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**THE EFFECT OF LABOR AND FINANCIAL FRICTIONS
ON AGGREGATE FLUCTUATIONS**

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The Effect of Labor and Financial Frictions on Aggregate Fluctuations*

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Abstract

This paper embeds labor market search frictions into a New Keynesian model with financial frictions as in Bernanke, Gertler and Gilchrist (1999). The econometric estimation establishes that labor market frictions substantially improve the empirical fit of the model. The effect of the interaction between labor and financial frictions on aggregate fluctuations depends on the nature of the shock. For monetary policy, technology and entrepreneurial wealth shocks, labor market frictions amplify the effect of financial frictions since robust changes in hiring lead to persistent movements in employment and the return on capital that reinforce the original effect of financial frictions. For cost-push, labor supply, marginal efficiency of investment and preference shocks, labor market frictions dampen the effect of financial frictions by reducing the real cost of repaying existing debt that lowers the external finance premium.

JEL: E24, E32, E52.

Keywords: Financial frictions, search and matching frictions, New Keynesian model.

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1 Introduction

Developments in credit markets play an important role for the amplification and propagation of shocks. Seminal work by Bernanke, Gertler and Gilchrist (1999) show that asymmetric information in credit markets generates a negative relation between the firms' financial value and the cost of raising external funds, whose interaction amplifies the magnitude and persistence of macroeconomic fluctuations. Subsequent studies show that allowing for financial frictions in macroeconomic models enables an accurate account of aggregate fluctuations.¹ A parallel realm of the literature, initiated by Merz (1995) and Andolfatto (1996), shows that labor market frictions are important in describing the amplification and persistence of macroeconomic shocks.

The aim of this paper is to investigate the effect of the links between labor and financial frictions on aggregate fluctuations by using a prototype dynamic, stochastic, general equilibrium (DSGE) model characterized by nominal price rigidities. In particular, we focus on the following question: how do labor market frictions interact with financial frictions to alter the response of macroeconomic aggregates to shocks?

Existing models with financial frictions, with a few noticeable exceptions detailed below, assume that adjustments in the labor market are costless. In this paper we instead assume that labor market search and matching frictions prevent the competitive allocation of resources and it is costly to hire workers. In this way, the labor market frictions interact with financial frictions to determine aggregate fluctuations. Our modeling strategy is to set up a New Keynesian model with financial frictions, as in Bernanke, Gertler and Gilchrist (1999, henceforth BGG), enriched with labor market frictions, as in Blanchard and Galí (2010). To establish the importance of labor market frictions and investigate their interaction with financial frictions, we estimate two versions of the model using macroeconomic time-series data for the US from the 1970s onwards. We first consider a version characterized by financial frictions and a frictionless labor market, as in BGG, and second, a version that also allows for labor market frictions. In this way, we are able to evaluate the importance of labor market frictions over and above the BGG model with financial frictions. Furthermore, by estimating the model using Bayesian methods, we provide an empirically-grounded assessment of the effects of both frictions on aggregate fluctuations.

¹Recent noticeable contributions are Christensen and Dib (2008), De Graeve (2008) and Nolan and Thoenissen (2009) among others.

The econometric estimation establishes that the data strongly prefer the model that includes labor market frictions over and above the model with financial frictions only. The analysis shows that labor market frictions interact with financial frictions to generate two effects on macroeconomic aggregates. On the one hand, by affecting the firm's real cost of repaying existing debt, they change the reaction of the external finance premium to shocks, thereby altering the effect of financial frictions on macroeconomic fluctuations. For instance, in the aftermath of a contractionary monetary policy shock (i.e. an increase in the nominal interest rate), inflation falls less due to labor market frictions, which decreases the real cost of servicing existing debt due to a debt-deflation effect and consequently attenuates the fall in the firm's net worth. A higher net worth generates a lower leverage ratio, which attenuates the increase in the external finance premium, thereby increasing the demand for capital and dampening the original contractionary effect of financial frictions. On the other hand, in the presence of labor market frictions, the firm posts vacancies to recruit new workers, and employment adjusts slowly since a fraction of jobs are destroyed in every period. To counteract the slow accumulation of labor, the firm adjusts hiring aggressively, thereby generating persistent movements in employment and the return on capital, which in turn triggers fluctuations in the stock of capital and output. For instance, a contractionary monetary policy shock reduces the return on capital, inducing the firm to robustly decrease hiring. A strong fall in hiring reduces employment, the productivity of capital and the demand for capital, whose effect is to suppress investment, output and consumption.

Hence, in principle, labor market frictions may either dampen or magnify the effect of financial frictions on aggregate fluctuations. The econometric estimation of the model establishes that for monetary policy, technology and entrepreneurial wealth shocks, labor market frictions amplify the effect of financial frictions, since robust changes in hiring lead to persistent movements in employment, the return on capital and, consequently, investment and macroeconomic aggregates that reinforce the original effect of financial frictions. In contrast, for cost-push, labor supply, marginal efficiency of investment and preference shocks labor market frictions lower the external finance premium due to a reduction in the real cost of repaying existing debt, thereby dampening the effect of financial frictions.

The econometric estimation identifies the model's structural parameters and characterizes the unobservable shocks that hit the US economy over the sample period. We establish that labor market frictions leave the estimates of the model's parameters in line with related studies that abstract from both labor and financial frictions, as in Smets and Wouters (2007).

This finding also echoes the findings in Christensen and Dib (2008), De Graeve (2008) and Iacoviello and Neri (2010), who show that inclusion of a more detailed functioning of asset markets in models with financial frictions leaves the estimates of the structural parameters of the model substantially unchanged. Furthermore, the estimated mild degree of nominal price rigidities implies that firms change prices every two and a half quarters on average, which is shorter than the macro estimates of approximately one year in Sbordone (2002) and in line with estimates based on microdata, as in Klenow and Kryvtsov (2008). This finding shows that the coexistence of labor market and financial frictions lowers the degree of nominal price rigidities needed by the model to match the data.²

We find that shocks to preferences, labor supply, marginal efficiency of investment, entrepreneurial wealth and technology are persistent, unlike cost-push shocks. Moreover, shocks to technology and preferences play a primary role in explaining macroeconomic fluctuations in the long run, and monetary policy shocks play a supporting role in the short run. Cost-push, labor supply and marginal efficiency of investment shocks play a minimal role. These results reinforce the findings in models without financial and labor market frictions, as in Smets and Wouters (2007) and Ireland (2007), as well as models that separately consider either financial frictions, as in Christensen and Dib (2008) and De Graeve (2008), or labor market frictions, as in Gertler, Sala and Trigari (2008). Our findings are also in line with Christiano, Trabandt and Walentin (2011), who also develop a model with labor market and financial frictions, as detailed below. Finally, using a Kalman filter on the model's reduced form, we provide estimates for the unobservable shocks that characterize the US economy. In general, we find that the magnitude of shocks has decreased from the mid-1980s until 2008. Furthermore, we find that the volatility of monetary policy shocks declined during the same period. These findings corroborate the results of empirical studies by Sims and Zha (2006), Gambetti, Pappa and Canova (2008) and Benati and Mumtaz (2007), which detected a period of macroeconomic stability triggered by a lower volatility of shocks in the US from the mid-1980s until 2008.

The remainder of the paper is structured as follows. Section 2 discusses connections to the existing literature. Section 3 presents the model. Section 4 discusses the data, the empirical methodology and results, and Section 5 concludes.

²For a recent overview on the frequency of price adjustments and its implication on macroeconomic models, see Nakamura and Steinsson (2008) and references therein.

2 Connections to the Existing Literature

This paper contributes to two realms of the literature. First, it enriches the BGG financial accelerator framework with a more realistic modelling of the labor market. Recent studies by Christensen and Dib (2008), De Graeve (2008) and Nolan and Thoenissen (2009) show that financial frictions improve the empirical performance of a standard New Keynesian model in the context of a frictionless labor market. A growing body of research shows that labor market frictions are a key element to replicate important stylized facts in the US data.³ Our paper points out that labor market frictions, over and above financial frictions, are highly supported by the data, and they work together with financial frictions to amplify or dampen the variables' reaction to shocks. Along these lines, Wasmer and Weil (2004) show that an integrated model with labor and credit market imperfections, characterized by search costs in both labor and credit markets, works towards amplifying macroeconomic volatility. Ernst, Mitnik and Semmler (2010) enrich this framework with endogenous credit frictions in the form of state-dependent bond-issuing costs, thereby allowing financial matching efficiency to depend on the firm's net worth. They find that the interaction between labor and capital markets generates multiple equilibria that may magnify the transmission mechanism of macroeconomic shocks. Christiano, Trabandt and Walentin (2011) develop a large-scale DSGE model estimated on Swedish data that includes financial and labor market frictions in an open economy model characterized by multi-sector firms. The results of their paper are related on how the corporate leverage ratios affect the cost of external finance in an open economy, while in our model the propagation mechanism is simpler and based on fluctuations in the firm's leverage ratio and their effect on the cost of external finance, as in BGG or Kiyotaki and Moore (1997). Finally, our analysis uses a closed economy model estimated on US data.

This paper is also related to Petrosky-Nadeau (2009), Petrosky-Nadeau and Wasmer (2012) and Chugh (2009) that also combine labor market frictions with financial frictions. These studies show that credit market frictions in a search and matching model of the labor market address the lack of amplification and persistence to productivity shocks on labor market variables. Our paper differs from these studies across several dimensions. First, these studies are based on a real business cycle framework. Our model instead includes nominal price rigidities and therefore extends the analysis to nominal variables. Second, our focus is

³See, among others, Merz (1995), Andolfatto (1996) and more recently Hall (1999), Gertler and Trigari (2009) and references therein.

different since we investigate the propagation mechanism of both real and nominal shocks as a source of business cycle fluctuations. We also study the reaction of a broad set of macroeconomic variables, including the firm's net worth and leverage ratio. Third, we estimate the theoretical framework and use it to study the model's transmission mechanism and interpret economic developments in the data.

This paper also contributes to the growing literature that investigates the effect of labor market frictions on aggregate fluctuations. Gertler, Sala and Trigari (2008), Christoffel, Kuester and Linzert (2006) and Thomas (2011) are recent studies that embed labor market frictions into a standard New Keynesian model and find that the enriched model matches the data more closely. We contribute to this realm of research by showing that labor market frictions interact with financial frictions to affect aggregate fluctuations, and they either magnify or dampen the effect of exogenous disturbances on macroeconomic aggregates, depending on the nature of the shock.

3 The Economic Environment

The theoretical model combines the financial accelerator framework of BGG, as detailed in Christensen and Dib (2008) and Nolan and Thoenissen (2009), with labor market frictions, as in Blanchard and Galí (2010). The model economy is comprised of households, entrepreneurs, capital producers, a continuum of retailers indexed by $i \in [0, 1]$ and a monetary authority.

In the financial market, asymmetric information between entrepreneurs and financial intermediaries creates financial frictions that make entrepreneurs demand capital depending on their financial strength. The labor market is similar to Blanchard and Galí (2010) and is based on the assumption that the processes of job search and recruitment are costly for both the firm and the worker.⁴ Job creation takes place when a firm and a searching worker meet

⁴Since the focus of the paper is on the effects of the links between labor and financial frictions, we model labor market frictions in the form of a cost per hire, as in Blanchard and Galí (2010). We opt for this theoretical framework since when hiring costs are absent, the model nests the standard BGG model and therefore enables a straightforward comparison across the two theoretical settings. Despite this parsimonious approach to embed labor market frictions, the theoretical model is able to capture important labor market stylized facts, as shown in Galí (2011). A more sophisticated alternative is to model the labor market as in Gertler, Sala and Trigari (2008) by introducing a matching technology and a staggered wage setting mechanism, but this framework would substantially complicate the comparison across models without altering the contribution of labor market frictions. Extending the analysis to a more sophisticated theoretical framework where also nominal price rigidities play a role in the dynamics of the model would certainly be a useful extension for

and agree to form a match at a negotiated wage, which depends on the joint surplus from working. The match continues until the parties exogenously terminate the relationship.

The goods market is comprised of entrepreneurs, capital producers and a continuum of retailers indexed by $i \in [0, 1]$. During each period $t = 0, 1, 2, \dots$, entrepreneurs manufacture intermediate goods using capital and labor, and they borrow from financial intermediaries who convert households' deposits into business financing for the purchase of capital.⁵ Entrepreneurs acquire labor by hiring new workers from households and they purchase capital from capital producers. The adjustment of both labor and capital is costly. To adjust labor, entrepreneurs recruit workers at a constant cost per hire, and it takes time to build up labor. Capital producers face costs of adjusting the capital stock, which, as in Kiyotaki and Moore (1997), makes the asset price volatility to contribute to the volatility in entrepreneurial net worth. During each period $t = 0, 1, 2, \dots$, retailers purchase intermediate goods from entrepreneurs and sell them in a monopolistic competitive market at an established price. To introduce nominal rigidities in the model, each retailer is allowed to set a new price with probability φ , as in Calvo (1983). The presence of nominal rigidities enables the monetary authority to influence the behavior of real variables in the short run.

The monetary authority is modelled with a modified Taylor (1993) rule as in Clarida, Galí and Gertler (1998): it adjusts the nominal interest rate in response to deviations of inflation and output growth from their steady-state values.

The next subsections describe in detail the agents' tastes, technologies, the policy rule and the structure of the goods and labor markets.

3.1 The Representative Household

During each period $t = 0, 1, 2, \dots$, the representative household maximizes the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[e_t \ln C_t - \chi_t N_t^{1+\phi} / (1 + \phi) \right], \quad (1)$$

where the variable C_t is consumption, N_t is units of labor, β is the discount factor $0 < \beta < 1$ and e_t and χ_t are the aggregate preference and labor supply shocks that follow the

future research.

⁵Differently from the original BGG model, borrowers sign a debt contract that specifies a fixed nominal interest rate. Therefore the loan repayment (in real terms) depends on the ex post real interest rate. An unanticipated increase (decrease) in inflation reduces (increases) the real cost of debt repayment.

autoregressive processes

$$\ln(e_t) = \rho_e \ln(e_{t-1}) + \varepsilon_{et}, \quad (2)$$

and

$$\ln(\chi_t) = (1 - \rho_\chi) \ln(\chi) + \rho_\chi \ln(\chi_{t-1}) + \varepsilon_{\chi t}, \quad (3)$$

where $(\rho_e, \rho_\chi) < 1$. The zero-mean, serially uncorrelated innovations ε_{et} and $\varepsilon_{\chi t}$ are normally distributed with standard deviation σ_e and σ_χ . The representative household enters period t with deposits D_{t-1} , which pay interest, providing $R_{t-1}D_{t-1}$ additional units of currency, where R_t represents the gross nominal interest rate between t and $t+1$. At the beginning of the period, the household receives a lump-sum nominal transfer T_t from the central bank and another lump-sum nominal transfer Π_t , which include profits from retailers and equity from entrepreneurs who exit business. The household supplies N_t units of labor at the wage rate W_t to entrepreneurs and, if unemployed, receives unemployment benefits B_t during period t . The household uses its income for consumption, C_t , and carries D_t deposits into period $t+1$, subject to the budget constraint

$$[R_{t-1}D_{t-1} + W_tN_t + \Pi_t + T_t + (1 - N_t)B_t] / P_t = C_t + D_t/P_t, \quad (4)$$

for all $t = 0, 1, 2, \dots$.⁶ Thus the household chooses $\{C_t, D_t\}_{t=0}^\infty$ to maximize its utility (1) subject to the budget constraint (4) for all $t = 0, 1, 2, \dots$. Letting $\pi_t = P_t/P_{t-1}$ denote the gross inflation rate and Λ_t the non-negative Lagrange multiplier on the budget constraint (4), the first-order conditions for this problem are

$$\Lambda_t = e_t/C_t, \quad (5)$$

and

$$\Lambda_t = \beta R_t E_t(\Lambda_{t+1}/\pi_{t+1}). \quad (6)$$

According to equation (5), the Lagrange multiplier must equal the households' marginal utility of consumption. Equation (6), once equation (5) is substituted in, is the households Euler equation that describes the optimal consumption decision.

⁶As in Merz (1995) and Andolfatto (1996), to avoid distributional issues from heterogeneity in income, members of the household are able to perfectly insure each other against fluctuations in income.

3.2 The Labor Market

During each period $t = 0, 1, 2, \dots$, the flow into employment results from the number of workers who survive from the exogenous separation and the number of new hires, H_t . Hence, total employment evolves according to

$$N_t = (1 - \delta_n)N_{t-1} + H_t, \quad (7)$$

where N_t and H_t represent the number of workers employed and hired by firm i in period t , and δ_n is the exogenous separation rate and $0 < \delta_n < 1$. It is convenient to introduce the variable x_t , the job finding rate

$$x_t = H_t/U_t \quad (8)$$

and assume, as in Blanchard and Galí (2010), full participation in the labor market such that

$$U_t = 1 - (1 - \delta_n)N_{t-1} \quad (9)$$

is the beginning of period unemployment.

Let \mathcal{W}_t^N and \mathcal{W}_t^U denote the value of the expected income of an employed and unemployed worker, respectively. The employed worker earns a wage, suffers disutility from work and may lose her job with probability δ_n . Hence, the marginal value of a new match is:

$$\mathcal{W}_t^N = \frac{W_t}{P_t} - \chi_t \frac{N_t^\phi}{\Lambda_t} + \beta E_t \frac{\Lambda_{t+1}}{\Lambda_t} \{ [1 - \delta_n (1 - x_{t+1})] \mathcal{W}_{t+1}^N + \delta_n (1 - x_{t+1}) \mathcal{W}_{t+1}^U \}. \quad (10)$$

This equation states that the value of a job for a worker is given by the real wage reduced for the marginal disutility of working and the expected-discounted net gain from being either employed or unemployed during period $t + 1$.

The unemployed worker expects to move into employment with probability x_t . Hence, the marginal value of unemployment is:

$$\mathcal{W}_t^U = \frac{B_t}{P_t} + \beta E_t \frac{\Lambda_{t+1}}{\Lambda_t} [x_{t+1} \mathcal{W}_{t+1}^N + (1 - x_{t+1}) \mathcal{W}_{t+1}^U]. \quad (11)$$

This equation states that the value of unemployment is made up of unemployment benefits together with the expected-discounted capital gain from being either employed or unemployed during period $t + 1$. Similarly to Nickell (1997), unemployment benefits are set as a proportion, ρ_b , of the established wage, such that $B_t = \rho_b W_t$, where ρ_b represents the replacement ratio.

The structure of the model guarantees that a realized job match yields some pure economic surplus. The share of this surplus between the worker and the firm is determined by the wage

level. The wage is set according to the Nash bargaining solution. The worker and the firm split the surplus of their matches with the absolute share η , and $0 < \eta < 1$. The difference between equation (10) and (11) determines the worker's surplus. To keep the model simple, as in Pissarides (2000), we assume that the firm's surplus is given by the real cost per hire, κ . Hence, the total surplus from a match is the sum of the worker's and the firm's surpluses. The wage bargaining rule for a match is

$$\eta\kappa = (1 - \eta)(\mathcal{W}_t^N - \mathcal{W}_t^U).$$

Substituting equations (10) and (11) into this last equation produces the agreed wage:

$$W_t/P_t = \chi_t N_t^\phi / \Lambda_t + B_t/P_t + \kappa [\eta / (1 - \eta)] \{1 - \beta (1 - \delta_n) E_t (\Lambda_{t+1} / \Lambda_t) (1 - x_{t+1})\}, \quad (12)$$

where η is the bargaining power of the worker. Equation (12) gives the wage consistent with the wage bargaining. It shows that the wage equals the disutility of working plus unemployment benefits together with current hiring costs as well as the expected savings in terms of the future hiring costs if the match continues in period $t + 1$.

3.3 The Goods Market

As described, the production sector is comprised of entrepreneurs, capital producers and retailers indexed by $i \in [0, 1]$, characterized by staggered price-setting, as in Calvo (1983).

3.3.1 The Entrepreneurs

As in BGG, entrepreneurs use labor and capital to manufacture goods and borrow funds from financial intermediaries to acquire the capital used in the production process. Entrepreneurs are risk neutral and face a constant probability ν of surviving to the next period. This ensures that the entrepreneurs' net worth would never exceed the value of new capital acquisition. To finance new acquisitions, entrepreneurs issue debt contracts to cover the capital acquisition in excess of net worth.

During each period $t = 0, 1, 2, \dots$, entrepreneurs acquire capital, K_{t+1} , at the real price q_t , such that the total cost of new capital acquisition is $K_{t+1}q_t$. The acquisition is financed using their net worth, ω_t , and issuing debt contracts of the amount of $K_{t+1}q_t - \omega_t$ to financial intermediaries, who purchase debt by using the households' deposits at the cost R_t .

As in BGG, we express the expected gross return of holding a unit of capital, $E_t r_{t+1}^K$, to depend on the expected return on capital and the expected marginal financial cost, such that

$$E_t r_{t+1}^K = E_t \left[\Xi_{t+1} \alpha \frac{Y_{t+1}}{K_{t+1}} + (1 - \delta_k) q_{t+1} \right] / q_t, \quad (13)$$

where Ξ_{t+1} is the real marginal cost at $t+1$, $\Xi_{t+1} \alpha Y_{t+1} / K_{t+1}$ is the real marginal productivity of capital at $t+1$, and $(1 - \delta_k) q_{t+1}$ is the cost of acquiring a unit of capital at $t+1$. Equation (13) represents the demand for new capital and states that the return on capital depends inversely on the level of investment, due to diminishing returns.

Asymmetry of information between entrepreneurs, financial intermediaries and associated monitoring costs breaks down the Modigliani-Miller Theorem and makes the entrepreneurs' external borrowing costs higher than internal funds. As shown in BGG, the external finance premium, $S(\cdot)$, depends on the entrepreneur's leverage ratio, $K_{t+1} q_t / \omega_t$, whose elasticity depends on the structure of the financial contracts.⁷ In this setting, the external financing cost equates the premium for external funds plus the real opportunity cost of investing in risk-free deposits:

$$E_t r_{t+1}^K = E_t [S(\cdot)(R_t / E_t \pi_{t+1})], \quad (14)$$

where $R_t / E_t \pi_{t+1}$ is the real interest rate (i.e. the risk-free rate). Note that, as shown in BGG, the higher the leverage ratio, the higher the external finance premium, i.e. $S'(\cdot) > 0$, and similarly, in the limiting case in which all the new acquisitions are financed through the entrepreneur's net worth, the external finance premium disappears, such that the cost of external finance equals the risk-free rate (i.e. $S(1) = 1$). Note that equation (14) represents the demand of capital, which up to a first-order approximation, becomes

$$\hat{r}_{t+1}^K = \hat{R}_t - \hat{\pi}_{t+1} + \psi(\hat{q}_t + \hat{K}_{t+1} - \hat{\omega}_t),$$

where ψ is the elasticity of the external finance premium with respect to the leverage ratio and a hat superscript denotes the variable's deviation from its steady state.

As in BGG, the aggregate entrepreneurial net worth is given by

$$\omega_{t+1} = \nu \gamma_t v_t + (1 - \nu) g_t, \quad (15)$$

where ν is the probability of the entrepreneurs surviving to the next period, v_t is the net worth of the entrepreneurs at time $t - 1$ who are still in business at time t and g_t is the transfer

⁷BGG reports the complete derivation of the external finance premium and its elasticity to the leverage ratio.

that surviving entrepreneurs receive from those who perish during the current period. The variable γ_t represents a shock to the entrepreneurial wealth and follows the autoregressive process

$$\ln(\gamma_t) = \rho_\gamma \ln(\gamma_{t-1}) + \varepsilon_{\gamma t},$$

where $0 < \rho_\gamma < 1$. The zero-mean, serially uncorrelated innovation $\varepsilon_{\gamma t}$ is normally distributed with standard deviation σ_γ . The net worth of the entrepreneurs who survive is equal to the ex-post value of capital, $r_t^K K_t q_{t-1}$, minus the cost of borrowing, $E_{t-1} r_t^K (K_t q_{t-1} - \omega_t)$, such that

$$v_t = r_t^K K_t q_{t-1} - E_{t-1} r_t^K (K_t q_{t-1} - \omega_t). \quad (16)$$

During each period $t = 0, 1, 2, \dots$, entrepreneurs hire N_t units of labor from the households and K_t units of capital from the capital producers to produce Y_t units of goods according to the constant returns to scale production technology

$$Y_t = A_t K_t^\alpha N_t^{1-\alpha}, \quad (17)$$

where the aggregate technology, A_t , follows the autoregressive process

$$\ln(A_t) = \rho_a \ln(A_{t-1}) + \varepsilon_{at}, \quad (18)$$

where $0 < \rho_a < 1$. The zero-mean, serially uncorrelated innovation ε_{at} is normally distributed with standard deviation σ_a . The capital stock evolves according to

$$K_{t+1} = (1 - \delta_k) K_t + z_t I_t, \quad (19)$$

where $0 < \delta_k < 1$ is the capital depreciation rate and I_t is investment. The variable z_t represents a shock to the marginal efficiency of investment (MEI) and follows the autoregressive process

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

where $0 < \rho_z < 1$. The zero-mean, serially uncorrelated innovation ε_{zt} is normally distributed with standard deviation σ_z . The entrepreneurs maximize their total value of profits given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t (\Theta_t / P_t), \quad (20)$$

subject to the constraints imposed by (7), (17) and (19). In equation (20), the term $\beta^t \Lambda_t$ measures the marginal utility value to the household of an additional dollar in profits received during period t and

$$\Theta_t / P_t = Y_t - N_t W_t / P_t - H_t \kappa - I_t q_t \quad (21)$$

for all $t = 0, 1, 2, \dots$. Thus, the entrepreneurs choose $\{N_t, H_t, K_t, I_t\}_{t=0}^{\infty}$ to maximize the profit (21), subject to production technology (17), the law of employment accumulation (7) and the law of capital accumulation (19). Solving equation (7) for H_t and equation (19) for I_t and substituting the outcomes into equation (21) and letting Ξ_t denote the non-negative Lagrange multiplier on equation (17) yields the first-order conditions⁸

$$\frac{W_t}{P_t} = \frac{\Xi_t}{\Lambda_t}(1 - \alpha)\frac{Y_t}{N_t} - \kappa E_t \left[1 - \beta(1 - \delta_n)\frac{\Lambda_{t+1}}{\Lambda_t}\frac{1}{\pi_{t+1}} \right], \quad (22)$$

and

$$\Lambda_t q_t = \beta E_t \left[\Xi_{t+1} \alpha \frac{Y_{t+1}}{K_{t+1}} + \Lambda_{t+1} q_{t+1} (1 - \delta_k) \right]. \quad (23)$$

Equation (22) is the entrepreneurs' labor demand condition that equates the real wage with the marginal product of labor minus the hiring costs to pay in period t plus the expected saving on the hiring costs foregone in period $t + 1$ if the job is not dismissed. Equation (23) is the standard Euler equation for capital, which links the intertemporal marginal utility of consumption with the real remuneration of capital. Note that equation (22) gives the wage consistent with the firm's profit maximization. In equilibrium, the bargained wage (12) equates to the firm's wage (22).

3.3.2 Capital Producers

During each period $t = 1, 2, 3, \dots$, capital producers manufacture capital goods and sell them to entrepreneurs. They use final goods from retailers and are subject to the quadratic capital adjustment costs $(\chi_K/2)(I_t/K_t - \delta_k)^2 K_t$ so that asset price volatility contributes to the volatility in entrepreneurial net worth. Hence, capital producers choose $\{I_t\}_{t=0}^{\infty}$ to maximize their profits

$$q_t I_t - I_t - (\chi_K/2)(I_t/K_t - \delta_k)^2 K_t.$$

This yields the first-order condition

$$q_t = 1 + (\chi_K)(I_t/K_t - \delta_k), \quad (24)$$

which is the standard Tobin's Q equation of investment and represents the supply curve for new capital. Equation (24) equates the price of capital with its marginal adjustment cost. As in Kiyotaki and Moore (1997), equation (24) enables asset price volatility to affect the entrepreneurial net worth, an important mechanism of shocks propagation in BGG.

⁸Note that the non-negative Lagrange multiplier Ξ_t can also be interpreted as the entrepreneur's real marginal cost.

3.3.3 Retailers

There is a continuum of monopolistically competitive retailers indexed by $i \in [0, 1]$. Retailers buy goods from entrepreneurs, transform each unit of these goods into a unit of retail goods and re-sell them at an established price. During each period $t = 0, 1, 2, \dots$, each retailer i faces the following demand curve for its own product

$$Y_t(i) = [P_t(i)/P_t]^{-\theta_t} Y_t,$$

where θ_t is the time-varying elasticity of demand for each intermediate good, as first introduced by Ireland (2004) and Smets and Wouters (2007), which acts as a cost-push shock and follows the autoregressive process

$$\ln(\theta_t) = (1 - \rho_\theta) \ln(\theta) + \rho_\theta \ln(\theta_{t-1}) + \varepsilon_{\theta t}, \quad (25)$$

where $\rho_\theta < 1$. The zero-mean, serially uncorrelated innovation $\varepsilon_{\theta t}$ is normally distributed with standard deviation σ_θ . During each period $t = 0, 1, 2, \dots$, each retail firm sets prices, as described by Calvo (1983), such that a fraction $(1 - \varphi)$ of retail firms sets a new price while the remaining fraction φ charges the previous period's price updated for the steady-state inflation. Hence, firm i sets a new price $P_t(i)$ in time t and maximizes

$$E_0 \sum_{k=0}^{\infty} (\beta\varphi)^k (\Lambda_{t+k}/\Lambda_t) \left\{ [P_t(i)/P_t]^{-\theta_t} Y_{t+k} [P_t(i)/P_{t+k} - \Xi_{t+k}] \right\},$$

where Ξ_t is the real marginal cost. First-order conditions for this problem are

$$P_t^*(i) = \frac{\theta_t \sum_{k=0}^{\infty} (\varphi\beta)^k E_t \left(\Lambda_{t+k} P_{t+k}^{\theta_t} Y_{t+k} \Xi_{t+k} \right)}{(\theta_t - 1) \sum_{k=0}^{\infty} (\varphi\beta\pi)^k E_t \left(\Lambda_{t+k} P_{t+k}^{\theta_t-1} Y_{t+k} \right)}, \quad (26)$$

where $P_t^*(i)$ is the price chosen by the retailer and P_t is the aggregate price index

$$P_t = \left[\varphi P_{t-1}^{1-\theta_t} + (1 - \varphi) P_t^{*1-\theta_t} \right]^{\frac{1}{1-\theta_t}}. \quad (27)$$

Using equations (26) and (27) yields the standard Phillips curve

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + k_p \left(\hat{\Xi}_t + \hat{\theta}_t \right), \quad (28)$$

where the coefficient $k_p \equiv (1 - \beta\varphi)(1 - \varphi)/\varphi$.

3.4 The Monetary Authority

During each period $t = 0, 1, 2, \dots$, the monetary authority conducts monetary policy using a modified Taylor (1993) rule,

$$\ln(R_t/R) = \rho_y \ln(Y_t/Y_{t-1}) + \rho_\pi \ln(\pi_t/\pi) + \varepsilon_{vt}, \quad (29)$$

where R and π are the steady-state values of the nominal interest rate and inflation. The zero-mean, serially uncorrelated policy shock ε_{vt} is normally distributed with standard deviation σ_v . According to equation (29), the monetary authority adjusts the nominal interest rate in response to movements in output growth and inflation from their steady-state levels. As Clarida, Galí and Gertler (1998) show, this modelling strategy for the central bank consistently describes the conduct of monetary policy in the US.⁹

3.5 Equilibrium and Solution

In a symmetric, dynamic equilibrium, all agents make identical decisions so that $Y_t(i) = Y_t$, $N_t(i) = N_t$, $H_t(i) = H_t$, $D_t(i) = D_t$ and $P_t(i) = P_t$ for all $i \in [0, 1]$ and $t = 0, 1, 2, \dots$. In addition, the market clearing conditions $D_t = D_{t-1} = 0$ and $T_t + (1 - N_t)B_t = 0$ must hold for all $t = 0, 1, 2, \dots$. The aggregate market clearing condition states that output is the sum of consumption, investment, the aggregate costs of hiring, the adjustment costs of capital and the monitoring costs of loans,¹⁰

$$Y_t = C_t + I_t + H_t \kappa + (\chi_K/2)(I_t/K_t - \delta_k)^2 K_t. \quad (30)$$

The model describes the behavior of 22 variables $\{Y_t, I_t, C_t, N_t, K_t, H_t, U_t, B_t, x_t, R_t, \pi_t, \omega_t, v_t, r_t^K, \Xi_t, q_t, W_t, \Lambda_t, e_t, \chi_t, A_t, \theta_t\}$. The equilibrium is then described by the representative household's first-order conditions (5) and (6), the law of employment (7), the definition of the job finding rate (8), the definition of unemployment accumulation (9), the agreed wage (12), expected gross return of holding a unit of capital (13), the external financing cost (14), aggregate

⁹Note that equation (29) does not include a lagged interest rate since the presence of output growth already internalizes the effect of past interest rate movements on the conduct of monetary policy. Christensen and Dib (2008) use a similar formulation in an estimated model with financial frictions as does Galí (2011) in a model with labor market frictions. As a robustness check, we have estimated the model including a lagged interest rate in equation (29) and established that the results remain similar across different specifications.

¹⁰Note that since the costs of monitoring loans have a small impact on the dynamic of the model, as detailed in BGG and Gilchrist and Leahy (2002), we can safely abstract from them.

entrepreneurial net worth (15), the surviving entrepreneurs' net worth (16), the production technology (17), the labor demand equation (22), the cost of new capital (24), the law of capital accumulation (19), the Phillips curve (28), the monetary authority policy rule (29), the aggregate resource constraint (30), the definition of unemployment benefits ($B_t = \rho_b W_t$) and the specifications of the disturbances for the preference shock (2), the labor supply shock (3), the technology shock (18), and the cost-push shock (25).¹¹

The equilibrium conditions do not have an analytical solution. Instead, the model's dynamics are characterized by log-linearizing them around the steady state. The solution to the system is derived using Klein (2000), which is a modification of Blanchard and Kahn (1980), and it takes the form of a state-space representation. This latter, as detailed below, can be used conveniently in the estimation procedure.

4 Estimation and Findings

The econometric estimation uses US quarterly data for output, unemployment, the nominal interest rate, inflation, real wages, investment and the corporate interest rate spread for the sample period 1970:1 through 2009:3. Output is defined as real gross domestic product, unemployment is defined as the civilian unemployment rate, the nominal interest rate is defined as quarterly averages of the Federal Funds rate, inflation is defined as the quarterly growth rate of the GDP deflator, real wages are defined as the real compensation in the non-farm business sector, investment is defined as real gross private domestic investment and the corporate interest rate spread is defined as the difference between corporate bond yields and the three month treasury bill. All the data are taken from the FRED database. The data are demeaned, and the output and investment series are expressed in per capita terms prior to the estimation.

As in other similar studies, such as Christensen and Dib (2008), a first attempt to estimate the model led to unreasonable values for some parameters. More sensible results are obtained when these parameters are fixed prior to the estimation. Thus we calibrate the value of the following parameters. We set the production capital share, α , equal to 0.33, a value commonly used in the literature. We set the discount factor, β , equal to 0.99 to generate an annual real interest rate of 4%, as in the data. We set the disutility parameter, χ , equal to 2.5 to match

¹¹Note that the model that embeds labor market frictions nests the standard BGG model once the cost of posting a vacancy is set to zero, $\kappa = 0$, and the exogenous separation parameter is set to zero, $\delta_n = 0$.

the steady-state unemployment rate of approximately 6%, as in the data. The fraction of hiring costs of total output, κ , is set equal to 0.11, as in Blanchard and Galí (2010), so that hiring costs represent approximately 1% of total output. We set the capital depreciation rate, δ_k , equal to 0.025, as in King and Rebelo (1999), to produce a 10% annual depreciation rate. The steady-state value of the elasticity of substitution between intermediate goods, θ , is set equal to 10, implying that the equilibrium mark-up is approximately equal to 11%, as suggested in Rotemberg and Woodford (1999). We set the capital adjustment cost parameter, χ_k , equal to 0.25, as suggested in BGG. We calibrate the steady-state interest rate on external funds equal to the average of the business prime loan rate over the sample period, as in BGG and Christensen and Dib (2008). This gives a gross external finance premium, $S(\cdot)$, of about 1.03, or 3.0% annualized and on a net basis. We set the steady-state capital to asset ratio equal to 2. This value implies a firm leverage ratio, defined as the ratio of debt to assets, of 0.5. Finally, we set the survival rate of entrepreneurs, ν , equal to 0.96, in line with BGG.

We estimate the remaining parameters $\{\delta_n, \eta, \phi, \rho_b, \psi, \varphi, \rho_\pi, \rho_y, \rho_a, \rho_\theta, \rho_e, \rho_\chi, \rho_z, \rho_\gamma, \sigma_a, \sigma_\theta, \sigma_e, \sigma_\chi, \sigma_v, \sigma_z, \sigma_\gamma\}$ by using Bayesian methods, as described in Schorfheide (2000). The solution of the linearized DSGE model results in a state-space representation of the reduced form. The Kalman filter can be used to evaluate the likelihood function of the state-space model and this is then combined with the prior distribution of the parameters to derive the posterior for a given set of parameter values. To approximate the posterior distribution, we employ the random walk Metropolis-Hastings algorithm. We use 50,000 replications and discard the first 25,000 as burn-in. We save every 25th remaining draw. The sequence of retained draws is stable, providing evidence on convergence.¹²

As detailed above, we estimate two versions of the model: first, a model with both labor market and financial frictions and, second, the standard BGG model with financial frictions only, obtained by setting the cost of posting a vacancy, κ , and the exogenous separation rate, δ_n , equal to zero. In this way, we are able to empirically assess the difference across the two models and evaluate the contribution of labor market frictions over and above the BGG model with financial frictions. Table 1 reports the prior distributional forms, means, standard deviations and 90% confidence intervals for the model that embeds both labor and financial frictions. The standard BGG model uses the same priors for the common parameters, and sets κ and δ_n to zero. To enable comparisons with the literature, we use the prior distributions for the shocks, the Calvo parameter and monetary policy parameters from Smets and Wouters

¹²An appendix that details evidence on convergence is available on request from the authors.

(2007). For the labor market parameters, we resort to a variety of studies. The prior mean of the job destruction rate, δ_n , is set to 0.03, as estimated in Fujita and Ramey (2009); the prior mean of the wage bargaining parameter, η , is set to 0.5, which is standard in the literature; the prior mean of the inverse of elasticity of labor supply, ϕ , is set to 1, similar to Blanchard and Galí (2010); and the prior mean of the elasticity of the external finance premium with respect to a change in the leverage position of the entrepreneur, ψ , is set to 0.04, as in BGG. The prior distributions on these parameters are set large enough to cover the relevant domain.

To establish what theoretical framework fits the data more closely, we use the marginal log-likelihood of each model to compute the posterior odds ratio. The marginal or the integrated log-likelihood represents the posterior distribution, with the uncertainty associated with parameters integrated out, and therefore it also reflects the model prediction performance. The marginal likelihood is approximated using the modified harmonic mean, as detailed in Geweke (1999). Considering that this criterion penalizes overparametrization, the model with labor market frictions does not necessarily rank better if the extra frictions do not sufficiently help in explaining the data. As from the last row of Table 2, the marginal log-likelihood associated with the model with both labor and financial frictions is equal to 2143.7 while the one associated with the BGG model is equal to 2050.8. To econometrically test the extent to which the model with both financial and labor market frictions improves the fit of the data, we use the posterior odds ratio. This measure is computed as the difference between the marginal log-likelihood of the model that embeds both labor and financial frictions and the marginal log-likelihood of the BGG model with financial frictions only. The posterior odds ratio is equal to $e^{92.9}$, which represents very strong evidence in favour of the model with labor market frictions.¹³

Table 2 displays the value of the posterior mean of the parameters together with their lower 5% and upper 95% bounds.¹⁴ Column 2 reports the BGG model, and column 3 re-

¹³ As a robustness check, we have estimated the two competing models with more diffuse priors and established that the model with labor market frictions fits the data more closely. In addition, we have investigated how the fit of a model with labor market frictions only compares with those of the alternative specifications. As shown in Christensen and Dib (2008), by setting the elasticity of the external finance premium with respect to the leverage ratio ψ equal to zero, the dynamics related with the financial accelerator are not present. The marginal log-likelihood associated with the model with labor market frictions only is equal to 2098.2, which shows that the model with both labor and financial frictions fits the data better.

¹⁴ It is worth noting that the prior and posterior distributions of the parameters are different, supporting the presumption that the data are informative about the values of the estimated parameters. An appendix that shows the prior and posterior densities for each estimated parameter is available upon request from the

ports the model with both labor and financial frictions. The posterior mean estimates are remarkably close among models, indicating that parameter estimates are consistently and robustly estimated across the two different settings. This finding echoes those in Christensen and Dib (2008), De Graeve (2008) and Iacoviello and Neri (2010), who show that although financial frictions enhance a more detailed functioning of the economy, they leave the values of the estimated parameters substantially unchanged compared to the standard New Keynesian model without financial frictions. The estimate of the job destruction rate, δ_n , is equal to 0.04, indicating that on average approximately 4% of jobs disappears in every quarter, which is in line with the recent estimates by Jolivet, Postel-Vinay and Robin (2006). The posterior mean of the wage bargaining parameter, η , is equal to 0.811, which is close to the estimate in Gertler, Sala and Trigari (2008). The posterior mean of the inverse of the Frisch intertemporal elasticity of substitution in labor supply, ϕ , equals 1.451, which implies a labor supply elasticity approximately equal to 0.7. This value is consistent with that suggested by Rogerson and Wallenius (2007) and more generally with the calibrated values used in the macro literature, as advocated by King and Rebelo (1999). The posterior mean of the replacement ratio parameter, ρ_b , is equal to 0.385, which is in line with the estimate in Nickell (1997). The posterior mean of the elasticity of the external financial premium parameter, ψ , is equal to 0.041, which is remarkably close to the value used in BGG and similar to the estimate in Christensen and Dib (2008). The posterior mean of the degree of nominal price rigidities, φ , is equal to 0.612, implying that firms change prices every two and a half quarters on average, which is lower than the empirical estimates of approximately one year in Sbordone (2002). Hence, the coexistence of labor and financial frictions enables the model to generate a degree of nominal price rigidities in line with estimates from microdata, as in Klenow and Kryvtsov (2008).

The parameters' estimates of the Taylor rule in equation (29) characterize the conduct of monetary policy. The estimate of the reaction coefficient to fluctuations of output growth, ρ_y , is 1.327, and the estimate of the reaction coefficient to fluctuations of inflation from the inflation target, ρ_π , is 1.812. These estimates suggest that the nominal interest rate reacts more strongly to fluctuation in inflation than output, in line with the estimates in Smets and Wouters (2007) and Ireland (2007) and the empirical evidence in Clarida, Galí and Gertler (1998).

The estimates of the autocorrelation coefficients of the exogenous disturbances show that

authors.

technology shocks are highly persistent, with the posterior mean of ρ_a equal to 0.983. On the other hand, preferences, labor supply, cost-push, MEI and entrepreneurial wealth shocks are less so, with the posterior mean of ρ_e , ρ_χ , ρ_θ , ρ_z and ρ_γ equal to 0.913, 0.973, 0.851, 0.931 and 0.925 respectively. The estimates of the volatility of the exogenous disturbances show that cost-push and labor supply shocks are slightly more volatile, with σ_θ and σ_χ equal to 0.052 and 0.053, respectively, while technology, monetary policy, preference, MEI and entrepreneurial wealth shocks are of lower magnitude, with σ_a , σ_v , σ_χ , σ_z and σ_γ equal to 0.035, 0.025, 0.031, 0.023 and 0.048 respectively. Clearly, these values suggest that differences among shocks are not sizable.

To investigate how the variables of the model react to each shock, Figures 1-6 plot the impulse responses of selected variables to one standard deviation of the exogenous shocks. In each figure the dashed line shows the reaction of the BGG model with financial frictions only, and the solid black line shows the model that also includes labor market frictions.

Figure 1 shows the reaction of key aggregates to a one standard deviation monetary policy shock (i.e. contractionary monetary policy). The qualitative dynamics are similar across models, although the response of macroeconomic aggregates is stronger and more persistent in the model with labor market frictions. A monetary policy shock induces the firm to cut back on the input of production and the household to decrease consumption. Lower consumption generates a sharp fall in output, which in turn reduces inflation. Lower inflation, together with the rise in the nominal interest rate, increases the firm's cost of servicing its external debt, thereby reducing its net worth and raising the costs of external finance. Labor market frictions interact with financial frictions to generate two competing effects on aggregate fluctuations. On the one hand, they dampen the reaction of inflation which decreases the real cost of repaying existing debt. Hence, the fall in the firm's net worth is contained, and the associated cost of external finance is lower. A lower external finance premium should induce higher investment. However, investment is lower in the presence of labor market frictions. Why is the effect of the external finance premium contained? In the presence of labor market frictions, a positive monetary policy shock induces the firm to robustly reduce hiring on impact. Lower hiring decreases employment persistently, as from equation (7), which reduces the return on capital and its demand. This process generates a contractionary effect on macroeconomic aggregates.

Figure 2 shows the reaction of key variables to a one standard deviation technology shock. Across the two models, output and consumption rise. Labor input falls since improved tech-

nology enables higher production with lower labor input for a given demand, as outlined in Galí (1999). The increase in technology reduces the unit cost of production, which lowers inflation. The fall in inflation increases the real cost of repaying existing debt, which reduces the firm's net worth. The decrease in the firm's value increases its leverage ratio and generates higher external financing costs. Hence the firm's cost of external finance rises. Note that in the model with labor market frictions, the firm's finance premium is lower, which in principle, as predicted by the financial accelerator channel, should lead to higher investment on impact. However, the contraction in investment is stronger for the model with labor market frictions. The reason for this is straightforward. In the presence of labor market frictions, the firm aggressively reduces hiring on impact. Employment falls and then slowly returns to equilibrium, which decreases the demand for capital and its value, thereby suppressing investment, output and consumption.

Figure 3 shows the reaction of key variables to a one standard deviation cost-push shock. In the aftermath of the shock, inflation rises and output falls sharply, which triggers a decrease in the nominal interest rate, as dictated by the Taylor rule. The fall in the nominal interest rate decreases the cost of servicing the external debt, which increases the firm's net worth and reduces the external finance premium. Note that in the model with labor market frictions, the external finance premium is lower since the firm's real cost of repaying existing debt falls, thereby generating a contained contraction in investment on impact. However, due to the fall in hiring, employment decreases and adjusts slowly, inducing a protracted contraction in the capital remuneration, its demand and consequently, investment and other macroeconomic aggregates.

Figure 4 shows the response of key aggregates to a one standard deviation preference shock. In the model without labor frictions, inflation increases on impact and, due to the Taylor rule, the nominal interest rate increases. The strong increase in inflation decreases the cost of servicing the external debt, thereby raising the firm's net worth and decreasing the costs of external finance, which generates a lower fall in investment in the aftermath of the shock.

Figure 5 shows the response of key aggregates to a one standard deviation MEI shock. Labor market frictions reduce the reaction of inflation to shocks, decreasing the external finance premium and therefore dampening the response of the variables to the shock. However, the qualitative responses of the variables are similar across the different model specifications.

Figure 6 shows the response of key aggregates to a one standard deviation entrepreneurial

wealth shock. In response to the shock, net worth increases and the external finance premium falls, thereby increasing investment and output. In the presence of labor market frictions, the firm aggressively hires workers, whose effect is to further increase employment, output and support investment. Therefore labor market frictions amplify the effect of the shock.

Looking across all these impulse responses provides some insights into how the presence of labor market frictions affects the transmission mechanism of a standard New Keynesian framework with financial frictions. For all shocks, with the exception of preference shocks, the presence of labor market frictions does not affect the sign of the variables' response to shocks. This result is similar to Christensen and Dib (2008), De Graeve (2008) and Iacoviello and Neri (2010), who show that adding a more detailed structure of the banking sector in the standard BGG model leaves the variables' response to shocks broadly unchanged.¹⁵ However, we find that labor market frictions amplify the reaction of key macroeconomic variables such as output, investment and the input of production to technology, monetary policy and entrepreneurial wealth shocks. Moreover, irrespective of the shock, labor market frictions increase the persistence of key macroeconomic variables due to the sluggish adjustment of employment.

To understand the extent to which movements of each variable are explained by each shock, Table 3 reports the asymptotic forecast error variance decompositions of selected variables. Each left entry reports the statistics from the BGG model with labor market frictions, whereas each right entry reports the statistics from the BGG model with financial frictions only. The results show that in the BGG model with labor market frictions, technology shocks explain short-run movements in output, consumption and inflation while nominal interest rate shocks play an important role in driving short-run fluctuations in the nominal interest rate and a supporting role in inflation and output. On the other hand, in the long run, technology shocks play a primal role on output and consumption while preference shocks explain a sizable fraction of fluctuations in the nominal interest rate, and entrepreneurial wealth are important for fluctuations in investment. This latter finding is similar to Christiano, Trabandt and Walentin (2011). Nominal interest rate shocks compete with technology and preference shocks to explain long-run movements in inflation. The results in the BGG model with financial frictions only are similar. However, labor supply shocks are more important to explain movements in the data, and preference shocks explain the bulk of long-run fluctuations

¹⁵It is worth noting that Christiano, Trabandt and Walentin (2011) detect differences in the parameter estimates in a small open economy model with labor and financial frictions.

in the nominal interest rate.

To detail how the exogenous shocks have evolved during the estimation period, Figure 7 plots estimates of the shocks using the Kalman smoothing algorithms from the state-space representation of the estimated models. The estimated shocks are similar across the model with financial frictions only (dashed line) and the model that also includes labor market frictions (solid line). In addition, we find that the magnitude of shocks has somewhat decreased in the period from the mid-1980s until the late 2000s and that the volatility of monetary policy shocks declined during the same period. These findings corroborate the empirical results in Sims and Zha (2006), Gambetti, Pappa and Canova (2008) and Benati and Mumtaz (2007), which detected a period of macroeconomic stability generated by a lower volatility of shocks in the US from the mid-1980s until 2008.

To investigate how shocks contribute to observed movements in economic activity, Figures 8 reports the historical variance decomposition of each shock to output from 2000 on for the BGG model with labor market frictions (panel A) and the BGG model with financial frictions (panel B). In general, across the two models, four facts stand out. First, technology shocks contribute negatively to output in the late 1990s, but their contribution turns positive after the 2001 recession, as in Smets and Wouters (2007). In the mid-2000s, their contribution turns negative to then return positive over the end of the sample period, as in Gali, Smets and Wouters (2012). Second, demand shocks (labor supply shocks) contribute positively to output before 2001, but their contribution turns negative in the mid-2000s, similar to Smets and Wouters (2007), to then return positive from mid-2005 on, as in Gali, Smets and Wouters (2012). Third, shocks to the entrepreneurial wealth contribute negatively to output since 2007 onwards, while their contribution is limited in earlier years. This echoes the findings in Christiano, Trabandt and Walentin (2011), who also establish a similar contribution of entrepreneurial wealth shocks in a model estimated on Swedish data. Fourth, the contribution of MEI shocks is limited over the sample period. This results is in line with Christiano, Trabandt and Walentin (2011). Finally, a comparison between panel A and B shows that although estimated contributions of the shocks to historical movements in output are similar across the two models, preference shocks have a more sizeable contribution in the model that includes both labor and financial frictions. As discussed in Smets and Wouters (2007), preference shocks can be interpreted as risk premium shocks because they introduce a wedge between the riskless rate on bonds and the return on assets held by the household. Equation (23), once equation (5) is substituted in, links the risk premium shocks with the return on

assets. It shows that asset return depends on the marginal product of capital, expected asset return and risk premium. In the presence of labor market frictions, employment adjusts slowly to shocks, and the marginal product of capital is less sensitive to fluctuations due to the complementarity between inputs of production in Cobb-Douglas technology. Hence, shocks to the risk premium move sharply in reaction to changes in the return on assets, and they have a greater contribution to movements in output.

5 Conclusion

This paper has investigated the interactions between labor and financial frictions by using a dynamic, stochastic, general equilibrium model. Our modelling strategy involved setting up a standard New Keynesian model with financial frictions, as in BGG, enriched with labor market frictions, as in Blanchard and Galí (2010). To establish the importance of labor market frictions and their interaction with financial frictions, we estimated two versions of the model using macroeconomic time-series data for the US from the 1970s on: first, a version characterized by financial frictions only, as in BGG and, second, a version that also allows for labor market frictions. The econometric estimation establishes that the data strongly prefer the model with both labor and financial frictions. Labor market frictions generate two effects on aggregate fluctuations. On the one hand, they dampen aggregate fluctuations due to the lower external finance premium induced by the reduction in the real cost of repaying existing debt. On the other hand, they amplify the effect of financial frictions since robust changes in hiring lead to large movements in employment, the return on capital and consequently, in investment that reinforce the original effect of financial frictions. The overall effect depends on the nature of the shock. The econometric estimation establishes that for monetary policy, technology and entrepreneurial wealth shocks, labor market frictions amplify the effect of financial frictions whereas for cost-push, labor supply, MEI and preference shocks dampen aggregate fluctuations.

The analysis of this paper is conducted using labor market frictions based on the labor market search paradigm and financial market frictions based on asymmetric information in credit markets, which is only one possible way of analyzing the links between labor and financial frictions. It would be interesting to establish whether the same results carry over to other environments such as models with an articulated banking sector (Christiano, Motto and Rostagno (2010) and Dib (2010)), models with a well-defined housing sector (Iacoviello

(2005) and Rubio (2011)), and models with endogenous job destruction (Den Haan, Ramey and Watson (2000) and Zanetti (2011)). To establish to what extent the results hold for refinements of the theoretical framework remains an outstanding task for future research.

6 References

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Table 1. Summary Statistics for the Prior Distribution of the Parameters

Parameters		Prior distribution			
		Density	Mean	Standard Deviation	90% Interval
δ_n	Job destruction rate	Beta	0.03	0.01	[0.008,0.052]
η	Wage bargaining power	Beta	0.5	0.15	[0.198,0.802]
ϕ	Inverse of the Frisch elasticity	Gamma	1	0.05	[1.420,1.582]
ρ_b	Replacement ratio	Beta	0.35	0.01	[0.191,0.523]
ψ	Elasticity of the finance premium	Beta	0.04	0.01	[0.025,0.058]
φ	Calvo price parameter	Beta	0.4	0.15	[0.098,0.702]
ρ_π	Taylor rule response to inflation	Gamma	1.5	0.2	[1.078,1.922]
ρ_y	Taylor rule response to output	Gamma	0.25	0.12	[0.008,0.492]
Autoregressive parameters					
ρ_a	Technology	Beta	0.6	0.2	[0.201,0.999]
ρ_θ	Cost-push	Beta	0.6	0.2	[0.201,0.999]
ρ_e	Preferences	Beta	0.6	0.2	[0.201,0.999]
ρ_χ	Labor supply	Beta	0.6	0.2	[0.201,0.999]
ρ_z	MEI	Beta	0.6	0.2	[0.201,0.999]
ρ_γ	Entrepreneurial wealth	Beta	0.6	0.2	[0.201,0.999]
Standard deviations		Degree of freedom			
σ_a	Technology	Inverse Gamma	0.1	10	
σ_θ	Cost-push	Inverse Gamma	0.1	10	
σ_e	Preferences	Inverse Gamma	0.1	10	
σ_χ	Labor supply	Inverse Gamma	0.1	10	
σ_v	Monetary policy	Inverse Gamma	0.1	10	
σ_z	MEI	Inverse Gamma	0.1	10	
σ_γ	Entrepreneurial wealth	Inverse Gamma	0.1	10	

Table 2. Summary Statistics for the Posterior Distribution of the Parameters

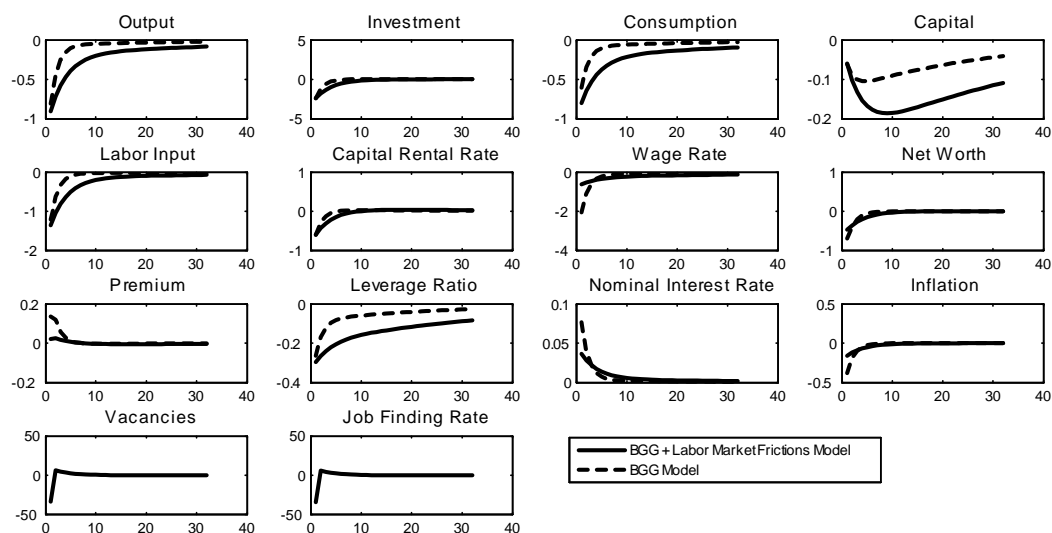
Parameters		BGG			BGG+Labor market frictions		
(1)		(2)			(3)		
		Mean	5%	95%	Mean	5%	95%
δ_n	Job destruction rate	-	-	-	0.05	0.034	0.062
η	Wage bargaining power	-	-	-	0.811	0.795	0.886
ϕ	Inverse of the Frisch elasticity	1.251	1.023	1.343	1.451	1.258	1.642
ρ_b	Replacement ratio	0.367	0.343	0.421	0.385	0.311	0.454
ψ	Elasticity of the finance premium	0.039	0.025	0.043	0.041	0.038	0.049
φ	Calvo price parameter	0.738	0.698	0.792	0.612	0.593	0.692
ρ_π	Taylor rule response to inflation	1.664	1.567	1.975	1.812	1.662	1.992
ρ_y	Taylor rule response to output	0.957	0.826	1.354	1.327	0.932	1.442
Autoregressive parameters							
ρ_a	Technology	0.962	0.956	0.981	0.983	0.965	0.992
ρ_θ	Cost-push	0.736	0.671	0.818	0.851	0.797	0.932
ρ_e	Preferences	0.889	0.829	0.935	0.913	0.891	0.943
ρ_χ	Labor supply	0.951	0.915	0.978	0.973	0.901	0.989
ρ_z	MEI	0.949	0.911	0.965	0.931	0.921	0.957
ρ_γ	Entrepreneurial wealth	0.952	0.948	0.967	0.925	0.916	0.952
Standard deviations							
σ_a	Technology	0.034	0.021	0.037	0.035	0.022	0.037
σ_θ	Cost-push	0.055	0.041	0.063	0.052	0.045	0.055
σ_e	Preferences	0.028	0.019	0.034	0.031	0.021	0.036
σ_χ	Labor supply	0.029	0.021	0.033	0.053	0.045	0.054
σ_v	Monetary policy	0.022	0.019	0.029	0.025	0.021	0.037
σ_z	MEI	0.027	0.019	0.032	0.023	0.018	0.033
σ_γ	Entrepreneurial wealth	0.042	0.039	0.043	0.048	0.036	0.052
Marginal log-likelihood		2050.8			2143.7		

Table 3. Asymptotic Forecast Error Variance Decomposition

	Output	Consumption	Investment	Inflation	Interest Rate
One Quarter					
σ_a	58.4 - 46.4	53.3 - 48.1	1.1 - 1.0	60.1 - 53.8	26.1 - 15.4
σ_v	34.1 - 40.2	4.4 - 18.5	1.0 - 5.9	28.2 - 32.4	32.5 - 12.4
σ_θ	2.7 - 5.5	0.2 - 1.5	0.6 - 1.6	1.2 - 4.7	5.9 - 2.5
σ_e	1.6 - 0.2	0.1 - 2.1	2.5 - 2.1	3.7 - 4.0	13.0 - 55.3
σ_χ	1.2 - 3.1	0.8 - 6.4	0.9 - 9.5	0.9 - 0.3	1.1 - 5.8
σ_z	0.1 - 0.1	0.1 - 0.1	0.2 - 0.4	0.0 - 0.1	0.0 - 0.1
σ_γ	1.9 - 4.4	41.1 - 23.2	93.7 - 79.6	5.9 - 4.8	21.4 - 8.4
One Year					
σ_a	70.3 - 74.3	54.9 - 55.9	1.1 - 24.7	55.7 - 48.8	19.6 - 8.5
σ_v	13.5 - 10.7	5.2 - 11.5	2.7 - 2.3	24.6 - 28.4	16.5 - 6.2
σ_θ	5.4 - 3.8	1.8 - 2.2	1.9 - 1.7	1.4 - 4.2	6.3 - 1.5
σ_e	4.7 - 0.1	1.1 - 1.0	4.4 - 3.8	8.4 - 4.5	24.0 - 59.2
σ_χ	0.9 - 2.9	2.5 - 7.8	0.5 - 0.9	1.5 - 7.7	1.4 - 9.1
σ_z	0.1 - 0.1	0.0 - 0.1	0.1 - 0.1	0.0 - 0.0	0.0 - 0.0
σ_γ	5.3 - 8.1	34.5 - 21.5	89.3 - 66.6	8.4 - 6.4	32.3 - 15.4
Five Years					
σ_a	77.8 - 80.2	74.0 - 72.0	13.0 - 21.7	52.4 - 42.9	12.1 - 6.5
σ_v	2.1 - 4.1	1.5 - 7.3	1.1 - 2.1	22.8 - 23.2	7.8 - 2.9
σ_θ	3.4 - 1.2	2.6 - 0.8	2.1 - 1.3	1.4 - 3.9	3.3 - 1.1
σ_e	8.2 - 0.1	5.9 - 0.6	6.5 - 3.6	13.2 - 7.5	32.8 - 62.3
σ_χ	0.7 - 8.6	4.2 - 6.9	1.3 - 9.6	1.5 - 15.0	0.8 - 5.7
σ_z	0.1 - 0.0	0.0 - 0.0	0.1 - 0.1	0.0 - 0.0	0.0 - 0.0
σ_γ	7.8 - 5.8	11.7 - 12.5	75.9 - 61.7	8.7 - 7.4	43.2 - 21.4

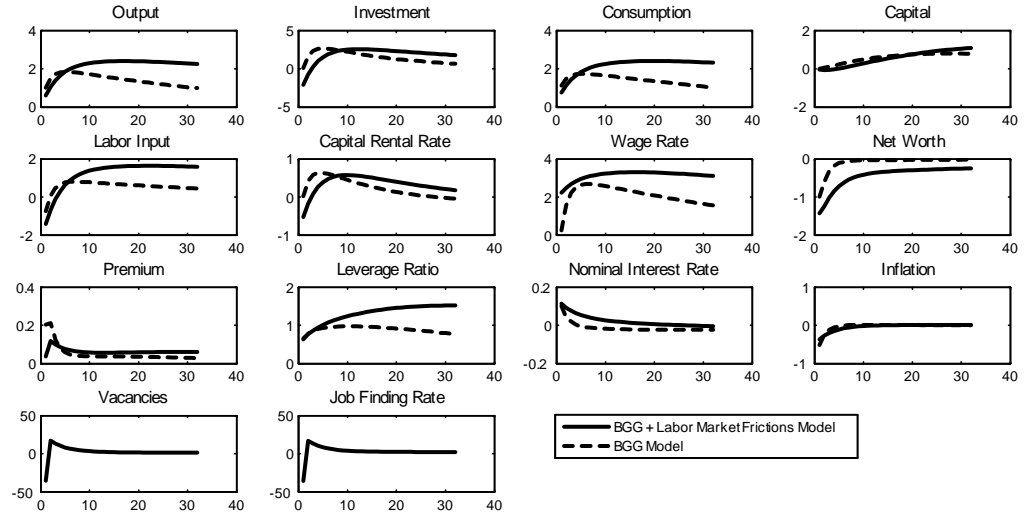
Notes: Each cell reports the forecast variance decomposition from the BGG model with labor market frictions (left entry) against the same statistics from the BGG model with financial frictions only (right entry).

Figure 1. Impulse Responses to One-standard-deviation Monetary Policy Shock



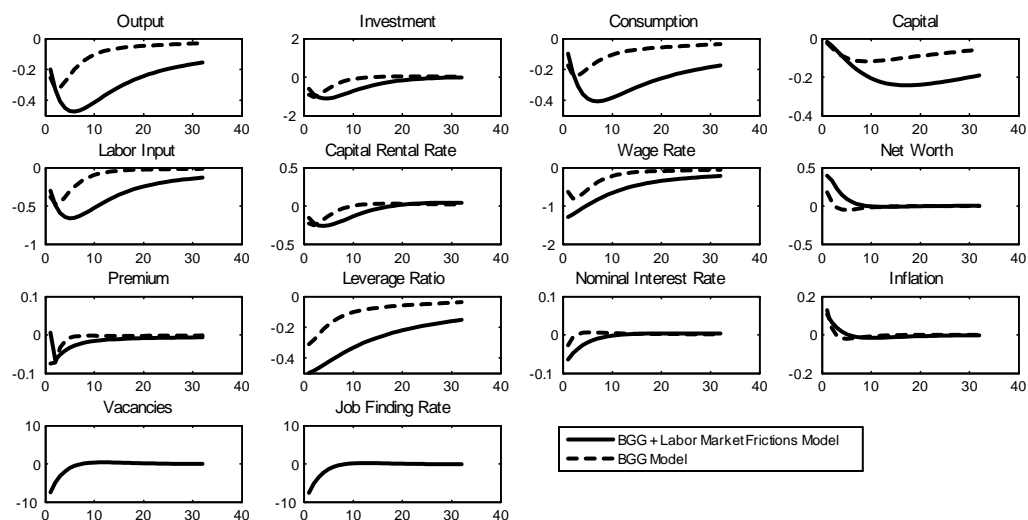
Notes: Each entry shows the percentage point response of one of the model's variables to a one-standard-deviation monetary policy shock. The dashed line reports the response of the BGG model with financial frictions, and the solid line reports the response of the model that also includes labor market frictions.

Figure 2. Impulse Responses to One-standard-deviation Technology Shock



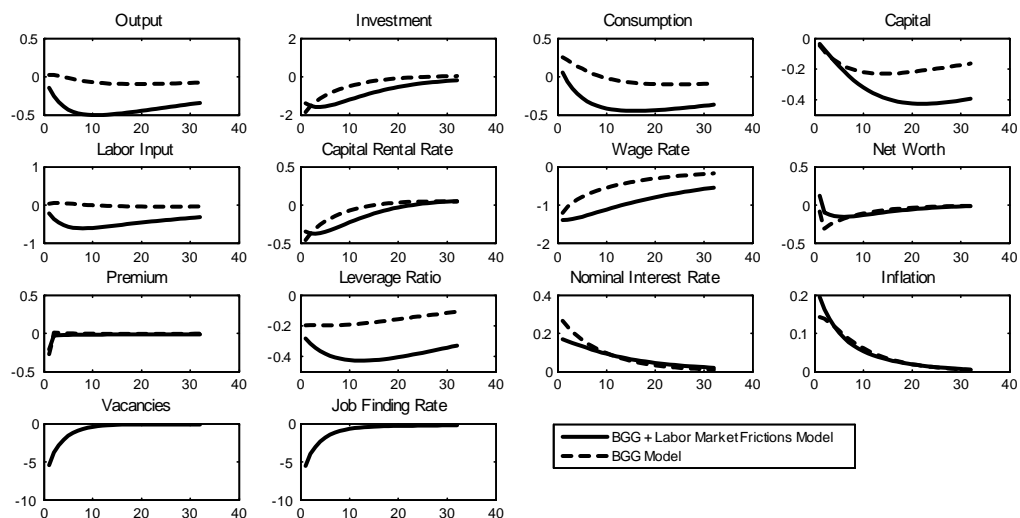
Notes: Each entry shows the percentage point response of one of the model's variables to a one-standard-deviation neutral technology shock. The dashed line reports the response of the BGG model with financial frictions, and the solid line reports the response of the model that also includes labor market frictions.

Figure 3. Impulse Responses to One-standard-deviation Cost-push Shock



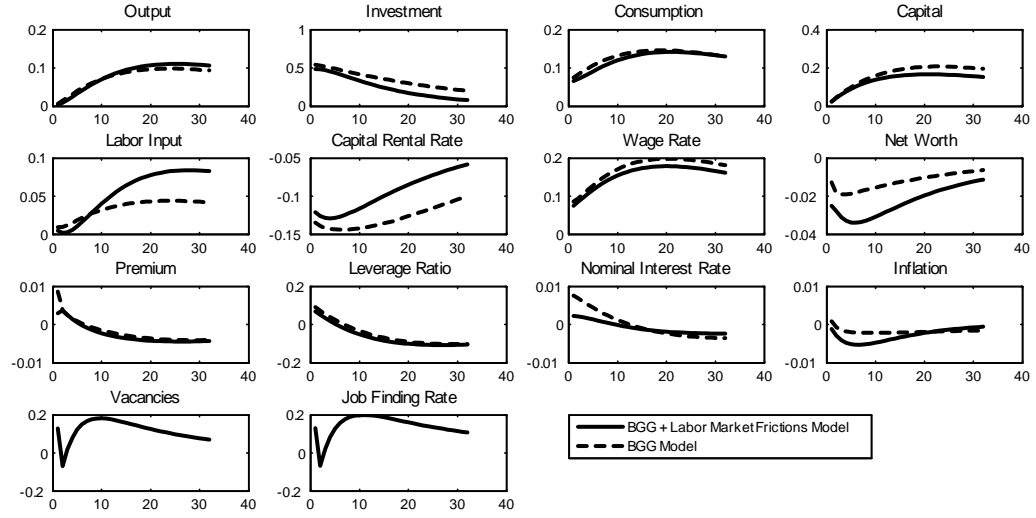
Notes: Each entry shows the percentage point response of one of the model's variables to a one-standard-deviation cost-push shock. The dashed line reports the response of the BGG model with financial frictions, and the solid line reports the response of the model that also includes labor market frictions.

Figure 4. Impulse Responses to One-standard-deviation Preference Shock



Notes: Each entry shows the percentage point response of one of the model's variables to a one-standard-deviation preference shock. The dashed line reports the response of the BGG model with financial frictions, and the solid line reports the response of the model that also includes labor market frictions.

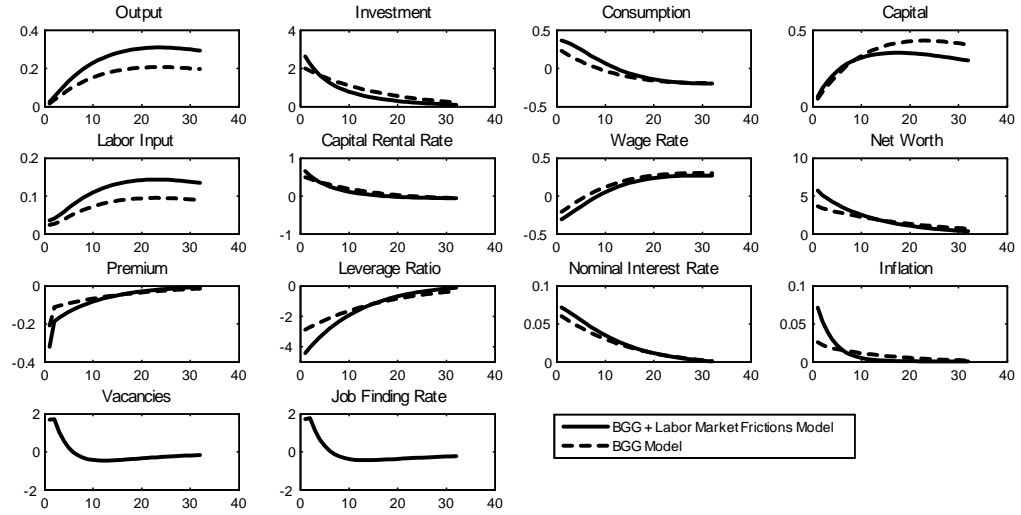
Figure 5. Impulse Responses to One-standard-deviation MEI Shock



Notes: Each entry shows the percentage point response of one of the model's variables to a one-standard-deviation MEI shock. The dashed line reports the response of the BGG model with financial frictions, and the solid line reports the response of the model that also includes labor market frictions.

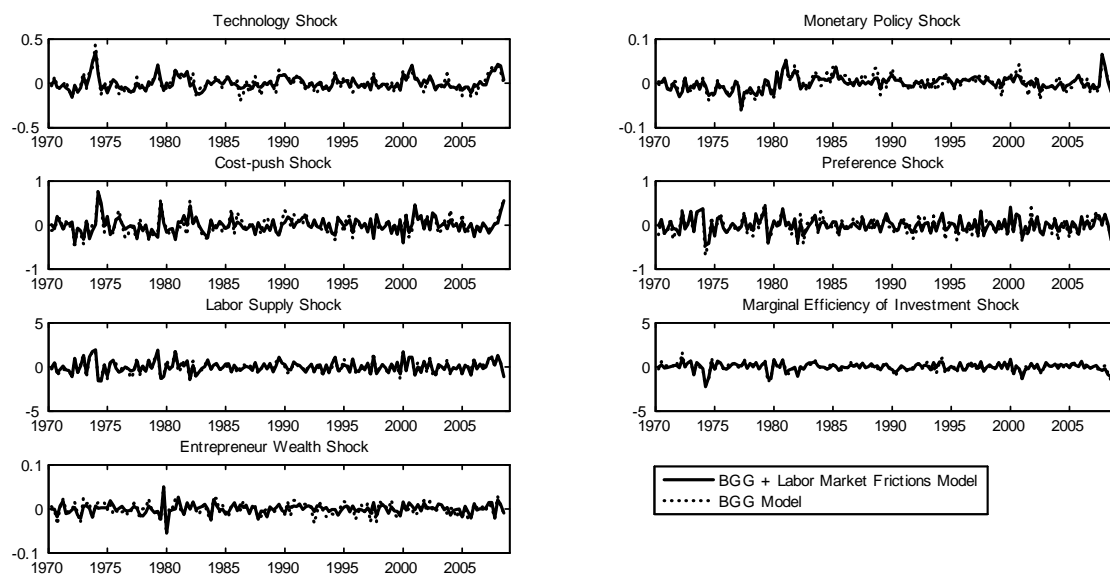
Figure 6. Impulse Responses to One-standard-deviation Entrepreneur Wealth

Shock



Notes: Each entry shows the percentage point response of one of the model's variables to a one-standard-deviation entrepreneur wealth shock. The dashed line reports the response of the BGG model with financial frictions, and the solid line reports the response of the model that also includes labor market frictions.

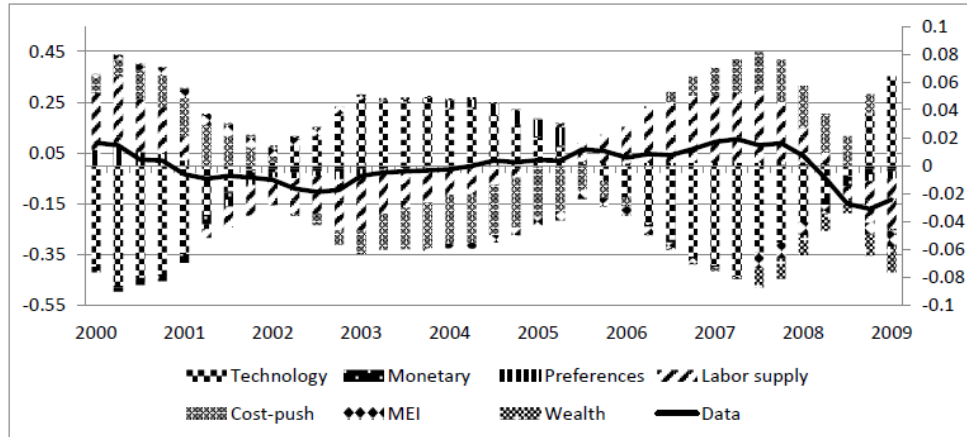
Figure 7. Smoothed Estimates of the Shocks



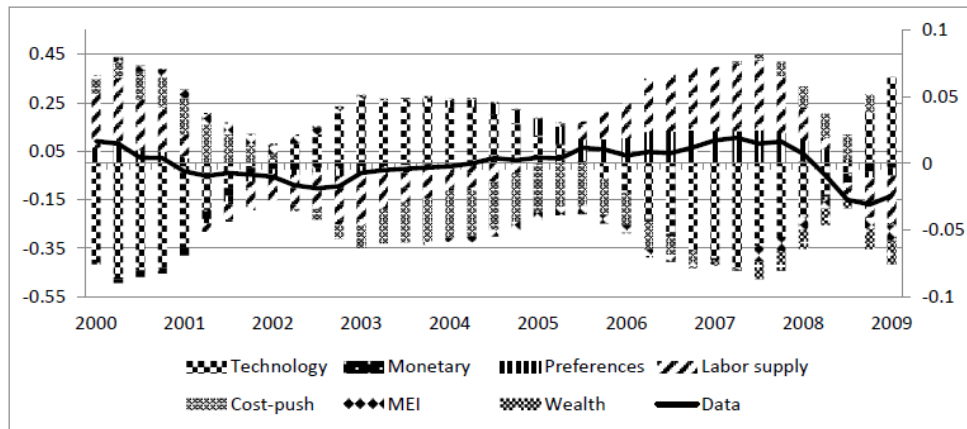
Notes: Each entry shows the shock estimate using the Kalman smoothing algorithms from the state-space model with financial frictions only (dashed line) and the model that also includes labor market frictions (solid line).

Figure 8. Historical Variance Decomposition of Output

A: BGG Model



B: BGG + Labor Market Frictions Model



Notes: Panel A (Panel B) shows the historical variance decomposition of output in the BGG (BGG + labor market frictions) model. The solid line reports output in the data.