Hiring and Investment Frictions as Inflation Determinants

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Abstract

We embed convex hiring and investment frictions in a New Keynesian DSGE model with intrafirm wage bargaining. We show that these frictions have crucial implications for the response of marginal costs, and consequently inflation, and for the co-movement of inflation with real variables. We elucidate how the presence of hiring and investment frictions affects the transmission mechanism of monetary and technological shocks by means of impulse responses. We find that hiring frictions are a key determinant of current period marginal costs; investment frictions also matter, by affecting expectations of future marginal costs.

Estimating the model with private-sector US data shows that both hiring frictions and investment frictions help explain inflation dynamics. Smoothed estimates of marginal costs are radically different in models with and without hiring frictions. Our results indicate that hiring frictions explain around 50% of the variation in marginal costs, the real wage component explains around 35% while the remain 15% is accounted for by an intrafirm bargaining component. These estimates rely only on moderate levels of the relevant frictions.

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1 Introduction

New Keynesian models posit that inflation dynamics are driven by current and expected future real marginal costs. Because real marginal costs are proportional to the labor share of income, the labor market is implicitly given a key role in driving inflation. However, the characterization of the labor market in the standard model abstracts from frictions. Krause, Lopez-Salido and Lubik (2008), have shown that the explicit modelling of labor market frictions along the lines of Diamond Mortensen and Pissarides adds a new term in the expression for real marginal costs, and thereby potentially generates an independent role for frictions to affect inflation. However, these authors find that this additional component is unlikely to quantitatively affect the transmission of shocks to inflation dynamics. Gali (2010) finds similar results, and concludes that such frictions are too small to affect the behavior of marginal costs as well as the co-movement of inflation with other variables. His argument is simple: because hiring costs only account for about 1% of GDP, while the labor share is around 66% of GDP, frictions cannot matter, 'at least in the absence of implausibly large fluctuations in net hiring costs relative to wages'. So the bottom line is that modelling labor market frictions explicitly, complicates the model without affecting inflation dynamics. In this paper we revisit this issue in a new way.

We embed convex hiring and investment frictions as in Merz and Yashiv (2007) and Yashiv (2014) into a very simple New Keynesian DSGE model with intrafirm wage bargaining. We undertake two explorations. First, in the spirit of Gali (2010) we look at how frictions affect the impulse responses of marginal costs and inflation, or the co-movement with other real variables. Our reference framework is Gali (2010), from which we depart by explicitly modelling capital. This allows us to extend the analysis beyond hiring frictions: our frictions costs function allows for hiring and investment frictions to be shut down one at a time, so as to disentangle their separate role and their general equilibrium interaction in the propagation of shocks.

We show that introducing hiring frictions into a frictionless New-Keynesian model smooths the response of real wages and thereby reduces the elasticity of the 'labor share' to the underlying shocks. This endogenous rigidity in the response of real wages operates through the response of the marginal rate of substitution and the marginal revenue product of labor. However, wage stickiness magnifies the response in the discounted value of jobs, boosting the response of the frictional component of marginal costs. These two effects counteract each other; whether the net effect is null, positive or negative, will depend on the particular calibration and on the shock. However, even in cases where the response of marginal costs is independent of the presence of hiring frictions, this is not because hiring frictions are to small too matter and the real wage response is virtually identical in the two models. In our calibration, the wage component and the frictional component of marginal costs are about equally important in driving marginal costs.

Hiring frictions produce a dramatic effect on the co-movement between inflation and real variables. As a result, models with and without hiring frictions imply radically different views on the propagation of shocks. As explained in Faccini and Yashiv (2015), hiring frictions offset the mechanism at work in New Keynesian (NK) models in a non-trivial way. When hiring frictions are calibrated to tiny values that are meant to capture only vacancy posting costs, as in Gali (2010), the responses of real variables *are close to* the ones generated in the frictionless NK benchmark. But these results are very sensitive to the precise parameterization. When hiring frictions are calibrated to reflect conservative estimates of training costs, monetary policy loses effectiveness to stimulate output, and the response of employment to technology shocks turns positive.

The conventional assumption that new capital operates in production only with a one quarter lag implies that investment frictions do not affect current period marginal costs, but the expectations of next period marginal costs. These frictions also smooth the response of employment, generating endogenous rigidity in the wage component of marginal costs. In the absence of hiring frictions, current period marginal costs are *essentially* driven by the wage component of marginal costs, so the rigidity in wages directly translates into a dampened response of marginal costs and inflation. Investment frictions also affect the conditional co-movement between inflation and real variables, but their impact is less dramatic when compared to hiring frictions. So the bottom line of our impulse response analysis is that labor frictions have first order implications for the co-movement of inflation with real variables, while capital frictions mostly affect the response of inflation to shocks.

In a second exploration, we take the DSGE model to the data and carry out structural estimation of various specifications of the model, where we restrict the frictions costs function so as to shut down different frictions one at a time. Looking at the marginal data density for the whole model and the conditional marginal data density for the inflation series, we find that adding labor frictions to the New Keynesian benchmark greatly helps explain inflation dynamics, as well as the joint behavior of our full set of observables. Adding investment frictions separately also helps fit both inflation and the full set of observables, but less than hiring frictions. Adding both frictions simultaneously increases statistical fit even further.

Our preferred version of the NK model, which includes both hiring and investment frictions, produces a smoothed series of marginal costs that is considerably different from the one generated by the frictionless benchmark model. In particular, from the 2000s onwards, marginal costs are estimated to push up on inflation, as opposed to the results obtained in the frictionless benchmark. The difference between the two series is largely driven by the behavior of the frictional component of marginal costs, which is estimated to be quantitatively more important than the wage share of income in driving the fluctuations of current marginal costs.

Our study shows that large fluctuations in net marginal hiring costs are not implausible, rather, they are validated by our estimation. As we point out in the paper, the frictional component of marginal costs can also be interpreted as the ratio of the marginal profit of a new hire over the marginal product of labor. A large strand of research, which has extensively investigated the determinants of unemployment fluctuations within search and matching models of the labor market, has produced many different mechanisms of amplification to productivity shocks, but most of them rely on the ability to generate large fluctuations in marginal hiring profits to an underlying productivity shock. So the role of marginal hiring profits has been found to be central in almost any theory that can successfully account for unemployment fluctuations at business cycle frequencies. By incorporating labor frictions into a New-Keynesian model, we are able to extend the importance of fluctuations in marginal hiring profits to inflation dynamics.

Section 2 presents a short review of the relevant literature. Section 3 presents the model. Section 4 inspects the mechanism by which frictions affect marginal costs and the co-movement of inflation with real variables, making use of calibration and impulse responses. Section 5 introduces estimation of the full DSGE model, including discussion of the data, and the methodology. The results are presented and discussed in Sections 6. The full derivation of the model is relegated to the Appendix.

2 Literature

This paper relates to three strands of literature:

(i) *New Keynesian DSGE models* – see Woodford (2003), Gali (2008) and Christiano et al (2010) for surveys and discussions – which offer a model of inflation as a function of current and future expected marginal costs.

(ii) *Search and matching models of the labor market,* which feature dynamic, optimal hiring decisions by firms in the face of frictions; see Pissarides (2000), Yashiv (2007) and Rogerson and Shimer (2011) for overviews and surveys. Hiring costs and time lags are the expression of frictions in these models.

Within this literature, there is a strand that investigates the role of intrafirm wage bargaining in macroeconomic models of the labor market. In an application of the bargaining model proposed by Stole and Zwiebel (1996) to search and matching models, Cahuc and Wasmer (2001) have shown that when firms are 'large', in the sense that they employ a positive measure of workers, and wages are negotiated through Nash bargaining, the firm should anticipate the impact of its hiring policy on the negotiated wage. This modification of the standard bargaining problem is known as intrafirm bargaining. Cahuc, Marque and Wasmer (2008) have further shown that accounting for intrafirm bargaining can have important implications for the equilibrium in the labor market.

(iii) *Models of frictions in investment*, following the seminal contributions of Lucas and Prescott (1971) and of Tobin (1969) and Hayashi (1982). The idea in these models is that costs are key to the understanding of investment behavior.

We note two important extensions in the current context:

First, In recent years, various studies have embedded frictional models of the labor market into the standard New-Keynesian framework to shed light on the channels by which the modelling of unemployment could affect inflation dynamics. Early work by Walsh (2005) and Trigari (2009) sparked some enthusiasm about the possibility that explicitly modelling search frictions could help understand inflation dynamics. Both studies found that accounting for unemployment increases inflation persistence. However, the robustness of these results have been questioned by Gali (2010), while Heer and Maußner (2010), have found that they *fade out* when capital is introduced in the model. As shown in Krause, Lopez-Salido and Lubik (2008), the explicit modelling of labor market frictions adds a new term in the expression for real marginal costs, which can potentially affect inflation. However, these authors find that this additional component is unlikely to quantitatively affect the transmission of shocks to inflation dynamics. Gali (2010) finds similar results, and concludes that such frictions are too small to affect the behavior of marginal costs.

Second, a body of evidence, reviewed by Yashiv (2014), has documented the existence of frictions both in the capital and in the labor market. Work by Merz and Yashiv (2007) and Yashiv (2014) has shown the importance of accounting for their interactions in explaining the joint behavior of hiring and investment as well as the behavior of stock prices. Mumtaz and Zanetti (2015), provide additional evidence in this direction by means of Bayesian estimation of a DSGE model. While Mumtaz and Zanetti (2015) are interested in the estimation of the convexities in factor adjustment costs and their ability to fit asset prices, our interest is understanding the role of hiring and investment frictions for inflation dynamics.

3 The Model

3.1 The Set-Up

We introduce *convex* hiring and investment frictions *in the spirit of Lucas and Prescott (1971), and following the specification in Merz and Yashiv (2007),* into a benchmark New-Keynesian model. The model is an extension of Faccini and Yashiv (2015), to which we refer for a detailed exposition of the mechanism at work.

3.2 Households

The representative household, indexed by the subscript j, comprises a unit measure of workers searching for jobs in a frictional labor market. The mass of workers who are unemployed at the beginning of the period is denoted by $U^0_{j,t}$, and each unemployed worker finds a job by the end of the period with probability x_t. The law of large numbers implies that the measure of new hires in each period t is given by $x_t U^0_{j,t}$. Assuming that at the end of each period workers lose their job with probability δ_N, the stock of employed workers $N_{j,t}$ obeys the law of motion:

$$N_{jt} = (1 - \delta_N) N_{j,t-1} + x_t U^0_{j,t}. \tag{1}$$

The household enjoys utility from the aggregate consumption index $C_{j,t}$ and disutility from the measure of workers in employment, $N_{j,t}$. The discount factor of the household is denoted by β. Each period, the household receives a nominal wage income $W_{j,t}$ from employed workers, dividends from ownership of firms $\Upsilon_{j,t}$ and pays lump sum government taxes $T_{j,t}$. Wealth takes the form of nominal government bonds $B_{j,t}$, and can be transferred into the future at the present discounted value $B_{j,t+1}/R_t$, where R_t is the gross nominal interest rate.

The intertemporal problem of the households is to maximize the discounted present value of current and future utility:

$$\max_{\{C_{t+s}\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \beta^s \left[\eta_{t+s}^p \ln \left(C_{j,t+s} - \vartheta C_{t+s-1} \right) - \frac{\eta_{t+s}^l \chi}{1+\varphi} N_{j,t+s}^{1+\varphi} \right],$$

subject to the budget constraint

$$P_t C_{j,t} + \frac{B_{j,t+1}}{R_t} = W_{jt} N_{jt} + B_{jt} + \Upsilon_{jt} - T_{j,t}, \tag{2}$$

and the law of motion of employment (1).

The parameters φ denotes the inverse Frish elasticity of labor supply, χ is a scale factor on the disutility of work and ϑC_t is an index of external habits in consumption. The variables η^p and η^l denote preference and labor supply shocks, respectively.

Denoting by $\lambda_{j,t}$ the Lagrange multiplier associated with the budget constraint, the first order necessary conditions and co-states are:

$$\lambda_{j,t} = \frac{\eta_t^p}{P_t \left(C_{j,t} - \vartheta C_{t-1} \right)},$$

$$\frac{1}{R_t} = \beta E_t \frac{\lambda_{j,t+1}}{\lambda_{j,t}}, \tag{3}$$

$$V_{j,t}^N = \frac{W_{j,t}}{P_t} - \frac{\eta_t^l \chi N_{j,t}^{\varphi}}{\lambda_{j,t} P_t} - \frac{x_t}{1-x_t} V_{j,t}^N + E_t \Lambda_{t,t+1} \left(1 - \delta_N \right) V_{j,t+1}^N, \tag{4}$$

where $\Lambda_{t,t+1} = \beta \frac{\lambda_{j,t+1}}{\lambda_{j,t}} \frac{P_t}{P_{t+1}} = \frac{1}{R_t/\pi_{t+1}}$ denotes the real discount factor and $\pi_{t+1} = P_{t+1}/P_t$.

The value of a job for the household expressed in units of the numeraire good equals the real wage net of the opportunity cost of work $\frac{\eta_t^l \chi N_{j,t}^{\varphi}}{\lambda_{j,t} P_t}$, and a re-employment value $\frac{x_t}{1-x_t} V_{j,t}^N$, plus the continuation value. In a model with no frictions, where employment generates no rents and thus $V_{j,t}^N = 0$, the marginal rate of substitution equals the real wage: $\frac{W_t}{P_t} = \eta_t^l \chi N_{j,t}^{\varphi} / \lambda_{j,t} P_t$, which governs labor supply.

3.3 Firms

We assume three types of firms: intermediate good producers, final good producers and retailers. Intermediate producers hire labor and invest in capital to produce a homogeneous product, which is then sold to final producers in perfect competition. Final producers transform each unit of the homogeneous product into a unit of a differentiated product facing price rigidities a la Rotemberg

(1982). We also assume that retailers buy a bundle of differentiated goods from the final producers and transform it into homogeneous consumption and investment goods. In turn, these goods are sold in perfect competition to the households, the government and the intermediate firms.

Firms: Retailers

We assume that identical and competitive retailers produce a homogeneous good Y_t, using the technology:

$$Y_t = \left(\int_0^1 Y_t(i)^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)}. \tag{5}$$

Retailers choose the specialized inputs $Y_t(i)$ so as to maximize profits:

$$P_t Y_t - \int_0^1 Y_t(i) di,$$

subject to the technology in (5). The outcome of the maximization problem is a demand function for each specialized product:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} Y_t. \tag{6}$$

The retailers transform the output good Y_t into a consumption good or an investment good. It is assumed that one unit of the output good can be turned into one unit of the consumption good, and one unit of the output good can be transformed into $1/\eta_t^q$ units of the investment good. η_t^q is the relative price of the investment good, which is assumed to follow an exogenous AR(1) stochastic process.

Intermediate Goods Producers

A unit measure of intermediate firms combine capital and labor in order to produce a homogenous, intermediate output good, denoted by Z, which is sold to final producers in perfect competition. The constant returns to scale production function is $f(A_t, N_t, u_t, K_{t-1}) = a_t (A_t N_t)^{\alpha} (u_t K_{t-1})^{1-\alpha}$, where K_{t-1} denotes physical capital and u_t its utilization rate. We assume that $\eta_t^A = A_t / A_{t-1}$ is a labor-augmenting stochastic trend that follows the process

$$\ln \eta_t^A = \left(1 - \rho^A\right) \ln \eta^A + \rho^A \ln \eta_{t-1}^A + \varsigma_{t-1}^A, \tag{7}$$

where η^A denotes a steady-state value that equals the economy's growth rate μ. We further assume that a_t denotes a transitory shock to the level of technology:

$$\ln a_t = \rho^a \ln a_{t-1} + \varsigma_t^a.$$

We assume a frictions costs function g, capturing the disruption in economic activity that is associated with hiring and investment. As discussed in details in Faccini and Yashiv (2015), this function is meant to capture all the frictions involved in getting newly employed workers to work and capital to operate in production, including worker training costs, organizational costs, implementation costs, financial premia on certain projects, capital installation costs, learning the use of new equipment, etc. So our notion of frictions extends beyond, say, just capital adjustment costs or vacancy costs. Following Merz and Yashiv (2007) and Yashiv (2014) we assume that the frictions costs function is constant returns to scale and is increasing in each of the firm's decision variables. In particular, we assume the following explicit functional form:

$$g(a_t, A_t, I_t, K_{t-1}, H_t, N_t) = \left[\frac{e_1}{2}\left(\frac{I_t}{u_t K_{t-1}}\right)^2 + \frac{e_2}{2}\left(\frac{H_t}{N_t}\right)^2\right] a_t \left(A_t N_t\right)^{\alpha} \left(u_t K_{t-1}\right)^{1-\alpha}, \tag{8}$$

where the quadratic adjustment costs function is consistent with estimates in Yashiv (2014).[1]

The net output of a representative firm at time t is:

$$Z_t = f(a_t, A_t, N_t, u_t, K_{t-1}) - g(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t).$$

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

$$K_t = (1-\delta_K)K_{t-1} + I_t, \quad 0 \leq \delta_K \leq 1, \tag{9}$$

Together with the production function, this law of motion implies, following a convention in DSGE modelling, that newly installed capital only becomes effective with a one period (quarter) lag.

Similarly, the number of a firm's employees decreases at the rate δ_N and it is augmented by new hires H_t. The law of motion for employment reads:

$$N_t = (1-\delta_N)N_{t-1} + H_t, \quad 0 \leq \delta_N \leq 1, \tag{10}$$

which implies that new hires are immediately productive.

The intertemporal maximization problem of the firm is to maximize the present discounted value of cashflows:

$$\max E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ mc_{t+j} \left[f(a_{t+j}, A_{t+j}, N_{t+j}, u_{t+j}, K_{t+j-1}) - g(a_{t+j}, A_{t+j}, I_{t+j}, u_{t+j}, K_{t+j-1}, H_{t+j}, N_{t+j}) \right] \right.$$

$$\left. - \frac{W_{t+j}(I_{t+j}, u_{t+j}, K_{t+j-1}, H_{t+j}, N_{t+j})}{P_{t+j}} N_{t+j} - \eta^q_{t+j} \left[I_{t+j} + \nu\left(u_t\right) \right] \right\},$$

[1] A rationale for the use of such functional forms, emphasizing consistency of aggregate employment and capital dynamics with hiring and investment decisions at plant level is provided by King and Thomas (2006) and Kahn and Thomas (2008), respectively.

subject to the laws of motion for capital (9) and labor (10), where $\Lambda_{t,t+1} = \frac{\lambda_{j,t+1}}{\lambda_{j,t}} \frac{P_{t+1}}{P_t} = \frac{1}{R_t/\pi_{t+1}}$ is the real discount factor of the households who own the firms, $mc_t \equiv P_t^Z/P_t$ is the relative price of the intermediate firm's good and $\nu(u_t) = A_t \left[u_t^{1+\xi} - u^{1+\xi}\right]/(1+\xi)$ is a convex cost function for the utilization of capital. This functional form implies that steady-state utilization costs $\nu(u)$ are zero. Notice that when choosing factors of production and the utilization of capital, the firm correctly anticipates the impact of its decisions on the negotiated wage bill.

The first-order necessary conditions and co-states for dynamic optimality are:

$$mc_t \left(f_{u,t} - g_{u,t}\right) = \frac{W_{u,t}}{P_t} N_t + \eta_t^q \nu'(u_t) \tag{11}$$

$$Q_t^K = E_t \Lambda_{t,t+1} \left[\left(mc_{t+1}(f_{K,t+1} - g_{K,t+1}) - \frac{W_{K,t+1}}{P_{t+1}} N_{t+1} \right) + (1-\delta_K) Q_{t+1}^K \right], \tag{12}$$

$$Q_t^K = mc_t g_{I,t} + \frac{W_{I,t}}{P_t} N_t + \eta_t^q, \tag{13}$$

$$Q_t^N = mc_t \left(f_{N,t} - g_{N,t}\right) - \frac{W_t}{P_t} - \frac{W_{N,t}}{P_t} N_t + (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N, \tag{14}$$

$$Q_t^N = mc_t g_{H,t} + \frac{W_{H,t}}{P_t} N_t, \tag{15}$$

where Q_t^K and Q_t^N are the Lagrange multipliers associated with the capital and the employment laws of motion, respectively. One can label Q_t^K as Tobin's Q for capital or the value of capital and Q_t^N as Tobin's Q for labor or the value of labor. For an extensive discussion of their economic significance, see Yashiv (2014) and Faccini and Yashiv (2015).

In a New Keynesian model with no frictions and no bargaining, these four equations boil down to two standard first order conditions, which equate the real wage to the marginal revenue product of employment

$$W_t/P_t = mc_t f_{N,t},$$

and the opportunity cost of capital to the marginal revenue product of capital:

$$\eta_t^q = E_t \frac{1}{R_t/\pi_{t+1}} \left[mc_{t+1} f_{K,t+1} + (1-\delta_K) \eta_{t+1}^q \right].$$

Final good producers

There is a unit measure of monopolistically competitive final good firms indexed by $i \in [0,1]$. Each firm i transforms $Z(i)$ units of the intermediate good into $Y(i)$ units of a differentiated good, where $Z(i)$ denotes the amount of intermediate input used in the production of good i. Monopolistic competition implies that each final firm i faces the demand retailers' demand function (6).

We assume price stickiness *à la* Rotemberg (1982), meaning firms maximize current and expected discounted profits subject to quadratic price adjustment costs. We assume that adjustment costs depend on the ratio between the new reset price and the one set in the previous period, adjusted by a geometric average of steady state inflation and past inflation.

Final good firms maximize the following expression:

$$\max E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \frac{P_t}{P_{t+s}} \left[\left(P_{t+s}(i) - P_{t+s} mc_{t+s}\right) Y_{t+s}(i) - \frac{\zeta}{2} \left(\frac{P_{t+s}(i)}{\left(\pi_{t+s-1}\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi} P_{t+s-1}(i)} - 1 \right)^2 P_{t+s} Y_{t+s} \right],$$

subject to the demand function (6) from the retailers. The optimality condition is:

$$\begin{aligned} &\left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t - \epsilon \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon-1} \frac{P_{t+s}(i) - P_{t+s} mc_{t+s}}{P_t} Y_t \\ &- \zeta \left(\frac{P_t(i)}{\left(\pi_{t-1}\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi} P_{t-1}(i)} - 1 \right) \frac{P_t Y_t}{\left(\pi_{t-1}\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi} P_{t-1}(i)} \\ &+ E_t \Lambda_{t,t+1} \frac{P_t}{P_{t+1}} \left[-\zeta \left(\frac{P_{t+1}(i)}{\left(\pi_t\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi} P_t(i)} - 1 \right) P_{t+1} Y_{t+1} \frac{-\left(\pi_t\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi} P_{t+1}(i)}{\left[\left(\pi_t\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi} P_t(i)\right]^2} \right] = 0. \end{aligned}$$

Since all firms set the same price and therefore produce the same output in equilibrium, the above equation can be rearranged as follows:

$$\begin{aligned} \left(\frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi}} - 1 \right) \frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi}} &= \frac{1-\epsilon}{\zeta} + \frac{\epsilon}{\zeta} mc_t \\ + E_t \frac{1}{R_t / \pi_{t+1}} &\left[\left(\frac{\pi_{t+1}}{\left(\pi_t\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi}} - 1 \right) \frac{\pi_{t+1}}{\left(\pi_t\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi}} \frac{Y_{t+1}}{Y_t} \right]. \end{aligned} \tag{16}$$

This equation specifies that inflation depends on marginal costs as well as past and expected future inflation. Solving forward equation (16), it is possible to show that inflation depends on the expected marginal cost sequence.

In turn, an expression for current marginal costs can be obtained by rearranging the dynamic optimality condition for employment in (14):

$$mc_t = \frac{\frac{W_t}{P_t}}{f_{N,t} - g_{N,t}} + \frac{\frac{W_{N,t}}{P_t} N_t}{f_{N,t} - g_{N,t}} + \frac{Q_t^N - (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N}{f_{N,t} - g_{N,t}}, \tag{17}$$

while the dynamic optimality condition for capital (12) can be solved to obtain a cross-equation restriction for $E_t mc_{t+1}$:

$$E_t mc_{t+1} = E_t \frac{\frac{W_{K,t+1}}{P_{t+1}} N_{t+1}}{f_{K,t+1} - g_{K,t+1}} + E_t \frac{1}{\Lambda_{t,t+1}} \frac{Q_t^K - \Lambda_{t,t+1}(1-\delta_K) Q_{t+1}^K}{f_{K,t+1} - g_{K,t+1}}. \tag{18}$$

For a detailed discussion of the terms in the two equations above we refer to Faccini and Yashiv (2015).

Recent work by Gali (2010) has raised the question whether the frictional component of marginal costs, i.e., the last term in equation (17) matters for marginal costs and inflation. Before getting into the quantitative analysis, an intuitive way to approach this question is to notice that the term $Q_t^N - (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N$ in equation (14) equals the marginal flow profit of a match:

$$\Pi = mc_t \left(f_{N,t} - g_{N,t} \right) - \frac{W_t}{P_t} - \frac{W_{N,t}}{P_t} N_t,$$

so the frictional component of marginal costs in equation (17) equals the ratio of marginal hiring profits to the marginal product of labor. A large literature that started following the work by Shimer (2005), has developed a range of models to overcome the inability of the standard textbook search and matching model to match the volatility of unemployment at business cycle frequencies. While there is yet no consensus on what model is most appropriate to explain unemployment dynamics, frictional models of the labor market can account for the volatility of unemployment only if the volatility of marginal profits is sufficiently high, or otherwise incentives for job creation would not fluctuate enough over the cycle. A benchmark paper in this literature, Hagedorn and Manovskii (2008), generates cyclical fluctuations in the ratio of marginal hiring profits to the marginal product of labor, with a standard deviation that is over forty times as large as that of the labor share.[2] A rule of thumb calculation based on this result suggests that the importance of the frictional component in driving marginal costs should be around 60% that of the labor share. In this new light, we would find it surprising if hiring frictions didn't matter for inflation dynamics.[3]

3.4 Wage bargaining

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

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

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

[2] Authors' calculations based on Hagedorn and Manovskii's (2008) calibration, as illustrated in their Table 2, page 1701.

[3] Gali (2010) shows that a log linearization of the marginal costs yields: $\widehat{mc}_t = (1-\Phi)\, \hat{s}_t + \Phi \hat{f}_t$, where s_t denotes the labor share, f_t denotes the frictional component, a hat denotes percentage deviations from steady-state and $\Phi = \frac{f}{f+s} \simeq 0.015$ assuming that at the steady state s is about 66% of GDP and f is roughly 1% of GDP. However, if $\hat{f}_t \simeq 40 \hat{s}_t$, then the contributions of the frictional component relative to the labor share is approximately $40\Phi / (1-\Phi) \simeq 61\%$.

$$(1-\gamma)V_t^N = \gamma Q_t^N. \tag{19}$$

Substituting (30) and (14) into the above equation and using the sharing rule (19) to eliminate the terms in Q_{t+1}^N and V_{t+1}^N one gets the following expression for the real wage:

$$\frac{W_t}{P_t} = \gamma mc_t\left(f_{N,t} - g_{N,t}\right) - \gamma\frac{W_{N,t}}{P_t}N_t + (1-\gamma)\left[\frac{\eta_t^l \chi N_t^{\varphi}}{\lambda_t P_t} + \frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}Q_t^N\right]. \tag{20}$$

The analytic solution to this partial differential equation is provided in the Appendix.

3.5 Closing the model

We assume that the government runs a balanced budget:

$$P_t G_t - T_t = \frac{B_{t+1}}{R_t} - B_t, \tag{21}$$

where G_t denotes real government consumption expenditures, which are given by:

$$G_t = \left(1 - \frac{1}{\eta_t^G}\right)Y_t,$$

and η_t^G is a government shock that follows the stochastic process:

$$\ln \eta_t^G = \rho^G \ln \eta_{t-1}^G + \left(1-\rho^G\right)\ln \eta^G + \varsigma_t^G.$$

The monetary authority obeys a standard Taylor rule:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\rho_1^r}\left(\frac{R_{t-2}}{R^*}\right)^{\rho_2^r}\left[\left(\frac{\left(\prod_{j=-2}^{1} E_t\Pi_{t+j}\right)^{1/4}}{\Pi_t^*}\right)^{\phi_\pi}\left(\frac{\left(\prod_{j=-2}^{1} E_t\tilde{Y}_{t+j}\right)^{1/4}}{\bar{Y}}\right)^{r_y}\right]^{1-\rho_r^1-\rho_r^2}\varsigma_t^R, \tag{22}$$

where $\tilde{Y}_t \equiv Y_t/A_t$ and the bar sign over a variable denotes its steady-state value, the parameter r_s represents interest rate smoothing, and r_y and r_π govern the response of the monetary authority to deviations of output and inflation from their steady-state values. The term η_t^R captures a monetary policy shock. We assume that the monetary shock is Gaussian and iid whereas the process Π_t^* captures persistent deviations from the inflation target $\ln \Pi_*$. More specifically, we assume that

$$\ln \Pi_t^* = (1-\rho_\pi)\ln \Pi_* + \rho_\pi \ln \Pi_{t-1}^* + \varsigma_t^\pi$$

Finally, consolidating the households and the government budget constraint, and substituting for the profits of intermediate and final good producers yields the market clearing condition:

$$Y_t \left[\frac{1}{\eta_t^G} - \frac{\zeta}{2} \left(\frac{\pi_t}{(\pi_{t-1})^{\psi} (\bar{\pi})^{1-\psi}} - 1 \right)^2 \right] = C_t + \eta_t^q \left[I_{t+j} + \nu (u_t) \right] = f - g. \tag{23}$$

4 Frictions and Inflation Dynamics: an Impulse Response Analysis

This section explores the mechanisms by which frictions affect the response of marginal costs and the co-movement of inflation with real variables. We first calibrate the steady-state equilibrium of the model that allows for both hiring and investment costs. We will then inspect how frictions affect marginal costs and inflation by comparing the impulse responses generated by the unrestricted model and those obtained from three different versions of the model, where frictions are shut down one at a time. Specifically, the version of the model with hiring (investment) frictions only is obtained by restricting $e_1 \simeq 0$ ($e_2 \simeq 0$), while the standard New Keynesian model with no frictions corresponds to the case of $e_1 = e_2 = 0$. In what follows we look at the calibrated (or prior) equilibrium in order to compare models with the same parameter values except for the parameters of L and K frictions.

Remark 1 *In the last paragraph do you mean* $= 0$ *or* $\simeq 0$*? RF: I mean =0 only in the frictionless benchmark.*

4.1 Calibration

The model is calibrated to the US economy over the period 1984Q1-2014Q2. The discount factor β is consistent with a quarterly nominal interest rate of 1.34% as measured by the Federal Fund Rate, a quarterly inflation rate of 0.62%, and an economy's growth rate of 0.50%. Together, these numbers imply a value for $\beta = 0.9979$. The job separation rate δ_N is set 0.122 to reflect separations from employment into either unemployment or inactivity, while the capital depreciation rate δ_K is set to 0.02 consistent with evidence in Yashiv (2015). Notice that this value for the depreciation rate implies an investment to capital ratio of 2.5%, which is also consistent with the data.[4] The inverse Frisch elasticity on the extensive margin φ is set equal to 3, in line with the range of estimates by Domeji and Floden (2006) and in between the value of 5 used in Gali (2010) and the more standard value of 1 as in Christiano Eichenbaum and Trabant (2013) among many others. The elasticity of substitution in demand ϵ is set to the conventional value of 11, implying a steady-state markup of 10%, consistent with estimates presented in Burnside (1996) and Basu and Fernald (1997). The elasticity of output to the labor input α is set to 0.66, which implies a labor share of income around 2/3.[5] The habit parameter is set to 0.6 as in ???.

[4] See Appendix B in Yashiv (2015) for details on the construction of these time series.

[5] In this model the elasticity of output to the labor income does not correspond exactly to the labor share of income, but these two values are close at the calibrated stationary equilibrium.

Table 1

This leaves us with only five parameters to calibrate are: the bargaining power γ, the two scale parameters in the frictions costs functions, e_1 and e_2, the scale parameter χ in the utility function and the parameter, which governs the disutility of work, and the parameter ξ, which governs the curvature of the utilization cost function. These parameters are calibrated to match: i) marginal hiring costs, $g_H / [(f-g)/N]$, equal to 0.20 as estimated by Yashiv (2015), which corresponds to nearly four weeks of wages; ii) marginal investment costs equal to 5% of the investment price as estimated by Yashiv (2015); iii) an unemployment rate of 10%, which is consistent with our measure of the separation rate that includes separation from employment into both unemployment and inactivity and is in line with BLS estimates; iv) a replacement ratio of the opportunity cost of work over the marginal revenue product around 0.75, as advocated by Costain and Reiter (2015). We emphasize here that this implies a moderate calibration of the fundamental surplus fraction, so our results that frictions matter for inflation dynamics do not hinge on extremely low values of this notion of surplus; v) a value of the parameter $\xi = uv'^{/}(u)/v'(u) = 0.7$ as estimated by Gertler Sala and Trigari (2008).

Notice that our calibration allows labor frictions to account for a higher share of marginal costs than in the papers of Krause, Lopez-Salido and Lubik (2008) and Gali (2010). These studies assume that average and marginal hiring costs equal nearly 5% of quarterly wages, following empirical evidence by Silva and Toledo (2009) on vacancy posting costs. Our functional form for frictions costs allows for hiring costs to be interpreted in a wider sense, which also includes training as well as all other sources of forgone output associated with hiring and discussed in Section 3.3. As reported by Silva and Toledo (2009), average training costs are about 55% of quarterly wages, nearly two months of wages. In the calibration marginal hiring costs equal approximately 30% of quarterly wages, approximately one month of wages, while average hiring friction costs are about half as large, around two weeks of wages. We consider this value as conservative in the light of the evidence above. Faccini and Yashiv (2015) also show that the frictions costs function implies only a mild degree of convexity: because marginal hiring costs can be expressed as a function of the hiring rate and parameter values using the functional form in (8), it is possible to compute how the ratio of marginal hiring costs over steady state wages changes with hiring rates. For a value of the hiring rate equal to 0.161, which is the highest value measured in the data since they were first collected in 1976Q1, the fraction of marginal hiring friction costs over wages is only 37% of quarterly wages, implying an upper bound of marginal hiring costs that is well below the average training costs reported by Silva and Toledo (2009).

4.2 Impulse responses

In what follows we focus on TFP, investment and monetary shocks. This is sufficient to highlight the following common themes: 1) the interaction of both hiring/investment frictions and price frictions dampens the response of employment. In turn, this reduces the response of the marginal rate of substitution and real wages and implies a smoother response of the wage component of marginal costs. 2) *In models with labor frictions* the smoother response of wages affects the value of a job Q_t^N in such a way that the frictional component of marginal costs offsets the response of the wage component. Depending on the precise parameterization, this can result in a smaller, larger or perfect offset. *In the model with capital frictions instead, this offset does not take place, so for all shocks there is no counter-effect of Q_t^N and the change in mc_t is mitigated.*

Remark 2 *This last point is not clear. RF: Replace the emphasized text in the very last sentence above with the following sentence and footnote:* In the model with capital frictions only instead, Q_t^N is too small to matter, so this offset does not take place, and the change in mc_t is mitigated.[6]

3) Frictions do not offset the sign of the response of marginal costs and inflation on the impact of shocks, but hiring frictions, and to a lesser extent investment frictions change the sign response of real variables. This implies that hiring frictions, and to a lesser extent investment frictions, affect the conditional co-movement of inflation with real variables.

4.2.1 Technology Shocks

Remark 3 *I find the following sub-section not clear enough; can u use equations directly and speak about their components? equations such as*

Remark 4

$$mc_t = \frac{\frac{W_t}{P_t}}{f_{N,t} - g_{N,t}} + \frac{\frac{W_{N,t}}{P_t} N_t}{f_{N,t} - g_{N,t}} + \frac{Q_t^N - (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N}{f_{N,t} - g_{N,t}}, \tag{24}$$

$$E_t mc_{t+1} = E_t \frac{\frac{W_{K,t+1}}{P_{t+1}} N_{t+1}}{f_{K,t+1} - g_{K,t+1}} + E_t \frac{1}{\Lambda_{t,t+1}} \frac{Q_t^K - \Lambda_{t,t+1}(1-\delta_K) Q_{t+1}^K}{f_{K,t+1} - g_{K,t+1}}. \tag{25}$$

Figure 1 reports impulse responses for a set of key variables to a 1% increase in TFP. Figure 2 decomposes the impulse responses of marginal costs and real wages into contributions from the various components on the right hand side of equations (17) and (20), respectively. Each figure highlights the response of the four benchmark parameterizations discussed above. Figure 1 shows that marginal costs and inflation fall in all models, but less strongly in the presence of capital frictions. Hiring, investment, employment and capital fall in the frictionless NK model on the impact of shocks. This reflects the standard mechanism at work in NK models: output is demand driven when prices are rigid, therefore following an increase in productivity, less input is needed to produce the same quantity of goods. Introducing separately hiring and investment frictions can

[6] Notice that with capital frictions only, Q_t^N does not equal zero because the intra-firm bargaining term $\frac{W_{H,t}}{P_t^C} N_t$ in equation (15) is non zero

reverse some of these responses. For instance, hiring frictions (but not investment frictions) turn the response of employment *to* positive, while either hiring or investment frictions turn the response of investment *to* positive. As discussed in Faccini and Yashiv (2015), the interaction between hiring or investment frictions with price frictions generates a relative price effect *on* the value of employment and capital that offsets the mechanism at work in the frictionless NK model.

The smoother fall in employment in the model with capital frictions, and the increase in employment in the model with labor frictions, imply that the marginal rate of substitution falls less, and respectively rises, relative to the frictionless benchmark (see Figure 2). Because real wages increase with the marginal rate of substitution (equation 20), hiring frictions, and to a lesser extent capital frictions, endogenously dampen the fall in the real wage on the impact of the shock. In addition, in the model with hiring frictions only, the low bargaining power decrease the impact of the fall in marginal costs on the marginal revenue product and hence on the negotiated wage. Relative to the frictionless model, the response of the marginal revenue product is dampened also in the presence of capital frictions. As we explain in the next paragraph, the smooth response of real wages with capital frictions translates into a dampened response of marginal costs. This feeds-back to the negotiated wage, entailing a subdued response of the marginal revenue product. So the endogenous rigidity in real wages arises in models with frictions through the endogenous responses of both the marginal rate of substitution and the marginal revenue product (Figure 2).

The resilience of wages to technology shocks implies a dampening effect on Q_t^N, and thereby a fall in the frictional component of marginal costs. The response of the intrafirm component of marginal costs is small, although not negligible, so the first-order effect is that the frictional component of marginal costs almost entirely offsets the response of the wage component, resulting in a similar response of marginal costs in the frictionless model and in the model with hiring frictions only. In the model with capital frictions only instead, mc_t only depends on the real wage component. So marginal costs and inflation will fall by less in this model, relative to the frictionless benchmark. In the model with both hiring and investment frictions, the response of marginal costs and inflation lies in between the values obtained in the parameterizations where only one friction is active. It is worth emphasizing that in models with hiring frictions, the contribution of the frictional component to changes in marginal costs appears to be about as important as that of the wage share of income, even if hiring frictions are calibrated to relatively conservative values.

4.2.2 Monetary shocks

Figures 3 shows that following a negative shock to the interest rate, marginal costs and inflation increase in all models. Hiring, investment, employment, capital and output increase in the frictionless NK model, whereby an expansionary monetary shock engenders a fall in the real rate, which stimulates both consumption and investment. The same variables increase also in the model with capital frictions, albeit less strongly so, while in the model with hiring frictions they barely move. As explained in Faccini and Yashiv (2015), this reflects a relative price effect on the value of employment and capital, which offsets the mechanism at work in the frictionless NK benchmark.

Remark 5 *This is not clear without the analysis of the type we did in the other paper, i.e., with showing expressions like* $\widetilde{\frac{Q^N}{mc}}$

For slightly higher values of hiring frictions, the response of hiring, employment and output can turn negative, generating a procyclical marginal cost conditional on monetary shock, in line with evidence by Nekarda and Ramey (2013). The result that monetary policy is neutral, if not contractionary, is consistent with VAR evidence by Uhlig (2005), who, based on an agnostic identification, concludes that a monetary stimulus is just as likely to increase output or to decrease it.

Remark 6 *I find the rest of the sub-section unclear; it needs direct reference to equations*

The smaller rise in employment in the model with capital frictions, implies a smoother response in the marginal rate of substitution and in real wages. With hiring frictions, the response of the MRS is muted, implying an even stronger dampening effect on real wages. In addition, for the same reasons discussed for technology shocks, both hiring and investment frictions contain the response of real wages by smoothing also the response of the marginal revenue product (Figure 4).

This rigid response of real wages translates into a dampened response of the wage component of marginal costs, relative to the frictionless benchmark. However, in models with hiring frictions, wage moderation implies a jump in the value of a job on the impact of the shock, and thus an increase in the frictional component of marginal costs, which, in the current calibration more than offsets the smoothing impact of frictions on the wage component. As a result, marginal costs increase by more in the model with labor frictions only, relative to the frictionless case. In the model with investment frictions only, instead, the wage share of income is the only component of marginal costs, so the dampening impact of capital frictions on wages directly translates into a smoother response of marginal costs and inflation. In the model with both labor and capital frictions, the response of marginal costs and inflation lies in between the two benchmarks with either labor or capital frictions only. In the model with hiring frictions only, the response of the frictional component of marginal costs appears to contribute to changes in marginal costs more than the wage component, while in the model with both capital and labor frictions, both component seem to be equally important.

4.2.3 Investment specific shocks

Remark 7 *This is clearer but still would be helped by equations*

Figure 5 shows that following an expansionary investment-specific technology shock, marginal costs and inflation increase in all models. In the frictionless NK model, hiring, investment, employment, capital and output increase, both because of the direct effect of the shock on investment rates, and because of the indirect impact of marginal costs on the marginal revenue product of capital and labor. Frictions offset this effect through a relative price effect on the values of labor and capital, leading to smoother responses in all real variables.

The dampened response of employment in the models with frictions smooths the response of the real wage via the marginal rate of substitution and the marginal revenue product of employment (Figure 6). In turn, the smoother response of real wages translates into a dampened response of the wage component of marginal costs, relative to the frictionless benchmark. With hiring frictions, the lower increase in wages generates an increase in the current value of a job, and thus an increase in the frictional component of marginal costs, which more than offsets the response of the wage share of income in the case where only hiring frictions are active. With capital frictions only, the wage share of income is the only component of marginal costs, so the smoother response in wages directly affects the response of marginal costs. In the model with both capital and labor frictions, the response of marginal costs and inflation is someway in between the responses of the two benchmarks with either friction active; in this model both the wage and the friction component appear about equally important in driving marginal costs.

5 Estimation of the DSGE Model

The previous section has shown that both hiring and investment frictions have crucial implications for the behavior of marginal costs and for the conditional co-movement of inflation with real variables. We now undertake estimation of the full DSGE model to compare how the statistical performance of the NK model changes with frictions. The question we address *in empirical work* is what specification of the model is most likely to have generated the inflation series, given a common set of observables and distributions of priors for the parameter values. This section describes the methodology, the data used and the choice of priors. The subsequent sections provide analyses of the results.

5.1 Methodology and Data

We estimate the model using Bayesian methods. First, we take a first-order approximation of the system of equations around a deterministic steady-state with zero inflation. We then solve the model and apply the Kalman filter to evaluate the likelihood function of the observable variables. The likelihood function and the prior distribution of the parameters are combined to obtain the posterior distributions. The posterior kernel is simulated numerically using the Metropolis-Hasting algorithm.

We first estimate the full model described in Section 3 using the priors and the shocks discussed below. Next, using the same shocks, the same observables and the same priors for all the parameters, we estimate versions of the same model, where we restrict the parameters e_1 and e_2 so as to shut down one friction at a time. We thus estimate three versions of the model with frictions costs: the unrestricted model, the model that allows only for hiring costs, restricting $e_1 = 0$, and the model that allows only for investment costs, restricting $e_2 = 0$. We will denote these three models by $\mathcal{M}_1$, $\mathcal{M}_2$, and $\mathcal{M}_3$, respectively. Each of these three versions is compared to the frictionless New Keynesian model, obtained by restricting $e_1 = e_2 = 0$ and denoted by $\mathcal{M}_0$.

We estimate the model using the minimum set of observables and shocks that are required to assess whether hiring and investment frictions costs help explain inflation dynamics in the context of New Keynesian models. Inflation, output and the interest rate are typically considered the very minimum set of observables when estimating any model of inflation dynamics. Given that our theoretical mechanism affects marginal costs through the interplay of hiring and investment dynamics, we add series of gross investment and gross hiring flows to this set of observables. Finally, to discipline fluctuations in marginal costs we make the labor share of income observable to the estimation. To keep both the model and the estimation as simple as possible, we have abstracted from the government sector. Our data set will therefore include only observables pertaining to the private sector in the spirit of Gali and Gertler (1999), thus not confounding the analysis with government output, inflation, hiring and investment.

The model is estimated on quarterly US data over the period 1976 Q1 to 2014 Q2. The data pertain to the U.S. private sector and have been downloaded from the Federal Reserve Economics Data (FRED) set. We make the following mapping between model variables and observable data series: output in the model corresponds to non-farm business sector output scaled by civilian non-institutional population; inflation is the implicit price deflator; the interest rate is the effective federal funds rate; investment corresponds to real gross private domestic investment scaled by civilian non-institutional population; the hiring rate is gross hiring flows scaled by civilian non-institutional population.[7] The inflation rate and the interest rate series are demeaned prior to estimation, while the output, investment, hiring and labor share series are detrended with an Hodrik-Prescott filter with smoothing parameter 1,600.[8]

Because no assumption on the wage setting process is uncontroversial in models with frictional labor markets, we include a measurement error in the observation equation for the labor share to capture model misspecification. We then use five shocks to match the behavior of the remaining five

[7] The classification codes of the series used in the estimations are the following: FEDFUNDS for the effective federal funds rate, IPDNBS for the price deflator, OUTNFB for output, GPDIC96 for investment, and CNP16OV for the population series. The computation of the hiring series first builds on the flows between E (employment), U (unemployment) and N (not-in-the-labor-force) that correspond to the E,U,N stocks published by CPS. The methodology of adjusting flows to stocks is taken from BLS, and is given in Frazis et al (2005). This methodology, applied by BLS for the period 1990 onward, produces a dataset that appears in http://www.bls.gov/cps/cps_flows.htm. Here the series have been extended back to 1976.

[8] The labor share series is detrended because it features a major trend decline starting in the years 2000s. King and Watson (2012) argue that real factors might have influenced the trend in the labor share in ways that are largely unrelated to inflation. Karabarbounis and Neiman (2014) document that the decline in the labor share is a global phenomenon and can be attributed to a large extent to the secular decline in the price of investment goods. Because our model cannot account for trends in the labor share we simply remove the low frequency component. The results in this paper are robust to excluding the labor share from the set of observable series.

observable series. The shocks include a preference shock, a technology neutral shock, a monetary policy shock, a labor supply shock and an investment technology shock. All shocks are assumed to follow a first-order autoregressive process with i.i.d. normal errors.

5.2 Parameter priors and posteriors

The model contains 13 structural parameters, excluding the shock parameters. For the parameters that affect the steady state, the prior means of the estimated parameters and the value of the parameters that are kept fixed in estimation, are assigned so as to follow the calibration discussed in Section 4.1. In terms of the distributions for our priors, we use the Beta distribution for priors that take values between zero and one, the Gamma distribution for parameters restricted to be positive and the Inverse Gamma distribution for the standard deviation of the shocks. Table 2 reports the parameters that are kept fixed in estimation.

Table 2

Because the elasticity of substitution ε and the coefficient of price stickiness ζ are not jointly identified, ε is fixed in estimation. A key feature of our estimation strategy is that we select priors of the frictions costs function to be tight around the calibrated means. The reason why we do so is because we are interested in understanding whether conservative parameterizations of frictions costs can help explain and predict inflation in the context of New-Keynesian models, so we want to enforce posterior estimates of frictions costs to remain at the lower end of the range of reasonable values.

This strategy allows us to examine whether (moderate) frictions costs matter for inflation dynamics. For the same reason, as seen in Table 2, we keep fixed in estimation a number of parameters that have a direct impact on the steady-state, and could therefore change the size of frictions costs relative to output. We can think about these parameters as being estimated with infinitely tight priors. A technical reason for either fixing or selecting tight priors for the parameters affecting the steady-state is that doing so ensures convergence of the steady-state non-linear solver, which is only possible if the starting values are not too far from the solution. So for these reasons, the workers' separation rate δ_N and the capital depreciation rate δ_K are fixed, as in Gertler, Sala and Trigari (2008), and the priors around the bargaining power parameter γ *are* tight. We select looser priors for the parameters that do not affect the steady-sate, such as the coefficients of the Taylor rule and the autocorrelation of shocks. We have also estimated versions of the model where we estimate a larger number of parameters and/or assume looser priors on the parameters affecting the steady-state. This alternative estimation strategy tends to increase the ability of frictions costs to explain inflation dynamics. However, these imply larger frictions costs and hence are less suited to address Gali's (2010) point that hiring frictions are too small to matter.

Tables 3 and 4 fully characterize the priors used for estimation as well as the posterior estimates.[9]

Tables 3-4

Overall, the posterior estimates of the parameters appear to be tightly estimated across all specifications. The estimated elasticity of labor supply ranges from 0.28 to 0.33 in the four estimated versions of the model, which *is* somewhat below our prior and in line with the synthesis of micro evidence reported by Chetty et al. (2012), pointing to Frisch elasticities around 0.25 on the extensive margin. Another result that is common across models is that the degree of interest rate smoothing in the Taylor rule is estimated to be lower than the prior mean. Models with hiring frictions costs tend to estimate a lower labor share of income than assumed in the calibration. In the specification that allows for both hiring and investment frictions costs, an estimated coefficient of $\alpha = 0.57$ maps into a labor share of income of 60%. Models with frictions costs estimate a small sensitivity of interest rates to output in the Taylor rule, as in Christiano, Eichenbaum and Trabandt (2013), who also estimate a DSGE model with hiring frictions. Turning to the shocks, all models estimate that preference shocks are quite persistent. In addition, both technology neutral and investment-specific shocks are more persistent in models with frictions, while monetary shocks are persistent only in the frictionless model.

6 Accounting for the Role of Frictions in Inflation

We now evaluate whether frictions costs affect marginal costs in a way that is useful to explain inflation. We also seek to determine what specific form of frictions matters. Table 5 shows the estimated marginal and total frictions costs for different specifications of the frictions costs function, evaluated at the posterior means reported in Tables 3 and 4.

Table 5

The fullest model, $\mathcal{M}_1$, has total frictions costs at 2.4% of GDP and marginal costs at magnitudes that were discussed in Section 4.1 above. The $\mathcal{M}_2$ model is estimated to imply similar costs: 1.6% of GDP for total costs and marginal hiring costs as in $\mathcal{M}_1$. The other model, $\mathcal{M}_2$ implies somewhat lower total costs, 1% of GDP, and marginal investment costs as in $\mathcal{M}_1$. In what follows we explain what role these frictions play in determining inflation.

6.1 Marginal Data Density Analysis

We rely on the marginal data density (MDD) as the measure of fit. The MDD is computed for each model using the modified harmonic mean estimator introduced by Geweke (1999). Considering

[9] Each estimation of the model is based on five parallel chains, each one consisting of 250,000 draws from the Metropolis algorithm, half of which are discarded as burn-in. Brooks and Gelman (1998) diagnostics provide evidence on convergence. Acceptance rates for all the models vary between 20 and 34 percent.

that this criterion penalizes overparametrization, models with less restrictions on the frictions costs function would rank better only if the extra parameters are informative in explaining the data. The relative fit of inflation across models is then assessed as in Neri and Ropele (2012) by computing the conditional marginal data density for the inflation rate in each specifications of the model $\mathcal{M}_j$ for $j \in \{0, 1, 2, 3\}$. The conditional MDD is the likelihood of observing the inflation rate series, conditional on the model and on the set of observables that excludes inflation.

We denote the set of observables excluding inflation as D_T and the inflation series as Π_T. The conditional MDD of inflation for a model $\mathcal{M}_j$ is:

$$p(\Pi_T \mid D_T, \mathcal{M}_j) = \frac{p(D_T, \Pi_T \mid \mathcal{M}_j)}{p(D_T \mid \mathcal{M}_j)}, \quad j \in \{0, 1, 2, 3\},$$

where the numerator of the ratio on the right hand side is the unconditional MDD of the model estimated on the full set of observables, and the denominator is the MDD of the same model estimated on the restricted sample (the full set without inflation).[10]

Table 6 reports the results.

Table 6

As shown in the table, the conditional MDD of inflation in the frictionless model is 377 log points. Introducing hiring and investment frictions costs separately increases the conditional MDD to 456 and 415 log points, respectively. As we discuss below, this improvement in log-likelihood, is very strong evidence that both hiring and investment frictions considered independently, help the New-Keynesian model fit inflation. Importantly, introducing hiring frictions into the benchmark NK model increases the ability of the model to fit both the inflation series and the whole set of observables much more than investment frictions. This result suggests that the important changes generated by hiring frictions in the co-movement between the observables are supported by the data. Introducing investment frictions on top of a NK model with hiring frictions significantly helps explaining the behavior of inflation and the other observables, but most of the increase in ability to fit the data relative to the frictionless benchmark is driven by the hiring frictions.

To provide some intuition on how large the estimated differences in log-points are, we follow Melosi (2014) and perform a Bayesian test of the null hypothesis that a model with frictions costs is at odds with the behavior of inflation. We do so by comparing the conditional MDD of inflation associated with a particular specification of frictions costs and the frictionless NK model.

[10] The conditional MDD can also be written as:

$$p(\Pi_T \mid D_T, \mathcal{M}_j) = \int p(\Pi_T \mid \Theta, D_T, \mathcal{M}_j)\, p(\Theta \mid D_T, \mathcal{M}_j)\, d\Theta,$$

where $p(\Pi_T \mid \Theta, D_T, \mathcal{M}_j)$ is the conditional likelihood and $p(\Theta \mid D_T, \mathcal{M}_j)$ is the conditional distribution of the parameters Θ.

The posterior probability of a model with frictions costs, conditional on the inflation series and denoted by $p(\mathcal{M}_j|\Pi_T)$ is:

$$p(\mathcal{M}_j|\Pi_T) = \frac{p(\Pi_T|D_T, \mathcal{M}_j)\, p_0(\mathcal{M}_j)}{p(\Pi_T|D_T, \mathcal{M}_j)\, p_0(\mathcal{M}_j) + p(\Pi_T|D_T, \mathcal{M}_0)\, p_0(\mathcal{M}_0)}, \quad j \in \{1, 2, 3\},$$

where $p(\Pi_T|D_T, \mathcal{M}_j)$ are the conditional MDD defined above, while $p_0(\mathcal{M}_j)$ and $p_0(\mathcal{M}_0) = 1 - p_0(\mathcal{M}_j)$ are the prior probabilities in favor of the two models. Given our estimates for the conditional MDDs, the null can be rejected so long as the prior probability in favor of the model with investment costs only and hiring costs only are not less than 2.2E-16 and 3.5E-34, respectively. Similarly, for the unrestricted model, the null can be rejected so long as the prior probability in its favor is no less than 1.E-53, an extremely small number, which offers substantial evidence in favor of the unrestricted model.

6.2 Decomposition of Marginal Costs

In order to understand what drives the different behavior of inflation in the two models

Remark 8 *two models or different models?*

we investigate the determinants of the estimated marginal costs series. In what follows we restrict our attention to the benchmark without frictions and our preferred specification of the model with frictions ($\mathcal{M}_1$), which is the one that allows for both hiring and investment costs. As reported in Table 5, the estimated frictions costs are moderate in this model. The smoothed series for estimated total frictions costs relative to output oscillates between 1.7% and 2.4% in sample, and marginal frictions costs exhibit very moderate fluctuations, so we are not estimating large swings in total or marginal frictions costs.

Marginal costs can be decomposed using either the optimality condition for employment or capital, which we report again for convenience in equations (26) and (27), respectively:

$$mc_t = \frac{\frac{W_t}{P_t}}{f_{N,t} - g_{N,t}} + \frac{\frac{W_{N,t}}{P_t} N_t}{f_{N,t} - g_{N,t}} + \frac{Q_t^N - (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N}{f_{N,t} - g_{N,t}}, \tag{26}$$

$$E_t mc_{t+1} = E_t \frac{\frac{W_{K,t+1}}{P_{t+1}} N_{t+1}}{f_{K,t+1} - g_{K,t+1}} + \frac{1}{\Lambda_{t,t+1}} E_t \frac{Q_t^K - \Lambda_{t,t+1}(1-\delta_K) Q_{t+1}^K}{f_{K,t+1} - g_{K,t+1}}. \tag{27}$$

In the frictionless model, marginal costs are proportional to the labor share, as the second and third term in equation (26) disappear. Equation (27) posits that expected future marginal costs must equal the sum of the positive expected impact of capital on wages and the expected change in the value of capital, both divided by the net marginal product of capital. In the frictionless model there is no intra-firm bargaining, which implies that the expected next-period marginal cost only reflects expected changes in the value of capital. In turn, this term only reflects expected changes in the relative price of the investment good.[11] Allowing for both hiring and investment frictions costs can potentially modify the dynamics of the marginal cost series by allowing for frictions and intrafirm bargaining to matter in both equations.

Figure 7 compares the smoothed estimates for the inflation series obtained in the benchmark NK model and in the preferred specification with frictions. The figure shows that the two series are very different: the marginal cost obtained by estimating the model with frictions is much more volatile than in the frictionless benchmark.[12]

Figure 7

Remark 9 *should we not add the data series to figure 7?*

Figure 8 decomposes marginal costs, using equation (26) and the preferred friction-cost specification M_1.

Figure 8

In this model, as shown by the figure, most of the fluctuations are explained by the frictional component. Specifically, we estimate hiring frictions to explain about 51% of the variation in marginal costs, the wage component of marginal costs to explain around 35%, while the remaining 14% is accounted for by the direct impact of intrafirm bargaining on marginal costs. Note, too, that these results have been obtained with moderate total and marginal frictions costs, as reported in Table 5. The result that labor frictions are more important than the labor share in driving marginal costs at business cycle frequencies, stands in contrast to previous literature, but should not come as a surprise in the light of the numerical properties of the model described in Section 4.1. This is an important result since New-Keynesian models of the labor market have so far identified marginal costs with the labor share of income, thereby implying that the labor share is the sole determinant of inflation dynamics.

Figure 9 plots the decomposition of the estimated marginal costs series using the optimality condition for investment in equation (27).

Figure 9

[11] In the frictionless model the first two terms in equation (13) wash out, so the marginal value of capital coincides with the relative price of investment.

[12] We have estimated versions of the model where we do not make the labor share of income observable to the estimation. In this case both the benchmark NK model and the model with frictions tend to estimate similar marginal cost series. However, the magnitude of fluctuations in the estimated marginal cost is much larger than observed fluctuations in the labor share of income, and therefore is incompatible with the notion of marginal costs implicit in the frictionless NK model. Fluctuations in the wage component of marginal costs are much less pronounced in the estimated model with frictions, because most of the variation in the marginal cost is explained by labor frictions.

The two determinants of expected marginal costs exhibit nearly perfect positive correlation, but the intrafirm bargaining component quantitatively plays a minor role. This term captures the effect of capital on wages and reflects a classical hold up problem.

As noted in Section 3.3, the frictional component of marginal costs can be interpreted as the ratio of marginal hiring profits, Π_t, to the marginal product of labor. A high elasticity of marginal profits to the marginal product of labor has been shown to be key for matching unemployment fluctuations at business cycle frequencies (Shimer (2005)). It turns out that in the context of New Keynesian models with frictional labor markets, the estimated behavior of marginal hiring profits relative to the marginal product is also key to explain changes in real marginal costs and, as a result, inflation. This is shown in Figure *10*, which plots a decomposition of the New Keynesian Phillips curve delineated in equation (16), where the marginal cost is in turn decomposed in three components, using equation (26):

$$\pi_t(1+\pi_t) = \frac{1-\varepsilon}{\zeta} + \frac{\varepsilon}{\zeta}\left[\frac{\frac{W_t}{P_t}}{f_{N,t}-g_{N,t}} + \frac{\frac{W_{N,t}}{P_t}N_t}{f_{N,t}-g_{N,t}} + \frac{\Pi_t}{f_{N,t}-g_{N,t}}\right] + E_t\frac{1}{1+r_t}\left(1+\pi_{t+1}\right)\pi_{t+1}\frac{y_{t+1}}{y_t} \tag{28}$$

Figure 10

We estimate that the forward looking component of inflation, i.e. the last term in the above equation, explains almost 40% of current inflation, while the contribution of hiring frictions, $\frac{\Pi_t}{f_{N,t}-g_{N,t}}$, accounts for 32%, the wage component accounts for 20% and the intrafirm component for the remaining 8%. The figure shows that current marginal hiring profits (Π_t) are nearly as important as the forward looking term of the Phillips curve in explaining current inflation. The figure also suggests that labor market frictions might have been an important force counteracting the deflationary pressure arising from expected inflation during the great recession and more in general throughout the years 2000s.

7 Conclusions

In the standard New Keynesian DSGE model there is no independent role for unemployment as a determinant of inflation over and above that of employment. The absence of unemployment from this model of inflation is in stark contrast with its prominence in monetary policy debates and strategies. In recent times central banks such as the Federal Reserve or the Bank of England, publicly committed to anchor their interest rate policies to the dynamic behavior of the unemployment rate. These monetary strategies make it even more important to achieve a better understanding of the linkages between the unemployment rate and inflation rate dynamics. This can only be achieved by properly modelling frictions in the labor market. We see our work as a step in this direction.

We set-up a very streamlined model in order to closely compare to a reference NK model and highlight sharply the role that hiring and investment frictions play in the transmission of shocks to inflation dynamics. We find that both frictions have crucial implications for the behavior of marginal costs and the conditional co-movement of inflation and real variables. In sharp contrast with the literature, we find that hiring frictions are more important than the labor share in driving inflation dynamics, and they account for about 50% of the variation in marginal costs. These frictions in equilibrium equal the ratio of marginal hiring profits to the marginal product of labor*, an object that is closely related to the fundamental surplus fraction (Ljungqvist and Sargent (2015)).* So, our result that marginal hiring profits are important in driving inflation dynamics echoes the well-known result on their importance for driving unemployment dynamics.

Remark 10 *Same as above, regarding Ljungqvist and Sargent. RF: addressed.*

Quite clearly, our simple model will be misspecified. But when we take the model to the data, and compare the statistical performance of different specifications of the model, each version of the model is equally misspecified except for frictions. The result that both frictions and particularly hiring frictions considerably help explain inflation dynamics provides some evidence in favor of the hypothesis that the very different structure of conditional co-movement generated by hiring frictions is supported by the data. An important exercise to carry-out in future work is to verify whether such results also hold in a richer model. While this might not prove difficult per se, understanding the role that each additional assumption plays in the transmission of shocks might be more complicated; the interaction between hiring frictions and other frictions in a NK model might not be trivial. This is exemplified in work by Krause and Lubik (2009), who show that wage rigidities are irrelevant for the dynamics of marginal costs when introduced in a NK model with search frictions, *in sharp contrast with the canonical result that would arise in the absence of frictions.*

Remark 11 *I do not understand the emphasized sentence.*

The estimated marginal cost series in the models with and without frictions appear to exhibit very different behavior. In particular, the hiring frictions component of marginal cost is estimated to have pushed up on marginal costs substantially since the early 2000s. This estimated role of frictions can potentially help reconcile within the NK framework the disconnect between the steady rate of inflation and the declining labor share observed over the last fifteen years. More in particular, during the Great Recession and in its aftermath, hiring frictions are estimated to have counteracted the deflationary pressure arising from expected inflation. This could potentially offer an explanation for the resilience of inflation in recent years, which can hardly be accounted for within the confines of a frictionless NK model, a point made by Hall (2011) in his presidential address to the American Economic Association. We leave this analysis for future work.

References

[1] Basu, Susanto and John Fernald, 1997. "Returns to Scale in US Production: Estimates and Implications," **Journal of Political Economy**, 105, 2, 249-283.

[2] Brooks, Stephen P. and Andrew Gelman, 1998. "General Methods for Monitoring Convergence of Iterative Simulations". **Journal of Computational and Graphical Statistics**, 7, 434–455.

[3] Cahuc, Pierre and Etienne Wasmer, 2001. "Does Intrafirm Bargaining Matter In The Large Firm'S Matching Model?," **Macroeconomic Dynamics** 5, 5, 742-747.

[4] Cahuc, Pierre, F. Marque, and Etienne Wasmer, 2008. "A Theory Of Wages And Labor Demand With Intra-Firm Bargaining And Matching Frictions," **International Economic Review**, 49, 3, 943-972.

[5] Chetty, Raj, A. Guren, D. Manoli, and Andrea Weber, 2013. "Does Indivisible Labor Explain the Difference between Micro and Macro Elasticities? A Meta-Analysis of Extensive Margin Elasticities", **NBER Macroeconomics Annual** 2012, 27, 1-56.

[6] Christiano, Larry J., M. S. Eichenbaum, and Matthias Trabandt, 2013. "Unemployment and Business Cycles," NBER Working Papers 19265, National Bureau of Economic Research.

[7] Christiano, Larry J., M. Trabandt, and Karl Walentin, 2010. "DSGE Models for Monetary Policy Analysis," Chapter 7 in Benjamin M. Friedman and Michael Woodford (eds.) **Handbook of Monetary Economics Vol 3A**, 285-367, Elsevier, Amsterdam.

[8] Costain, James and Michael Reiter, 2008. "Business Cycles, Unemployment Insurance, and the Calibration of Matching Models," **Journal of Economic Dynamics and Control**, vol. 32, 4, 1120-1155, April.

[9] Diebold, Francis X., and Roberto S. Mariano, 1995. "Comparing Predictive Accuracy," **Journal of Business & Economic Statistics**, American Statistical Association, 13, 3, 253-63, July.

[10] Domeij, David, and Martin Floden, 2006. "The Labor-Supply Elasticity and Borrowing Constraints: Why Estimates Are Biased", **Review of Economic Dynamics** 9, 242–262.

[11] Frazis, Harley J., Robison, Edwin L., Evans, Thomas D. and Marta A Duff, (2005). "Estimating Gross Flows Consistent with Stocks in the CPS," **Monthly Labor Review**, September, 3-9.

[12] Krause, Michael U., Lopez-Salido, David and Thomas A. Lubik, 2008. "Inflation Dynamics With Search Frictions: A Structural Econometric Analysis," **Journal of Monetary Economics** 55, 892– 916.

[13] Krause, Michael U., and Thomas A. Lubik, 2007. "The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions," **Journal of Monetary Economics**, Elsevier, vol. 54, 3, 706-727, April.

[14] Gali, Jordi 2008. **Monetary Policy, Inflation and the Business Cycle: An Introduction to the New Keynesian Framework.** Princeton University Press, Princeton.

[15] Gali, Jordi 2010. "Monetary Policy and Unemployment" in Benjamin M. Friedman and Michael Woodford (eds.) **Handbook of Monetary Economics Vol. 3A**, 487-546, Elsevier, Amsterdam.

[16] Gali, Jordi, and Mark Gertler, 1999. "Inflation Dynamics: a Structural Econometric Analysis." **Journal of Monetary Economics** 44, 195–222.

[17] Gertler, Mark, Sala, Luca and Antonella Trigari, 2008. "An Estimated Monetary DSGE Model With Unemployment and Staggered Nominal Wage Bargaining." **Journal of Money, Credit and Banking**, 40, 1, 713-64.

[18] Geweke, John 1999. "Using Simulation Methods for Bayesian Econometric Models: Inference, Development,and Communication," **Econometric Reviews**, 18, 1, 1-73.

[19] Hagedorn, Marcus and Iourii Manovskii, 2008. 'The Cyclical Behavior of Equilibrium Unemployment and Vacancies Revisited,' **American Economic Review**, 98, 4, 1692-1706.

[20] Hall, Robert E. 2011. "The Long Slump", **American Economic Review**, vol.101, 431-69, April.

[21] Hayashi, Fumio 1982. "Tobin's Marginal q and Average q: A Neoclassical Interpretation," **Econometrica** 50:213-224.

[22] Heer, Burkhard, and Alfred Maussner 2010. "Inflation and Output Dynamics in a Model with Labor Market Search and Capital Accumulation," **Review of Economic Dynamics**, 13, 3, 654-686.

[23] Karabarbounis, Loukas, and Brent Neiman, 2014. "The Global Decline of the Labor Share" **Quarterly Journal of Economics**, 129, 1, 61-103.

[24] Khan, Aubhi and Julia Thomas, 2008. "Idiosyncratic Shocks and the Role of Nonconvexities in Plant and Aggregate Investment Dynamics," **Econometrica** 76, 2, 395-436.

[25] King, Robert G., and Julia Thomas, 2006. "Partial Adjustment Without Apology," **International Economic Review,** 47, 3, 779-809.

[26] Lucas, Robert E. and Edward C. Prescott, 1971. "Investment Under Uncertainty," **Econometrica** 39, 5, 659-681.

[27] Melosi, Leonardo 2014. "Signaling Effects of Monetary Policy", Federal Reserve Bank of Chicago, mimeo.

[28] Merz, Monika and Eran Yashiv, 2007. "Labor and the Market Value of the Firm," **American Economic Review**, 97, 1, 419-31.

[29] Mumtaz, Haroon and Francesco Zanetti, 2015. "Factor Adjustment Costs: a Structural Investigation", **Journal of Economic Dynamics and Control**, 51 (February), 341-355.

[30] Nekarda, Christopher J. and Valerie A. Ramey, 2013. "The Cyclical Behavior of the Price-Cost Markup", NBER Working Papers 19099.

[31] Neri, Stefano and Tiziano Ropele, 2012. "Imperfect Information, Real-Time Data and Monetary Policy in the Euro Area," **Economic Journal** 122, 561, 651-674.

[32] Pissarides, Christopher A. 2000. **Equilibrium Unemployment Theory**, 2nd edition, Cambridge, MIT Press.

[33] Rogerson, Richard and Robert Shimer, 2011. "Search in Macroeconomic Models of the Labor Market,"in O. Ashenfelter and D. Card (eds.) **Handbook of Labor Economics Vol 4A**, Amsterdam, Elsevier – North Holland.

[34] Rotemberg, Julio J. 1982. "Monopolistic Price Adjustment and Aggregate Output", **Review of Economic Studies** 49, 517-31.

[35] Shimer, Robert 2005. "The Cyclical Behavior of Equilibrium Unemployment and Vacancies, " **American Economic Review**, 95, 1, 25-49.

[36] Silva, José I., and Manuel Toledo 2009. "Labor Turnover Costs and the Cyclical Behavior of Vacancies and Unemployment," **Macroeconomic Dynamics** 13, S1, 76-96.

[37] Stole, Lars A. and Jeffrey Zwiebel, 1996. "Intra-firm Bargaining under Non-binding Contracts," **Review of Economic Studies** 63, 3, 375-410.

[38] Tobin, James 1969. "A General Equilibrium Approach to Monetary Theory,"**Journal of Money, Credit, and Banking** 1, 15-29.

[39] Trigari, Antonella 2009. "Equilibrium Unemployment, Job Flows, and Inflation Dynamics," **Journal of Money, Credit and Banking**, 41, 1, 1-33.

[40] Walsh, Carl E. 2005. "Labor Market Search, Sticky Prices, and Interest Rate Policies," **Review of Economic Dynamics** 8, 4, 829-849.

[41] Woodford, Michael 2003. **Interest and Prices: Foundations of a Theory of Monetary Policy.** Princeton University Press, Princeton.

[42] Yashiv, Eran 2007. "Labor Search and Matching in Macroeconomics," **European Economic Review** 51, 8, 1859-1895.

[43] Yashiv, Eran 2014. "Capital Values, Job Values and the Joint Behavior of Hiring and Investment," mimeo, Tel Aviv University.

Appendix A1
The model

Households

Using $U^0_{j,t} = \frac{U_{j,t}}{1-x_t}$ and $U_{j,t} = 1 - N_{j,t}$, rewrite the law of motion for employment in (1) as:

$$N_{jt} = (1-\delta_N)N_{j,t-1} + \frac{x_t}{1-x_t}(1-N_{j,t})$$

We can write the Lagrangean as:

$$\begin{aligned}\max \mathcal{L} =& E_t \sum_{s=0}^{\infty} \beta^s \Bigg\{ \eta^p_{t+s} \ln(C_{j,t+s} - \vartheta C_{t+s-1}) - \frac{\eta^l_{t+s}\chi}{1+\varphi} N^{1+\varphi}_{j,t+s} \\ &-\lambda_{j,t+s} P_{t+s} \mathcal{V}^N_{j,t+s}\left[N_{j,t+s} - (1-\delta_N) N_{j,t+s-1} - \frac{x_{t+s}}{1-x_{t+s}}(1-N_{j,t+s})\right] \\ &-\lambda_{j,t+s}\left[P_{t+s}C_{j,t+s} + \frac{B_{j,t+s+1}}{R_{t+s}} - W_{j,t+s}N_{j,t+s} - B_{j,t+s} - \Upsilon_{jt} + T_{j,t}\right]\Bigg\}\end{aligned}$$

The FOCs with respect to $C_{j,t}$, $B_{j,t+1}$, and $N_{j,t}$ are:

$$\lambda_{j,t} = \frac{\eta^p_t}{P_t(C_{j,t} - \vartheta C_{t-1})}, \tag{29}$$

$$\frac{1}{R_t} = \beta E_t \frac{\lambda_{j,t+1}}{\lambda_{j,t}},$$

$$\mathcal{V}^N_{j,t} = \frac{W_{j,t}}{P_t} - \frac{\eta^l_t \chi N^{\varphi}_{j,t}}{\lambda_{j,t}C_{j,t}} - \frac{x_t}{1-x_t}\mathcal{V}^N_{j,t} + \beta(1-\delta_N)E_t\frac{C_{j,t}}{C_{j,t+1}}\mathcal{V}^N_{j,t+1}. \tag{30}$$

Market clearing condition

Consolidating the households' and the government budget constraints in (2) and (21) yields:

$$P_tC_t + P_tG_t = W_tN_t + \Upsilon_t. \tag{31}$$

The term Υ_t comprises the profits from both intermediate and final good producers.

The profits from the final good producers are given by:

$$P_t(1-mc_t)(f-g) - \frac{\zeta}{2}\left(\frac{\pi_t}{(\pi_{t-1})^{\psi}(\bar{\pi})^{1-\psi}} - 1\right)^2 P_tY_t,$$

while the profits of the intermediate good producers are given by:

$$P_tmc_t(f-g) - W_tN_t - \eta^q_t P_t[I_t + \nu(u_t)]$$

Consolidating profits yields:

$$\Upsilon_t = P_t\left(f-g\right) - \frac{\zeta}{2}\left(\frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi}\left(\bar{\pi}\right)^{1-\psi}} - 1\right)^2 P_t Y_t - W_t N_t - \eta_t^q P_t\left[I_t + \nu\left(u_t\right)\right]$$

Substituting Υ_t in the consolidated budget constraint in (31) gives:

$$Y_t = C_t + G_t + \eta_t^q\left[I_t + \nu\left(u_t\right)\right] + \frac{\zeta}{2}\left(\frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi}\left(\bar{\pi}\right)^{1-\psi}} - 1\right)^2 Y_t = \left(f-g\right).$$

Using

$$G_t = \left(1 - \frac{1}{\eta_t^G}\right) Y_t,$$

we get:

$$Y_t = C_t + \left(1 - \frac{1}{\eta_t^G}\right) Y_t + \eta_t^q\left[I_t + \nu\left(u_t\right)\right] + \frac{\zeta}{2}\left(\frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi}\left(\bar{\pi}\right)^{1-\psi}} - 1\right)^2 Y_t = f - g,$$

and rearranging:

$$Y_t\left[\frac{1}{\eta_t^G} - \frac{\zeta}{2}\left(\frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi}\left(\bar{\pi}\right)^{1-\psi}} - 1\right)^2\right] = C_t + \eta_t^q\left[I_t + \nu\left(u_t\right)\right] = f - g,$$

which is the market clearing condition specified in the main text.

Appendix A2
Solving for the Wage Function with Intrafirm Bargaining

We rewrite below the wage Nash sharing rule derived in equation (19):

$$(1-\gamma)\mathcal{V}_{jt}^{N} = \gamma \mathcal{Q}_{it}^{N}, \tag{32}$$

where we make use of subscripts j and i to denote a particular household j and firm i bargaining over the wage W_{it}.

Substituting (4) and (14) into the above equation one gets:

$$\gamma \left\{ \left[mc_{it}\left(f_{N,it} - g_{N,it}\right) - \frac{W_{it}}{P_t} - \frac{W_{N,it}}{P_t}N_{it} \right] + (1-\delta_N)E_t\Lambda_{t,t+1}\mathcal{Q}_{it+1}^{N} \right\} =$$

$$(1-\gamma)\left[\frac{W_{i,t}}{P_t} - \frac{\eta_t^l \chi N_{j,t}^{\varphi}}{\lambda_{j,t}P_t} - \frac{x_t}{1-x_t}V_{j,t}^{N} + E_t\Lambda_{t,t+1}\left(1-\delta_N\right)V_{j,t+1}^{N} \right].$$

Using the sharing rule in (32) to cancel out the terms in $\mathcal{Q}_{it+1}^{N}$ and $\mathcal{V}_{jt+1}^{N}$ we obtain the following expression for the real wage:

$$\frac{W_{it}}{P_t} = \gamma mc_{it}\left(f_{N,it} - g_{N,it}\right) - \gamma\frac{W_{N,it}}{P_t}N_{it} + (1-\gamma)\left[\frac{\eta_t^l \chi N_{j,t}^{\varphi}}{\lambda_{j,t}P_t} + \frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\mathcal{Q}_t^{N} \right]. \tag{33}$$

Ignoring the term in square brackets, which is independent of N_{it}, and dropping all subscripts from now onward with no risk of ambiguity, we can rewrite the above equation as follows:

$$W_N + \frac{1}{\gamma N}W - Pmc\left(\frac{f_N}{N} - \frac{g_N}{N}\right) = 0 \tag{34}$$

The solution of the homogeneous equation:

$$W_N + \frac{1}{\gamma N}W = 0, \tag{35}$$

is

$$W(N) = CN^{-\frac{1}{\gamma}}, \tag{36}$$

where C is a constant of integration of the homogeneous equation. Assuming that C is a function of N and deriving (36) w.r.t. N, yields:

$$W_N = C_N N^{-\frac{1}{\gamma}} - \frac{1}{\gamma}CN^{-1-\frac{1}{\gamma}}. \tag{37}$$

Substituting (36) and (37) into (34) one gets:

$$C_N = N^{\frac{1-\gamma}{\gamma}} Pmc(f_N - g_N). \tag{38}$$

Integrating (38) yields:

$$C = Pmc\int_0^N z^{\frac{1-\gamma}{\gamma}}(f_z - g_z)dz + D, \tag{39}$$

where D is a constant of integration. Let's solve for the two integrals in f_z and g_z, one at a time. Assuming that $f(a, A, z, u, K) = a\,(Az)^{\alpha}\,(uK)^{1-\alpha}$, we can write:

$$Pmc\int_0^N z^{\frac{1-\gamma}{\gamma}} f_z dz = Pmc\alpha\frac{\gamma}{1-\gamma\,(1-\alpha)} aA^{\alpha}N^{\frac{1-\gamma(1-\alpha)}{\gamma}}\,(uK)^{1-\alpha}. \tag{40}$$

Given our assumptions on the functional form of g as in (8), the function g_N can be rearranged as follows:

$$g_N = -aA^{\alpha}\,(uK)^{1-\alpha}\,e_2H^2N^{\alpha-3} + \alpha aA^{\alpha}\,(uK)^{1-\alpha}\left[\frac{e_1}{2}\left(\frac{I}{uK}\right)^2 N^{\alpha-1} + \frac{e_2}{2}H^2N^{\alpha-3}\right]. \tag{41}$$

Integrating the first term in the R.H.S. of the above equation yields:

$$Pmc\int_0^N z^{\frac{1-\gamma}{\gamma}} aA^{\alpha}\,(uK)^{1-\alpha}\,e_2H^2z^{\alpha-3}dz = Pmce_2H^2aA^{\alpha}\,(uK)^{1-\alpha}\,\frac{\gamma}{1-\gamma\,(3-\alpha)}N^{\frac{1-\gamma(3-\alpha)}{\gamma}}, \tag{42}$$

Integrating separately the two terms in square brakets in equation (41) yields:

$$-Pmc\int_0^N z^{\frac{1-\gamma}{\gamma}}\alpha aA^{\alpha}\,(uK)^{1-\alpha}\,\frac{e_1}{2}\left(\frac{I}{uK}\right)^2 z^{\alpha-1}dz = -Pmc\frac{e_1}{2}\left(\frac{I}{uK}\right)^2\alpha aA^{\alpha}\,(uK)^{1-\alpha}\,\frac{\gamma}{1-\gamma\,(1-\alpha)}N^{\frac{1-\gamma(1-\alpha)}{\gamma}}, \tag{43}$$

$$-Pmc\int_0^N z^{\frac{1-\gamma}{\gamma}}\alpha aA^{\alpha}\,(uK)^{1-\alpha}\,\frac{e_2}{2}H^2z^{\alpha-3}dz = -Pmc\frac{e_2}{2}H^2\alpha aA^{\alpha}\,(uK)^{1-\alpha}\,\frac{\gamma}{1-\gamma\,(3-\alpha)}N^{\frac{1-\gamma(3-\alpha)}{\gamma}}, \tag{44}$$

Denoting $A_1 \equiv \frac{\gamma}{1-\gamma(1-\alpha)}$ and $A_2 \equiv \frac{\gamma}{1-\gamma(3-\alpha)}$, we can now rewrite (39) as follows:

$$C = D + PmcaA^{\alpha}\,(uK)^{1-\alpha}\left\{\alpha A_1N^{1/A_1} + e_2H^2A_2N^{1/A_2} - \alpha\frac{e_1}{2}\left(\frac{I}{uK}\right)^2 A_1N^{1/A_1} - \alpha\frac{e_2}{2}H^2A_2N^{1/A_2}\right\}. \tag{45}$$

Plugging (45) into (36) one gets:

$$W(N) = DN^{-\frac{1}{\gamma}} + PmcaA^{\alpha}\left(uK\right)^{1-\alpha}\left\{\alpha\left[1-\frac{e_1}{2}\left(\frac{I}{uK}\right)^2\right]A_1N^{\alpha-1}+\left(1-\frac{\alpha}{2}\right)e_2H^2A_2N^{^{\alpha-3}}\right\}. \tag{46}$$

In order to eliminate the constant of integration D we assume that $\lim_{N\to 0} NW(N) = 0$. The solution to (33) therefore is:

$$\frac{W_t}{P_t} = \gamma mc_t a_t A_t^{\alpha}\left(u_tK_{t-1}\right)^{1-\alpha}\left\{\left[1-\frac{e_1}{2}\left(\frac{I_t}{u_tK_{t-1}}\right)^2\right]\frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)}+\left(1-\frac{\alpha}{2}\right)\frac{e_2H_t^2N_t^{^{\alpha-3}}}{1-\gamma\left(3-\alpha\right)}\right\}$$
$$+\left(1-\gamma\right)\left[\frac{\eta_t^l\chi N_t^{\varphi}}{\lambda_tP_t}+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\left(mc_tg_{H,t}+\frac{W_{H,t}}{P_t}N_t\right)\right]. \tag{47}$$

Appendix A3
The stationary model

Let $\tilde{X}_t \equiv X_t/A_t$ for any variable X_t and $\eta_t^A \equiv A_t/A_{t-1}$. Also let W_t^r denote the real wage W_t/P_t, and $W_{x,t}^r$ denote it's first order derivative with respect to the argument x. The stationary model is characterized by the following equations:

The Euler equation (3):

$$\begin{aligned}
\frac{1}{R_t} &= \beta E_t \frac{\eta_{t+1}^p \left(C_t - \vartheta C_{t-1}\right)}{\eta_t^p \left(C_{t+1} - \vartheta C_t\right)} \frac{1}{\pi_{t+1}} \\
&= \beta E_t \frac{\eta_{t+1}^p \left(\tilde{C}_t A_t - \vartheta \tilde{C}_{t-1} A_{t-1}\right)}{\eta_t^p \left(\tilde{C}_{t+1} A_{t+1} - \vartheta \tilde{C}_t A_t\right)} \frac{1}{\pi_{t+1}} \\
&= \beta E_t \frac{\eta_{t+1}^p \left(\tilde{C}_t - \vartheta \tilde{C}_{t-1}/\eta_t^A\right)}{\eta_t^p \left(\tilde{C}_{t+1} \eta_{t+1}^A - \vartheta \tilde{C}_t\right)} \frac{1}{\pi_{t+1}},
\end{aligned}$$

where $\pi_{t+1} = P_{t+1}/P_t$.

The production function $f(a_t, A_t, N_t, u_t, K_{t-1}) = a_t \left(A_t N_t\right)^{\alpha} \left(u_t K_{t-1}\right)^{1-\alpha}$:

$$\frac{f\left(a_t, A_t, N_t, u_t, K_{t-1}\right)}{A_t} \equiv \tilde{f}_t = a_t N_t^{\alpha} \left(u_t \tilde{K}_{t-1}\right)^{1-\alpha} \left(\eta_t^A\right)^{\alpha-1}.$$

The capital law of motion in eq. (9):

$$\tilde{K}_t = \left(1 - \delta_K\right) \tilde{K}_{t-1} \frac{1}{\eta_t^A} + \tilde{I}_t. \tag{48}$$

The employment law of motion in eq. (10):

$$N_t = (1 - \delta_N) N_{t-1} + H_t.$$

The adjustment cost function eq. (8)

$$\frac{g(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t)}{A_t} \equiv \tilde{g}_t =$$

$$\left[\frac{e_1}{2}\left(\frac{\tilde{I}_t}{u_t \tilde{K}_{t-1}} \eta_t^A\right)^2 + \frac{e_2}{2}\left(\frac{H_t}{N_t}\right)^2\right] a_t N_t^{\alpha} \left(u_t \tilde{K}_{t-1}\right)^{1-\alpha} \left(\eta_t^A\right)^{\alpha-1}.$$

The derivative of the adjustment cost function with respect to hiring:

$$\frac{g_H(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t)}{A_t} \equiv \tilde{g}_{H,t} = \frac{e_2 \frac{H_t}{N_t^2} f}{A_t} = e_2 \frac{H_t}{N_t^2} \tilde{f}_t.$$

The derivative of the adjustment cost function with respect to investment:

$$g_I(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t) = e_1 \frac{\tilde{I}_t}{\tilde{K}_{t-1}^2} \left(\eta_t^A\right)^2 \tilde{f}_t.$$

The derivative of the adjustment cost function with respect to employment:

$$\frac{g_N(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t)}{A_t} \equiv \tilde{g}_{N,t} = \frac{-e_2 \frac{f_t}{N_t} \frac{H_t^2}{N_t^2} + \frac{\alpha g_t}{N_t}}{A_t} = -e_2 \frac{\tilde{f}_t}{N_t} \frac{H_t^2}{N_t^2} + \frac{\alpha \tilde{g}_t}{N_t}.$$

The derivative of the adjustment cost function with respect to capital:

$$g_K(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t) = -e_1 f_t \frac{I_t^2}{u_t^2 K_{t-1}^3} + \frac{(1-\alpha) g_t}{K_{t-1}} = -e_1 \tilde{f}_t \frac{\tilde{I}_t^2}{u_t^2 \tilde{K}_{t-1}^3} \left(\eta_t^A\right)^3 + \frac{(1-\alpha)\tilde{g}_t}{\tilde{K}_{t-1}} \eta_t^A.$$

The derivative of the adjustment cost function with respect to the capital utilization rate:

$$\frac{g_u(a_t, A_t, I_t, u_t, K_{t-1}, H_t, N_t)}{A_t} \equiv \tilde{g}_{u,t} = -e_1 \frac{f_t}{A_t} \frac{I_t^2}{u_t^3 K_{t-1}^2} + \frac{(1-\alpha) g_t}{A_t u_t} = -e_1 \tilde{f}_t \frac{\tilde{I}_t^2}{u_t^3 \tilde{K}_{t-1}^2} \left(\eta_t^A\right)^2 + \frac{(1-\alpha)\tilde{g}_t}{u_t}.$$

The resource constraint in eq. (23):

$$\tilde{Y}_t = \tilde{C}_t + \eta_t^q \left[\tilde{I}_t + \tilde{\nu}\left(u_t\right)\right] + \tilde{G}_t = \left(\tilde{f}_t - \tilde{g}_t\right) \left[1 - \frac{\zeta}{2} \left(\frac{\pi_t}{\left(\pi_{t-1}\right)^{\psi} \left(\bar{\pi}\right)^{1-\psi}} - 1\right)^2\right], \tag{49}$$

where $\tilde{\nu}\left(u_t\right)$ equals

$$\tilde{\nu}\left(u_t\right) \equiv \frac{\nu\left(u_t\right)}{A_t} = \frac{u_t^{1+\xi} - u^{1+\xi}}{1+\xi}.$$

The first order conditions with respect to capital utilization in equation (11):

$$mc_t \left(\tilde{f}_{u,t} - \tilde{g}_{u,t}\right) = \frac{\tilde{W}_{u,t}}{P_t} N_t + \eta_t^q \tilde{\nu}'\left(u_t\right),$$

where $\tilde{f}_{u,t}$ is given by:

$$\tilde{f}_{u,t} \equiv \frac{f_{u,t}}{A_t} = \frac{(1-\alpha) f_t}{A_t u_t} = \frac{(1-\alpha)\tilde{f}_t}{u_t},$$

and $\tilde{\nu}'\left(u_t\right)$ equals:

$$\tilde{\nu}'\left(u_t\right) \equiv \frac{\nu'\left(u_t\right)}{A_t} = u_t^{\xi}.$$

The first order conditions with respect to capital in equations (12) and (13) can be merged by eliminating Q^K, which yields:

$$\left(mc_t g_{I,t} + W^r_{I,t} N_t + \eta^q_t\right) = E_t \Lambda_{t,t+1} \left\{ mc_{t+1}(f_{K,t+1} - g_{K,t+1}) - W^r_{K,t+1} N_{t+1} \right.$$

$$\left. +(1-\delta_K)\left(mc_{t+1} g_{I,t+1} + W^r_{I,t+1} N_{t+1} + \eta^q_{t+1}\right)\right\}, \tag{50}$$

where the superscript r denotes real variables, the real discount factor is

$$\Lambda_{t,t+1} = E_t \frac{1}{R_t/\pi_{t+1}},$$

and the marginal product of capital is:

$$f_{K,t} = a_t \left(A_t N_t\right)^\alpha (1-\alpha)\left(u_t K_{t-1}\right)^{-\alpha} u_t = (1-\alpha)\frac{f_t}{K_{t-1}} = (1-\alpha)\frac{\tilde{f}_t}{\tilde{K}_{t-1}} \eta^A_t.$$

The first order conditions with respect to employment in equations (30) and (15) can be merged by elimitating Q^N, and expressed as follows:

$$mc_t \tilde{g}_{H,t} + \tilde{W}^r_{H,t} N_t = mc_t\left(\tilde{f}_{N,t} - \tilde{g}_{N,t}\right) - \tilde{W}^r_t - \tilde{W}_{N,t} N_t$$

$$+(1-\delta_N) E_t \Lambda_{t,t+1}\left(mc_{t+1}\tilde{g}_{H,t+1} + \tilde{W}^r_{H,t+1} N_{t+1}\right)\eta^A_{t+1}, \tag{51}$$

where

$$\tilde{f}_{N,t} \equiv \frac{f_{N,t}}{A_t} = \frac{\alpha a_t A^\alpha_t N^{\alpha-1}_t \left(u_t K_{t-1}\right)^{1-\alpha}}{A_t} = \alpha \frac{f_t}{A_t N_t} = \alpha \frac{\tilde{f}_t}{N_t}.$$

The Phillips curve eq. (16):

$$\left(\frac{\pi_t}{\left(\pi_{t-1}\right)^\psi \left(\bar{\pi}\right)^{1-\psi}} - 1\right)\frac{\pi_t}{\left(\pi_{t-1}\right)^\psi \left(\bar{\pi}\right)^{1-\psi}} = \frac{1-\epsilon}{\zeta} + \frac{\epsilon}{\zeta} mc_t$$

$$+E_t \frac{1}{R_t/\pi_{t+1}}\left[\left(\frac{\pi_{t+1}}{\left(\pi_t\right)^\psi \left(\bar{\pi}\right)^{1-\psi}} - 1\right)\frac{\pi_{t+1}}{\left(\pi_t\right)^\psi \left(\bar{\pi}\right)^{1-\psi}} \frac{\tilde{Y}_{t+1}}{\tilde{Y}_t}\eta^A_{t+1}\right]. \tag{52}$$

The Taylor rule eq. (22) TO BE REWRITTEN:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{r_s}\left[\left(\frac{1+\pi_t}{1+\pi^*}\right)^{r_\pi}\left(\frac{\tilde{Y}_t}{\bar{Y}}\right)^{r_y}\right]^{1-r_s}\eta^R_t, \tag{53}$$

The equation for the real wage is derived by substituting for $\lambda_t P_t = \frac{\eta^p_t}{(C_t - \vartheta C_{t-1})}$ into eq. (47) :

$$\tilde{W}^r_t = \gamma mc_t a_t \left(\eta^A_t\right)^{\alpha-1}\left(u_t \tilde{K}_{t-1}\right)^{1-\alpha}\left\{\left[1 - \frac{e_1}{2}\left(\frac{\tilde{I}_t}{u_t \tilde{K}_{t-1}}\eta^A_t\right)^2\right]\frac{\alpha N^{\alpha-1}_t}{1-\gamma(1-\alpha)} + \left(1 - \frac{\alpha}{2}\right)\frac{e_2 H^2_t N^{\alpha-3}_t}{1-\gamma\left(3-\alpha\right)}\right\}$$

$$+(1-\gamma)\left[\frac{\eta_t^l \chi N_t^{\varphi}\left(\tilde{C}_{j,t}-\vartheta \tilde{C}_{t-1}/\eta_t^A\right)}{\eta_t^p}+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\left(mc_t \tilde{g}_{H,t}+\tilde{W}_{H,t}^r N_t\right)\right], \tag{54}$$

The derivative of the wage function with respect to investment:

$$\begin{aligned} W_{I,t}^r &= -\gamma mc_t a_t A_t^{\alpha}\left(u_t K_{t-1}\right)^{-\alpha} e_1 \frac{I_t}{u_t K_{t-1}}\frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)} \\ &= -\gamma mc_t a_t \left(\eta_t^A\right)^{\alpha+1}\left(u_t \tilde{K}_{t-1}\right)^{-\alpha} e_1 \frac{\tilde{I}_t}{u_t \tilde{K}_{t-1}}\frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)} \end{aligned}$$

The derivative of the wage function with respect to hiring:

$$\begin{aligned} \tilde{W}_{H,t}^r \equiv \frac{W_{H,t}^r}{A_t} &= \frac{\gamma mc_t a_t A_t^{\alpha}\left(u_t K_{t-1}\right)^{1-\alpha}\left(1-\frac{\alpha}{2}\right)\frac{2e_2 H_t N_t^{\alpha-3}}{1-\gamma(3-\alpha)}}{A_t} \\ &= \gamma mc_t a_t \left(\eta_t^A\right)^{\alpha-1}\left(u_t \tilde{K}_{t-1}\right)^{1-\alpha}\left(1-\frac{\alpha}{2}\right)\frac{2e_2 H_t N_t^{\alpha-3}}{1-\gamma\left(3-\alpha\right)} \end{aligned}$$

The derivative of the wage function with respect to capital:

$$\begin{aligned} W_{K,t}^r = {} & \frac{(1-\alpha)}{K_{t-1}}\left\{W_t^r-(1-\gamma)\left[\frac{\eta_t^l \chi N_t^{\varphi}\left(C_t-\vartheta C_{t-1}\right)}{\eta_t^p}+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\left(mc_t g_{H,t}+W_{H,t}^r N_t\right)\right]\right\} \\ & +\gamma mc_t a_t A_t^{\alpha}\left(u_t K_{t-1}\right)^{-\alpha} e_1 \frac{I_t^2}{u_t K_{t-1}^2}\frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)} \\ = {} & \frac{(1-\alpha)}{\tilde{K}_{t-1}}\eta_t^A\left\{\tilde{W}_t^r-(1-\gamma)\left[\frac{\eta_t^l \chi N_t^{\varphi}\left(\tilde{C}_t-\vartheta \tilde{C}_{t-1}/\eta_t^A\right)}{\eta_t^p}+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\left(mc_t \tilde{g}_{H,t}+\tilde{W}_{H,t}^r N_t\right)\right]\right\} \\ & +\gamma mc_t a_t \left(\eta_t^A\right)^{\alpha}\left(u_t \tilde{K}_{t-1}\right)^{-\alpha}\frac{e_1}{u_t}\left(\frac{\tilde{I}_t}{\tilde{K}_{t-1}}\eta_t^A\right)^2 \frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)}. \end{aligned}$$

The derivative of the wage function with respect to the rate of capital utilization:

$$\begin{aligned} \tilde{W}_{u,t}^r \equiv \frac{W_{u,t}^r}{A_t} = {} & \frac{(1-\alpha)}{A_t u_t}\left\{W_t^r-(1-\gamma)\left[\frac{\eta_t^l \chi N_t^{\varphi}\left(C_t-\vartheta C_{t-1}\right)}{\eta_t^p}+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\left(mc_t g_{H,t}+W_{H,t}^r N_t\right)\right]\right\} \\ & +\gamma mc_t a_t A_t^{\alpha-1}\left(u_t K_{t-1}\right)^{-\alpha} e_1 \frac{I_t^2}{u_t^2 K_{t-1}}\frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)} \\ = {} & \frac{(1-\alpha)}{u_t}\left\{\tilde{W}_t^r-(1-\gamma)\left[\frac{\eta_t^l \chi N_t^{\varphi}\left(\tilde{C}_t-\vartheta \tilde{C}_{t-1}/\eta_t^A\right)}{\eta_t^p}+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}\left(mc_t \tilde{g}_{H,t}+\tilde{W}_{H,t}^r N_t\right)\right]\right\} \\ & +\gamma mc_t a_t \left(\eta_t^A\right)^{\alpha+1}\left(u_t \tilde{K}_{t-1}\right)^{-\alpha} e_1 \frac{\tilde{I}_t^2}{u_t^2 \tilde{K}_{t-1}}\frac{\alpha N_t^{\alpha-1}}{1-\gamma(1-\alpha)} \end{aligned}$$

The derivative of the wage function with respect to employment:

$$\frac{W^r_{N,t}}{A_t} = \tilde{W}^r_{N,t} = \frac{\gamma mc_t a_t A^\alpha_t \left(u_t K_{t-1}\right)^{1-\alpha}}{A_t} \left\{ \left[1 - \frac{e_1}{2} \left(\frac{I_t}{u_t K_{t-1}} \right)^2 \right] \frac{\alpha \left(\alpha - 1\right) N^{\alpha-2}_t}{1 - \gamma(1-\alpha)} \right.$$
$$\left. + \left(1 - \frac{\alpha}{2}\right) \frac{e_2 H^2_t \left(\alpha - 3\right) N^{\alpha-4}_t}{1 - \gamma \left(3 - \alpha\right)} \right\},$$

$$\tilde{W}^r_{N,t} = \gamma mc_t a_t \left(\eta^A_t\right)^{\alpha-1} \left(u_t \tilde{K}_{t-1}\right)^{1-\alpha} \left\{ \left[1 - \frac{e_1}{2} \left(\frac{\tilde{I}_t}{u_t \tilde{K}_{t-1}} \eta^A_t \right)^2 \right] \frac{\alpha \left(\alpha - 1\right) N^{\alpha-2}_t}{1 - \gamma(1-\alpha)} \right.$$
$$\left. + \left(1 - \frac{\alpha}{2}\right) \frac{e_2 H^2_t \left(\alpha - 3\right) N^{\alpha-4}_t}{1 - \gamma \left(3 - \alpha\right)} \right\}.$$

Appendix A4
The Steady State Equilibrium

Normalization of labor force participation:

$$1 = N + U \tag{55}$$

Using (**??**):

$$\delta_N N = \frac{x}{1-x} U \tag{56}$$

Using (51), and substituting for the real discount factor $\Lambda \equiv \frac{1}{R/\bar{\pi}} = \frac{\beta}{\mu}$:

$$\left[1-\beta\left(1-\delta_N\right)\right]\left(mc\tilde{g}_H + \tilde{W}_H^r N\right) = mc(\tilde{f}_N - \tilde{g}_N) - \tilde{W}^r - \tilde{W}_N^r N, \tag{57}$$

where the superscript r denotes real variables.

Using (50):

$$\left[1-\left(1-\delta_K\right)\frac{\beta}{\mu}\right]\left(1 + mcg_I + W_I^r N\right) = \frac{\beta}{\mu}\left[mc\left(f_K - g_K\right) - W_K^r N\right] \tag{58}$$

Using (54):

$$\tilde{W}^r = \gamma mc\mu^{\alpha-1}\left(u\tilde{K}\right)^{1-\alpha}\left\{\left[1-\frac{e_1}{2}\left(\frac{\tilde{I}}{u\tilde{K}}\mu\right)^2\right]\frac{\alpha N^{\alpha-1}}{1-\gamma(1-\alpha)} + \left(1-\frac{\alpha}{2}\right)\frac{e_2 H^2 N^{\alpha-3}}{1-\gamma\left(3-\alpha\right)}\right\},$$

$$+\left(1-\gamma\right)\left[\chi N^{\varphi}\tilde{C}\left(1-\vartheta/\mu\right) + \frac{x}{1-x}\frac{\gamma}{1-\gamma}\left(mc\tilde{g}_H + \tilde{W}_H^r N\right)\right] \tag{59}$$

Using (49):

$$\tilde{f} - \tilde{g} = \tilde{C} + \tilde{I} \tag{60}$$

Using (48):

$$\tilde{K} = \frac{\tilde{I}}{1-\left(1-\delta_K\right)/\mu} \tag{61}$$

by definition of job finding rate:

$$x = \frac{H_t}{U_t/\left(1-x\right)} \tag{62}$$

and using (16)

$$mc = \frac{\varepsilon - 1}{\varepsilon}. \tag{63}$$

This system solves for $N, U, H, \tilde{I}, \tilde{W}^r, \tilde{C}, \tilde{K}, x, mc$ once the production function, the friction cost function, their derivatives and the derivatives of the wage function are substituted for.

Table 1: IR Analysis: Calibrated Parameters and Steady State Values

Description	*Parameter*	*Value*	*Source/Target*
Discount factor	β	0.99	Annual interest rate 4%
Separation rate	δ_N	0.133	Yashiv (2014)
Capital depreciation rate	δ_K	0.02	Yashiv (2014)
Elasticity of output to labor input	α	0.66	calibration
Adj. cost function investment term	e_1	20.3	calibration
Adj. cost function hiring term	e_2	1.75	calibration
Elasticity of substitution	ϵ	11	Basu and Fernald (1996)
Workers' bargaining power	γ	0.28	calibration
Inverse Frisch elasticity	φ	3	Domeij and Floden (2006)
External habits	ϑ	0.6	
Elasticity parameter of utilization cost fn	ξ	0.7	Gertler Sala and Trigari (2008)
Scale factor disutility of work	χ		calibration
Trend growth	μ	0.6	US data
Panel B: Steady State Values			
Definition	*Expression*	*Value*	
Total adjustment cost/ output	$\tilde{g}_t/\tilde{Y}_t$	0.02	Yashiv (2014)
Marginal investment adjustment cost	$g_{I,t}/(\tilde{Y}_t/\tilde{K}_t)$	0.80	Yashiv (2014)
Marginal hiring adjustment cost	$\tilde{g}_{H,t}/(\tilde{Y}_t/N_t)$	0.20	Yashiv (2014)
Labor share of income	$\frac{(\tilde{W}^r)}{\left[(\tilde{f}-\tilde{g})/N\right]}$	2/3	US National Accounts
Opportunity cost of work/real wage	$\frac{\chi N^{\varphi}\tilde{C}(1-\vartheta/\mu)}{mc\left(\tilde{f}_N-\tilde{g}_N\right)}$	0.75	Costain and Reiter (2008)
Unemployment rate	u_t	0.12	BLS

Table 2: Non-Estimated Parameters in the Frictions Models

Panel A: Parameters

Definition	**Parameter**	**Value**	**Target/Source**
Discount factor	β	0.99	Annual interest rate 4%
Separation rate	δ_N	0.133	Yashiv (2014)
Capital depreciation rate	δ_K	0.02	Yashiv (2014)
Elasticity of substitution	ϵ	11	Basu and Fernald (1996)

Table 3: Prior and Posterior Distributions for the Structural Parameters and the Shocks

			Prior dist.	*Posterior dist.*	
Model				$\mathcal{M}_0$	$\mathcal{M}_1$
Parametric restrictions				$e_1 = e_2 = 0$	*none*
		Distr.	Mean,Std	Mean,Std	Mean,Std
Structural Parameters					
Adj. Fn investment	e_1	G	$40, 2.0$	-	42.0, 1.73
Adj. Fn hiring	e_2	G	$1.5, 0.1$	-	1.75, 0.11
Workers' bargaining power	γ	B	$0.28, 0.01$	-	0.29, 0.01
Inverse Frisch elasticity	φ	G	$3, 0.2$	3.6, 0.05	3.0, 0.14
Elasticity of output to labor	α	B	$0.66, 0.02$	0.59, 0.01	0.57, 0.018
Price stickiness	ζ	G	$120, 10$	69.5, 2.6	83 ,7.5
Taylor response to infl	r_π	G	$1.5, 0.10$	2.1, 0.09	1.32, 0.07
Taylor response to output	r_y	G	$0.125, 0.05$	0.31, 0.03	0.01, 0.003
Interest rate smoothing	r_s	B	$0.75, 0.10$	0.13, 0.03	0.27, 0.05
Shocks: autoregressive parameters					
Technology neutral	ρ^A,	B	$0.5, 0.2$	0.66, 0.03	0.98, 0.01
Technology investment	ρ^q	B	$0.5, 0.2$	0.68, 0.02	0.86, 0.02
Monetary policy	ρ^r	B	$0.5, 0.2$	0.80, 0.02	0.07, 0.03
Preferences	ρ^p	B	$0.5, 0.2$	0.90, 0.02	0.90, 0.02
Labor supply	ρ^l	B	$0.5, 0.2$	0.74, 0.05	0.59,0.06
Shocks: standard deviations					
Technology neutral	σ^A	IG	$0.01, 0.1$	0.01, 0.001	0.010, 0.001
Technology investment	σ^q	IG	$0.01, 0.1$	0.011, 0.001	0.007, 0.001
Monetary policy	σ^r	IG	$0.01, 0.1$	0.006, 0.001	0.005, 0.001
Preferences	σ^p	IG	$0.01, 0.1$	0.022, 0.003	0.011, 0.001
Labor supply	σ^l	IG	$0.01, 0.1$	0.016, 0.001	0.063, 0.006
Measurement error labor share	σ_{ls}	IG	$0.01, 0.1$	0.014, 0.001	0.018, 0.001

Table 4: Prior and Posterior Distributions for the Structural Parameters and the Shocks

			Prior dist.	*Posterior dist.*	
Model				$\mathcal{M}_2$	$\mathcal{M}_3$
Parametric restrictions				$e_1 = 0$	$e_2 = 0$
		Distr.	Mean,Std	Mean,Std	Mean,Std
Structural Parameters					
Adj. Fn investment	e_1	G	$40, 2.0$	–	46.5, 2.5
Adj. Fn hiring	e_2	G	$1.5, 0.1$	1.79, 0.09	–
Workers' bargaining power	γ	B	$0.28, 0.01$	0.295, 0.01	0.28, 0.06
Inverse Frisch elasticity	φ	G	$3, 0.2$	3.0, 0.1	3.5, 0.2
Elasticity of output to labor	α	B	$0.66, 0.02$	0.54, 0.01	0.70, 0.01
Price stickiness	ζ	G	$120, 10$	79, 5.9	68, 1.4
Taylor response to infl	r_π	G	$1.5, 0.10$	1.52, 0.08	1.3, 0.07
Taylor response to output	r_y	G	$0.125, 0.05$	0.015, 0.004	0.01, 0.003
Interest rate smoothing	r_s	B	$0.75, 0.10$	0.28, 0.04	0.24, 0.05
Shocks: autoregressive parameters					
Technology neutral	ρ^A,	B	$0.5, 0.2$	0.98, 0.01	0.99, 0.004
Technology investment	ρ^q	B	$0.5, 0.2$	0.83, 0.02	0.85, 0.02
Monetary policy	ρ^R	B	$0.5, 0.2$	0.03, 0.02	0.22, 0.05
Preferences	ρ^p	B	$0.5, 0.2$	0.94, 0.02	0.88, 0.02
Labor supply	ρ^l	B	$0.5, 0.2$	0.62, 0.06	0.92, 0.04
Shocks: standard deviations					
Technology neutral	σ^A	IG	$0.01, 0.1$	0.01, 0.001	0.01, 0.001
Technology investment	σ^q	IG	$0.01, 0.1$	0.007, 0.001	0.007, 0.001
Monetary policy	σ^R	IG	$0.01, 0.1$	0.005, 0.001	0.005, 0.001
Preferences	σ^p	IG	$0.01, 0.1$	0.015, 0.002	0.009, 0.001
Labor supply	σ^l	IG	$0.01, 0.1$	0.057, 0.007	0.020, 0.001
Measurement error labor share	σ_{ls}	IG	$0.01, 0.1$	0.018, 0.002	0.024, 0.002

Table 5: Frictions Costs Implied by Estimation

	Specification	$\frac{g}{f}$		$\frac{g_I}{\frac{f}{K}}$		$\frac{g_H}{\frac{f}{N}}$	
		mean %	std. %	mean	std.	mean	std.
$\mathcal{M}_1$	both hiring and investment	2.4	0.13	0.84	0.067	0.23	0.021
$\mathcal{M}_2$	hiring costs only	1.6	0.05	–	–	0.24	0.021
$\mathcal{M}_3$	investment costs only	1.0	0.12	0.93	0.067	–	–

8 Measurement Equations

The same dataset as in Smets and Wouters. The data set ranges from 1966Q1 to 2007Q2.

$$\begin{aligned}\Delta \ln Cons_t \equiv \Delta \ln C_t &= \Delta \ln \tilde{C}_t + \Delta \ln A_t \\ &= \Delta \hat{c}_t + \ln \eta_t^A\end{aligned}$$

where

$$\ln \eta_t^A = \left(1 - \rho^A\right) \ln \eta^A + \rho^A \ln \eta_{t-1}^A + \varsigma_{t-1}^A,$$

The same applies to the GDP:

$$\Delta \ln GDP_t \equiv \Delta \ln Y_t = \Delta \hat{y}_t + \ln \eta_t^A$$

$$\Delta \ln Inv_t \equiv \Delta \ln I_t = \Delta \hat{\imath}_t + \ln \eta_t^A$$

$$\Delta W_t / P_t = \Delta \hat{w}_t^r + \ln \eta_t^A$$

All data are quarterly and in percent

Rescaling by 100..change prior for stdev

shocks on and off