(l)$ is lower than $\overline{\omega}_t(l)$ declare bankruptcy and the intermediary must pay a monitoring cost μ^e proportional to the realized gross payoff to recover the remaining assets. The debt contract undertaken in period $t-1$ consists of a triplet $\overline{\omega}_t(l)$, $B_{t-1}^e(l)$ and $Z_t(l)$ where $Z_t(l)$ represents the loan rate paid to the financial intermediary. The cut-off value satisfies the following equation

$$\overline{\omega}_t(l)\, R_t^{n,k} Q_{t-1}\overline{K}_{t-1}(l) = Z_t(l)\, B_{t-1}^e(l).$$

Note that the previous expression can be used to express $Z_t(l)$ in terms of $\overline{\omega}_t(l)$. Entrepreneurs maximize expected profits

$$E_{t-1}\left\{\left[1-\Gamma_{t-1}\left(\overline{\omega}_t(l)\right)\right]R_t^{n,k}Q_{t-1}\overline{K}_{t-1}(l)\right\},$$

subject to the lender's participation constraint that must be satisfied in each period t state of nature:

$$\left[\Gamma_{t-1}\left(\overline{\omega}_t(l)\right)-\mu^e G_{t-1}\left(\overline{\omega}_t(l)\right)\right]R_t^{n,k}Q_{t-1}\overline{K}_{t-1}(l)-R_{t-1}B_{t-1}^e(l)=0,$$

where $\Gamma_{t-1}\left(\overline{\omega}_t(l)\right)$ is the share of profits going to the lender and $\mu^e G_{t-1}\left(\overline{\omega}_t(l)\right)$ are the expected monitoring costs. As explained in detail by CMR (2014) and Del Negro and Schorfheide (2013), the previous problem can be solved with respect to $\overline{\omega}_t(l)$ and the ratio $B_{t-1}^e(l)/N_{t-1}(l)$, which is related to each entrepreneur's leverage. Notably, the solution of this program implies that the optimal choices of $\overline{\omega}_t(l)$ and $B_{t-1}^e(l)/N_{t-1}(l)$ are common across entrepreneurs, thus facilitating aggregation.

At the end of period t, after having sold undepreciated capital, collected rental income and paid the contractual rate to the financial intermediary, a fraction $1-\gamma_t^*$ of the entrepreneurs exits the economy, whereas the complementary fraction γ_t^* continues operating in the next period. A fraction of total net worth owned by exiting entrepreneurs is consumed upon exit, while the rest is transferred as a lump sum to the household. Note that a variety of decentralizations of the entrepreneur side of the model is possible. Bernanke, Gertler, and Gilchrist (1999) model entrepreneurs as distinct households and entrepreneurial consumption enters the resource as a separate, but quantitatively negligible, term.

Aggregate entrepreneurs' equity V_t evolves as follows

$$V_t=R_t^{n,k}Q_{t-1}\overline{K}_{t-1}-R_{t-1}\left(Q_{t-1}\overline{K}_{t-1}-N_{t-1}\right)-\mu^e G_{t-1}\left(\overline{\omega}_t\right)R_t^{n,k}Q_{t-1}\overline{K}_{t-1}.$$

The evolution of entrepreneurs' total net worth is

$$N_t=\gamma_t^*V_t+A_tW^e,$$

where γ_t^* is entrepreneurs' survival rate (or net worth shock) evolving as an independently and identically distributed $N\left(0,\sigma_{\gamma*}^2\right)$ shock, and W^e is an exogenous net worth transfer from

the household to new entrepreneurs.

It is worth reporting here one relevant log-linearized equation to highlight the presence of one parameter that is estimated. Combining the two first-order conditions from the entrepreneur's problem we obtain

$$E_t\left\{\widehat{R}^{n,k}_{t+1}-\widehat{R}_t\right\}=\zeta_{sp,b}\left(\widehat{q}_t+\widehat{\bar{k}}_t-\widehat{n}_t\right)+\zeta_{sp,\sigma}\widehat{\sigma}_t, \tag{1}$$

where hatted variables indicate log-deviation from steady state, $\widehat{S}_t=E_t\left\{\widehat{R}^{n,k}_{t+1}-\widehat{R}_t\right\}$ is the external finance premium (henceforth EFP) and the parameter of interest is its elasticity with respect to leverage, i.e. $\zeta_{sp,b}$, while $\zeta_{sp,\sigma}$ is derived from steady state restrictions, as shown in Online Appendix C.

Monetary and government policies and market clearing. The monetary policy authority sets the interest rate following a feedback rule

$$\frac{R_t}{R}=\left(\frac{R_{t-1}}{R}\right)^{\rho_R}\left[\left(\frac{\left(\prod_{s=0}^{3}\pi_{t-s}\right)^{1/4}}{\pi^*_t}\right)^{\phi_\pi}\left(\frac{(X_t/X_{t-4})^{1/4}}{e^{\gamma}}\right)^{\phi_X}\right]^{1-\rho_R}e^{\varepsilon^R_t}, \tag{2}$$

where R is the steady state gross nominal interest rate, (X_t/X_{t-4}) represents the observed annual GDP growth, ε^R_t is an independently and identically distributed $N\left(0,\sigma^2_R\right)$ monetary policy shock and π^*_t is the inflation target that varies exogenously over time in response to an independently and identically distributed $N\left(0,\sigma^2_{\pi^*}\right)$ inflation targeting shock $\varepsilon_{\pi^*,t}$, as in Ireland (2007), to account for the low frequency behavior of inflation

$$\log\pi^*_t=(1-\rho_{\pi^*})\log\pi^*+\rho_{\pi^*}\log\pi^*_{t-1}+\varepsilon_{\pi^*,t}.$$

In the optimal policy exercise we will assume that the central bank sets the interest rate to maximize the utility of the representative agent, and thus (2) will be substituted by the optimal (Ramsey) decision rule.

Public spending is a time-varying fraction of output

$$G_t=\left(1-\frac{1}{g_t}\right)Y_t,$$

where g_t varies exogenously over time in response to independently and identically distributed $N\left(0,\sigma_g^2\right)$ fiscal shocks $\varepsilon_{g,t}$, as follows

$$\log g_t = (1-\rho_g)\log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}.$$

Finally, the resource constraint is given by

$$P_t C_t + P_t I_t + P_t a\left(u_t\right)\overline{K}_{t-1} = \frac{1}{g_t} P_t Y_t.$$

where bankruptcy costs are omitted being quantitatively negligible.

3 The Bayesian Estimation

This section presents our empirical analysis. In a first step we describe the data and the details of the Bayesian estimation's procedure. In a second step we discuss the main results of our exercise in terms of posterior distributions for the estimated parameters and variance decompositions.

Data. We use eleven quarterly observable series for the US economy focusing on the sample 1964:Q2 - 2009:Q4. The eight macroeconomic variables include the inflation rate, the nominal interest rate, the logarithm of per-capita hours, the log-difference of real per-capita GDP, consumption and investment, and two measures of nominal hourly wage inflation. To match the wage inflation variable in the model, $\Delta \log W_t$, with the two data series, we use the following measurement equations

$$\begin{bmatrix} \Delta \log NHC_t \\ \Delta \log NE_t \end{bmatrix} = \begin{bmatrix} 1 \\ \Gamma \end{bmatrix} \Delta \log W_t + \begin{bmatrix} e_{1,t} \\ e_{2,t} \end{bmatrix}$$

$$e_{i,t} \sim i.i.d. \quad N\left(0,\sigma_{e_i}\right) \qquad i = 1,2$$

where $\Delta \log NHC_t$ represents the growth rate of nominal compensation per hour in the total economy, $\Delta \log NE_t$ represents the growth rate of average hourly earnings of production and nonsupervisory employees, Γ is a loading coefficient of the second wage series, while the first wage series' loading coefficient is normalized to one, and $e_{1,t}$ and $e_{2,t}$ are observation errors.

In addition, we use three financial variables, namely the credit spread measured by the difference between the interest rate on BAA-rated corporate bonds and the ten-year US government bond rate (as a proxy for the external finance premium), the log-difference of real per-capita

stock price index (as a proxy for net worth), and the log-difference of real per-capita credit to firms.[4] An independently and identically distributed observation error, following a Weibull distribution with zero mean and $\sigma_{e\gamma^*}$ standard deviation, is assumed for the net worth series, as in CMR (2014). A detailed description of the data is presented in Online Appendix D.

Prior and posterior distributions. The information on prior distributions is summarized in Table 6 while related figures are provided in Online Appendix E. We borrow the prior assumptions on the parameters that are related to the financial frictions block from CMR (2014) and Del Negro and Schorfheide (2013).

Following the standard practice in the literature, some parameters are fixed in the estimation procedure. The capital depreciation rate is calibrated at 0.025, the steady state ratio of government spending to GDP at 0.2, the steady state net wage mark-up at 25 percent and the persistence of the inflation target shock at 0.995. As for the financial sector, the entrepreneurs' default probability $F(\overline{\omega})$ is set at 0.0075 (3 percent in annual terms) and the entrepreneurs' survival rate γ^* at 0.99.[5] We also fix the steady-state value of technology growth (100γ), hours worked ($\log L_{ss}$) and inflation rate ($100(\pi - 1)$) at the JPT (2013) estimated posterior medians, i.e. 0.47, 0 and 0.24, respectively. The sample means of all observed variables have been removed before the estimation, with the exception of the credit spread mean $\left(\widetilde{S}\right)$ which is estimated as in Del Negro and Schorfheide (2013). This is to prevent the long-run means from affecting the estimation. For example, average consumption growth is higher than GDP growth in the data, while in the model the consumption to GDP ratio is stationary.

We estimate the posterior distributions by maximizing the log-posterior function, which combines the prior information on the parameters with the likelihood of the data. In the next step, the Metropolis-Hastings algorithm is used to obtain a complete picture of the posterior distribution and to evaluate the marginal likelihood of the model. We run two Metropolis-Hastings chains of 1 000 000 iterations each, with a 20 percent burn-in. Brooks and Gelman (1998)'s multivariate convergence statistics of MCMC are presented in Online Appendix E together with the full posterior distributions.

We report the estimated posterior medians of our baseline model with financial frictions in Table 6. The financial frictions parameters $\zeta_{sp,b}$ and $\widetilde{S}$, whose posterior medians are 0.04

[4]FOOTNOTE NOT INTENDED FOR PUBLICATION: As also pointed out in CMR (2014), we obtain similar results when we repeat our empirical analysis using the spread measure constructed by Gilchrist and Zakrajsek (2012).

[5]FOOTNOTE NOT INTENDED FOR PUBLICATION: CMR (2014), focusing on the shorter sample 1985-2010, estimate $F(\overline{\omega})$ at 0.0056, and calibrate γ^* at 0.985. Our results are largely unaffected under this alternative parameterization.

and 0.43 respectively, are in the ballpark of the estimates provided in Del Negro, Giannoni, and Schorfheide (2015) and CMR (2014). A few parameters display substantial changes with respect to the standard New Keynesian version of the model and play a key role in explaining our results. The most striking difference is in the process for the labor supply shock. Both its standard deviation and its persistence are found to be much lower in our baseline model. The former is estimated at a value of 0.52 (as opposed to 4.49), the latter at 0.47 (instead of 0.98). In contrast, financial and investment shocks are very persistent and capture the low frequency dynamics in financial data. The second important difference is in the parameters driving price and wage dynamics, specifically ξ_w and ι_p, together with, to a minor extent, the inverse of labor supply elasticity ν, which imply flatter New Keynesian Phillips curves for prices and wages, as further discussed below.[6]

Variance decompositions. The difference in the estimated parameters of the labor supply shock process has strong implications for the variance decomposition. In fact, while in the standard New Keynesian model labor supply shocks explain a large share of the low frequency fluctuations in actual output, as shown by the unconditional variance decomposition in Table 2, this is not the case in our baseline model with financial frictions, where actual output is mostly driven by investment shocks (62 percent) and financial shocks (35 percent). At business cycle frequencies, financial shocks are dominant as in CMR (2014). They explain a large fraction of output fluctuations (73 percent) and crowd out the investment specific shocks, which instead play a key role in the standard New Keynesian model (cf. JPT, 2010 and 2013).

An important result of our paper is to uncover the minor importance of labor supply shocks at low frequencies in favor of investment shocks which, despite losing importance at business cycle frequencies, become relevant in the long run (cf. Table 2).[7] The large effects of investment shocks and the limited propagation of labor supply shocks can be appreciated also from the impulse responses plotted in Figure 1 (solid red and dashed green lines, respectively). The lower

[6]FOOTNOTE NOT INTENDED FOR PUBLICATION: In fact, we estimate a substantially higher degree of wage rigidity in the model with financial frictions, as the Calvo wage parameter ξ_w is estimated at 0.93 instead of 0.73 in the standard New Keynesian model (while wage indexation remains unchanged). Another parameter affecting the slope of the wage curve is the inverse of the labor supply elasticity ν which we estimate as somewhat lower in our baseline model, i.e. 2.35 instead of 2.67. A flatter New Keynesian Phillips curve for wages implies that smaller labor supply shocks are necessary to reconcile data on wages and on the marginal rate of substitution (which is a function of consumption and hours worked). As far as the degree of price stickiness, measured by the parameter ξ_p, is concerned, we do not observe a relevant difference, but we find a higher indexation parameter ι_p, 0.53 as opposed to 0.15, which also translates into a flatter Phillips curve.

[7]CMR (2014) do not feature a labor supply shock in the published version of their paper. In previous versions, however, a wage mark-up shock was included and turned out to be almost irrelevant for economic fluctuations. The authors wrote *"While the irrelevance of labour supply shocks in our baseline model is very interesting in its own right, we do not study it further in this paper."* Our paper sheds light on that result which turns out to have important policy implications.

importance of labor supply shocks together with the relevance of financial and investment shocks have critical implications for the dynamics of potential output (and as a consequence for the output gap), as we will discuss in detail in the next sections.

At this stage, it is crucial to understand why the role of labor supply shocks is so marginal in our baseline model. The use of financial variables in the estimation and the estimated degree of nominal rigidities rationalize this result.

In fact, financial variables (credit, stock prices and the external finance premium) are more persistent than real variables and the permanent technology shock is not able on its own to fit this extra-persistence which is instead captured by very persistent investment-specific shocks. The standard New Keynesian model faces a similar issue with the hours worked series which also features an important low frequency component captured by labor supply shocks (with an autocorrelation coefficient of 0.98). The labor supply shock is the ideal candidate to capture the low frequency component in hours worked because it is the only shock which can deliver a quasi-permanent effect on hours worked. This same shock, however, is not appropriate to capture the extra-persistence of financial variables in our set-up, as shown by the dashed green lines in Figure 1, since it hardly propagates at all. The effect on credit and investment is limited even in a counterfactual in which we use the values of persistence and standard deviation estimated in the standard New Keynesian version of the model while keeping all the other parameters at the posterior median value estimated in our baseline model (cf. dotted blue lines in Figure 1). In fact, the shock propagates mainly through the labor market and much less via investment and credit (the credit response is even slightly negative for several quarters). In contrast, the investment shock (whose persistence is estimated to be at 0.99) generates large and persistent responses in credit and stock prices (as shown in Figure 1), thus being the ideal shock to capture the very persistent dynamics in these variables.

While the use of all three financial variables helps explain our results, a special role is played by the external finance premium. In fact, as it can be seen in Figure 3, the external finance premium is clearly pro-cyclical conditional on labor supply shocks, while it is strongly counter-cyclical unconditionally. This property of labor supply shocks has no practical implications in models that do not include a measure of the spread as an observable variable but it is of course relevant in our case. Why then a contractionary labor supply shock does lead to a decline in the premium? An exogenous decline in the labor input has a negative effect on the demand for capital, as the two factors of production are complements in the production function. This leads

to a decline in the price of capital, a reduction in its utilization rate and a decline in investment. Such a persistent decline in the value of the capital stock (the assets of entrepreneurs), translates into a decline in both the liabilities and the net worth of entrepreneurs. However, the decline in the value of assets is larger than the decline in net worth, thus leading to a reduction in leverage. A lower level of leverage is reflected in a decline in the external finance premium, as it can be seen in equation (1). We conclude that the use of data on the external finance premium helps explain the reduced role of labor supply shocks.

Finally, the estimated high degree of nominal rigidities in our model further limits the effects of labor supply shocks that propagate substantially more under flexible prices and wages, as shown in the first panel of Figure 3. A high degree of nominal rigidities is needed to match the fact that stock market booms (that are a proxy for the evolution of net worth in our model) and credit booms are associated to limited fluctuations in price and wage inflation, as can be seen in the first panel of Figure 2. The shaded areas highlight the US stock market booms, as classified by Christiano, Ilut, Motto, and Rostagno (2010). During those periods, the evolution of price and wage indexes does not exhibit any remarkable acceleration. Therefore, the model needs a high degree of nominal rigidities to reconcile large fluctuations in financial variables together with relatively stable nominal variables. Highly persistent investment and financial shocks rationalize the disconnect between financial variables and inflation (and to some extent also between financial variables and real economic activity) described in the Introduction of this paper.[8]

Alternative specifications. Our baseline model features a news component on the process for the risk shock. As in CMR (2014), the presence of such a news component improves the fit of the model: we find a marginal data density of -2238.6459 for our baseline, as opposed to -2741.4710 for the model with only unanticipated shocks. We considered also a specification with a news component attached only to the neutral technology shock. It turns out that our baseline model obtains a better fit than the alternative, having the latter a marginal data density of -2280.6348. We have also considered i) a specification with only one financial variable used as observable (the spread) as in Del Negro and Schorfheide (2013), ii) a version of the model with a second stochastic trend on the relative price of investment and iii) our baseline model estimated over a shorter sample (1985:Q1-2010:Q2), as in CMR (2014). In all three cases, our

[8] A similar intuition is developed in Del Negro, Giannoni, and Schorfheide (2015) to explain how a model with financial frictions accounts for the limited drop in inflation during the Great Recession through a flat New Keynesian Phillips curve for prices. Here, in the context of the same kind of model, but with more observables used in the estimation, we find a similar mechanism acting mainly through the wage equation.

main results (including the policy implications) are broadly confirmed.

4 Optimal monetary policy and financial frictions

In this section, we investigate whether the presence of pervasive financial frictions and large financial shocks is, in and of itself, a reason for central banks to abandon their focus on price stability in the context of our estimated model.

Monetary policy trade-offs. In small-scale models (cf. Erceg, Henderson, and Levin, 2000), the output gap, price inflation and wage inflation are the only variables entering in the microfounded loss function for the central bank. Furthermore, given the simple structure of the model, a stable output gap is compatible with stability in a weighted average of price and wage inflation (in the absence of cost-push shocks). In a medium-scale model with financial frictions, an analytical expression for the loss function derived as an approximation of the representative agent utility function is not available. Other variables may be of direct relevance for the central bank and trade-offs between different objectives may be more complicated.

We study the model's optimal equilibrium, i.e. the welfare-maximizing equilibrium chosen by the central bank under commitment subject to the constraints represented by the behavior of private agents. More specifically, we use the solution of the model under Ramsey monetary policy to compute the counterfactual path of output and other endogenous variables that would have emerged if policy had always been optimal and the economy had been perturbed by the series of shocks estimated in the baseline version of the model under the historical Taylor-type interest rate rule (with the exception of the two shocks entering the Taylor rule that do not affect the optimal equilibrium). We assume that the only instrument available to the central planner is the short-term interest rate.

In Figure 4 we plot with solid blue lines the historical evolution of price inflation and wage inflation together with the model-based estimate of the output gap, while the dashed-dotted red lines refer to the counterfactual evolution of the same variables under optimal policy. The underlying measure of potential output is defined as the counterfactual level of output in the absence of dynamic distortions and inefficient shocks, as in Smets and Wouters (2007). We note that under optimal policy, wage inflation is almost perfectly stabilized, which also implies, given the direct link between wages, marginal costs and prices, a low and stable price inflation rate over the sample period. Taken together, these results show the optimality of a strong focus on nominal stabilization to undo the effects of nominal rigidities for the monetary policy authority.

More specifically, we confirm previous results in the literature on the optimality of stabilizing wage inflation in New Keynesian models (cf. JPT, 2013, and Levin, Onatski, Williams, and Williams, 2005): this result survives even in presence of pervasive financial frictions and large financial shocks.

In panel A we compare the evolution of actual and optimal output (both plotted in deviation from potential output). While a substantial share of output gap fluctuations could have been avoided under optimal policy, we see that optimal output does not fully track potential output (cf. dashed-dotted line). This means that a non-negligible share of fluctuations (summarized by the difference between the dashed-dotted red line and the zero line) was unavoidable. While in the model without financial frictions the share of unavoidable fluctuations is extremely small and optimal monetary policy can achieve a "Trinity" by stabilizing the output gap, price inflation and wage inflation at the same time (cf. JPT, 2013), in our model optimal monetary policy can achieve only a "Weak Trinity": some fluctuations in the output gap are the unavoidable price to pay to achieve nominal stabilization. Nevertheless, the trade-offs between nominal and real stabilization remain relatively small under optimal policy (despite the presence of several distortions in the model).

What shocks are responsible for the unavoidable fluctuations, or in other words, what are the shocks responsible for the diverging dynamics between optimal output and potential output? In Figure 5 we plot the impulse responses of potential and optimal output to all shocks. We see that optimal output tracks the response of potential output in response to most shocks. The main discrepancies are found in response to price mark-up, wage mark-up and government spending shocks. Therefore, price and wage mark-up shocks are the main drivers of the unavoidable fluctuations even in the context of a complex medium-scale model with financial frictions, as is the case in small-scale models. The other shocks, that in principle could generate large trade-offs, generate in practice only small trade-offs (with the partial exception of government spending shocks and investment shocks at selected horizons), given the estimated set of parameters. Notably, financial shocks generate small trade-offs under optimal policy, and nominal stabilization turns out to offset the effect on output of risk and net worth shocks. In fact, these disturbances have large effects in presence of nominal rigidities whereas they propagate little under optimal policy. We can say that a "Conditional Trinity" emerges in response to the two financial shocks (but also to other shocks), thus showing that a policy of nominal stabilization is close to optimal in most cases. Somewhat surprisingly, financial shocks do not seem to pose

particular challenges to the monetary policy authority: in the end they behave like standard demand shocks and do not generate adverse trade-offs between nominal and real stabilization.

The Monetary Policy Score. Since a non-negligible share of output gap fluctuations was unavoidable (and actually desirable), the conventional output gap cannot be considered as an indicator of imbalances (or of inflationary pressures in particular) in the economy, unlike in small-scale models. An alternative measure of the output gap in our model is given by the difference between actual and optimal output, i.e. the difference between the solid blue and the dashed-dotted red line in Figure 4 that we plot in Figure 6 with dashed-starred green line. We name this gap Monetary Policy Score, since it reflects all fluctuations that could have been avoided under optimal monetary policy. In other words, it can be seen as a measure of policy mistakes due to the suboptimality of the estimated Taylor rule. The Monetary Policy Score identifies large imbalances that build up rapidly over the mid-1990s and vanish abruptly during the Great Recession.

Besides being a proper measure of monetary policy mistakes, the "Monetary Policy Score" features an additional advantage over the conventional measure of the output gap. In fact, in the computation of the "Monetary Policy Score" there is no need to distinguish between efficient and inefficient shocks, as is the case for the conventional output gap. As noted by Woodford (2003), it is often problematic to determine whether a specific real shock distorts the economy towards inefficiency or simply leads to fluctuations in the efficient frontier. Furthermore, it has proven challenging to distinguish between efficient and inefficient shocks even in the context of theoretical models: efficient labor supply shocks are observationally equivalent to inefficient wage mark-up shocks in standard models, whereas disentangling efficient productivity shocks from inefficient price mark-up shocks is often challenging in empirical exercises. The "Monetary Policy Score", and more specifically both actual and optimal output, is affected by all disturbances, regardless of their nature, and the distinction between efficient and inefficient shocks vanishes.

The recent period. Our model is estimated using data until 2009:Q4 for the sake of comparison with the existing relevant literature. Hence, we do not include the period in which the zero lower bound on the nominal interest rate is binding. Nonetheless, the analysis of the most recent years is particularly interesting and thus we extend here our sample to study the period 2010:Q1-2017:Q4. We follow Del Negro and Schorfheide (2013) to account for the non-linearities induced by the zero lower bound. In particular, we augment the process of the monetary policy shock by including anticipated shocks that capture future expected deviations

from the systematic part of the monetary policy rule (2) such that

$$\widetilde{\varepsilon}_t^R = \varepsilon_t^R + \sum_{k=1}^{K} \varepsilon_{k,t-k}^R$$

where the policy shocks $\varepsilon_{k,t-k}^R$, $k = 1, ..., K$, independently and identically distributed $N(0, \sigma_{R,k}^2)$, are known to agents at time $t-k$ but affect the policy rule with a k period delay in period t.[9] We consider the case $K = 6$. To inform the model about the extra shocks we use 6 extra observables, namely the expectations of the nominal interest rate up to 6 quarters ahead as from the Blue Chip Financial Forecasts survey. Six measurement equations are added: $R_{t+1+k}^{e,obs} = E_{t+1}[R_{t+1+k}]$, where $R_{t+1+k}^{e,obs}$ is the observed k-period-ahead interest rate expectation and $E_{t+1}[R_{t+1+k}]$ is the model-implied k-period-ahead interest rate expectation. We do not estimate the variances of the anticipated shocks. This facilitates the comparison between the old and the new counterfactuals because they are generated based on the same posterior distribution of model parameters. Following Del Negro and Schorfheide (2013) we set all $\sigma_{R,k}^2$ to the estimated value of σ_R^2. We run the Kalman smoother under such parameterization to "simulate" the model over the extended sample.

On the right side of Figure 4, it is possible to evaluate the policy exercise for recent years. Notably, the optimality of wage inflation stabilization is confirmed also in recent years. Such a policy would have implied limited fluctuations in price inflation (thus tracking well observed price inflation) and limited fluctuations in the output gap. This exercise reconfirms that the main source of welfare losses in the model is due to wage dispersion, even in presence of pervasive financial frictions and large financial shocks as in recent years.

5 The Output Gap and Financial Frictions

In this section we focus on the model-based estimated output gap plotted in Figure 4. In particular, we evaluate the importance of financial frictions and financial shocks for the measurement and the definition of the output gap, arguably an important intermediate target for monetary policy, as discussed in the previous section. The role of financial factors for output gap dynamics has long been emphasized in the policy discussion but our paper is, as far as we know, the first analysis in the context of an estimated macroeconomic model.

The reference level of output. In medium-scale models, the choice of the reference

[9] From a technical perspective we need to augment the state vector with K additional states $\nu_t^R, ..., \nu_{t-K}^R$, such that $\nu_{1,t}^R = \nu_{2,t-1}^R + \varepsilon_{1,t}^R, \nu_{2,t}^R = \nu_{3,t-1}^R + \varepsilon_{2,t}^R, ..., \nu_{K,t}^R = \varepsilon_{K,t}^R$. Therefore $\widetilde{\varepsilon}_t^R = \varepsilon_t^R + \nu_{1,t-1}^R$.

level of output to calculate the output gap is not obvious. As already mentioned, we follow Smets and Wouters (2007) and define potential output as the counterfactual level of output that emerges in the absence of dynamic distortions (sticky prices and wages) and in the absence of inefficient shocks (i.e. price mark-up and wage mark-up shocks).[10] However, while in the standard New Keynesian model nominal rigidities are the only distortions affecting the dynamics of the model, here also the financial accelerator mechanism distorts the economy's response to shocks. Therefore, our counterfactual is computed in the absence of *both* the nominal rigidities *and* the financial accelerator, with the aim of approximating the dynamics of the efficient frontier. This is achieved by a parametric restriction such that $\Lambda_{p,t} = \Lambda_{w,t} = 0$, and by imposing $\zeta_{sp,b} = 0$ in the counterfactual. Notably, the interpretation of financial shocks as inefficient or efficient is inconsequential in our model. In fact, both financial shocks do not propagate under flexible prices and wages and in the absence of a financial accelerator mechanism (cf. dashed lines in Figure 5). In the absence of financial frictions, variations in net worth have no impact and the spread is equal to zero, thus making the risk shocks immaterial. In other words, both financial shocks share the same properties of monetary shocks and do not propagate in our counterfactual exercise. Using the Borio, Disyatat, and Juselius (2017) terminology, our output gap is "finance neutral" because financial shocks do not affect potential output. While any choice for the reference level of output involve some arbitrariness, we show in the Appendix A that the estimated output gap is robust to the use of various alternative reference levels of output. The results are presented in Figure 6.

Estimated output gap. In the first panel of Figure 7 we plot again the output gap derived in our model *with* financial frictions and the output gap derived in the model *without* financial frictions. We note large differences between the two output gaps explained by the behavior of potential output, which we plot in the second panel of Figure 7. In the model with financial frictions, potential output is substantially higher in the 1980s and lower from 1993 until the beginning of the Great Recession than in the model without financial frictions.

Why then has potential output such a different shape in our model with financial frictions? Essentially because financial shocks absorb explanatory power from labor supply shocks (and to some extent also from investment-specific technology shocks, at least at business cycle frequencies). Notably, financial shocks do not affect potential output while labor supply shocks have

[10] As in the previous literature, steady-state distortions (positive price and wage mark-ups and positive external finance premium) are not closed on the basis of the argument that monetary policy is not the right instrument to deal with those (quantitatively minor) inefficiencies.

a larger effect on potential output than on actual output. The model with financial frictions identifies a large output gap during the second half of the 1990s, when the path of potential output is essentially flat, as the boom in actual output in that period is mainly driven by expansionary financial shocks. Importantly, the output gap is still positive in the pre-Great Recession period, but its size is much lower than in the previous decade.[11] In contrast, in the standard New Keynesian model potential output is much higher, sustained by large positive labor supply shocks. Put differently, the output boom is driven by growth in potential output, such that the output gap is almost always negative over the period 1995-2007. The standard New Keynesian model identifies a large drop in potential during the Great Recession, whereas potential even increases slightly in the model with financial frictions, despite the large decline in actual output, being it unaffected by the large negative financial shocks that lower actual output in that period. Finally, the standard New Keynesian model implies a large positive output gap during the Volcker disinflation and the twin recessions that followed it: negative labor supply shocks are responsible for this result, as they lower potential output more than actual output, thus opening a positive output gap.[12]

It is important to stress that we do not want to convince the reader that one or the other measure of the output gap is more plausible. Both measures differ in many respects from the "conventional view" of the US business cycle, often summarized by statistical measures of the output gap. Both models, with or without financial frictions, rely on measures of potential output that are volatile and have an important low frequency component and thus differ from conventional measures of the output gap almost by construction. We rather want to highlight how the mere presence of financial frictions and financial shocks has large effects on the estimated output gap. We re-emphasize here that the difference between the two lines plotted in the first panel of Figure 7 are driven exclusively by the presence of financial frictions and financial shocks.

Borio, Disyatat, and Juselius (2017) argue that standard measures of the output gap are unreliable since they do not properly take into account financial factors. They claim that those measures do not identify any imbalances in the pre-Great Recession period, essentially because boom-and-bust cycles in credit and asset prices are non-inflationary.[13] While they make their

[11]Note that large fluctuations in the output gap do not necessarily imply inflationary pressures given the lack of proportionality between marginal costs and the output gap in medium-scale models and the high degree of nominal rigidities estimated in our model.

[12]FOOTNOTE NOT INTENDED FOR PUBLICATION: These implications of the standard New Keynesian model have been criticized by Chari, Kehoe, and McGrattan (2009) and Walsh (2006) who argue that a joint decline in actual and efficient output during the recessionary period 1979-1984 is implausible given the monetary flavor of those recessions. The presence of large negative labor supply shocks over the period is also in contrast with the dynamics of steadily increasing labor force participation.

[13]Empirical evidence on the non-inflationary nature of financial shocks is provided by Furlanetto, Ravazzolo,

point in the context of a regression analysis,[14] we confirm their result in a structural model: financial factors have a large impact on the measurement of the output. At the same time, however, we find that a monetary policy focused on nominal stabilization is sufficiently powerful to achieve a relatively good stabilization of real economic activity.

Low frequency dynamics. Our estimated measure of the output gap exhibits an important low frequency component, driven by highly persistent shocks needed to match the behavior of the financial variables used as observables in the estimation. Such a non-stationary measure of the output gap is not specific to our estimated model. In Figure 8 we report the output gap derived in the original model by Smets and Wouters (2007) and we see how its shape, and to some extent also its magnitude resemble those of our estimated series. However, maximum values in the order of 10-15% are admittedly extreme. In order to address this issue, we follow Ferroni (2011) and Canova (2014) by bridging the gap between the dynamics of raw data and the model's variables through the measurement equations. In particular, we estimate the trend of each growing variable together with the rest of the model. We use a local linear specification for the trends (cf. Durbin and Koopman (2001), Chapter 3). The measurement equation for any trending variable J_t in the baseline model is given by

$$\Delta \log J_t^{obs} = \Delta \log J_t + z_t$$

where J_t^{obs} refers to the observed value of each trending variable and z_t represents the growth rate of the Solow residual. Under the local linear specification the measurement equations are modified as follows:

$$\Delta \log J_t^{obs} = \Delta \log J_t + \Delta \log J_t^T \tag{3}$$

where $\log J_t^T = \log J_{t-1}^T + \log \tau_{t-1} + \varepsilon_{J1,t}$, and $\log \tau_t = \log \tau_{t-1} + \varepsilon_{J2,t}$, while $\varepsilon_{J1,t}$ and $\varepsilon_{J2,t}$ are exogenous terms independently and identically distributed $N(0, \sigma_{J1})$ and $N(0, \sigma_{J2})$ respectively. The specification in (3) states that the observed variable is the sum of a cyclical component J_t, as characterized by the model, and of a trend component J_t^T which is specific to any growing

and Sarferaz (2019) in a Vector Autoregression (VAR) model. For a more general discussion on the link between monetary policy, inflation and boom-and-bust cycles, cf. Christiano, Ilut, Motto, and Rostagno (2010).

[14] Borio, Disyatat, and Juselius (2017) regress the output gap on a lagged measure of the output gap itself and on credit growth and house price growth to purify the output gap from the influence of financial factors ("finance-neutral" output gap). They use a measure of total credit that increases substantially in the pre-Great Recession period driven by the boom in credit to households. Given the structure of our model, we restrict our attention to credit to firms that is more stable in that period but that still exhibits the typical low frequency dynamics of the credit cycle.

variable.[15] Note that z_t is not included in (3) because we want J_t^T to be the only driver of low frequency dynamics for each variable. Hence, we set ρ_z and σ_z to zero. All new parameters are estimated together with the previously estimated parameters, by assigning as prior distribution an inverse gamma with mean 0.01 and infinite variance to σ_{J1} and σ_{J2}. Data will thus determine the appropriate trend for each variable. The advantage of this general specification is that it nests alternative well-known specifications for trends like deterministic trends or unit roots with drifts.[16] In its general specification, the local linear trend formulation implies a smooth stochastic trend for each variable which can be interpreted as a unit root with a time-varying drift. Finally, our baseline model can be seen as a special case of the more general specification with local linear trends.

In Figure 8 we see that the output gap is considerably more stationary when we estimate the model with local linear trends. This specification absorbs a large share of the low frequency dynamics introduced by the use of financial variables as observables and the output gap now almost overlaps with the estimate of Smets and Wouters (2007). As in their case, the remaining low frequency dynamics are induced by the hours worked series. Note, however, that despite its ability in generating more stationary dynamics for the output gap, the data penalize the specification with local linear trends by about 100 log-likelihood points when compared to our baseline model.

6 Conclusion

We have investigated whether the presence of pervasive financial frictions and large financial shocks is, in and of itself, a reason for central banks to abandon their focus on nominal stabilization. Our main result is that financial factors affect the optimal policy only to some extent. A policy of nominal stabilization (with a particular focus on targeting wage inflation) is still the optimal policy, although the central bank is now unable to fully stabilize economic activity around its potential level. While the policy prescriptions change only to some extent, the presence of financial frictions and financial shocks affects critically the perspective on economic fluctuations during the last 30 years. In fact, the size and the shape of the estimated output gap and the relative importance of different shocks change radically. More generally, we provide a

[15] In level, the local linear specification is $\log J_t^{Jobs} = \log J_t + \log J_t^T$. Equivalently one can write $\Delta \log J_t^{obs} = \Delta \log J_t + \Delta \log J_t^T$.

[16] If $\varepsilon_{J1,t} = \varepsilon_{J2,t} = 0$, $J_0^T = 0$, and $\tau_t = \tau_{t-1} = \tau$ for all t, we have a deterministic time trend, i.e. $J_t^T = \tau t$. If $\varepsilon_{J1,t} = \varepsilon_{J2,t} = 0$ and $\tau_t = \tau_{t-1} = \tau$ for all t, we have a unit root with drift, i.e. $\log J_t^T = \tau + \log J_{t-1}^T + \varepsilon_{J1,t}$.

model-based perspective on the importance of financial factors to compute measures of capacity utilization, as highlighted earlier in the policy discussion.

This opens up several avenues for future research. First, we have conducted our analysis using the most standard model with financial frictions (the financial accelerator model) which, however, completely ignores frictions in the banking sector and household debt. Extending our analysis to alternative models with different kinds of financial frictions seems of paramount importance for monetary policy analysis. A first step in that direction has been taken by Rabanal and Taheri Sanjani (2015).

Second, our estimated output gap features a low frequency component even in its specification with local linear trends. As in Smets and Wouters (2007), these dynamics are induced by the hours worked series. Galí, Smets, and Wouters (2011) show that modeling unemployment explicitly may be useful to obtain a more stationary measure of the output gap, since the unemployment series is more stationary than the hours worked series. In their model, however, unemployment is the only observable labor market variable. Investigating whether their result is confirmed in a model that combines labor market frictions, financial frictions and two observable labor market variables, reflecting the intensive and the extensive margins of labor adjustment, also seems an interesting avenue for future research.

Finally, financial shocks play an important role in our model as long as news components are attached to the shock process. While this is also the case in the state-of-the-art estimated model by CMR (2014), the more recent VAR evidence hints that purely unanticipated financial shocks may play an important role on their own (cf. Furlanetto, Ravazzolo, and Sarferaz, 2019, and the references therein). Finding alternative theoretical mechanisms (or alternative observable variables) in order to generate a more important role for unanticipated financial shocks also seems to be an urgent challenge for macroeconomic modelers.

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		Prior			Posterior			
					Standard NK	Baseline		
		Dist	Mean	SE	Median	Median	5 %	95 %
α	Capital share	N	0.30	0.05	0.16	0.16	0.15	0.17
ι_p	Price indexation	B	0.50	0.15	0.15	0.53	0.42	0.65
ι_w	Wage indexation	B	0.50	0.15	0.04	0.03	0.01	0.05
h	Habit formation	B	0.60	0.10	0.82	0.84	0.80	0.89
λ_p	SS price markup	N	0.15	0.05	0.25	0.13	0.10	0.16
$100(\beta^{-1}-1)$	Discount factor	G	0.25	0.10	0.18	0.09	0.04	0.15
ν	Inverse Frisch	G	2.00	0.75	2.67	2.35	1.67	2.79
ξ_p	Price stickiness	B	0.66	0.10	0.84	0.80	0.75	0.85
ξ_w	Wage stickiness	B	0.66	0.10	0.73	0.93	0.91	0.94
χ	Elasticity util. cost	G	5.00	1.00	5.25	3.49	2.75	4.23
S''	Invest. adj. costs	G	4.00	1.00	3.87	3.60	2.96	4.85
ϕ_π	Reaction infl.	N	1.70	0.30	2.33	2.16	1.93	2.35
ϕ_X	Reaction GDP gr.	N	0.40	0.30	0.84	0.57	0.46	0.70
Γ	Loading coeff.	N	1.00	0.50	0.65	0.89	0.82	0.96
$\widetilde{S}$	SS EFP	G	0.50	0.025	–	0.43	0.40	0.46
$\zeta_{sp,b}$	Elasticity EFP	B	0.05	0.005	–	0.04	0.03	0.04
$\rho_{\sigma,n}$	Correl. signals	N	0.00	0.50	–	0.64	0.57	0.71
ρ_R	Smoothing	B	0.60	0.20	0.70	0.75	0.71	0.79
ρ_z	Auto. tech.	B	0.40	0.20	0.13	0.20	0.09	0.30
ρ_g	Auto. gov. Spending	B	0.60	0.20	1.00	0.98	0.95	0.9984
ρ_μ	Auto. investment	B	0.60	0.20	0.69	0.9988	0.9973	0.9999
ρ_p	Auto. price markup	B	0.60	0.20	0.25	0.25	0.06	0.40
ρ_ψ	Auto. labor supply	B	0.60	0.20	0.98	0.47	0.38	0.58
ρ_b	Auto. intertemporal	B	0.60	0.20	0.64	0.78	0.71	0.84
ρ_σ	Auto. unanticipated risk	B	0.75	0.15	–	0.9961	0.9884	0.9998
$100\sigma_R$	Std mp	IG2	0.15	1.00	0.22	0.24	0.22	0.26
$100\sigma_z$	Std tech.	IG2	1.00	1.00	0.86	0.84	0.77	0.92
$100\sigma_g$	Std gov. spending	IG2	0.50	1.00	0.36	0.36	0.33	0.39
$100\sigma_\mu$	Std investment	IG2	0.50	1.00	7.45	5.50	4.93	6.08
$100\sigma_p$	Std price markup	IG2	0.15	1.00	0.16	0.17	0.15	0.19
$100\sigma_\psi$	Std labor supply	IG2	1.00	1.00	4.49	0.52	0.21	0.89
$100\sigma_b$	Std intertemporal	IG2	0.10	1.00	0.03	0.02	0.01	0.02
$100\sigma_w$	Std wage markup	IG2	0.15	1.00	0.06	0.05	0.02	0.08
$100\sigma_{\pi^*}$	Std inflation target	IG2	0.05	0.03	0.05	0.06	0.04	0.07
$100\sigma_\sigma$	Std unanticipated risk	IG2	0.20	1.00	–	0.13	0.11	0.16
$100\sigma_{\sigma,n}$	Std anticipated risk	IG2	0.10	1.00	–	0.10	0.09	0.11
$100\sigma_{\gamma^*}$	Std net worth	IG2	0.20	1.00	–	1.35	1.10	1.59
$100\sigma_{e_1}$	Std meas error 1	IG2	0.15	1.00	0.49	0.51	0.46	0.56
$100\sigma_{e_2}$	Std meas error 1	IG2	0.15	1.00	0.28	0.24	0.21	0.28
$100\sigma_{e_{\gamma^*}}$	Std meas error net worth	Weibull	0.01	5.00	–	0.01	0.01	0.01

Table 1: Estimated parameters.

Prior and posterior distributions. N = Normal, B = Beta, G = Gamma, IG2 = Inverse gamma type 2. The steady state of technology growth (100γ), hours worked ($logLss$), and inflation rate ($100(\pi-1)$) are fixed at the Justiniano et al. (2013) estimated posterior medians, i.e. 0.47, 0, and 0.24 respectively. Calibrated parameters: $G/Y = 0.2$, $\delta = 0.025$, $\lambda_w = 0.25$, $\rho_{\pi^*} = 0.995$, $F(\overline{\omega}) = 0.0075$, $\gamma^* = 0.99$.

	Standard NK		Baseline	
	Actual output	Potential output	Actual output	Potential output
		Business cycle frequency		
Monetary policy	0.94	0.00	1.91	0.00
Technology	23.42	14.14	11.09	46.55
Government spending	3.05	2.89	1.44	9.67
Inv. specific	50.39	21.70	0.94	41.81
Price markup	1.29	0.00	1.44	0.00
Labor supply	11.94	61.14	0.00	0.31
Intertemporal	7.89	0.12	7.52	1.66
Wage markup	0.05	0.00	0.15	0.00
Inflation target	1.03	0.00	1.71	0.00
Risk	–	–	73.15	0.00
Net worth	–	–	0.65	0.00
		Unconditional		
Monetary policy	0.21	0.00	0.20	0.00
Technology	2.47	1.28	0.34	0.09
Government spending	1.46	1.19	0.09	0.04
Inv. specific	16.37	4.00	62.23	99.84
Price markup	0.17	0.00	0.04	0.00
Labor supply	77.54	93.45	0.00	0.00
Intertemporal	1.13	0.07	0.63	0.03
Wage markup	0.02	0.00	0.01	0.00
Inflation target	0.63	0.00	1.44	0.00
Risk	–	–	34.80	0.00
Net worth	–	–	0.22	0.00

Table 2: Variance decomposition

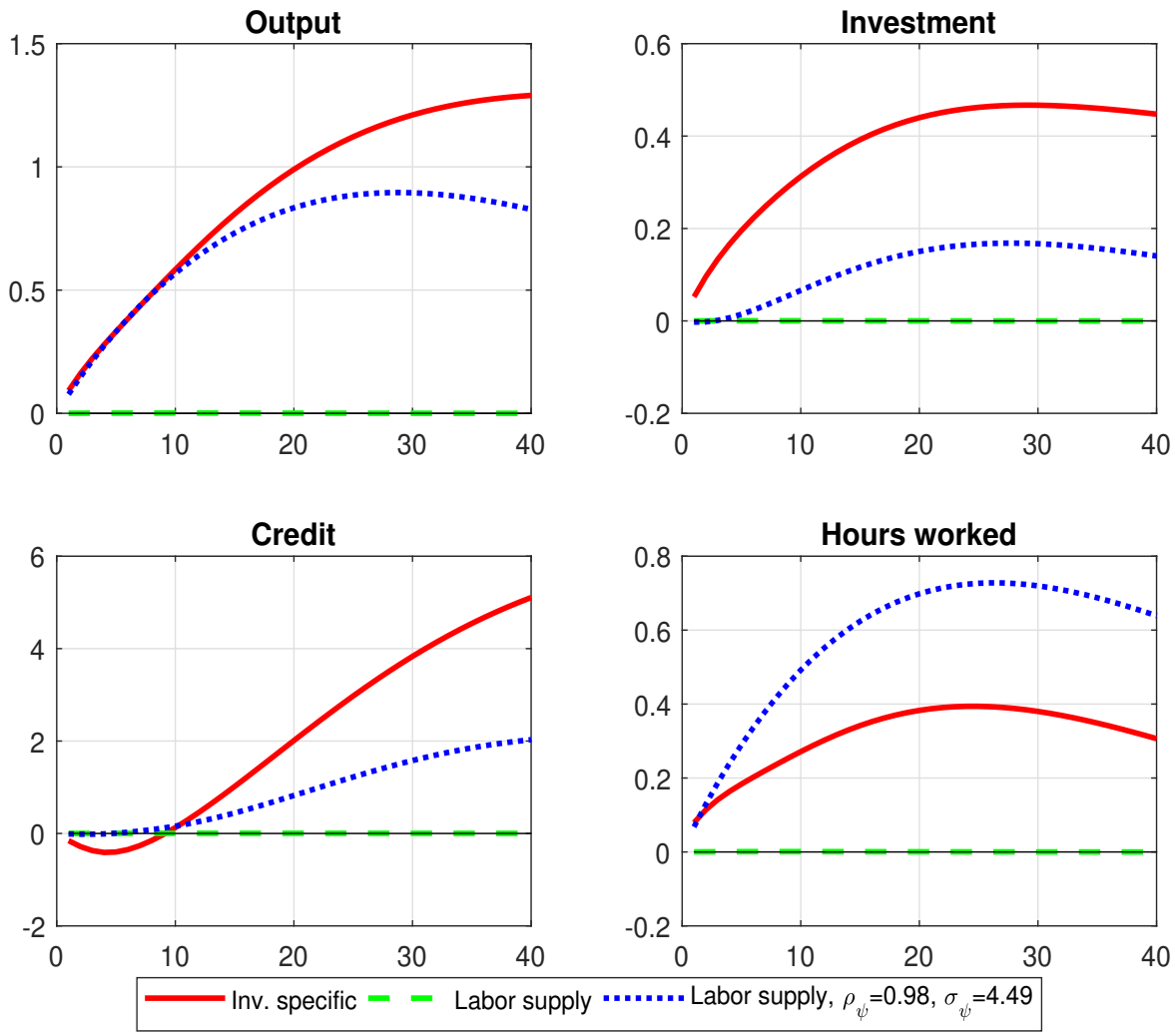

Figure 1: Impulse responses to investment-specific technology shocks (solid lines), labor supply shocks in our baseline model (dashed lines) and labor supply shocks in a counterfactual in which we change the persistence and the standard deviation of the shock (dotted lines) while keeping all remaining parameters at their estimated value.

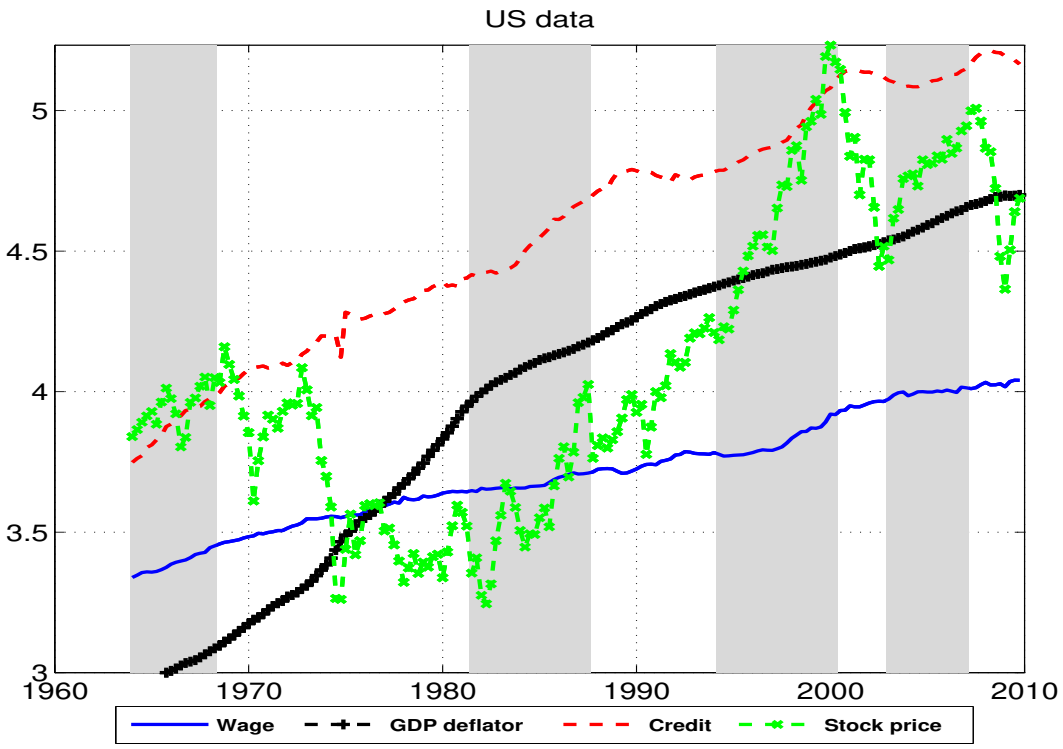

Figure 2: Evolution of wage, GDP deflator, credit to firms and stock prices. Shaded areas represent the periods of stock price booms as identified by Christiano, Ilut, Motto, and Rostagno (2010).

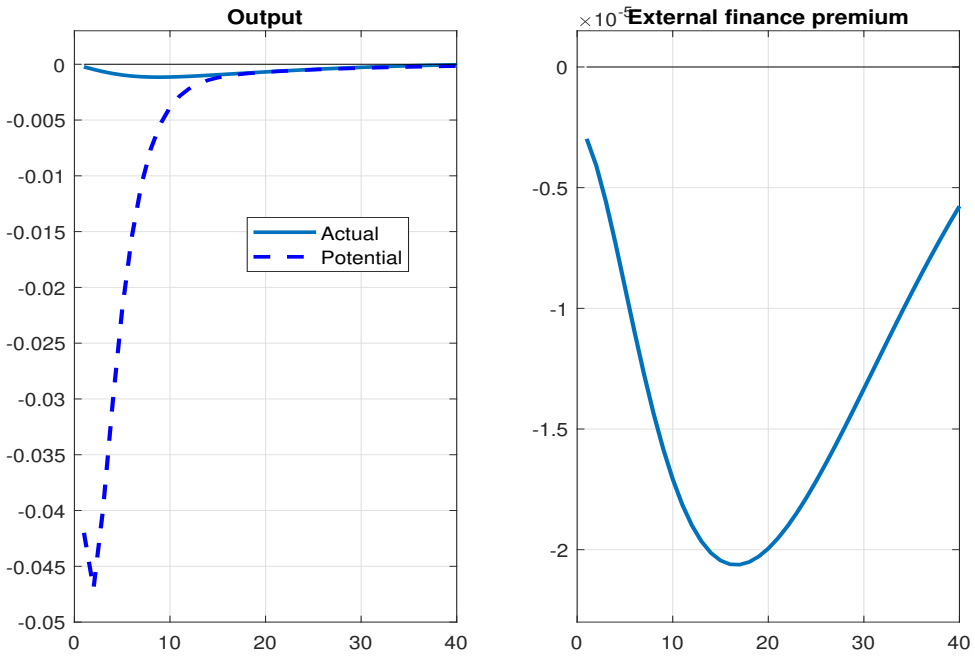

Figure 3: Impulse responses of output and potential output (left panel) and external finance premium (right panel) to a negative labor supply shock in the baseline model.

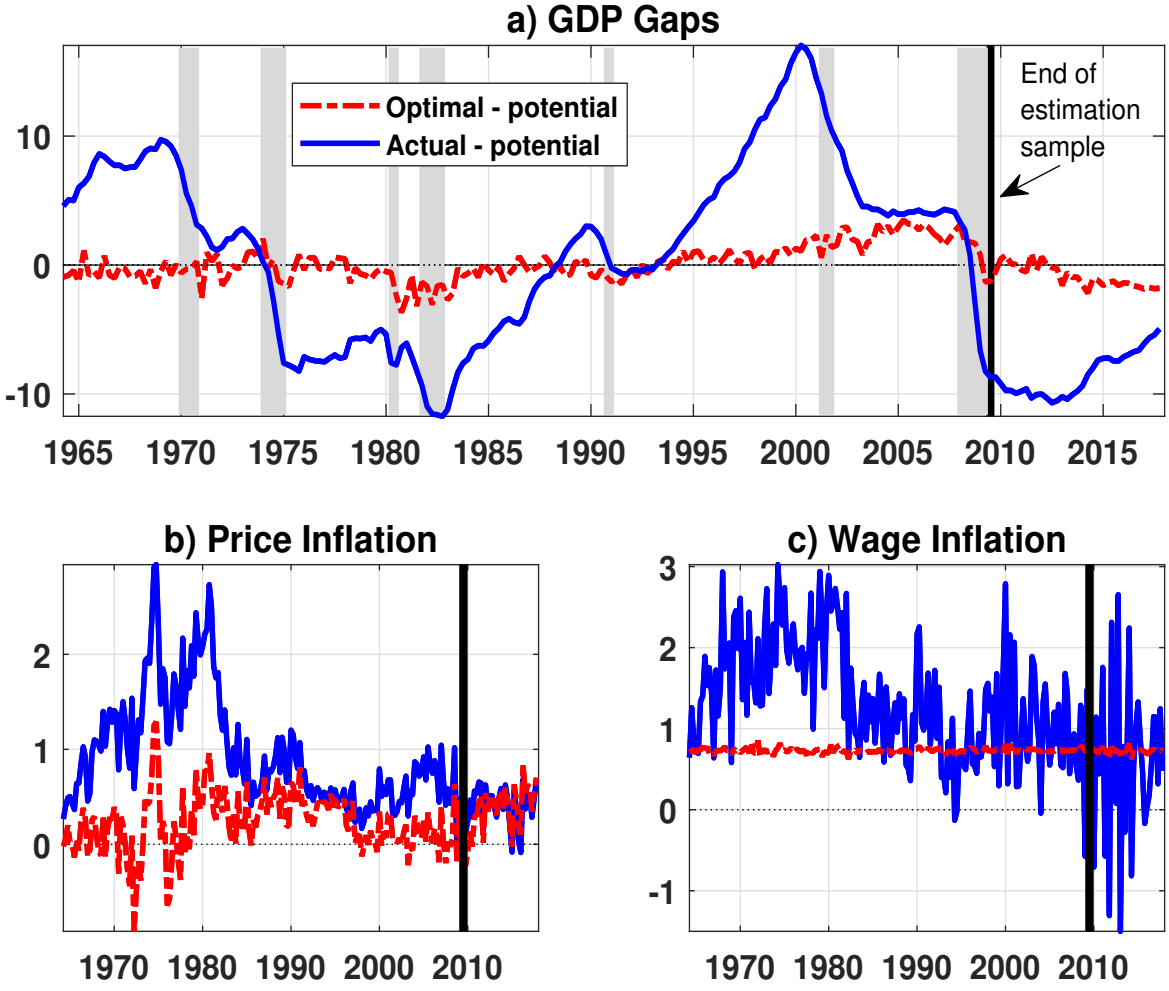

Figure 4: Monetary policy trade-offs in our baseline estimated model (solid lines) and in the counterfactual under optimal monetary policy (dashed-dotted lines).

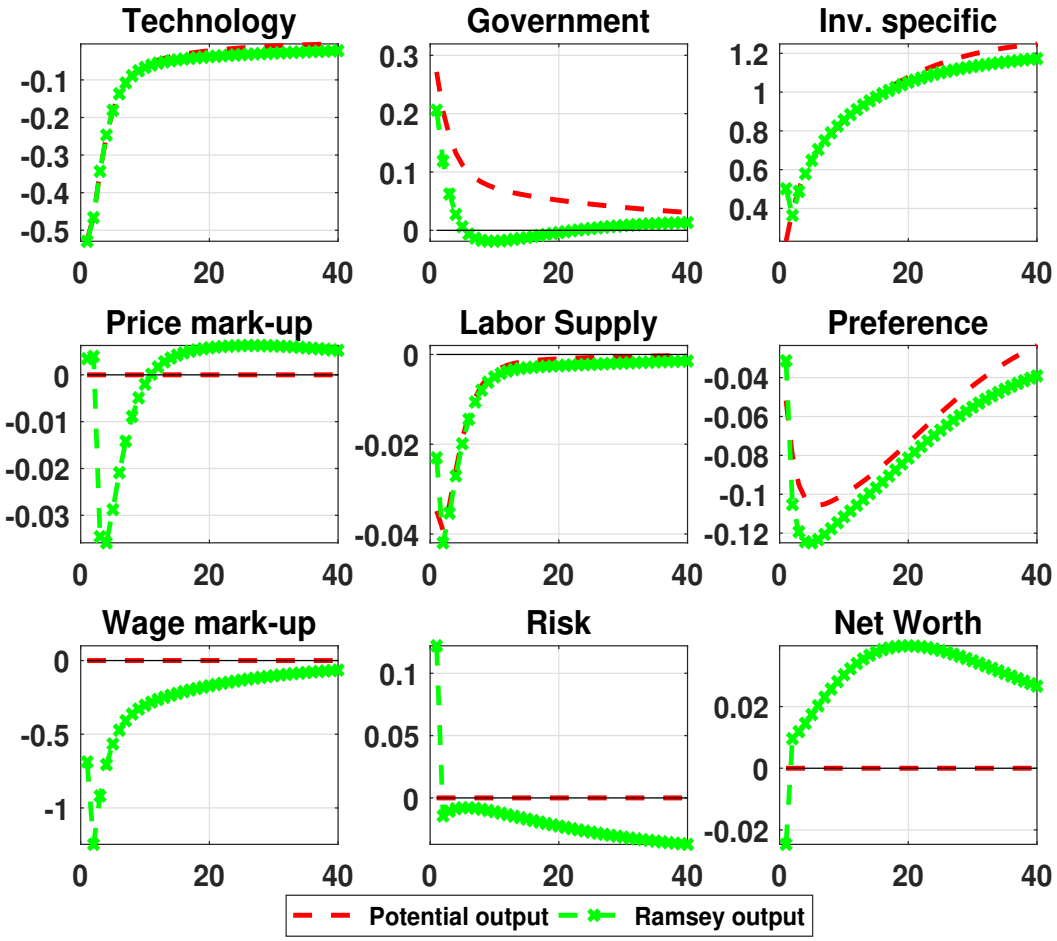

Figure 5: Impulse responses of potential output and optimal Ramsey output in the baseline model.

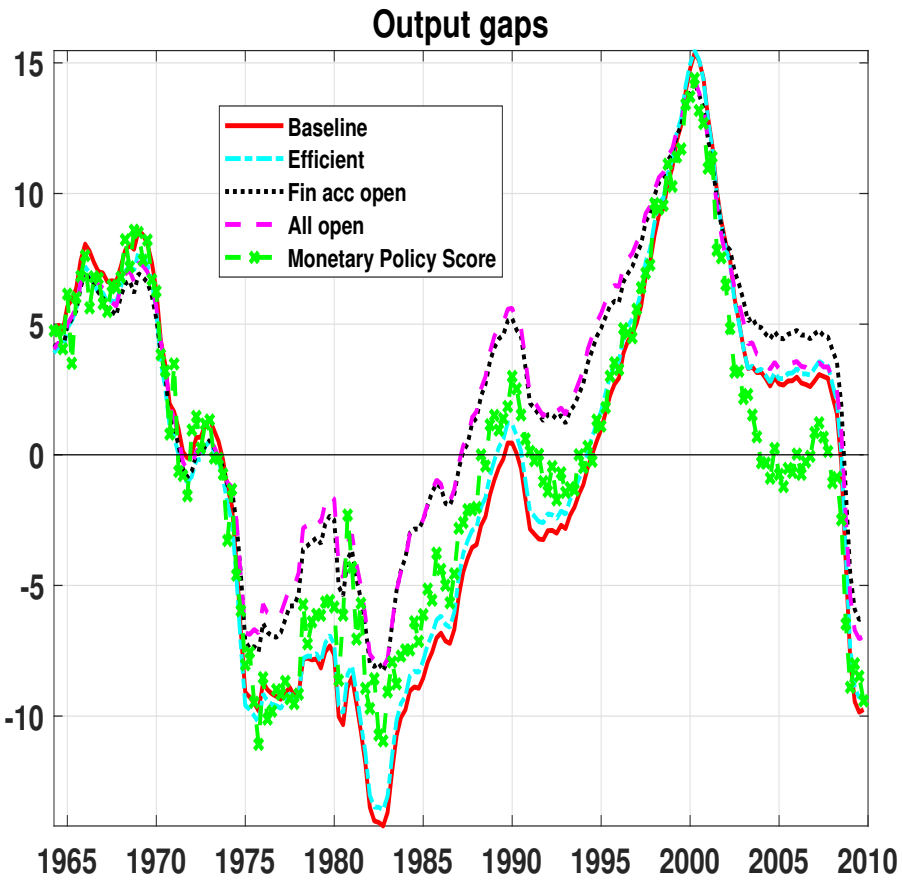

Figure 6: Alternative measures of the output gap in the baseline model. The solid red line refers to a measure of the output gap calculated in deviation from potential output. The dashed-dotted blue line refers to a measure of the output gap calculated in deviation from efficient output. The dotted black line refers to a measure of the output gap calculated in deviation from the counterfactual level of output under flexible prices and wages, with an active financial accelerator mechanism and in the absence of financial shocks. The dashed purple line refers to a measure of the output gap calculated in deviation from the counterfactual level of output under flexible prices and wages, with an active financial accelerator mechanism and in the presence of financial shocks. The dashed-starred green line refers to the Monetary Policy Score.

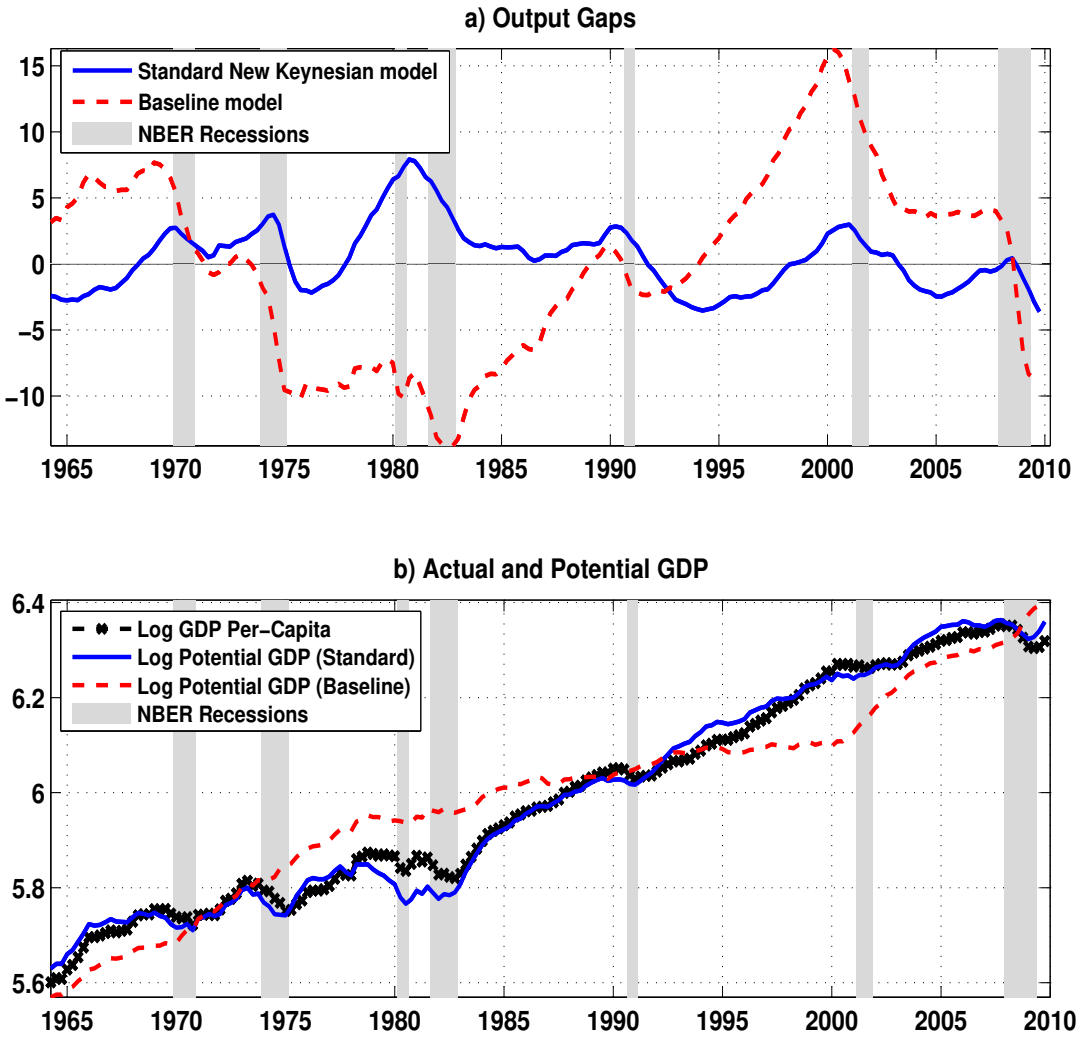

Figure 7: Output gap and potential output in the baseline model and in the standard New Keynesian model. Output gap is computed as the difference between actual output and potential output.

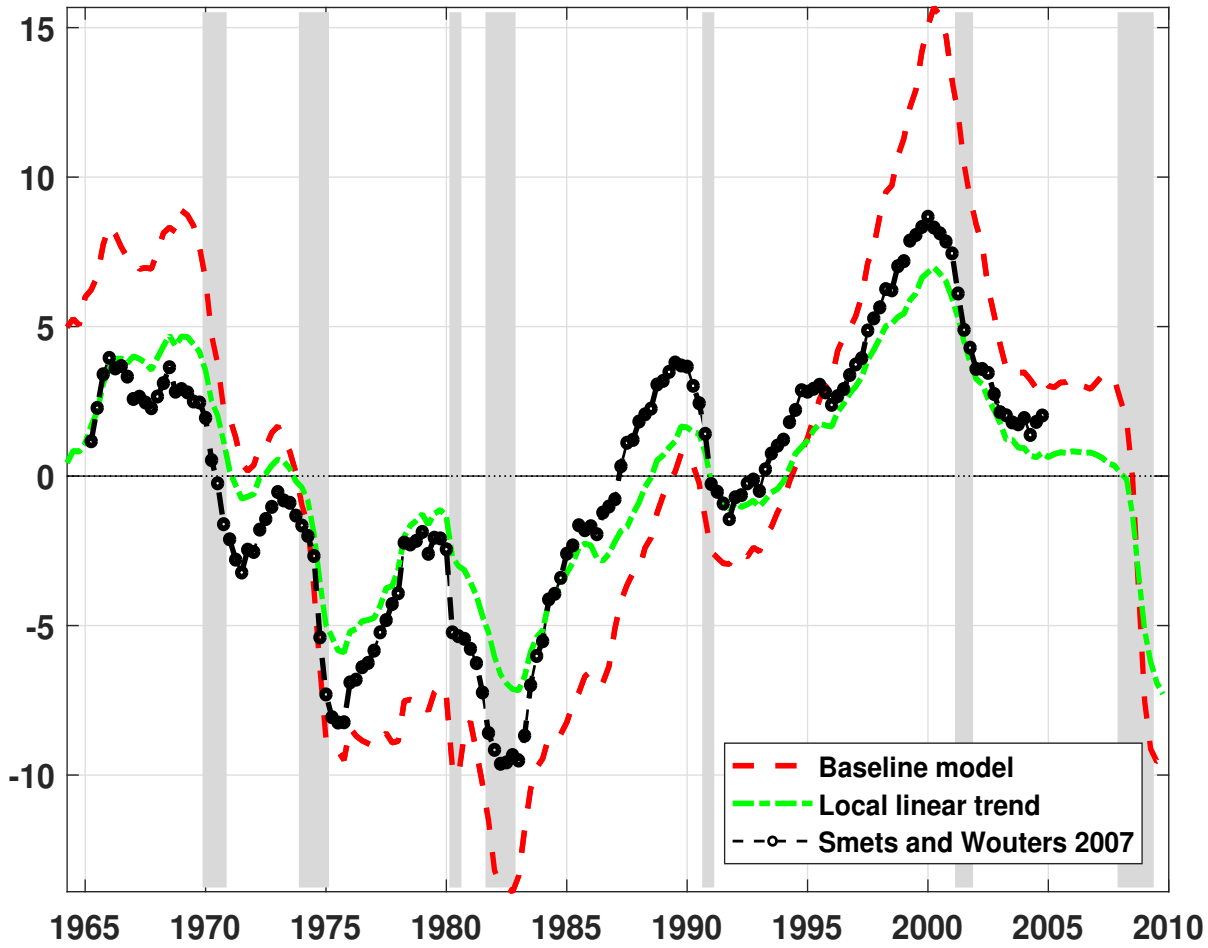

Figure 8: Output gap in the baseline model (dashed red lines), output gap in the model with local linear trends (dashed-dotted green lines) and output gap in the Smets and Wouters (2007) model (dashed-circled black line).

Appendix

A Alternative reference levels of output

In keeping with the previous literature, we used potential output as the reference level of output to compute the output gap in our baseline model. Potential output is affected by the static distortions, whereas it does not respond to the inefficient shocks and the dynamic distortions. While these choices closely follow the previous literature, they are not obvious (e.g. Dedola et al. 2013). Therefore, we now evaluate their impact on the estimation of the output gap. First, we consider the effect of the static distortions that make the potential level of output inefficiently low. These steady-state distortions have a minor effect on the dynamics, thus driving a small wedge between potential and efficient output.[17] We see in Figure 6 (dashed-dotted blue lines) that the effect of steady-state distortions on the dynamics is quantitatively minor. In fact, potential output and efficient output (both in deviation from their steady state) follow each other closely, thus showing that the choice of reference level of output to calculate the output gap is largely inconsequential.[18] Second, we evaluate the impact of closing the financial accelerator. In Figure 6 we plot (dotted black line) the output gap when the financial accelerator is left active both in the actual and in the counterfactual economy under flexible prices and wages. Somewhat surprisingly, we notice that the effect on the output gap is relatively minor and consists of a level shift in the middle and at the very end of the sample. These differences are due to the behavior of potential output that is mainly driven by investment-specific shocks, as labor supply shocks play a minor role. Finally, we reconsider the role of financial shocks. In our baseline model, financial shocks do not affect potential output as they do not propagate when the financial accelerator mechanism is inactive. We now evaluate what happens when we allow financial shocks to affect potential output in the model with an active financial accelerator mechanism (cf. dashed purple line in Figure 6). We see that, when we leave the financial shocks open, the effect on output is at most minor. This is due to the fact that financial shocks hardly propagate at all under flexible prices and wages in our model with an active financial accelerator. While a limited propagation under flexible prices and wages is a feature of most demand shocks, this is particularly striking

[17] The value of the spread in steady state enters in the log-linear system of first order conditions. Moreover, as in JPT (2013), the presence of the fixed cost in the distorted economy affects the elasticity of output with respect to changes in the inputs of production. In the competitive economy, this effect is not present.

[18] Ravenna and Walsh (2006), Carlstrom, Fuerst, and Paustian (2010) and De Fiore and Tristani (2013) derive welfare relevant measures of the output gap in small-scale models with financial frictions. In the three papers the gap is defined in terms of deviation from the efficient level of output.

for financial shocks. To sum up, closing or opening the static distortions, the dynamic distortion associated with the financial accelerator and financial shocks has a very limited impact in our model, thus highlighting that the shape of the estimated output gap does not depend on the choice of the reference level of output, which is arguably debatable.

Online appendices

A Model without financial frictions

In this appendix we report the set of non-linear equations characterizing the equilibrium dynamics of the following 24 endogenous variables of the model without financial frictions

$$y_t, D_{p,t}, L_t, s_t, \pi_t, M_{p,t}, N_{p,t}, \widetilde{p}_t, c_t, \lambda_t, r_t^k, q_t, R_t^k, i_t, k_t, \overline{k}_t, \widetilde{w}_t, M_{w,t}, N_{w,t}, w_t, D_{w,t}, R_t, x_t, u_t$$

Production function

$$D_{p,t} y_t = k_t^{\alpha} L_t^{1-\alpha} - F. \tag{A.4}$$

Price dispersion

$$D_{p,t} = (1-\xi_p)\, \widetilde{p}_t^{-\frac{1+\lambda_p}{\lambda_p}} + \xi_p \left[\left(\frac{\pi_{t-1}}{\pi} \right)^{\iota_p} \left(\frac{\pi_t}{\pi} \right)^{-1} \right]^{-\frac{1+\lambda_p}{\lambda_p}} D_{p,t-1}. \tag{A.5}$$

Capital-labor ratio

$$\frac{k_t}{L_t} = \frac{w_t}{r_t^k} \frac{\alpha}{1-\alpha}. \tag{A.6}$$

Marginal cost

$$s_t = \frac{1}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}} \left(r_t^k \right)^{\alpha} w_t^{1-\alpha}. \tag{A.7}$$

Phillips curve

$$\frac{N_{p,t}}{M_{p,t}} = \widetilde{p}_t, \tag{A.8}$$

$$M_{p,t} = \lambda_t y_t + \xi_p \beta E_t \left\{ \left[\left(\frac{\pi_t}{\pi} \right)^{\iota_p} \left(\frac{\pi_{t+1}}{\pi} \right)^{-1} \right]^{-\frac{1}{\lambda_p}} M_{p,t+1} \right\}, \tag{A.9}$$

$$N_{p,t} = \lambda_t y_t \lambda_{p,t} s_t + \xi_p \beta E_t \left\{ \left[\left(\frac{\pi_t}{\pi} \right)^{\iota_p} \left(\frac{\pi_{t+1}}{\pi} \right)^{-1} \right]^{-\frac{1+\lambda_p}{\lambda_p}} N_{p,t+1} \right\}, \tag{A.10}$$

$$\left[(1-\xi_p)\, \widetilde{p}_t^{-\frac{1}{\lambda_p}} + \xi_p \left[\left(\frac{\pi_{t-1}}{\pi} \right)^{\iota_p} \left(\frac{\pi_t}{\pi} \right)^{-1} \right]^{-\frac{1}{\lambda_p}} \right]^{-\lambda_p} = 1. \tag{A.11}$$

Marginal utility of income

$$\lambda_t = \frac{e^{z_t} b_t}{e^{z_t} c_t - h c_{t-1}} - h\beta E_t \left\{ \frac{b_{t+1}}{e^{z_{t+1}} c_{t+1} - h c_t} \right\}. \tag{A.12}$$

Euler equation

$$\lambda_t = \beta R_t E_t \left\{ \lambda_{t+1} \frac{e^{-z_{t+1}}}{\pi_{t+1}} \right\}. \tag{A.13}$$

Optimal capital utilization

$$r_t^k = r^k u_t^{\chi}. \tag{A.14}$$

Optimal choice of physical capital

$$\phi_t = \beta E_t \left\{ e^{-z_{t+1}} \lambda_{t+1} \left[r_{t+1}^k u_{t+1} - r^k \frac{u_{t+1}^{1+\chi} - 1}{1+\chi} \right] \right\} + (1-\delta)\, \beta E_t \left\{ \phi_{t+1} e^{-z_{t+1}} \right\},$$

where $\phi_t = q_t \lambda_t$, and q_t is the relative price of capital. With the aim of incorporating financial frictions into the model, we need to define the real gross return to capital R_t^k (and nominal gross $R_t^{n,k} = R_t^k \pi_t$). To do that, instead of the previous equation we use the following set of alternative but equivalent equations

$$R_t^k = \frac{r_t^k u_t - r^k \frac{u_t^{1+\chi} - 1}{1+\chi} + (1-\delta)\, q_t}{q_{t-1}}, \tag{A.15}$$

$$E_t \left\{ R_{t+1}^k \right\} = E_t \left\{ \frac{R_t}{\pi_{t+1}} \right\}. \tag{A.16}$$

Optimal choice of investment ($S'' = \zeta$)

$$\begin{aligned} \lambda_t \;=\; & \phi_t \mu_t \left\{ 1 - \frac{S''}{2} \left(\frac{i_t}{i_{t-1}} e^{z_t} - e^{\gamma} \right)^2 - \frac{i_t}{i_{t-1}} e^{z_t} S'' \left(\frac{i_t}{i_{t-1}} e^{z_t} - e^{\gamma} \right) \right\} \\ & + \beta E_t \left\{ \phi_{t+1} e^{-z_{t+1}} \mu_{t+1} \left(\frac{i_{t+1}}{i_t} e^{z_{t+1}} \right)^2 S'' \left(\frac{i_{t+1}}{i_t} e^{z_{t+1}} - e^{\gamma} \right) \right\}. \end{aligned} \tag{A.17}$$

Capital input

$$k_t = u_t \overline{k}_{t-1} e^{-z_t}. \tag{A.18}$$

Physical capital accumulation

$$\overline{k}_t = (1-\delta)\, e^{-z_t}\overline{k}_{t-1} + \mu_t \left[1 - \frac{S''}{2}\left(\frac{i_t}{i_{t-1}}e^{z_t} - e^{\gamma}\right)^2\right] i_t. \tag{A.19}$$

Wage Phillips curve

$$\widetilde{w}_t = w_t \left(\frac{N_{w,t}}{M_{w,t}}\right)^{\frac{\lambda_w}{\lambda_w+\nu(1+\lambda_w)}}, \tag{A.20}$$

$$M_{w,t} = \lambda_t L_t w_t + \xi_w \beta E_t \left\{ \left[\left(\frac{\pi_t e^{z_t}}{\pi e^{\gamma}}\right)^{\iota_w} \left(\frac{\pi_{t+1} e^{z_{t+1}}}{\pi e^{\gamma}}\right)^{-1} \left(\frac{w_{t+1}}{w_t}\right)^{-1} \right]^{-\frac{1}{\lambda_w}} M_{w,t+1} \right\}, \tag{A.21}$$

$$N_{t,w} = \lambda_{w,t}\varphi_t b_t L_t^{1+\nu} + \xi_w \beta E_t \left\{ \left[\left(\frac{\pi_t e^{z_t}}{\pi e^{\gamma}}\right)^{\iota_w} \left(\frac{\pi_{t+1} e^{z_{t+1}}}{\pi e^{\gamma}}\right)^{-1} \left(\frac{w_{t+1}}{w_t}\right)^{-1} \right]^{-\frac{(1+\nu)(1+\lambda_w)}{\lambda_w}} N_{w,t+1} \right\}, \tag{A.22}$$

$$(1-\xi_w)\left(\frac{\widetilde{w}_t}{w_t}\right)^{-\frac{1}{\lambda_w}} + \xi_w \left[\left(\frac{\pi_{t-1} e^{z_{t-1}}}{\pi e^{\gamma}}\right)^{\iota_w} \left(\frac{\pi_t e^{z_t}}{\pi e^{\gamma}}\right)^{-1} \frac{w_{t-1}}{w_t} \right]^{-\frac{1}{\lambda_w}} = 1, \tag{A.23}$$

$$D_{w,t} = (1-\xi_w)\left(\frac{\widetilde{w}_t}{w_t}\right)^{-\frac{(1+\lambda_w)(1+\nu)}{\lambda_w}} + \xi_w \left[\frac{w_{t-1}}{w_t} \left(\frac{\pi_t e^{z_t}}{\pi e^{\gamma}}\right)^{-1} \left(\frac{\pi_{t-1} e^{z_{t-1}}}{\pi e^{\gamma}}\right)^{\iota_w} \right]^{-\frac{(1+\lambda_w)(1+\nu)}{\lambda_w}} D_{w,t-1}. \tag{A.24}$$

Monetary policy rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\left(\prod_{s=0}^{3} \pi_{t-s}\right)^{1/4}}{\pi_t^*} \right)^{\phi_\pi} \left(\frac{(x_t/x_{t-4})^{1/4}}{e^{\gamma}} \right)^{\phi_X} \right]^{1-\rho_R} e^{\varepsilon_{R,t}}. \tag{A.25}$$

Definition of GDP

$$x_t = c_t + i_t + \left(1 - \frac{1}{g_t}\right) y_t. \tag{A.26}$$

Resource constraint

$$c_t + i_t + r^k e^{-z_t} \overline{k}_{t-1} \frac{u_t^{1+\chi} - 1}{1+\chi} = \frac{1}{g_t} y_t. \tag{A.27}$$

B Financial frictions block

The financial block determines the dynamics of the following 5 variables

$$\overline{\omega}_t, v_t, n_t, b_t^e, S_t$$

The zero profit condition is

$$\left[\Gamma_{t-1}\left(\overline{\omega}_t\right) - \mu^e G_{t-1}\left(\overline{\omega}_t\right)\right] \frac{R_t^{n,k}}{R_{t-1}} = \frac{q_{t-1}\overline{k}_{t-1} - n_{t-1}}{q_{t-1}\overline{k}_{t-1}}. \tag{B.1}$$

Let's define the cumulative and marginal distribution (*normcdf* and *normpdf* in MATLAB respectively) of a variable as follows

$$\Phi\left(z_t^{\overline{\omega}}\right) = \int_{-\infty}^{z_t^{\overline{\omega}}} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2} dx,$$

$$\phi\left(z_t^{\overline{\omega}}\right) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\left(z_t^{\overline{\omega}}\right)^2},$$

where

$$z_t^{\overline{\omega}} = \frac{\ln \overline{\omega}_t + \frac{1}{2}\sigma_{t-1}^2}{\sigma_{t-1}}.$$

Then

$$\Gamma_{t-1}\left(\overline{\omega}_t\right) = \overline{\omega}_t \left[1 - \Phi\left(z_t^{\overline{\omega}}\right)\right] + \Phi\left(z_t^{\overline{\omega}} - \sigma_{t-1}\right),$$

$$G_{t-1}\left(\overline{\omega}_t\right) = \Phi\left(z_t^{\overline{\omega}} - \sigma_{t-1}\right).$$

The equity value

$$v_t e^{z_t} \pi_t = R_t^{n,k} q_{t-1}\overline{k}_{t-1} - R_{t-1}\left(q_{t-1}\overline{k}_{t-1} - n_{t-1}\right) - \mu^e G_{t-1}\left(\overline{\omega}_t\right) R_t^{n,k} q_{t-1}\overline{k}_{t-1}. \tag{B.2}$$

The law of motion for net worth

$$n_t = \gamma_t^* v_t + w^e. \tag{B.3}$$

Entrepreneurs debt

$$b_t^e = q_t \overline{k}_t - n_t. \tag{B.4}$$

The first order condition with respect to capital

$$E_{t-1}\left[\left[1-\Gamma_{t-1}\left(\overline{\omega}_t\right)\right]\frac{R_t^{n,k}}{R_{t-1}} + \frac{\Gamma'_{t-1}\left(\overline{\omega}_t\right)}{\Gamma'_{t-1}\left(\overline{\omega}_t\right)-\mu^e G'_{t-1}\left(\overline{\omega}_t\right)}\left\{\left[\Gamma_{t-1}\left(\overline{\omega}_t\right)-\mu^e G_{t-1}\left(\overline{\omega}_t\right)\right]\frac{R_t^{n,k}}{R_{t-1}} - 1\right\}\right] = 0, \tag{B.5}$$

where

$$\Gamma'_{t-1}\left(\overline{\omega}_t\right) = 1 - \Phi\left(z_t^{\overline{\omega}}\right).$$

$$G'_{t-1}\left(\overline{\omega}_t\right) = \frac{1}{\sigma_{t-1}}\phi\left(z_t^{\overline{\omega}}\right).$$

Equation B.5 replaces equation A.16. In fact, it shows that there is a wedge between the expected return to capital and the real interest rate, the so called external finance premium. If combined with equation B.1 it can be showed that the premium positively depends on the entrepreneurs' leverage. In the steady state section we will show that using the log-linearized equations. Finally the definition of the external finance premium

$$S_t = E_t\left\{\frac{R_{t+1}^{n,k}}{R_t}\right\}. \tag{B.6}$$

C Steady state

In this section we derive the steady state expressions for the endogenous variables. For the financial frictions block we closely follow Del Negro and Schorfheide (2013). From equations A.15 and A.16 we have

$$R = r^k + (1-\delta).$$

According to equation A.13 $R = \frac{e^{\gamma}}{\beta}$, so

$$\frac{e^{\gamma}}{\beta} = r^k + (1-\delta)\,,$$

$$r^k = \frac{e^{\gamma}}{\beta} - (1-\delta)\,. \tag{C.1}$$

With r^k, equation A.7 and A.8-A.11 imply

$$w = \left[\frac{1}{1+\lambda_p}\alpha^{\alpha}\,(1-\alpha)^{1-\alpha}\,\frac{1}{(r^k)^{\alpha}}\right]^{\frac{1}{1-\alpha}}. \tag{C.2}$$

With r^k and w, A.6 can be used to compute

$$\frac{k}{L} = \frac{w}{r^k}\frac{\alpha}{1-\alpha}. \tag{C.3}$$

The zero profit condition for intermediate goods producers

$$y - r^k k - wL = \left(\frac{k}{L}\right)^{\alpha} L - F - r^k k - wL = 0,$$

implies

$$\frac{F}{L} = \left(\frac{k}{L}\right)^{\alpha} - r^k\frac{k}{L} - w. \tag{C.4}$$

Therefore

$$\frac{y}{L} = \left(\frac{k}{L}\right)^{\alpha} - \frac{F}{L}. \tag{C.5}$$

From A.19 and A.27

$$\frac{i}{L} = \left[1-(1-\delta)\,e^{-\gamma}\right]\frac{e^{\gamma}k}{L}, \tag{C.6}$$

$$\frac{c}{L} = \frac{y}{L}\frac{1}{g} - \frac{i}{L}. \tag{C.7}$$

And from equation A.12

$$\lambda L = \left(\frac{c}{L}\right)^{-1}\frac{e^{\gamma}-h\beta}{e^{\gamma}-h},$$

so that from A.20-A.24 it is possible to obtain an expression for L

$$L = \left[\frac{w}{(1+\lambda_w)\,\varphi} \lambda L \right]^{\frac{1}{1+\nu}}. \tag{C.8}$$

The easiest choice is to parametrize L (so that φ is uniquely determined). This implies that

$$k = \frac{k}{L} L, \tag{C.9}$$

$$y = \frac{y}{L} L, \tag{C.10}$$

$$i = \frac{i}{L} L, \tag{C.11}$$

$$c = \frac{c}{L} L. \tag{C.12}$$

All the other steady state values follow straightforwardly. Turning to the financial frictions block, equation C.1 becomes

$$r^k = S \frac{e^{\gamma}}{\beta} - (1-\delta),$$

where $S = 1 + \widetilde{S}/100$. The steady state relationships C.1-C.12 and those following from them remain unchanged. To derive financial variables steady state values it is worth first to log-linearize some equations because some elasticities appearing in those equations are relevant to explain how the steady state is computed. First equation B.5 which yields (where hatted variables represent log-deviation from steady state)

$$E_t \left\{ \widehat{R}^{n,k}_{t+1} - \widehat{R}_t \right\} + \zeta_{b,\overline{\omega}} E_t \left\{ \widehat{\overline{\omega}}_{t+1} \right\} + \zeta_{b,\sigma} \widehat{\sigma}_t = 0, \tag{C.13}$$

where

$$\zeta_{b,x} = \frac{\frac{\partial}{\partial x} \left[\left[1 - \Gamma\left(\overline{\omega}\right)\right] \frac{R^{n,k}}{R} + \frac{\Gamma'(\overline{\omega})}{\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})} \left\{ \left[\Gamma\left(\overline{\omega}\right) - \mu^e G\left(\overline{\omega}\right)\right] \frac{R^{n,k}}{R} - 1 \right\} \right]}{\left\{ \left[1 - \Gamma\left(\overline{\omega}\right)\right] + \frac{\Gamma'(\overline{\omega})}{\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})} \left[\Gamma\left(\overline{\omega}\right) - \mu^e G\left(\overline{\omega}\right)\right] \right\} \frac{R^{n,k}}{R}} x \qquad x = \overline{\omega}, \sigma$$

$$\Gamma\left(\overline{\omega}\right) = \overline{\omega} \left[1 - \Phi\left(z^{\overline{\omega}}\right)\right] + \Phi\left(z^{\overline{\omega}} - \sigma\right),$$

$$G\left(\overline{\omega}\right) = \Phi\left(z^{\overline{\omega}} - \sigma\right),$$

$$\Gamma'\left(\overline{\omega}\right) = 1 - \Phi\left(z^{\overline{\omega}}\right),$$

$$G'(\overline{\omega}) = \frac{1}{\sigma}\phi\left(z^{\overline{\omega}}\right),$$

$$z^{\overline{\omega}} = \frac{\ln\overline{\omega} + \frac{1}{2}\sigma^2}{\sigma}.$$

Log-linearization of the zero profit condition (expression B.1) yields

$$\widehat{R}_t^{n,k} - \widehat{R}_{t-1} + \zeta_{z,\overline{\omega}}\widehat{\overline{\omega}}_t + \zeta_{z,\sigma}\widehat{\sigma}_{t-1} = -\left(\frac{\overline{k}}{n} - 1\right)^{-1}\left(\widehat{n}_{t-1} - \widehat{q}_{t-1} - \widehat{\overline{k}}_{t-1}\right), \tag{C.14}$$

where

$$\zeta_{z,x} = \frac{\frac{\partial}{\partial x}\left[\Gamma(\overline{\omega}) - \mu^e G(\overline{\omega})\right]}{\Gamma(\overline{\omega}) - \mu^e G(\overline{\omega})}x \qquad x = \overline{\omega}, \sigma$$

Combining equations C.13 and C.14 yields the well-known positive relationship between the external finance premium and the entrepreneur's leverage

$$E_t\left\{\widehat{R}_{t+1}^{n,k} - \widehat{R}_t\right\} = \zeta_{sp,b}\left(\widehat{q}_t + \widehat{\overline{k}}_t - \widehat{n}_t\right) + \zeta_{sp,\sigma}\widehat{\sigma}_t,$$

where

$$\zeta_{sp,b} = -\frac{\frac{\zeta_{b,\overline{\omega}}}{\zeta_{z,\overline{\omega}}}}{1 - \frac{\zeta_{b,\overline{\omega}}}{\zeta_{z,\overline{\omega}}}}\frac{\frac{n}{\overline{k}}}{1 - \frac{n}{\overline{k}}}, \tag{C.15}$$

$$\zeta_{sp,\sigma} = \frac{\frac{\zeta_{b,\overline{\omega}}}{\zeta_{z,\overline{\omega}}}\zeta_{z,\sigma} - \zeta_{b,\sigma}}{1 - \frac{\zeta_{b,\overline{\omega}}}{\zeta_{z,\overline{\omega}}}}.$$

Elasticities $\zeta_{b,\overline{\omega}}$, $\zeta_{b,\sigma}$, $\zeta_{z,\overline{\omega}}$, and $\zeta_{z,\sigma}$ have the following expressions

$$\zeta_{b,\overline{\omega}} = \frac{\mu^e\frac{n}{\overline{k}}\frac{\Gamma''(\overline{\omega})G'(\overline{\omega}) - G''(\overline{\omega})\Gamma'(\overline{\omega})}{\left[\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})\right]^2}}{\left\{\left[1 - \Gamma(\overline{\omega})\right] + \frac{\Gamma'(\overline{\omega})}{\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})}\left[\Gamma(\overline{\omega}) - \mu^e G(\overline{\omega})\right]\right\}\frac{R^{n,k}}{R}}\overline{\omega},$$

$$\zeta_{b,\sigma} = \frac{\left(\frac{1 - \mu^e\frac{G_\sigma(\overline{\omega})}{\Gamma_\sigma(\overline{\omega})}}{1 - \mu^e\frac{G'(\overline{\omega})}{\Gamma'(\overline{\omega})}} - 1\right)\Gamma_\sigma(\overline{\omega})\frac{R^{n,k}}{R} + \mu^e\frac{n}{\overline{k}}\frac{G'(\overline{\omega})\Gamma'_\sigma(\overline{\omega}) - \Gamma'(\overline{\omega})G'_\sigma(\overline{\omega})}{\left[\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})\right]^2}}{\left[1 - \Gamma(\overline{\omega})\right]\frac{R^{n,k}}{R} + \frac{\Gamma'(\overline{\omega})}{\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})}\left(1 - \frac{n}{\overline{k}}\right)}\sigma,$$

$$\zeta_{z,\overline{\omega}} = \frac{\Gamma'(\overline{\omega}) - \mu^e G'(\overline{\omega})}{\Gamma(\overline{\omega}) - \mu^e G(\overline{\omega})}\overline{\omega},$$

$$\zeta_{z,\sigma} = \frac{\Gamma_\sigma(\overline{\omega}) - \mu^e G_\sigma(\overline{\omega})}{\Gamma(\overline{\omega}) - \mu^e G(\overline{\omega})}\sigma,$$

where

$$G''(\overline{\omega}) = -\frac{z^{\overline{\omega}}}{\overline{\omega}\sigma^2}\phi\left(z^{\overline{\omega}}\right),$$

$$\Gamma''(\overline{\omega}) = -\frac{1}{\overline{\omega}\sigma}\phi\left(z^{\overline{\omega}}\right),$$

$$G_\sigma(\overline{\omega}) = -\frac{z^{\overline{\omega}}}{\sigma}\phi\left(z^{\overline{\omega}} - \sigma\right),$$

$$G'_\sigma(\overline{\omega}) = -\frac{\phi\left(z^{\overline{\omega}}\right)}{\sigma^2}\left\{1 - z^{\overline{\omega}}\left[z^{\overline{\omega}} - \sigma\right]\right\},$$

$$\Gamma_\sigma(\overline{\omega}) = -\phi\left(z^{\overline{\omega}} - \sigma\right),$$

$$\Gamma'_\sigma(\overline{\omega}) = \left(\frac{z^{\overline{\omega}}}{\sigma} - 1\right)\phi\left(z^{\overline{\omega}}\right).$$

The strategy to compute financial variables steady states is to start by computing the value of σ. To do that, we start from expression C.15 and we make it dependent only on known quantities and on one unknown, i.e. σ, for which it is solved for. The elements that have to be set or made function of σ are: $z^{\overline{\omega}}$, $\overline{\omega}$, $\frac{R^{n,k}}{R}$, μ^e, $\frac{n}{k}$, and $\zeta_{sp,b}$. Two of them, i.e. $\frac{R^{n,k}}{R} = S$ and $\zeta_{sp,b}$, are estimated from data. Then by calibrating the entrepreneurs default probability $F(\overline{\omega})$ we can compute $z^{\overline{\omega}}$ using the inverse cumulative distribution (*norminv* in MATLAB)

$$z^{\overline{\omega}} = \Phi^{-1}\left(F(\overline{\omega})\right),$$

which we can use to write $\overline{\omega}$ as a function of σ only

$$\overline{\omega} = \exp\left\{\sigma z^{\overline{\omega}} - \frac{1}{2}\sigma^2\right\}. \tag{C.16}$$

Then, solving expression B.5 for $\frac{R^{n,k}}{R}$ yields

$$S^{-1} = 1 - \mu^e\left\{\frac{G'(\overline{\omega})}{\Gamma'(\overline{\omega})}\left[1 - \Gamma(\overline{\omega})\right] + G(\overline{\omega})\right\},$$

which can be used to set μ^e as a function of σ only

$$\mu^e = \frac{1 - S^{-1}}{\frac{G'(\overline{\omega})}{\Gamma'(\overline{\omega})}\left[1 - \Gamma(\overline{\omega})\right] + G(\overline{\omega})}. \tag{C.17}$$

Finally, from expression B.1 we can set $\frac{n}{\overline{k}}$ as a function of σ only

$$\frac{n}{\overline{k}} = 1 - \left[\Gamma\left(\overline{\omega}\right) - \mu^e G\left(\overline{\omega}\right)\right] S. \tag{C.18}$$

Once we get the value for σ, it is straightforward to obtain the values of $\overline{\omega}$, $\frac{n}{\overline{k}}$, and μ^e through equations C.16, C.17, and C.18 respectively. As a consequence

$$n = \frac{n}{\overline{k}}\overline{k}.$$

Using expressions B.2 and B.3 and calibrating entrepreneurs' survival rate γ^* we can derive a value for $\frac{w^e}{\overline{k}}$ (and for w^e as a consequence as $w^e = \frac{w^e}{\overline{k}}\overline{k}$)

$$\frac{w^e}{\overline{k}} = \left(1 - \frac{\gamma^*}{\beta}\right)\frac{n}{\overline{k}} - \frac{\gamma^*}{\beta}\left\{S\left[1 - \mu^e G\left(\overline{\omega}\right)\right] - 1\right\}.$$

From equation B.3

$$\frac{n}{\overline{k}} = \gamma^* \frac{v}{\overline{k}} + \frac{w^e}{\overline{k}},$$

$$\frac{v}{\overline{k}} = \frac{1}{\gamma^*}\left(\frac{n}{\overline{k}} - \frac{w^e}{\overline{k}}\right),$$

$$v = \frac{v}{\overline{k}}\overline{k}.$$

Finally the value for the entrepreneurs debt

$$b^e = \overline{k} - n.$$

D Data

Inflation rate: quarterly log difference of the GDP deflator. **Nominal interest rate**: effective Federal Funds rate. **Per-capita hours**: number of hours worked in the total economy, divided by the civilian non-institutional population, 16 years and older. **Real per-capita GDP**: nominal GDP divided by population and the GDP deflator. **Real per-capita consumption**: sum of nominal expenditure on non-durables and services divided by population and the GDP deflator. **Real per-capita investments**: sum of nominal expenditure on consumer durables and total private investment divided by population and the GDP deflator. **Hourly wage in-**

flation: nominal compensation per hour in the total economy, from NIPA, and average hourly earnings of production and non-supervisory employees, computed by Bureau of Labor Statistics from the Establishment Survey. **Credit spread**: difference between the interest rate on BAA-rated corporate bonds and the ten-year U.S. government bond rate. **Real per-capita net worth**: Market Value of Equities Outstanding - Net Worth (Market Value) - Balance Sheet of Nonfarm Nonfinancial Corporate Business (MVEONWMVBSNNCB) divided by population and the GDP deflator. **Real per-capita credit**: sum of total Liabilities - Balance Sheet of Nonfarm Nonfinancial Corporate Business (TLBSNNCB) and total Credit Market Instruments - Liabilities - Balance Sheet of Nonfarm Nonfinancial Corporate Business (TCMILBSNNCB) divided by population and the GDP deflator.

E Prior and posterior distributions and convergence

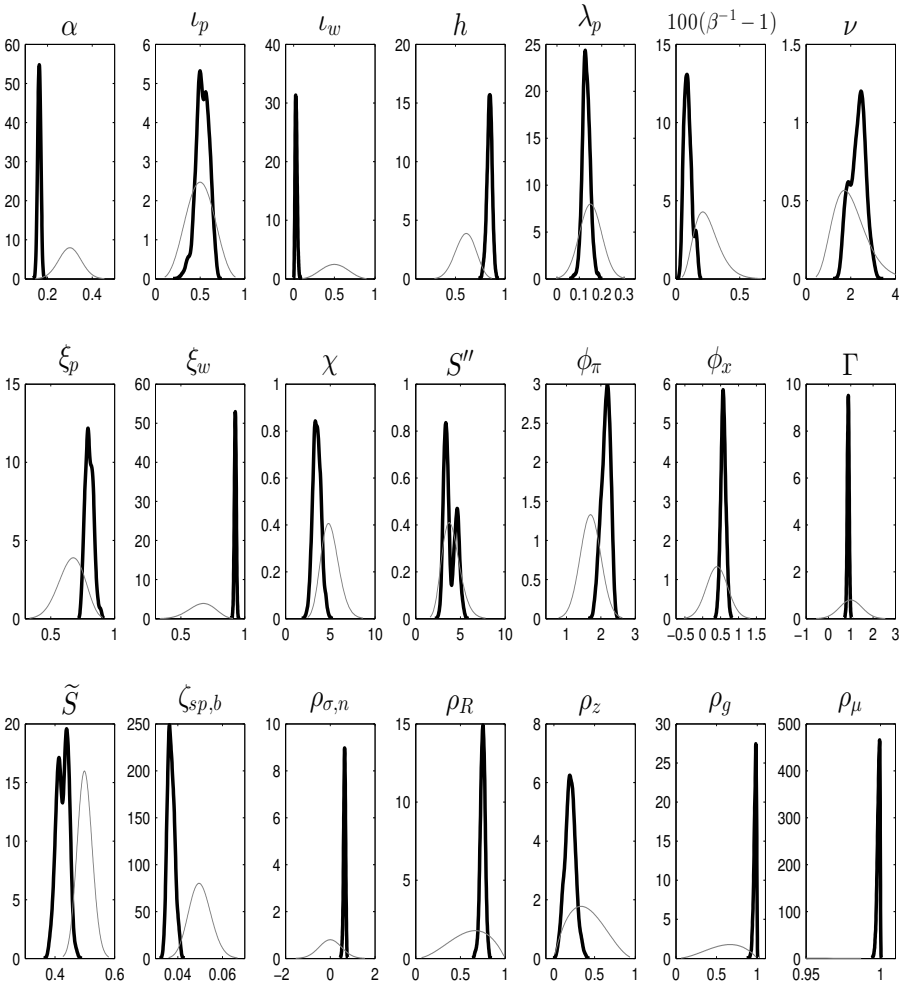

Figure E.9: Prior (grey thin line) and posterior (dark thick line) distributions

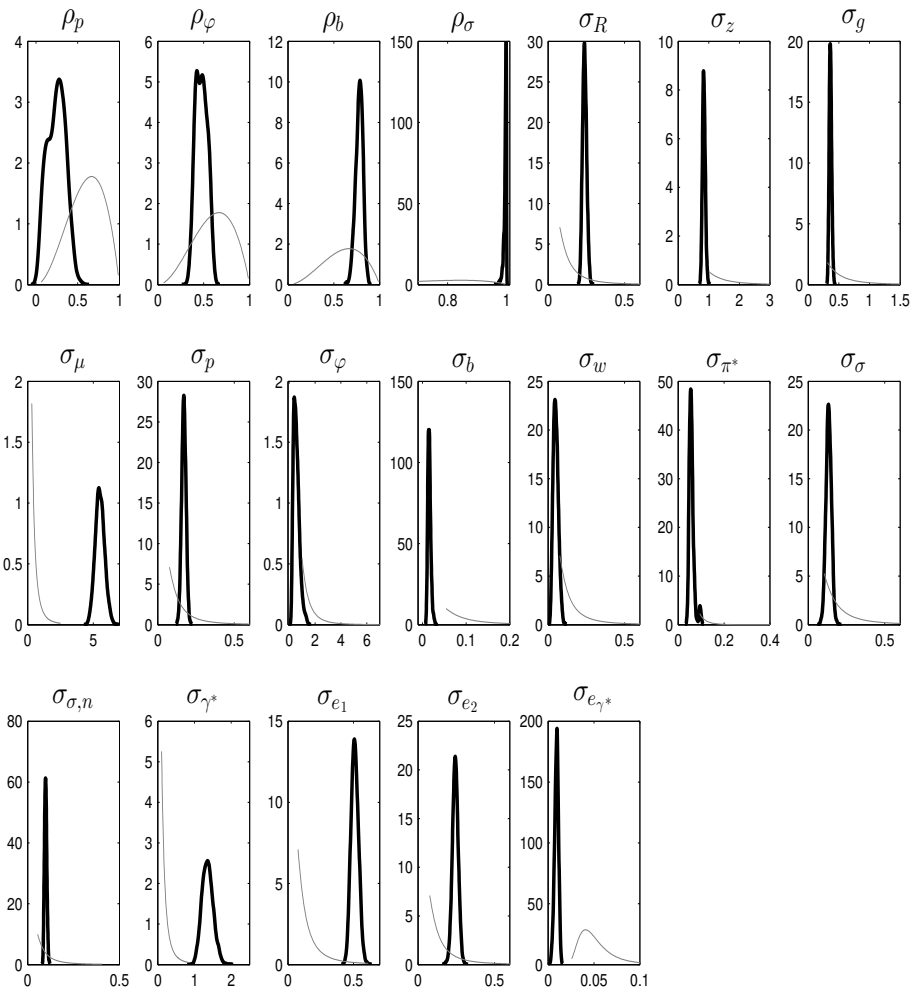

Figure E.10: Prior (grey thin line) and posterior (dark thick line) distributions

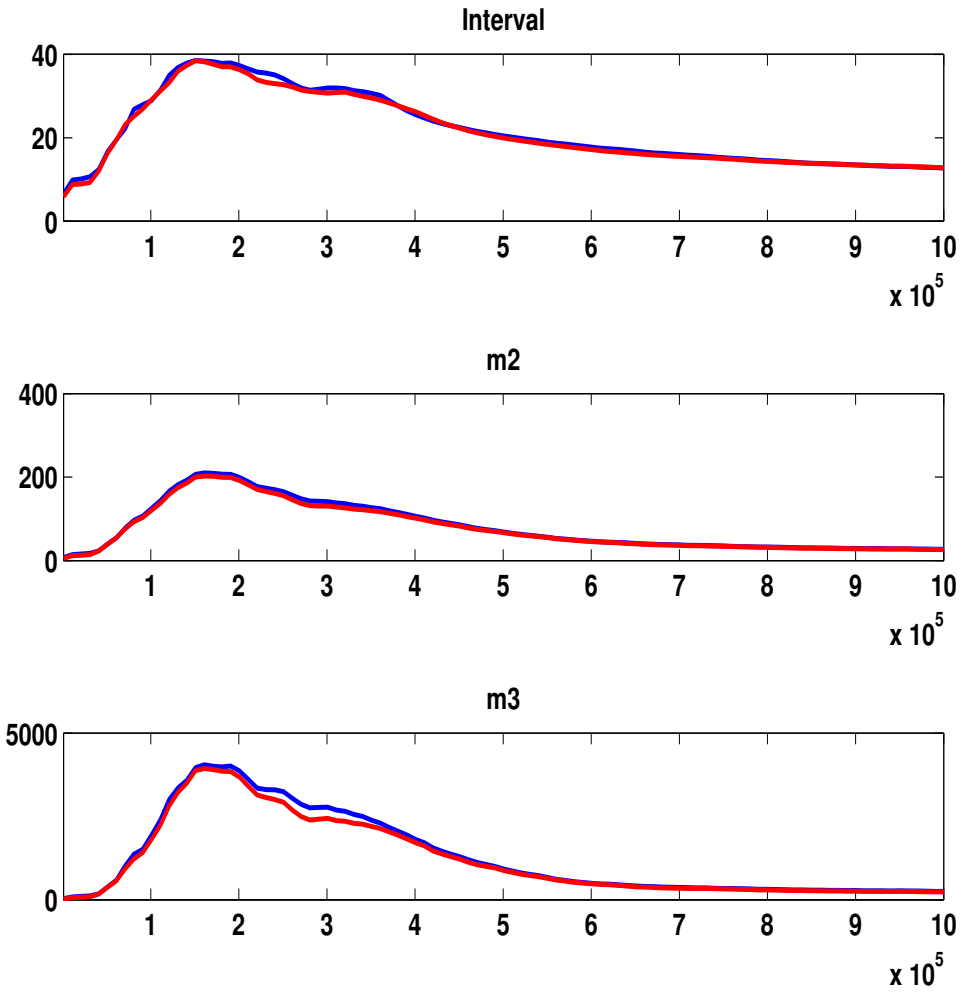

Figure E.11: Brooks and Gelman (1998) convergence diagnostics. The red and blue lines represent specific measures of the parameter vectors both within and between chains. First panel: constructed from an 80% confidence interval around the parameter mean. Second panel: a measure of the variance.Third panel: based on third moments. The overall convergence measures are constructed on an aggregate measure based on the eigenvalues of the variance-covariance matrix of each parameter.