The Importance of Hiring Frictions in Business Cycles

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Abstract

Hiring is a costly activity reflecting firms' investment in their workers. Because it generates disruption to production, cyclical fluctuations in the value of output, induced by the presence of price rigidities, have consequences for the optimal intertemporal allocation of hiring activities over the cycle. This mechanism generates strong propagation and amplification of all key macroeconomic variables in the responses to technology shocks and mutes the traditional transmission of monetary policy shocks. These results run counter to conventional arguments, whereby hiring frictions do not matter per se, but only insofar as they support bargaining setups conducive to wage rigidity. We highlight a new mechanism, implying that hiring frictions are as important as price frictions for the propagation of shocks over the business cycle.

Keywords: hiring as investment; intertemporal allocation; business cycles; confluence of hiring and price frictions; propagation and amplification.

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1 Introduction

Hiring is a costly activity, which reflects firms' investment in their workers, and entails disruption to production. Indeed, the literature, reviewed below, has provided microeconomic evidence showing that hiring involves output costs, stemming from the allocation of resources to hiring activities. The optimal allocation of these resources over the business cycle must reflect fluctuations in the (forgone) value of production. Namely, firms have an incentive to time the accumulation of their stock of workers to periods when the value of production is relatively low, and postpone hiring when this value is relatively high. In this paper, we show that such optimal intertemporal allocation engenders an important role for hiring frictions in business cycles.

This mechanism has been overlooked for two reasons. The canonical search and matching model of the labor market is a real model, which abstracts from price rigidities. As such, it does not give rise to fluctuations in the shadow value of production. This shadow value is instead a central element of New-Keynesian models, since it coincides in equilibrium with real marginal costs, or the inverse of the mark-up, the key determinant of inflation. But in the latter class of models, labor market frictions are typically modeled as third-party payments for hiring services. Hence, fluctuations in the shadow value of output have no bearing on the optimal allocation of hiring activities over the cycle.

We also note that a prevalent view states that wages are the key costs for firms, while hiring costs are small. Hence much attention in the business cycle literature is given to wage cyclicality, including issues of rigidity, while hiring costs are seen as a factor mitigating worker flows dynamics. Ultimately, hiring frictions are considered to be important for business cycles, only insofar as they as they support bargaining setups conducive to wage rigidity. Thus, they make room for privately efficient wage rigidities to matter and they do not play any direct meaningful role. We show that while hiring costs are indeed small, even quite moderate within the range of estimates in the literature, they interact with price frictions to generate substantial effects. Namely, we find that hiring frictions are an important source of propagation and amplification of technology shocks, that they play a key role in the transmission of monetary policy shocks, and that they endogenously dampen the response of real wages.

The mechanism we explore works as follows. Consider an expansionary TFP shock, which increases productivity and, everything else equal, output supply. If prices are sticky, they cannot drop and stimulate aggregate demand enough to restore equilibrium in the output market. This generates excess supply and hence a fall in the shadow price of output. In the textbook business cycle model with price frictions (the New Keynesian model), where the only use of labor is to produce output for sales, employment unambiguously falls to clear the market. In our model instead, workers can be used either to produce or to hire new workers. Because hiring involves a forgone cost of production, the fall in the afore-cited shadow price implies that it is more profitable to allocate resources to hiring. As a result, the firm substitutes future hiring for current hiring. The stronger the fall in the shadow price, the stronger the increase in hiring and the positive response of employment.

Now consider an expansionary monetary policy shock. This induces excess output demand, as prices do not increase enough to clear the market. Hence, the shadow price rises. In the textbook model, employment unambiguously increases to restore the equilibrium. In our model instead, the rise in the shadow price increases the cost of the marginal hire, dampening the incentives for hiring. Intuitively, putting resources into recruiting is less valuable at times when sales are more profitable. As a result, the firm substitutes current hiring for future hiring.

We note that a key feature that induces amplification in our model is the countercyclicality of marginal hiring costs conditional on technology shocks. This outcome is in sharp opposition to the procyclical marginal cost of hiring, due to aggregate labor market conditions, in the search and matching model. In that model, in good times aggregate vacancies rise, so vacancies become harder to fill and the cost of hiring increases. This mechanism dampens the propagation induced by the shadow value of output in our model too. However, empirical studies show that vacancy costs account only for a relatively small fraction of overall hiring costs. These studies unambiguously point to internal costs of hiring, such as training costs, as the dominant source of costs. Hence, the precise nature of hiring costs matters for propagation.

The mechanism presented here rests on the interaction between price and hiring frictions. While the empirical literature on price frictions has reached a relatively mature stage of development, empirical work that tries to measure hiring frictions in conjunction with price frictions is scant. This lacuna is all the more striking given the extensive empirical work on gross hiring flows (and other worker flows) by Davis and Haltiwanger and co-authors.[1] Much more work is needed for business cycle models to confidently rely on a specific calibration. In this paper we inspect how the transmission of shocks yields different outcomes allowing for both hiring frictions and price frictions, using a grid of plausible parameter values. This analysis shows that hiring frictions are just as important as price frictions for the propagation of shocks in business cycle models. At the same time, the macro modelling of labor market dynamics needs to recognize the important role played by price frictions in its interaction with hiring frictions. This interaction, or confluence of frictions, is key.

The paper is organized as follows. Section 2 reviews two issues in the literature: the formulation of hiring costs and the role of these costs in business cycles. Section 3 presents the baseline model with a minimal set of assumptions. Section 4 explores the mechanism using calibration and impulse response analysis. Section 5 provides further exploration, with a richer macroeconomic general equilibrium model, different forms of hiring frictions, and different parameterizations of the Taylor rule. It also examines the roles of exogenous and endogenous wage rigidity in the model. Section 6 concludes.

2 Literature

To understand the workings of the model and the importance of hiring costs in business cycles, we briefly review two strands of literature: the formulation of hiring costs in micro and macro

[1] Starting from their early work, Davis, Haltiwanger and Schuh (1996) and Davis and Haltiwanger (1999), and going up to the recent contribution in Davis and Haltiwanger (2014).

studies, and the role given to these costs in the current business cycle literature.

2.1 The Modelling of Hiring Frictions

Because our modelling of hiring frictions is key for the mechanism, we start with a brief review of the different approaches to hiring costs adopted in the literature and the related empirical evidence. Three distinctions regarding the hiring cost function matter for the current paper. One pertains to the nature of these costs – are the costs pecuniary, i.e., paid to other firms for the provision of hiring services, or rather production costs entailing a loss of output within the firm? A second relates to the arguments of the function – are these costs are related to actual hires, or related to aggregate labor market conditions, such as vacancy filling rates? A third pertains to the shape of the function.

The traditional search and matching literature relates to vacancy costs, in the form of pecuniary costs, and modelled as a linear function. This formulation was conceived for simplicity and tractability in a theoretical framework, such as the one presented in Pissarides (2000). It was not based on empirical evidence or formulated to make an empirical statement. In particular, it is part of a model that has a one worker-one firm set up. In this formulation, there is no meaning for costs rising in the hiring rate. If there were no effects of market conditions via the job filling rate, the optimal hiring condition would lack an endogenous variable relating to hiring.

Pecuniary costs paid to other agents vs output costs. In much of the macroeconomic literature that makes use of models with monopolistic competition, hiring costs are expressed in units of the final composite good, and contribute to aggregate GDP (see, among many others, Gertler, Sala, and Trigari (2008), Galí (2011), and Christiano, Eichenbaum, and Trabandt (2016)). As such, these costs can be interpreted as pecuniary payments to other firms for the provision of hiring services. However, the microeconomic evidence on hiring costs provides little indication of substantial hiring activities being outsourced to other firms or hiring costs being recorded in accounting books as third-party payments. Specifically, using personnel records of big US companies, Bartel (1995) and Krueger and Rouse (1998) find that the forgone cost of production related to training activities was much higher than pecuniary costs of training, such as expenses related to course material and external teachers salaries. The forgone cost of production is measured by them as the opportunity cost of work incurred by co-workers, managers, and the new hires themselves, in connection with recruitment or training activities.[2]In the same vein, the reviews in Silva and Toledo (2009) and Blatter et al (2016) compute hiring costs as forgone output. The latter study provides evidence of some expenses being incurred for external advisors/headhunters, but these costs are very small. Bartel, Beaulieu, Phibbs, and Stone (2014) find, studying a large hospital system, that the arrival of a new nurse in a hospital is associated with lowered team-productivity, and that this effect is significant only when the

[2]The opportunity costs of training are calculated from data on the salaries of the workers involved in these activities.

nurse is hired externally. Similarly, Cooper, Haltiwanger, and Willis (2015), using the Longitudinal Research Dataset on US manufacturing plants, find that labor adjustment costs reduce plant-level production. These results suggests that hiring disrupts the production process, generating a loss of output.

In this paper we model hiring costs in a way that accords with the evidence above, that is, as an opportunity cost of production.[3] This implies that in our model aggregate hiring costs take away from GDP rather than add to GDP. In Section 5 below we explore the implications of replacing output costs by pecuniary costs.

Cost of hires vs cost of vacancies Vacancy costs have been referred to as external costs of hiring as they depend on aggregate labor market conditions, i.e., on the ratio of aggregate vacancies to aggregate job seekers. This modeling of hiring costs is intended to capture the costs of recruitment, which encompass the cost of advertising vacancies, interviewing, and screening. Costs of actual hires have been defined in the literature as internal costs as they depend on firm-level conditions, namely the ratio of new hires to the workforce of the firm, i.e. the gross hiring rate. The underlying idea is that internal costs consist of training costs, including the time costs associated with learning how to operate capital. Costs may also be incurred in the implementation of new organizational structures within the firm and the introduction of new production techniques; for the latter, see Alexopoulos (2011) and Alexopoulos and Tombe (2012).

In a review of the microeconomic evidence, Manning (2011, p.982) writes that: "the bulk of these [hiring] costs are the costs associated with training newly-hired workers and raising them to the productivity of an experienced worker. The costs of recruiting activity are much smaller." Other reviews of the hiring costs literature, provided by Silva and Toledo (2009, Table 1), Blatter et al (2016, Table 1), and Mühlemann and Leiser (2018, in particular Tables 1 and 2), share the conclusions that internal costs are far more important than external costs. For instance, according to Silva and Toledo (2009), training costs are about ten times as large as recruiting costs. The bottom line of these microeconomic studies aligns well with conclusions based on macro estimates. Christiano, Trabandt, and Walentin (2011), using Bayesian estimation of a DSGE model of Sweden, conclude that "employment adjustment costs are a function of hiring rates, not vacancy posting rates." Sala, Soderstrom, and Trigari (2012) estimate external and internal costs for a number of countries including the US, the UK, Sweden and Germany. With the exception of Germany, internal costs account for most of the costs of hiring. In our modelling, we follow these results.

[3]There is a seminal and highly influential early macroeconomic literature on internal output costs, studying the accumulation of all factors of production. Key papers include Lucas (1967) and Mortensen (1973), who derived firm optimal behavior with convex adjustment costs for n factors of production. Mortensen's summary of Lucas (footnote 4 on p. 659), states that "Adjustment costs arise in the view of Lucas either because installation and planning involves the use of internal resources or because the firm is a monopsonist in its factor markets. Since Lucas rules out the possibility of interaction with the production process, the costs are either the value of certain perfectly variable resources used exclusively in the planning and installation processes or the premium which the firm must pay in order to obtain the factors at more rapid rates." Treadway (1971) considered (p.878) "the marginal internal cost of investment $(-f_{\dot{x}})$ arising from the current product "lost" due to the expansion activity of the firm." Lucas and Prescott (1971) embedded these convex adjustment costs in stochastic industry equilibrium.

It should be noted that a host of macroeconomic papers has estimated and/or used a formulation of costs related to actual hiring. See, for example, Yashiv (2000), Merz and Yashiv (2007), Gertler, Sala, and Trigari (2008), Gertler and Trigari (2009), Christiano, Trabandt and Walentin (2011), Sala, Soderstrom, and Trigari (2013), Yashiv (2016), Furlanetto and Groshenny (2016), Coles and Mortensen (2016), and Christiano, Eichenbaum and Trabandt (2016).

Quantitatively, moving away from the vacancy cost formulation allows us to inspect the effects of hiring costs under a broad spectrum of parameterizations. But while our benchmark model has costs relating only to the gross hiring rate, in Section 5 below we look at a more general specification, which encompasses also vacancy costs.

Functional form. Those cited papers which have used structural estimation (Yashiv (2000, 2016, 2018), Merz and Yashiv (2007), and Christiano, Trabandt, and Walentin (2011)) point to convex formulations as fitting the data better than linear ones. Blatter et al (2016, page 4) offer citations of additional studies indicating convexity of hiring costs. One can also rely on the theoretical justifications of King and Thomas (2006) and Khan and Thomas (2008) for convexity. Note, though, that for the mechanism delineated above, and explored below to operate qualitatively the precise degree of convexity in costs does not matter.

2.2 Hiring Frictions in Business Cycle Models

In current business cycle models, hiring frictions do not play a substantive *direct* role.

First, labor market frictions in the tradition of the Diamond, Mortensen, and Pissarides (DMP) model, have been found to play a negligible direct role in explaining business cycle fluctuations. In a survey of the literature, Rogerson and Shimer (2011) conclude that, by acting like a labor adjustment cost, search frictions dampen the volatility of employment. If anything then, they exacerbate the difficulties of the frictionless New Classical (NC) paradigm to account for the cyclical behavior of the labor market. These models typically abstract from price frictions, emphasized by the canonical New Keynesian (NK) approach.

Second, when labor market frictions, as modelled in DMP have been explicitly incorporated within NK models, they still do not contribute directly to the explanation of business cycles. In particular, the propagation of shocks is virtually unaffected by the presence of these frictions (see, for example, Galí (2011)). Frictions in the labor market have been found to be important, but only *indirectly*. They create a match surplus, allowing for privately efficient wage setting that involves wage stickiness, which, in turn, has business cycle implications. Prominent contributions to this type of analysis include Gertler and Trigari (2009) and Christiano, Eichenbaum, and Trabandt (2016). While we do not argue against this latter channel of effects, the current paper proposes a mechanism, overlooked by these strands of literature. The model here features output costs of hires, as discussed in the preceding sub-section, which imply a substantial *direct* role for hiring frictions, as they interact with price frictions.

3 The Model

The model features two frictions: price adjustment costs and costs of hiring workers. Absent both frictions, the model boils down to the benchmark New Classical model with labor and capital. Following the Real Business Cycle tradition, capital is included because it plays a key role in producing a positive response of employment to productivity shocks.[4] Introducing price frictions into the otherwise frictionless model yields the New Keynesian benchmark, and introducing hiring frictions into the NK benchmark allows us to analyze how the interplay between these frictions affects the propagation of technology and monetary policy shocks.

In this section, and in order to focus on the above interplay, our modeling strategy deliberately abstracts from all other frictions and features that are prevalent in general equilibrium models and which are typically introduced to enhance propagation and improve statistical fit, namely, habits in consumption, investment adjustment costs, exogenous wage rigidities, etc. In Section 5 below we examine the robustness of our results with respect to such modifications.

3.1 Households

The representative household comprises a unit measure of workers who, at the end of each time period, can be either employed or unemployed: $N_t + U_t = 1$. We therefore abstract from participation decisions, on the job search and from variation of hours worked on the intensive margin.[5] The household enjoys utility from the aggregate consumption index C_t, reflecting the assumption of full-consumption sharing among the household's members. In addition, the household derives disutility from the fraction of household members who are employed, N_t. It can save by either purchasing zero-coupon government bonds, at the discounted value $\frac{B_{t+1}}{R_t}$, or by investing in physical capital, K_t. The latter evolves according to the law of motion:

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

where it is assumed that the existing capital stock depreciates at the rate δ_K and is augmented by new investment I_t. We further assume that both consumption and investment are purchases of the same composite good, which has price P_t. The household earns nominal wages W_t from the workers employed, and receives nominal proceeds $X_t^K K_{t-1}$ from renting physical capital to the firms. The budget constraint is:

$$P_tC_t + P_tI_t + \frac{B_{t+1}}{R_t} = W_tN_t + X_t^K K_{t-1} + B_t + \Omega_t - T_t, \tag{2}$$

[4]With standard logarithmic preferences over consumption, and labor as the only input of production, income and substitution effects cancel out and a NC model with or without hiring frictions would not produce any change in employment or unemployment to productivity shocks (see Blanchard and Gali (2010)).

[5]Rogerson and Shimer (2011) have shown that most of the fluctuations in US total hours worked at business cycle frequencies are driven by the extensive margin, so our model deliberately abstracts from other margins of variation. For a theory of how on-the-job search affects real marginal costs (and inflation) see Moscarini and Postel-Vinay (2017).

where $R_t = (1 + i_t)$ is the gross nominal interest rate on bonds, Ω_t denotes dividends from ownership of firms, and T_t lump sum taxes.

The labor market is frictional and workers who are unemployed at the beginning of the period are denoted by U_t^0. It is assumed that these workers can start working in the same period if they find a job with probability $x_t = \frac{H_t}{U_t^0}$, where H_t denotes the total number of new hires. It follows that the workers who remain unemployed for the rest of the period, denoted by U_t, is $U_t = (1 - x_t)U_t^0$. Consequently, the evolution of aggregate employment N_t is:

$$N_t = (1 - \delta_N)N_{t-1} + x_t U_t^0, \tag{3}$$

where δ_N is the separation rate.

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

$$\max_{\{C_{t+j}, I_{t+j}, B_{t+j+1}\}_{j=0}^{\infty}} E_t \sum_{j=0}^{\infty} \beta^j \left(\ln C_{t+j} - \frac{\chi}{1+\varphi} N_{t+j}^{1+\varphi} \right), \tag{4}$$

subject to the budget constraint (2), and the laws of motion for employment, in equation (3), and capital, in equation (1). The parameter $\beta \in (0, 1)$ denotes the discount factor, φ is the inverse Frisch elasticity of labor supply, and χ is a scale parameter governing the disutility of work.

The solution to the intertemporal problem of the household yields the standard Euler equation:

$$\frac{1}{R_t} = \beta E_t \frac{P_t C_t}{P_{t+1} C_{t+1}}, \tag{5}$$

an equation characterizing optimal investment decisions:

$$1 = E_t \Lambda_{t,t+1} \left[\frac{X_{t+1}^K}{P_{t+1}} + (1 - \delta_K) \right], \tag{6}$$

where $\Lambda_{t,t+1} = \beta \frac{C_t}{C_{t+1}}$ denotes the real discount factor, and an asset pricing equation for the marginal value of a job to the household,

$$V_t^N = \frac{W_t}{P_t} - \chi N_t^{\varphi} C_t - \frac{x_t}{1 - x_t} V_t^N + (1 - \delta_N) E_t \Lambda_{t,t+1} V_{t+1}^N, \tag{7}$$

where V_t^N is the Lagrange multiplier associated with the employment law of motion. It represent the marginal value to the household of having an unemployed worker turning employed at the beginning of the period. Equation (6) equalizes the cost of one unit of capital to the discounted value of the expected rental rate plus the continuation value of future undepreciated capital. The value of a job, V_t^N in equation (7), is equal to the real wage, net of the opportunity cost of work, $\chi N_t^{\varphi} C_t$, and the re-employment value for unemployed workers,[6] plus a continu-

[6] A worker unemployed at the beginning of the period would become employed at the end of the period with probability x_t, in which case the household would get a net payoff of V_l^N. The term $1 - x_t$ at the denominator is a

ation value. It is worth noting that relative to the DMP model, where the opportunity cost of work is assumed to be constant, deriving the net value of employment from a standard problem of the households implies that this opportunity cost equals the marginal rate of substitution between consumption and leisure. As we show later, this feature of the model endogenously dampens the response of real wages in the presence of hiring frictions.

3.2 Firms

3.2.1 Intermediate and final good firms

We assume two types of firms: intermediate good producers and final good producers. Both firms have a unit measure. Intermediate firms, indexed by i, produce a differentiated good $Y_{t,i}$ using labor and capital as inputs of production. At the beginning of each period, capital is rented from the households at the competitive rental rate X_t^K, and workers are hired in a frictional market. Next, wages are negotiated. When setting the price $P_{t,i}$ under monopolistic competition, the representative intermediate firm faces price frictions à la Rotemberg (1982). This means that firms face quadratic price adjustment costs, given by $\frac{\zeta}{2}\left(\frac{P_{t+s,i}}{P_{t+s-1,i}}-1\right)^2 Y_{t+s}$, where ζ is a parameter that governs the degree of price rigidity, and Y_t denotes aggregate output. The latter is produced by final good firms as a bundle of all the intermediate goods in the economy, and is sold to the households in perfect competition. Specifically, this aggregate output good, which is used for consumption and investment, is a Dixit-Stiglitz aggregator of all the differentiated goods produced in the economy, $Y_t = \left(\int_0^1 Y_{t,i}{}^{(\epsilon-1)/\epsilon} di\right)^{\epsilon/(\epsilon-1)}$, where ϵ denotes the elasticity of substitution across goods. The price index associated with this composite output good is $P_t = \left(\int_0^1 P_{t,i}{}^{1-\epsilon} di\right)^{1/(1-\epsilon)}$, and the demand for the intermediate good i is:

$$Y_{t,i} = \left(\frac{P_{t,i}}{P_t}\right)^{-\epsilon} Y_t. \tag{8}$$

3.2.2 Hiring Frictions

We assume that the net output of a representative firm i at time t is:

$$Y_{t,i} = f_{t,i}\left(1-\tilde{g}_{t,i}\right), \tag{9}$$

where $f(A_t, N_{t,i}, \check{K}_{t,i}) = A_t N_{t,i}^{\alpha} K_{t,i}^{1-\alpha}$, is a Cobb Douglas production function in which $K_{t,i}$ denotes capital, and A_t is a standard TFP shock that follows the stochastic process $lnA_t = \rho_a lnA_{t-1} + e_t^a$, with $e_t^a \sim N(0, \sigma_a)$.

The term $\tilde{g}_{t,i}$ denotes the fraction of output that is lost due to hiring activities. In Sub-Section 2.1 above we have reviewed the literature on these hiring frictions. The formulation proposed here follows the substantial microeconomic evidence reviewed above. The explicit functional

rescaling coming from the relation between beginning- and end-of-period unemployment $U_{0,t} = \frac{U_t}{1-x_t}$.

form for these costs follows previous work by Merz and Yashiv (2007), Gertler Sala and Trigari (2008), Gertler and Trigari (2009), Christiano, Trabandt, and Walentin (2011), Sala, Soderstrom, and Trigari (2013), and Furlanetto and Groshenny (2016). All these studies assume that these costs are a quadratic function of the hiring rate, i.e. the ratio of new gross hires to the workforce, $\frac{H_{t,i}}{N_{t,i}}$:

$$\tilde{g}_{t,i} = \frac{e}{2}\left(\frac{H_{t,i}}{N_{t,i}}\right)^2, \tag{10}$$

where $e > 0$ is a scale parameter.[7]

Note that this specification captures the idea that frictions or costs increase with the extent of hiring, relative to the size of the firm. The intuition is that hiring 10 workers implies different levels of hiring activity for firms with 100 workers or with 10,000 workers. Following Garibaldi and Moen (2009) we can state this logic: each worker i makes a recruiting and training effort h_i; with convexity it is optimal to spread out the efforts equally across workers so $h_i = \frac{h}{n}$; formulating costs as a function of these efforts and putting them in terms of output per worker one gets $c\left(\frac{h}{n}\right)\frac{f}{n}$; as n workers do it then the aggregate cost function is given by $c\left(\frac{h}{n}\right) f$.

In the simple model presented here we restrict attention to internal costs of hiring only, excluding vacancy costs. We interpret hiring costs as those associated with investment activities, such as training costs. In Section 5 we will introduce both costs and investigate their separate role.

We emphasize that the functional form above is rather standard. The main deviation from the literature is the assumption that hiring costs are not pecuniary, that is, they are not purchases of the composite good, which has price P_t, but a disruption to production or equivalently, forgone output at the level of the firm i. See, again, the evidence cited in Section 2.

3.2.3 Optimal Behavior

Intermediate firms maximize current and expected discounted profits:

$$\max_{\{P_{t+s,i}, H_{t+s,i}, K_{t+s,i}\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \begin{array}{c} \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s}}{P_{t+s}} N_{t+s,i} - \frac{X^K_{t+s}}{P_{t+s}} K_{t+s,i} \\ -\frac{\zeta}{2}\left(\frac{P_{t+s,i}}{P_{t+s-1,i}} - 1\right)^2 Y_{t+s} \end{array} \right\}, \tag{11}$$

substituting for $Y_{t+s,i}$ using the demand function (8), and subject to the law of motion for labor (12),

$$N_{t,i} = (1-\delta_N)N_{t-1,i} + H_{t,i}, \quad 0 < \delta_N < 1, \tag{12}$$

[7] We could have alternatively assumed a production function given by $f_{i,t} = a_t \left[N_{i,t} - g\left(\frac{H_{i,t}}{N_{i,t}}\right)\right]^{\alpha} K_{i,t}^{1-\alpha}$, where the hiring cost function is specified as a labor cost. We have run the model with this alternative formulation and verifed that it gives rise to the same mechanism. This is not surprising, because this formulation indirectly implies that hiring carries a disruption in production. We therefore stick to the production function in eq.(9) so as to minimize deviations from the literature.

and the constraint that output must equal demand:

$$\left(\frac{P_{t,i}}{P_t}\right)^{-\epsilon} Y_t = f_{it}\left(1 - \tilde{g}_{it}\right), \tag{13}$$

which is obtained by combining equations (8) and (9).

Imposing symmetry, the first order condition with respect to $P_{t,i}$ yields the standard New Keynesian Phillips curve:

$$\pi_t(1+\pi_t) = \frac{1-\varepsilon}{\zeta} + \frac{\varepsilon}{\zeta}\Psi_t + E_t\Lambda_{t,t+1}\left(1+\pi_{t+1}\right)\pi_{t+1}\frac{Y_{t+1}}{Y_t}, \tag{14}$$

where Ψ_t is the Lagrange multiplier associated with the constraint (13), and which we have called the shadow price or value of output. It represents the real marginal revenue, which in equilibrium equals the real marginal cost and will play an important role in the transmission of shocks. Equation (14) specifies that inflation depends on this real marginal cost as well as expected future inflation.[8]

The first-order conditions with respect to H_t, N_t and K_t, are:

$$Q_t^N = \Psi_t\left(f_{N,t} - g_{N,t}\right) - \frac{W_t}{P_t} + (1-\delta_N)E_t\Lambda_{t,t+1}Q_{t+1}^N, \tag{15}$$

$$Q_t^N = \Psi_t g_{H,t}, \tag{16}$$

$$\frac{X_t^K}{P_t} = \Psi_t\left(f_{K,t} - g_{K,t}\right), \tag{17}$$

where Q_t^N is the Lagrange multiplier associated with the employment law of motion, and $f_{Z,t}, g_{Z,t}$, denote the derivatives of the functions f_t and $g_t \equiv \tilde{g}_t f_t$ with respect to variable Z, respectively. One can label Q_t^N as Tobin's Q for labor or the value of the job. We notice that the value of a marginal job in equation (15) can be expressed as the sum of current-period profits – the marginal revenue product $\Psi_t\left(f_{N,t} - g_{N,t}\right)$ less the real wage $\frac{W_t}{P_t}$ – and a continuation value. In equation (16), the value of jobs is equated to the real marginal cost of hiring $\Psi_t g_{H,t}$. Note that because hiring entails a forgone cost of production, the marginal hiring cost depends on the shadow price Ψ_t. Finally, the rental cost of capital on the LHS of equation (17) is equated to the marginal revenue product of capital $\Psi_t\left(f_{K,t} - g_{K,t}\right)$.

Solving the F.O.C. for employment in equation (15) for Ψ_t, and eliminating Q_t^N using (16) we get:

$$\Psi_t = \frac{\frac{W_t}{P_t}}{f_{N,t} - g_{N,t}} + \frac{\Psi_t g_{H,t} - (1-\delta_N)E_t\Lambda_{t,t+1}\Psi_{t+1}g_{H,t+1}}{f_{N,t} - g_{N,t}}, \tag{18}$$

which shows that the marginal revenue Ψ_t is equalized to the real marginal cost (on the RHS). The first term on the RHS is the wage component of the real marginal cost, expressed as the ratio of real wages to the net marginal product of labor. The second term shows that with

[8]For the role of real marginal costs in inflation dynamics see Woodford (2003), Giannoni and Woodford (2005), and Sbordone (2005).

frictions in the labor market, the real marginal cost also depends on expected changes in the real marginal costs of hiring. So, for instance, an expected increase in marginal hiring costs $E_t\Lambda_{t,t+1}\Psi_{t+1}g_{H,t+1}$ translates into a lower current real marginal cost, reflecting the savings of future recruitment costs that can be achieved by recruiting in the current period. The dynamics of Ψ_t given by equation (18) play a big role in the mechanism below.

3.3 Wage Bargaining

We posit that hiring costs are sunk for the purpose of wage bargaining. This follows the standard approach in the literature; see, for example, Gertler, Sala, and Trigari (2008), Pissarides (2009), Christiano, Trabandt and Walentin (2011), Sala, Soderstrom and Trigari (2012), Furlanetto and Groeshny (2016), and Christiano, Eichenbaum, and Trabandt (2016).

Wages are therefore 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:[9]

$$W_t = \arg\max \left\{ \left(V_t^N\right)^{\gamma} \left(Q_t^N\right)^{1-\gamma} \right\}. \tag{19}$$

The solution to this problem is a standard wage equation:

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

3.4 The Monetary and Fiscal Authorities and Market Clearing

We assume that the government runs a balanced budget:

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

and the monetary authority sets the nominal interest rate following the Taylor rule:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\rho_r}\left[\left(\frac{1+\pi_t}{1+\pi^*}\right)^{r_\pi}\left(\frac{Y_t}{Y^*}\right)^{r_y}\right]^{1-\rho_r}\xi_t, \tag{22}$$

where π_t measures the rate of inflation of the aggregate good, i.e., $\pi_t = \frac{P_t - P_{t-1}}{P_t}$, and an asterisk superscript denotes the steady-state values of the associated variables. When linearizing the model around the stationary equilibrium we will assume that $\pi^* = 0$. The parameter ρ_r 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 ξ_t captures a monetary policy shock, which is assumed to follow the autoregressive process $ln\xi_t = \rho_\xi ln\xi_{t-1} + e_t^{\xi}$, with $e_t^{\xi} \sim N(0, \sigma_\xi)$.

[9] We have solved a version of the model that allows for intrafirm bargaining as in Brugemann, Gautier and Menzio (2018). We found that intrafirm bargaining amplifies the mechanism discussed in the following sections (see Faccini and Yashiv (2017) for specific results). For the sake of simplicity and comparability with the richer model presented in Section 5, we simplify along this dimension.

Consolidating the households and the government budget constraints, and substituting for the firm profits yields the market clearing condition:

$$(f_t - g_t)\left[1 - \frac{\zeta}{2}\pi_t^2\right] = C_t + I_t. \tag{23}$$

Finally, clearing in the market for capital implies that the capital demanded by the firms equals the capital supplied by the households, $\int_{i=0}^{1} K_{t,i}di = \int_{j=0}^{1} K_{t-1,j}dj$, where i and j index firms and households, respectively.

4 The Mechanism

This section presents the calibration of the model and inspects the mechanism by showing impulse responses. We linearize the model around the non-stochastic steady state, provide a benchmark calibration for the model with both hiring and price frictions, and then investigate how the impulse responses of key macroeconomic variables change as we vary the degree of the two frictions. In what follows we look at both technology and monetary policy shocks.

4.1 Calibration

Parameter values are set so that the steady-state equilibrium of our model matches key averages of the 1976Q1-2014Q4 U.S. economy, assuming that one period of time equals one quarter. We start by discussing the parameter values that affect the stationary equilibrium.

Table 1

The discount factor β equals 0.99 implying a quarterly interest rate of 1%. The quarterly job separation rate δ_N, measuring separations from employment into either unemployment or inactivity, is set at 0.126, and the capital depreciation rate δ_K is set at 0.024. These parameters are selected to match the hiring to employment ratio, and the investment to capital ratio measured in the US economy over the period 1976Q1-2014Q4 (see Appendix B in Yashiv (2016) for details on the computations of these series).

The inverse Frisch elasticity φ is set equal to 4, in line with the synthesis of micro evidence reported by Chetty et al. (2013), pointing to Frisch elasticities around 0.25 on the extensive margin.[10] 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). Finally, the scale parameter χ in the utility function is normalized to equal 1 and the elasticity of output to the labor input α is set to 0.66 to match a labor share of income of about two thirds.

[10]We calibrate φ to reflect estimates of the Frisch elasticity on the extensive margin only for consistency with the model, which does not feature an intensive margin. We have checked that the precise value of the Frisch elasticity parameter is not important for the mechanism discussed here.

This leaves us with two parameters to calibrate: the bargaining power γ, and the scale parameter in the hiring costs function e. These two parameters are calibrated to match: i) a ratio of marginal hiring costs to the average product of labor, $\frac{g_H}{\frac{f-g}{N}}$, equal to 0.20 reflecting estimates by Yashiv (2016); ii) An unemployment rate of 10.6%. This value is the average of the time series for expanded unemployment rates (U-6) produced by the BLS, and is consistent with our measure of the separation rate. This unemployment rate includes the officially unemployed, as well as other searching workers, or those available for work, beyond the latter pool. We also note that the calibration implies a ratio of the opportunity cost of work to the marginal revenue product of labor of 0.72, which turns out to be close to the value of 0.745 advocated by Costain and Reiter (2008).

Following our discussion in Section 2, hiring costs are to be interpreted in terms of training costs as well as all other sources of forgone output associated with hiring. This calibration of hiring costs is intentionally conservative in the sense that the costs are at the lower bound of the spectrum of estimates reported in the literature. Thus, our calibration engenders the following moderate costs: in terms of total costs, $\frac{g}{f-g}$, we get 1.3% of output; in terms of average costs, while Silva and Toledo (2009) show that training costs are equivalent to 55% of quarterly wages,[11] we get that they are 17% of quarterly wages ($\frac{\frac{g}{H}\Psi}{\frac{W}{P}} \simeq 2$ weeks of wages); in terms of marginal costs, on which we focus in our discussion below, $\frac{\Psi \cdot g_{Ht}}{W/P}$, we get, at the steady state, 30% of quarterly wages, i.e., less than one month of wages.[12]

Turning to the remaining parameters that have no impact on the stationary equilibrium, we set the Taylor rule coefficients governing the response to inflation and output to 1.5 and 0.125, respectively, as in Galí (2011), while the degree of interest rate smoothing captured by the parameter ρ_r is set to the conventional value of 0.75 as in Smets and Wouters (2007).

The Rotemberg parameter governing price stickiness is set to 120, to match a slope of the Phillips curve of about 0.08, as implied by Galí's (2011) calibration.[13] As for the technology shocks, we assume an autocorrelation coefficient $\rho_a = 0.95$, while monetary policy shocks are assumed to be i.i.d.

4.2 Exploring the Mechanism

In order to explore the mechanism we look at the effect upon impact of technology shocks and of monetary policy shocks. We do so across different parameterizations of hiring and price

[11] This figure is nearly ten times as large as that of vacancy posting costs. The papers of Krause, Lopez-Salido and Lubik (2008) and Galí (2011) assume that average vacancy costs equal to around 5% of quarterly wages, following empirical evidence by Silva and Toledo (2009) on vacancy advertisement costs.

[12] The hiring rate H_t/N_t in the data lies in the interval $[0.110, 0.152]$ in the period 1976Q1-2014Q4. Hence the implied ratio of $\frac{\Psi \cdot g_{Ht}}{W/P}$, using our calibration values, ranges between 24% and 33% of quarterly wages. This represents relatively little variation and an upper bound that is well below the training costs found in the literature. This exercise also shows that the convexity assumed in the hiring cost function (10) is mild.

[13] Our value for ζ is obtained by matching the same slope of the linearized Phillips Curve as in Gali: $\frac{\varepsilon-1}{\zeta} = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$, where θ_p is the Calvo parameter. Notice that for given values of ϵ and β, this equation implies a unique mapping between θ_p and ζ. Hence, while Gali (2011) assumes Calvo pricing frictions, with $\theta_p = 0.75$, we adopt Rotemberg pricing frictions, which implies that in our specification prices are effectively reset every quarter.

frictions, in order to illustrate the interaction produced by these two frictions and to provide intuition.

For each shock we plot the response of four variables: hiring rates, investment rates, real wages, and output. Using 3D graphs, for each variable we look at how the response on impact changes as we change the parameters governing price frictions, ζ, and hiring frictions, e. All other parameter values remain fixed at the calibrated values reported in Table 1. The impulse responses obtained over the full horizon will be presented in Section 5 for a richer version of the model.[14] The impulse responses are reported in Figures 1 and 2.

Figures 1 and 2

The area colored in blue (red) denotes the pairs of (ζ, e) for which the impact response is positive (negative). The price stickiness parameter $\zeta \in (0, 150]$ covers values of price rigidity that range from full flexibility to considerable stickiness, whereby the upper bound of 150, in Calvo space would correspond to an average frequency of price negotiations of four-and-a-half quarters. The hiring frictions parameter $e \in (0, 5.5]$ ranges from the frictionless benchmark to a value of average hiring costs equal to seven weeks of wages, somewhat above the estimate implied by the evidence in Silva and Toledo (2009).

For expositional convenience, we mark with colored points in the figure five reference points, which correspond to the following five model variants: (i) the NC model with no frictions obtained by setting $\zeta \simeq 0$ and $e \simeq 0$ (black point); (ii) the NC model with hiring costs; this is obtained by setting a level of price frictions close to zero, i.e. $\zeta \simeq 0$, while maintaining hiring frictions as in the baseline calibration (blue point); (iii) the standard NK model obtained by maintaining a high degree of price frictions, i.e. $\zeta = 120$, but setting hiring costs close to zero, i.e. $e \simeq 0$ (red point); (iv) the NK model embodying price frictions together with hiring frictions as calibrated in Table 1 (green point); (v) finally, a NK model with a higher scale of hiring frictions, corresponding to the estimate in Silva and Toledo (2009), $e = 5$ and $\zeta = 120$ (orange point).[15]

We emphasize that while we indicate five points in this space, corresponding to the aforecited model variants, these serve as reference points, and the graphs offer a "bigger picture".

Technology Shocks To see the mechanism, it is useful to go through the five model variants reference points. Starting from the NC case, the black point, where both price and hiring frictions are shut down, the model delivers the standard results, whereby a technology shock increases hiring and employment, investment, real wages and output (see the black points in Figure 1). Adding hiring frictions to this frictionless benchmark, i.e., moving from the black

[14]The very simple model presented here lacks propagation and hence some key differences in the impulse responses across the different versions of the model are only visible on impact. For a discussion of impulse responses of the simple model over the full horizon see Faccini and Yashiv (2017), Appendix B.

[15]When shutting down price and hiring frictions we set $\zeta \simeq 0$ and/or $e \simeq 0$. This is close to zero and not exactly equal to zero for ease of exposition, as at 0 there are discontinuities. Solving the model using exactly 0 shows the same qualitative pattern reported in Figures 3 and 4 below. Hence we abstract from this minor complication for illustrative purposes.

to the blue points, results in relatively small changes, which reflect the moderate size of hiring frictions. The responses appear somewhat smoothed by the presence of hiring frictions, recovering the conclusions of DMP-based analyses that hiring frictions operate as an adjustment cost, thereby exacerbating the difficulties of the standard NC model to account for the cyclical behavior of the labor market.

Adding price frictions to the NC model, i.e. moving from the black to the red point, recovers the standard NK results that hiring and employment fall on the impact of technology shocks, reversing the standard NC results. Because of the complementarities in the production function investment also falls, and output increases less. The reason for these results is well known: in the NK model, an expansionary technology shock generates excess output supply as firms cannot freely lower prices to stimulate demand. The only way to restore equilibrium in the output market is that employment falls.

Adding hiring frictions to the NK model, that is, moving from the red point to the right along the e-axis generates very substantial differences. Increasing hiring frictions, gradually reduces the fall in employment, and eventually turns the response of employment from negative to positive. In the case represented by the green point, where hiring frictions are calibrated to the lower-bound of the estimates for internal costs of hiring reported by the literature, the hiring rate – and therefore employment – still falls, though much less than in the standard NK model. For higher, but still plausible values of hiring costs (orange point), employment increases. Notably, in this case the response of employment is stronger than in the NC benchmark, which shows that the interaction between price and hiring frictions generates amplification in the response of labor market outcomes.

Formally, consider the optimal hiring condition, obtained by merging the FOCs for hiring and employment in equations (15) and (16), eliminating Q_t^N:

$$\Psi_t \left(f_{N,t} - g_{N,t} \right) - \frac{W_t}{P_t} + (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N = \Psi_t g_{H,t}. \tag{24}$$

The left hand side of the above expression represents the profits of the marginal hire, and the right hand side the costs. With flexible prices, the shadow price Ψ_t is constant and the propagation of technology shocks operates in the standard way, by generating amplification in profits through the marginal product of labor (see the black point in Figure 1). Namely, an expansionary TFP shock raises the term $f_{N,t} - g_{N,t}$, leading to an increase in job creation. But with price rigidity, the propagation is also affected by the endogenous response of the shadow price Ψ_t, which falls in the wake of an expansionary technology shock. Because Ψ_t appears both on the LHS and on the RHS of the job creation condition (24), the partial effect of changes in shadow price on job creation is ambiguous. To resolve this ambiguity, note that

$$\frac{\partial \left(\Psi_t g_{H,t} \right)}{\partial \Psi_t} = g_{H,t} = e \frac{H_t}{N_t} \frac{f_t}{N_t} = \frac{Q_t^N}{\Psi_t}, \tag{25}$$

where the second equality follows from substituting the explicit functional form for $\tilde{g}_t$ in equation (10) and the third equality follows from the FOC in equation (16), which implies that

$Q_t^N = g_{H,t}\Psi_t$.

The role of the shadow price Ψ_t is key and in the next Section we elaborate more on it using quantitative analysis. Qualitatively, note that equation (25) shows that the sensitivity of marginal hiring costs $\Psi_t g_{H,t}$ to the shadow price Ψ_t depends on the scale of hiring frictions. For very low values of e, the marginal cost of hiring is virtually unaffected by the shadow price. This limit case recovers the standard New Keynesian result, whereby employment falls following an expansionary technology shock (red point in Figure 1). But as the scale of hiring frictions increases, the fall in marginal hiring costs, induced by the fall in Ψ_t, makes employment fall by less (green point in Figure 1). Eventually, beyond a certain threshold the response of the hiring rate – and therefore employment – turns positive and for sufficiently large values of e may even be stronger than in the NC case (orange point in Figure 1).

What drives this amplification is the countercyclical behavior of marginal hiring costs engendered by the endogenous fluctuations in the shadow price. Notice that this result marks an important difference relative to the standard DMP model, where marginal hiring costs are procyclical conditional on technology shocks. Indeed, in the DMP model an increase in vacancies leads to a fall in the vacancy filling rate, and hence to an increase in vacancy duration and costs.

An essential intuition of the mechanism here is the following. In standard business cycle models, the only use of employment is to produce output for sales. In our model instead, workers can be used either to produce or hire new workers. The latter hiring activity is, in essence, an investment activity in workers. Because it involves a forgone cost of production, a fall in the shadow price with the productivity shock implies a fall in this cost, so that it becomes more profitable to move hiring to the current period. The increase in employment with hiring frictions induces a stronger increase in investment (in capital) and in output.

As for wages, hiring frictions endogenously mitigate their fall. Indeed, in the NK model with a frictionless labor market real wages fall, as the marginal revenue product falls. Here, hiring frictions, by sustaining employment, also raise the opportunity cost of work, $\chi C_t N_t^{\varphi}$ in equation (20). This increase in the workers' threat point in wage negotiations endogenously leads to a lower fall in their wages.

In the next Section we elaborate on the role of internal vs external costs, and on pecuniary vs output costs, and show how the mechanism presented here is affected by changing the hiring costs formulations.

Monetary Policy Shocks Turning to monetary policy shocks in Figure 2, the impulse responses show that in the absence of price frictions, monetary policy is neutral, independently of labor market frictions (compare the black and blue points). In the NK benchmark instead (red point), the monetary policy shock has real effects, which lead to an increase in employment, investment, output and real wages. Most importantly, increasing hiring frictions (higher e) in the presence of price frictions offsets the expansionary effects of monetary policy shocks. At the lower bound of estimates for hiring costs (low e, green point), the effects of monetary shocks are small. For higher, but still reasonable levels of hiring frictions (orange point), output, employment and investment can even fall on the impact of an expansionary shock. In between these two points, there is an area of frictions costs for which key macroeconomic aggregates virtually do not respond to monetary policy shocks.[16]

The reason why hiring frictions offset the standard NK propagation mechanism is that the rise in aggregate demand that follows an expansionary monetary policy shock, induces an increase in the shadow price. Because hiring implies foregoing production, the marginal cost of hiring increases (RHS of equation (24) rises), dampening the incentives for job creation. Intuitively, diverting resources from production into recruiting is less attractive at times where sales are more profitable. Hence, firms have an incentive to postpone their investment in hiring.

As shown by equation (25), the marginal cost of hiring becomes more sensitive to changes in the shadow price as the scale of the hiring cost function increases. Hence, if hiring frictions are strong enough, employment may even fall on the impact of an expansionary monetary policy shock, leading to a contraction in investment and output. We also notice that the response of real wages is endogenously smoothed when hiring frictions are introduced into the baseline NK model. The reason is that hiring frictions make employment increase by less, dampening the increase in the opportunity cost of work, and thereby lowering the workers' threat point in wage negotiations.

We conclude that hiring frictions matter substantially in the transmission of both technology and monetary policy shocks.

5 Further Explorations

In this section we provide further explorations of the model and its mechanism. Sub-Section 5.1 presents an extended model, which is essentially a medium-scale general equilibrium model, catering for a richer framework. Sub-Section 5.2 presents the full impulse response functions of this extended model, revisiting the mechanism discussed above. Two sub-sections then examine the role of our formulation of hiring costs: in 5.3 we look at internal vs external costs and in 5.4 we look at output costs vs pecuniary costs. Sub-Section 5.5 looks at the role of wages in our framework, and in particular endogenous and exogenous wage rigidity. Finally Sub-Section 5.6 reports on the robustness of the results to variations in the Taylor rule.

5.1 The Extended Model

The model laid-out in Section 3 is relatively simple and abstracts from various features that are prevalent in medium-scale general equilibrium models. The simplicity of that model was necessary to obtain monotone effects of hiring and price frictions, which are visible in Figures

[16] These results are reminescent of Head, Liu, Menzio, and Wright (2012), who develop a new-monetarist model where prices are sticky, and yet money is neutral. They conclude that nominal rigidities do not necessarily imply that policy can exploit these rigidities. We show that similar conclusions can be derived within a standard New Keynesian framework augmented with hiring frictions. An alternative dampening mechanism for the transmission of monetary policy shocks is provided by Melosi (2017), who shows that if economic agents are imperfectly informed about the state of the economy, monetary policy acts as a signalling device, hindering the transmission of the shocks to real variables.

1 and 2, helping with the exposition of the mechanism. On the other hand, one may wonder whether the results discussed above are robust to the inclusion of a richer set of assumptions including in particular the conventional modelling of a matching function and vacancy posting costs. In this sub-section we add these elements to the simple model of Section 3 together with investment adjustment costs (see Christiano, Eichenbaum, and Trabandt (2016)), external habits in consumption, exogenous wage rigidity, trend inflation and indexation to past inflation. We do not aim to produce a fully-fledged model that should be considered as our best characterization of the actual US economy; rather, we want to show that the effects generated by internal hiring frictions remain important even in a richer model. Because most of these modelling ingredients are standard, we relegate the full description of the model to the Appendix. Here we only spell out those changes that pertain to the labor market.

We now assume that in the labor market, unemployed workers and vacancies come together through the constant returns to scale matching function

$$H_t = \frac{U_{0,t} V_t}{\left(U_{0,t}^l + V_t^l\right)^{\frac{1}{l}}}, \tag{26}$$

where H_t denotes the number of matches, or hires, V_t aggregate vacancies, $U_{0,t}$ the aggregate measure of workers who are unemployed at the beginning of each period t, and l is a parameter. This matching function was used by Den Haan, Ramey, and Watson (2000) and ensures that the matching rates for both workers and firms are bounded above by one. We denote the job finding rate by $x_t = \frac{H_t}{U_{0,t}}$ and the vacancy filling rate by $q_t = \frac{H_t}{V_t}$.

To ensure comparability with a literature that has modelled hiring costs predominantly as vacancy posting costs, we follow Sala, Soderstrom, and Trigari (2013), and assume that the fraction of output forgone due to hiring activities is given by the hybrid function:

$$\tilde{g}_{t,i} = \frac{e}{2} q_t^{-\eta^q} \left(\frac{H_{t,i}}{N_{t,i}}\right)^2, \tag{27}$$

where $q_t = \frac{H_t}{V_t}$ and H_t, V_t are aggregates.[17]

When $\eta^q = 0$ this function reduces to

$$\tilde{g}_{t,i} = \frac{e}{2} \left(\frac{H_{t,i}}{N_{t,i}}\right)^2,$$

which is the same expression as (10), where all friction costs depend on the firm-level hiring rate and are not associated with the number of vacancies per se. In this case, marginal hiring costs are not affected by the probability that a vacancy is filled. When instead $\eta^q = 2$ the

[17]The function can also be written as

$$\tilde{g}_{t,i} = \frac{e}{2} \left(\frac{V_{t,i}}{N_{t,i}}\right)^{\eta^q} \left(\frac{H_{t,i}}{N_{t,i}}\right)^{2-\eta^q}$$

function becomes

$$\tilde{g}_t = \frac{e}{2}\left(\frac{V_{t,i}}{N_{t,i}}\right)^2,$$

and is only associated with posting vacancies. In this case, an increase in the vacancy filling rate q_t decreases the marginal cost of hiring. For intermediate values of $\eta^q \in (0,2)$, the specification in (27) allows for both hiring rates and vacancy rates to matter for the costs of hiring in different proportions.

Finally, we assume wage rigidity in the form of a wage norm, as suggested by Hall (2005):

$$\frac{W_t}{P_t} = \omega \frac{W_{t-1}}{P_{t-1}} + (1-\omega)\,\frac{W_t}{P_t}^{NASH}, \tag{28}$$

where ω is a parameter governing real wage stickiness, and W_t^{NASH} denotes the reference wage

$$\frac{W_t}{P_t}^{NASH} = \arg\max\left\{\left(V_t^N\right)^{\gamma}\left(Q_t^N\right)^{1-\gamma}\right\}. \tag{29}$$

This simple wage-setting rule allows for targeting the persistence of the real wage data series in the calibration of the model.

We relegate a detailed description of the calibration to the Appendix. Here we simply highlight the values of three key parameters. In the relatively low friction benchmark, the parameter e governing the scale of hiring frictions is set following the same strategy as in Section 4.1: the value of e is set to 1.2 so as to target a ratio of marginal hiring costs to productivity of 0.20. To inspect the mechanism, we will also report impulse responses for a relatively high frictions benchmark, where the scale of the hiring costs function is raised to 5, in order to match the empirical evidence in Silva and Toledo (2009), where average hiring costs are equal to 55% of quarterly wages. The parameter controlling wage inertia, ω, is set to 0.87, to match an autocorrelation of real wages conditional on technology shocks of 0.9 (which we derive by computing the AR1 coefficient of a real wage series conditioned on TFP shocks).

Finally, we set the elasticity of the hiring friction function η^q to 0.49, which is value estimated by Sala, Soderstrom, and Trigari (2013) for the US economy. We note that this estimate implies a stronger influence of vacancy filling rates in hiring costs than what would be implied by the micro-evidence reported by Silva and Toledo (2009), which would map into a coefficient of η^q of 0.145.

5.2 The Mechanism Revisited

We discuss the results of the extended model and revisit the mechanisms discussed above. We do so, again, through variation of the values of key parameters with respect to the benchmark calibration of Table 2. The figures now give the full impulse response functions over 15 quarters for ten key variables. The top row in each figure shows five main macroeconomic variables – output, consumption, investment (in rates out of capital), the real rate of interest, and Ψ_t, the shadow price. The bottom row in each figure shows five main macro/labor variables –

employment and unemployment rates, hiring (in rates out of employment), the real wage, and the value of the job (Q_t^N).

Technology shocks. Figure 3 reports impulse responses for a positive technology shock obtained under the benchmark parameterization with small friction costs (low e, the green solid line), and an alternative parameterization with a higher, but still reasonable, friction cost (higher e, the orange broken line).

Figure 3

Figure 3 shows that the response of employment in the relatively low calibration of the scale of hiring costs remains negative, as in the standard NK model. Under the relatively higher friction parameterization (e) the response turns positive. In the latter case, the shadow price Ψ_t, a key driver in our mechanism, falls considerably more upon impact. Note that this latter change is in addition to the effect discussed in Sub-Section 4.2, whereby the sensitivity of marginal hiring costs,$\Psi_t g_{H,t}$, depends on e via $g_{H,t}$. Here the value of e matters for the movement in Ψ_t itself, as seen in the top row of the figure, whereby a higher value of e engenders a higher fall in Ψ_t. The path of Ψ_t, the shadow price, which is also the inverse of the mark-up, is a dominant dynamic in our mechanism.

The mechanism inherent in Figure 3 is as follows. The positive technology shock, under conventional price rigidity, generates a fall in the marginal cost and hence an increase in the mark-up. The ensuing decline in hiring costs (manifested in the fall in job values Q_t^N, which equal $\Psi_t g_{H,t}$) raises the hiring rate in the high e case. Strikingly, at a higher scale of hiring costs (higher value of e), and in the presence of price frictions, a technology shock implies much stronger expansionary responses of employment, investment, output and consumption, which increase over the impulse response horizon, showing persistent, hump-shaped dynamics. This counterintuitive result, whereby, at a higher scale of frictions, technology shocks are magnified in terms of the response of real variables in a NK model, is in accordance with the discussion of the mechanism presented in Sub-Section 4.2. The key point is that hiring frictions interact with price frictions to increase the countercyclicality of marginal hiring costs. Thus, following a positive technology shock, hiring costs decline with the fall in the shadow price Ψ_t, which is stronger the higher is e, as shown in the figure.

A complementary and insightful approach to identify and visualize the effect of the interaction between price frictions and hiring frictions is to show how price frictions affect the transmission of technology shocks in a model with hiring frictions. The natural focus, in this context, is on the behavior of unemployment. We do so in Figure 4, where we compare the impulse responses obtained under the same "high" hiring friction case reported in Figure 3 (traced out by the orange broken lines), with the otherwise identical model where we shut down price frictions, i.e. we set $\zeta \simeq 0$ (this is traced out by the light blue solid lines).

Figure 4

Because the latter is effectively a rich specification of the DMP model with capital, Figure 4 allows us to pin down the effects of introducing price frictions into this DMP benchmark. As a result, any difference between the two models is due to the endogenous response of the shadow value of output, Ψ_t. The figure reveals that the mechanism produces strong amplification of unemployment to the underlying TFP shock, with an impact elasticity around 4 and a peak elasticity around 6 in the presence of both hiring frictions and price frictions. This compares with an impact – and peak – elasticity around $1\frac{1}{2}$ under flexible prices. In addition, the hump-shaped impulse response of unemployment to technology shocks is much more pronounced in the presence of price stickiness. Hence, introducing price frictions into a model with hiring frictions generates both volatility and endogenous persistence in the response of unemployment to technology shocks. The mechanism, once again, is the one discussed in Sub-Section 4.2, which operates through the countercyclicality of the shadow price and hiring costs induced by price rigidities.

It is worth noting that in the case where there are no price frictions (the light blue line), the model lacks amplification, despite the high level of real wage rigidities imposed in the calibration. This is so, as in this case there is no effect of the shock on the shadow price Ψ_t. Moreover, note that the mechanism presented here operates even in the presence of a procyclical opportunity cost of work. Using detailed microdata, Chodorow-Reich and Karabarbounis (2016) provide evidence that the opportunity cost of work is procyclical; they show that under this assumption many leading models of the labor market, including models with endogenously rigid wages, fail to generate amplification, irrespective of the level of the opportunity cost. The amplification of labor market outcomes generated in our model is instead robust to the procyclicality of the opportunity cost of work.

Monetary policy shocks. In analogy with Figure 3, Figure 5 reports impulse responses for an expansionary monetary policy shock obtained under the same "low" and "high" parameterizations of friction costs.

Figure 5

The impulse response analysis reveals that at the lower level of friction costs (green line), an expansionary monetary policy shock produces real effects, increasing output, consumption, employment, investment, and real wages. At the higher level of friction costs instead (orange line), monetary policy shocks still produce real effects, but in the opposite direction. Again a key role is played by the response of the shadow price Ψ_t as shown in the top row of Figure 5, an effect which strengthens as e rises.

These results are consistent with those that were obtained with the simple model of Section 3, whereby if hiring frictions are strong enough, the ensuing procyclicality of marginal hiring costs can even induce contractionary effects of expansionary policies.

We emphasize that the parameterization of hiring costs underlying the orange line, which corresponds to the survey evidence of hiring costs reported in Silva and Toledo (2009), is a perfectly reasonable parameterization, and is labeled in Figures 3 and 5 as "high" friction cost purely for comparative reasons. So the bottom line of the analysis presented in this sub-section, is that changing hiring costs within a reasonable, moderate range of parameterizations, has dramatic implications for the propagation of shocks even in a relatively rich specification of the model.

5.3 Internal vs. External Costs of Hiring

The medium-scale model considered so far allows for both external and internal costs to affect the propagation of shocks. Here we show how this propagation changes when we exclude internal costs altogether. This exercise is convenient to relate to a literature, which has predominantly focussed on external costs of hiring. Namely, we report the impulse responses obtained under the "high" friction cost parameterization, comparing the benchmark case of $\eta^q = 0.49$ with the case of $\eta^q = 2$, which implies that hiring frictions are entirely driven by external vacancy rates. The results are shown in Figures 6 and 7 for technology shocks and monetary policy shocks, respectively.

Figures 6 and 7

The figures show that the offset to the standard NK propagation produced by our mechanism is considerably diluted in the case where hiring costs depend only on vacancy posting. Indeed, the amplification in the response of labor market variables to technology shocks is very much reduced. To understand why the mechanism presented in Section 4.2 is weakened in the case of $\eta^q = 2$ consider the FOC for hiring, where now

$$Q_t^N = \Psi_t g_{H,t} = \Psi_t e \frac{1}{q_t} \frac{V_t}{N_t} \frac{f(z_t, N_t, K_t)}{N_t},$$

As before, a fall in the shadow price Ψ_t engendered by an expansionary technology shock still decreases the marginal cost of hiring, thereby increasing vacancy creation. But the congestion externalities in the matching function imply a strong fall in the vacancy filling rate q_t, which in turn increases the marginal cost of hiring, offsetting the initial effect of Ψ_t. Note, that for values of η^q less than 2, as examined above, aggregate labor market conditions, expressed via q_t, matter less for the marginal cost of hiring, and the strong feedback effect of vacancy rates on the marginal cost of hiring is muted.

5.4 Output Costs vs. Pecuniary Costs of Hiring

So far we have assumed that the hiring costs specified in equation (27) are expressed in units of (forgone) output. Alternatively we could have assumed, following the convention in the literature, that hiring costs are pecuniary, meaning that they are specified in units of the composite good. In this case the production function (9) is simply $Y_{i,t} = f(A_t, N_{t,i}, K_{t,i})$, and the maximization problem of the firm becomes

$$\max_{P_{t+s,i}, H_{t+s,i}, \check{K}_{t+s,i}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s} N_{t+s,i}}{P_{t+s}} - \frac{X_{t+s}^K}{P_{t+s}} K_{t+s,i} \right.$$
$$\left. - g(A_{t+s,i}, H_{t+s,i}, N_{t+s,i}, K_{t+s,i}) - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \right\} \quad (30)$$

subject to the technology constraint (13), the law of motion for employment (12), and the demand function (8).

The main implication of assuming pecuniary costs is that the first order condition for hiring becomes:

$$Q_t^N = g_{H,t},$$

which implies that the cost of the marginal hire is no longer affected directly by the shadow price Ψ_t.

This model with pecuniary costs does not generate reversals of the NK outcomes, unlike the model with output-costs. The role of hiring frictions then, is to smooth impulse responses, with negligible effects if frictions are calibrated to reflect only vacancy costs (as in Galí (2011), for example).

Interestingly, we find that the model with pecuniary costs of hiring is prone to indeterminacy even for moderate values of hiring frictions. Specifically, for the parameter vector underlying our "high" hiring cost calibration, which underpins the orange lines in Figures 3 to 5, the model with pecuniary costs does not satisfy the conditions for determinacy. The intuition for this indeterminacy is as follows. If firms expect aggregate demand to be high, they will hire more workers to increase production and meet this high level of demand. If prices are sticky and hiring costs are pecuniary, i.e., they are purchases of the composite good, the increase in the demand for hiring services stimulates aggregate demand. Hence, expectations of higher demand become self-fulfilling. If hiring costs are forgone output instead, higher hiring does not stimulate demand, and the model is less prone to indeterminacy. This implies that the conventional modelling of hiring costs as pecuniary costs, can only support equilibria where hiring frictions are sufficiently small. Thus, any estimation of such friction costs in general equilibrium can only deliver quantitatively small estimates.

5.5 The Role of Wages

The real wage solution in this extended version of the model is given by:

$$\frac{W_t}{P_t} = \omega \frac{W_{t-1}}{P_{t-1}} + (1-\omega) \left[\gamma \Psi_t \left(f_{N,t} - g_{N,t} \right) + (1-\gamma) \left[\frac{\chi N_t^{\varphi}}{P_t \lambda_t} + \frac{x_t}{1-x_t} \frac{\gamma}{1-\gamma} Q_t^N \right] \right]. \quad (31)$$

where λ_t denotes the marginal utility of consumption. The optimal hiring equation given by:

$$Q_t^N = \Psi_t \left(f_{N,t} - g_{N,t} \right) - \frac{W_t}{P_t} + (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N. \tag{32}$$

Combining equations (31) and (32) yields an expression for the job value Q_t^N. This value represents the expected marginal profits of the worker to the firm, which in equilibrium equals the marginal cost of hiring:

$$\begin{aligned} Q_t^N &= \Psi_t g_{H,t} \qquad\qquad (33) \\ &= \Xi_t (1 - \gamma(1-\omega)) \Psi_t \left(f_{N,t} - g_{N,t} \right) \\ &\quad - \Xi_t \left[\omega \frac{W_{t-1}}{P_{t-1}} + (1-\omega)(1-\gamma) \frac{\chi N_t^{\varphi}}{\lambda_t P_t} \right] \\ &\quad + \Xi_t (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N \end{aligned}$$

where:

$$\begin{aligned} \Xi_t &\equiv \left[1 + (1-\omega) \gamma \frac{x_t}{1 - x_t} \right]^{-1} > 0 \\ \frac{\partial \Xi_t}{\partial x_t} &< 0, \frac{\partial \Xi_t}{\partial \gamma} < 0, \frac{\partial \Xi_t}{\partial \omega} > 0 \end{aligned}$$

Equations (32) and (33) are useful in the analysis of the role of wages, and within that, the role of the opportunity cost of work. Endogenous wage cyclicality plays a role via the opportunity cost term $\frac{\chi N_t^{\varphi}}{P_t \lambda_t}$, as discussed above. By equation (33) this term is expected to play an offsetting role to increases in productivity $f_{N,t}$, as $\frac{\partial Q_t^N}{\partial \frac{\chi N_t^{\varphi}}{\lambda_t P_t}} = -\Xi_t (1-\omega)(1-\gamma) < 0$. This is in line with the logic laid down by Chodorow-Reich and Karabarbounis (2016) cited above. The indexation parameter ω has an effect here as it influences Ξ_t positively and $(1-\omega)$ negatively. Thus, the effect of the opportunity cost is mediated, inter alia, by wage indexation. To see the net results for the calibrated model, Table 3 presents the impact effects of the shocks – TFP and monetary policy – on the different terms in equation (33).

Table 3

The table shows the differences across specifications of the values of the scale of price frictions ζ and of hiring frictions e, and the indexation parameter ω. A number of conclusions emerge from the table in its two panels. First, the opportunity cost term plays a relatively small role across all specifications. When there is less indexation (lower ω), its role is relatively enhanced but is still small. Second, the dominant movements are in marginal hiring costs, $\Psi_t g_{H,t}$, and in adjusted net marginal productivity $\Xi_t \left(\Psi_t \left(f_{N,t} - g_{N,t} \right) (1 - \gamma(1-\omega)) \right)$, with the movements in the shadow price Ψ_t playing a major role, as noted above.

Third, some small, but non-negligible, role is played by the indexation term, $\Xi_t \omega \frac{W_{t-1}}{P_{t-1}}$, and by the expected present value term $\Xi_t (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N$. To see more about the role of the former, exogenous wage rigidity, Figures 8 and 9 reproduce the results of Figures 3 and 5 for technology and monetary policy shocks, respectively. The dashed orange line shows the "high" e case with the benchmark indexation parameter ω set to 0.87 as in Table 2 and in Figures 3 and 5. The solid yellow line uses a much lower value of indexation, 0.1.

Figures 8 and 9

The figures show that after the initial impact, which is very similar across indexation levels for all variables but for the real wage, the response with low indexation is less persistent and less strong than in the high indexation case. For real wages, unsurprisingly, the response is far greater and less persistent with low indexation (though not upon impact). The figures show that the basic amplification of the model is not dependent on exogenous wage rigidity, but there is some contributing effect after the initial impact.

5.6 Variations in the Taylor Rule

It is well known that in NK models the dynamics of the endogenous variables are sensitive to the precise parameterization of the Taylor rule coefficients. For instance, a positive technology shock implies that the same level of demand can be achieved with less labor, so everything else equal the demand for labor falls. But at the same time inflation also drops, inducing a fall in the nominal interest rate via the Taylor rule, which in turn offsets the tendency for employment to decline. In equilibrium, employment can rise or fall, depending on the endogenous response of interest rates.

So, in order to show that the offsetting effect of hiring frictions on the standard NK propagation does not depend on the parameters of the Taylor rule, we have carried out the following robustness exercise. We take as a benchmark the version of the extended model parameterized with comparatively high frictions, i.e. $e = 5$. Under this parameterization an expansionary technology shock produces an increase in employment and an expansionary monetary policy shock produces a contraction in output (Figures 3 and 5). To show that these substantial results are a genuine manifestation of the offsetting effect of friction costs, and not an artifact of a specific Taylor rule, we inspect impulse responses obtained by randomizing the Taylor rule coefficients over a broad parameter space, leaving all other parameters fixed at the values reported in Table 2.

Specifically, we have generated 10,000 parameterization vectors, which differ only in the coefficients governing the Taylor rule. These parameter values are assigned by drawing randomly from uniform distributions defined over the support of $r_y \sim U(0, 0.5)$, $r_\pi \sim U(1.1, 3)$ and $\rho_r \sim U(0, 0.8)$. Our results indicate that output responded negatively on the impact of a monetary stimulus in every single parameterization, and the sign of the response was never overturned one year or two years after the impact. Similarly, on the impact of the technology shock instead, employment responded positively in every single parameterization. The sign of the response was not overturned after one year in any of the parameterizations and remained in positive territory, after two years, in 99.8% of the parameterizations.

6 Conclusions

We have shown that because hiring frictions involve forgone output, the optimal intertemporal allocation of hiring activities over the cycle is directly affected by fluctuations in the value of output. This mechanism implies that hiring frictions matter in a significant way for business cycles, and not only through wage setting mechanisms. Indeed, the interaction between price and hiring frictions has key implications for the transmission of both technology and monetary policy shocks.

These results highlight the importance of empirical estimates. There is a need for research exploring the **joint** optimality equations for firms hiring and pricing. This may be undertaken through empirical examination of the optimality equations of the firm, at the aggregate, sectorial, and firm levels. Currently, such empirical evidence is scant, especially at the dis-aggregated levels. The scarcity of research on this topic is striking, particularly when compared to the vast literature that has measured the frequency of price adjustments.[18]Indeed, most of the empirical research in this field has focused on measuring price rigidities under the prevalent belief that this is a necessary statistic to gauge the strength of the New-Keynesian mechanism. On the other hand, the empirical macroeconomic literature, related to business cycles, has neglected the measurement of hiring frictions, under the belief that these frictions are small, and not so important for our understanding of the business cycle. Our results indicate that if hiring frictions are more than tiny, though still moderate, they are of key importance. We leave this essential task for future research.

[18]See, for example, the recent sectorial study of price frictions in De Graeve and Walentin (2015) and the references therein.

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7 Appendix

The Extended Model

This Appendix characterizes the extended model used to derive the results reported in Figures 3 to 9. The model augments the simple set-up of Section 3 to specifically include a matching function in the labor market, external habits in consumption and investment adjustment costs to the problem of the households, external hiring costs, trend inflation and inflation indexation in the problem of the intermediate firms, and exogenous wage rigidity in the wage rule.

Households Let $\vartheta \in [0,1)$ be the parameter governing external habit formation. The intertemporal problem of a household indexed by subscript j is to maximize the discounted present value of current and future utility:

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

subject to the budget constraint (2) and the laws of motion for employment (3) and capital:

$$K_{t,j} = (1-\delta_K) K_{t-1,j} + \left[1 - S\left(\frac{I_{t,j}}{I_{t-1,j}}\right)\right] I_{t,j}, \quad 0 \le \delta_K \le 1, \tag{34}$$

where S is the investment adjustment cost function. It is assumed that $S(1) = S'(1) = 0$, and $S''(1) \equiv \phi > 0$. Denoting by λ_t the Lagrange multiplier associated with the budget constraint, and by Q_t^K the Lagrange multiplier associated with the law of motion for capital, under the assumption that all households are identical in equilibrium, the conditions for dynamic optimality are:

$$\lambda_t = \frac{1}{P_t \left(C_t - \vartheta C_{t-1}\right)},$$

$$\frac{1}{R_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}, \tag{35}$$

$$Q_t^K = E_t \Lambda_{t,t+1} \left[\frac{X_{t+1}^K}{P_{t+1}} + (1-\delta_K) Q_{t+1}^K \right] \tag{36}$$

where $\Lambda_{t,t+1} = \frac{\frac{P_{t+1}}{P_t}}{R_t}$.

$$V_t^N = \frac{W_t}{P_t} - \frac{\chi N_t^{\varphi}}{\lambda_t P_t} - \frac{x_t}{1-x_t} V_t^N + E_t \Lambda_{t,t+1} \left(1-\delta_N\right) V_{t+1}^N, \tag{37}$$

and

$$Q_t^K \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}} \right] + E_t \Lambda_{t,t+1} Q_{t+1}^K S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 = 1, \tag{38}$$

where the Euler equation (35), the value of capital (36), and the value of a marginal job to the household (37) correspond to equations (5), (17) and (7) in the simple model of Section 3, respectively.

Intermediate Firms 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 gross steady state inflation, $1 + \bar{\pi}$, and past inflation. We denote by ψ the parameter that captures the degree of indexation to past inflation.

Firms maximize the following expression:

$$\begin{aligned} \max_{\left\{P_{t+s,i}, H_{t+s,i}, \breve{K}_{t+s,i}\right\}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \Bigg\{ & \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s,i}}{P_{t+s}} N_{t+s,i} - \frac{X_{t+s}^K}{P_{t+s}} K_{t+s,i} \\ & - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{(1+\pi_{t+s-1})^{\psi} (1+\bar{\pi})^{1-\psi} P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \Bigg\} \end{aligned} \tag{39}$$

where $\Lambda_{t,t+s}$, defined above, is the real discount factor of the households who own the firms, taking as given the demand function (8) and subject to the law of motion for employment (12) and the constraint that output equals demand:

$$\left(\frac{P_{t,i}}{P_t}\right)^{-\epsilon} Y_t = f(A_t, N_{t,i}, K_{t,i}) - g(A_t, H_{t,i}, N_{t,i}, K_{t,i}). \tag{40}$$

The friction cost function in the above constraint is given by

$$g(A_t, H_{t,i}, N_{t,i}, K_{t,i}) = \frac{e}{2} q_t^{-\eta^q} \left(\frac{H_{t,i}}{N_{t,i}}\right)^2 f_{t,i}, \tag{41}$$

where V_t are aggregate vacancies and $q_t = \frac{H_t}{V_t}$ is the vacancy filling rate implied by the matching function in equation (26).

Following a similar argument to the one proposed by Gertler, Sala and Trigari (2008), we note that by choosing vacancies, the firm directly controls the total number of hires $H_{t,i} = q_t V_{t,i}$, since it knows the vacancy filling rate q_t. Hence, $H_{t,i}$ can be treated as a control variable.

The optimality conditions with respect to $H_{t,i}$, $N_{t,i}$, $K_{t,i}$ and $P_{t,i}$ are:

$$Q_t^N = \Psi_t g_{H,t}, \tag{42}$$

$$Q_t^N = \Psi_t \left(f_{N,t} - g_{N,t} \right) - \frac{W_t}{P_t} + (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N, \tag{43}$$

$$\frac{X_t^K}{P_t} = \Psi_t \left(f_{K,t} - g_{K,t} \right) \tag{44}$$

and

$$(1-\epsilon) \left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon} \frac{Y_t}{P_t} + \Psi_t \epsilon \left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon-1} \frac{Y_t}{P_t}$$
$$- \zeta \left(\frac{P_{t,i}}{(1+\pi_{t-1})^{\psi} (1+\bar{\pi})^{1-\psi} P_{t-1,i}} - 1 \right) \frac{Y_t}{(1+\pi_{t-1})^{\psi} (1+\bar{\pi})^{1-\psi} P_{t-1,i}}$$

$$+ E_t \Lambda_{t,t+1} \zeta \left(\frac{P_{t+1,i}}{(1+\pi_t)^{\psi} (1+\bar{\pi})^{1-\psi} P_{t,i}} - 1 \right) Y_{t+1} \left(\frac{P_{t+1,i}}{\left((1+\pi_{t-1})^{\psi} (1+\bar{\pi})^{1-\psi} P_{t,i} \right)^2} \right) = 0.$$

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

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

$$+ E_t \frac{1}{R_t / (1+\pi_{t+1})} \left[\left(\frac{1+\pi_{t+1}}{(1+\pi_t)^{\psi} (1+\bar{\pi})^{1-\psi}} - 1 \right) \frac{1+\pi_{t+1}}{(1+\pi_t)^{\psi} (1+\bar{\pi})^{1-\psi}} \frac{Y_{t+1}}{Y_t} \right]. \tag{45}$$

Merging the FOCs for capital of households and firms (36) and (44) we get:

$$Q_t^K = E_t \Lambda_{t,t+1} \left[\Psi_{t+1} \left(f_{K,t+1} - g_{K,t+1} \right) + (1-\delta_K) Q_{t+1}^K \right] \tag{46}$$

Wage norm We assume wage rigidity in the form of a Hall (2005) type wage norm:

$$\frac{W_t}{P_t} = \omega \frac{W_{t-1}}{P_{t-1}} + (1-\omega) \frac{W_t}{P_t}^{NASH}, \tag{47}$$

where ω is a parameter governing real wage stickiness, and W_t^{NASH} denotes the Nash reference wage

$$\frac{W_t}{P_t}^{NASH} = \arg\max \left\{ \left(V_t^N \right)^{\gamma} \left(Q_t^N \right)^{1-\gamma} \right\}, \tag{48}$$

which yields

$$\frac{W_t}{P_t}^{NASH} = \gamma \Psi_t \left(f_{N,t} - g_{N,t} \right) + (1-\gamma) \left[\chi N_t^{\varphi} \left(C_t - \vartheta C_{t-1} \right) + \frac{x_t}{1-x_t} \frac{\gamma}{1-\gamma} Q_t^N \right]. \tag{49}$$

Final good firms Final firms maximize

$$\max P_t Y_t - \int_0^1 P_{i,t} Y_{i,t} di$$

subject to

$$Y_t = \left(\int_0^1 Y_{t,i}{}^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)}.$$

Taking first order conditions with respect to Y_t and Y_{it} and merging we can solve for the demand function

$$Y_{t,i} = \left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon} Y_t. \tag{50}$$

The Monetary and Fiscal Authorities and Market Clearing The model is closed by assuming that the government runs a balanced budget, as per equation (21), the monetary authority follows the Taylor rule in equation (22), the goods market clears as per equation (23) and the capital market clears, i.e. $\int_{i=0}^{1} K_{t,i} di = \int_{j=0}^{1} K_{t-1,j} dj$, where i and j index firms and households, respectively.

Calibration The model is calibrated following the same steps as in Sub-Section 4.1. The parameter values for the friction cost scale parameter e and the bargaining power γ are set so as to hit the same targets as in the calibration of the simple model. The parameter of the matching function l is calibrated to target a vacancy filling rate (q) of 70%, as in Den Haan, Ramey and Watson (2000). The scale parameter in the utility function χ is no longer normalized to equal one, but is set so as to target the same replacement ratio of the opportunity cost of work over the marginal revenue product (77%), as implied by the benchmark calibration in Sub-Section 4.1. All other parameter values that are common to the simple model are set to the same value reported in Table 1. As for the new parameters, the investment adjustment cost parameter ϕ is set to 2.5, and the habit parameter to $\vartheta = 0.8$, reflecting the estimate by Christiano, Eichenbaum and Trabandt (2016). The parameter governing trend inflation is set to $\bar{\pi} = 0.783\%$, which corresponds to the average of the US GDP deflator over the calibration period. Given that, the value of the discount factor β, is set so as to match a 1% nominal rate of interest. We set the degree of indexation to a moderate value of $\psi = 0.5$, and the parameter governing wage rigidity to $\omega = 0.87$, in order to match the persistence of the US real wage data. Finally, we set the elasticity of the hiring friction function η^q to 0.49, which is value estimated by Sala, Soderstrom, and Trigari (2013) for the US economy. Parameter values and calibration targets for the extended model are reported in Table 2.

Table 1: Calibrated Parameters and Steady State Values, Baseline Model

Description	*Parameter*	*Value*
Discount factor	β	0.99
Separation rate	δ_N	0.126
Capital depreciation rate	δ_K	0.024
Elasticity of output to labor input	α	0.66
Hiring frictions scale parameter	e	1.57
Elasticity of substitution	ϵ	11
Workers' bargaining power	γ	0.41
Scale parameter in utility function	χ	1
Inverse Frisch elasticity	φ	4
Price frictions (Rotemberg)	ζ	120
Taylor rule coefficient on inflation	r_π	1.5
Taylor rule coefficient on output	r_y	0.125
Taylor rule smoothing parameter	ρ_r	0.75
Autocorrelation technology shock	ρ_a	0.95
Autocorrelation monetary shock	ρ_ξ	0
Panel B: Steady State Values		
Definition	*Expression*	*Value*
Total adjustment cost/ output	$g/\left(f-g\right)$	0.013
Marginal hiring cost/ net output per worker	$g_H/\left[\left(f-g\right)/N\right]$	0.20
Marginal hiring cost/ wage	$\Psi g_H/\left(\frac{W}{P}\right)$	0.30
Average hiring cost/wage	$\frac{g}{H}\Psi/\left(\frac{W}{P}\right)$	0.17
Opportunity cost of work/ marginal revenue prod.	$\frac{\chi C N^\varphi}{mc(f_N-g_N)}$	0.72
Unemployment rate	u	0.106

Table 2: Calibrated Parameters and Steady State Values, Extended Model

Description	*Parameter*	*Value*
Discount factor	β	0.9978
Separation rate	δ_N	0.126
Capital depreciation rate	δ_K	0.024
Elasticity of output to labor input	α	0.66
Hiring friction scale parameter	e	1.2
Elasticity of hiring costs to vacancy filling rate	η^q	0.49
Elasticity of substitution	ϵ	11
Workers' bargaining power	γ	0.44
Scale parameter in utility function	χ	5.44
Inverse Frisch elasticity	φ	4
Matching function parameter	l	1.42
Price frictions (Rotemberg)	ζ	120
External habits	ϑ	0.8
Exogenous wage rigidity	ω	0.87
Investment adjustment costs	ϕ	2.5
Trend inflation	$\overline{\pi}$	0.783
Inflation indexation	ψ	0.5
Taylor rule coefficient on inflation	r_π	1.5
Taylor rule coefficient on output	r_y	0.125
Taylor rule smoothing parameter	ρ_r	0.75
Autocorrelation technology shock	ρ_a	0.95
Autocorrelation monetary shock	ρ_ξ	0
Panel B: Steady State Values		
Definition	*Expression*	*Value*
Total adjustment cost/ output	$g/\left(f-g\right)$	0.011
Marginal hiring cost	$g_H/\left[\left(f-g\right)/N\right]$	0.20
Marginal hiring cost/ wage	$\Psi g_H/\left(\frac{W}{P}\right)$	0.30
Average hiring cost/wage	$\frac{g}{H}\Psi/\left(\frac{W}{P}\right)$	0.13
Opportunity cost of work/ marginal revenue prod.	$\frac{\chi C(1-\vartheta)N^{\varphi}}{mc(f_N-g_N)}$	0.72
Unemployment rate	u	0.106

Table 3
Decompositions of the Job Value Q_t^N :
Changes Upon Impact of Shocks

$$\begin{aligned}
\triangle \quad Q_t^N =& \triangle\ \Psi_t g_{H,t} \\
= \quad & \triangle\ \Xi_t (1-\gamma(1-\omega))\Psi_t \left(f_{N,t} - g_{N,t}\right) \\
& - \triangle\ \Xi_t \left[\omega \frac{W_{t-1}}{P_{t-1}} + (1-\omega)\left(1-\gamma\right) \frac{\chi N_t^{\varphi}}{\lambda_t P_t}\right] \\
& + \triangle\ \Xi_t (1-\delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N
\end{aligned}$$

a. TFP Shock

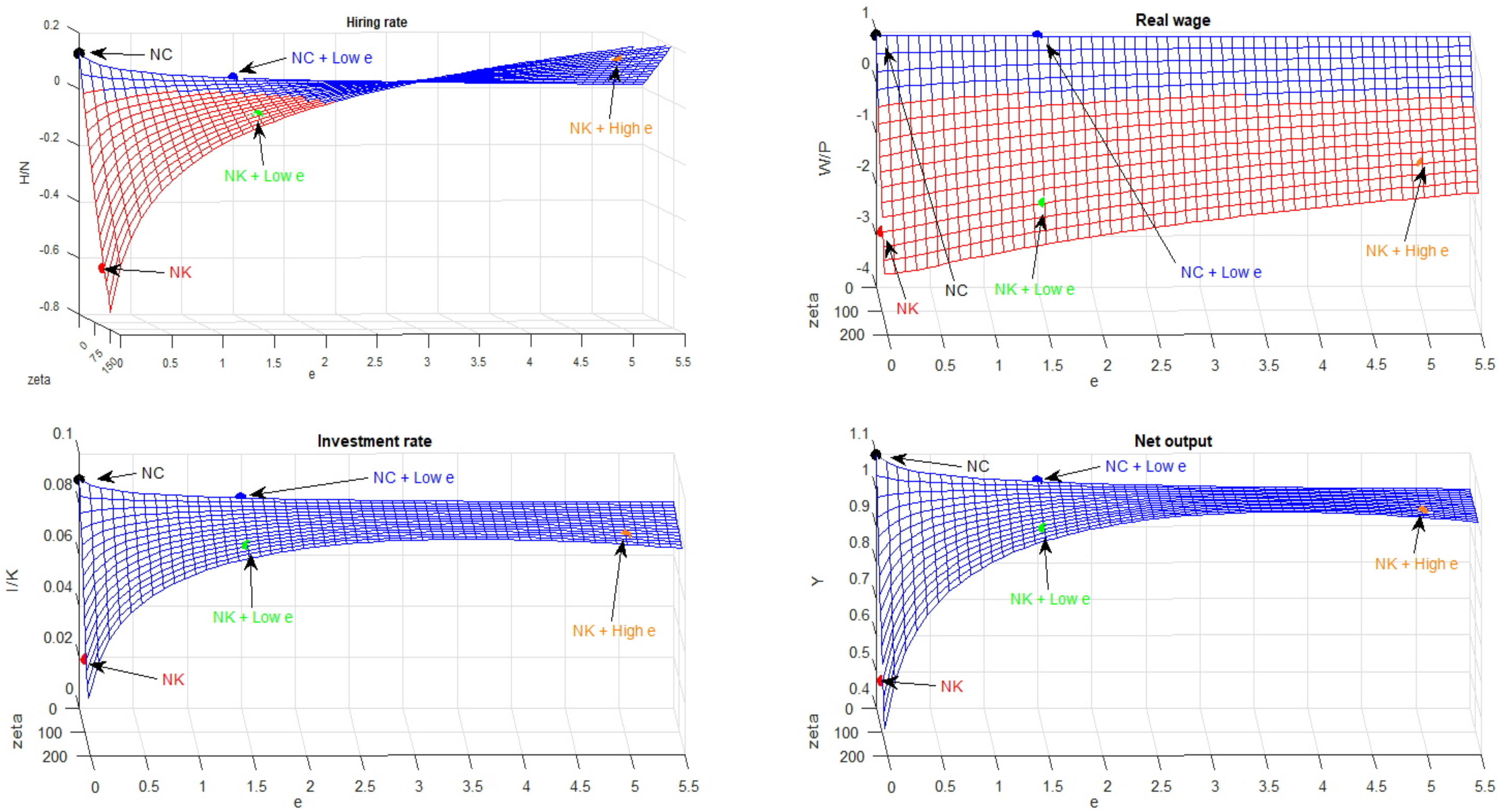
model	ω	ζ	e	$\triangle\ \Psi_t g_{H,t}$	$\triangle \left[\Xi_t \begin{pmatrix} \Psi_t \left(f_{N,t} - g_{N,t}\right) \\ (1-\gamma(1-\omega)) \end{pmatrix}\right]$	$\triangle\ \Xi_t \omega \frac{W_{t-1}}{P_{t-1}}$	$\triangle \begin{bmatrix} \Xi_t(1-\omega) \\ (1-\gamma) \frac{\chi N_t^{\varphi}}{\lambda_t P_t} \end{bmatrix}$	$\triangle \begin{bmatrix} \Xi_t(1-\delta_N) \\ E_t \Lambda_{t,t+1} Q_{t+1}^N \end{bmatrix}$
NC	0.87	0	0	0.00	−0.03	−0.04	0.01	0.00
NC+L	0.87	0	1.2	0.03	0.01	−0.01	0.01	0.02
NK	0.87	120	0	0.00	0.05	0.05	−0.00	0.00
NK+low e	0.87	120	1.2	−0.08	−0.10	0.02	−0.00	0.04
NK+ high e	0.87	120	5	−0.56	−0.72	−0.01	0.00	0.16
NK, high e, low ω	0.10	120	5	−0.48	−0.38	−0.00	0.02	−0.09

b. Monetary Policy shock

model	ω	ζ	e	$\triangle\ \Psi_t g_{H,t}$	$\triangle \left[\Xi_t \begin{pmatrix} \Psi_t \left(f_{N,t} - g_{N,t} \right) \\ (1-\gamma(1-\omega)) \end{pmatrix} \right]$	$\triangle\ \Xi_t \omega \frac{W_{t-1}}{P_{t-1}}$	$\triangle \begin{bmatrix} \Xi_t(1-\omega) \\ (1-\gamma)\frac{\chi N_t^{\varphi}}{\lambda_t P_t} \end{bmatrix}$	$\triangle \begin{bmatrix} \Xi_t(1-\delta_N) \\ E_t \Lambda_{t,t+1} Q_{t+1}^N \end{bmatrix}$
NC	0.87	0	0	0.00	−0.00	−0.00	0.00	0.00
NC+L	0.87	0	1.2	0.00	0.00	−0.00	0.00	−0.00
NK	0.87	120	0	0.00	−0.01	−0.01	0.00	0.00
NK+low e	0.87	120	1.2	0.01	0.01	−0.00	0.00	−0.00
NK+ high e	0.87	120	5	0.13	0.15	0.00	−0.00	−0.01
NK, high e, low ω	0.1	120	5	0.09	0.06	0.00	−0.00	0.03

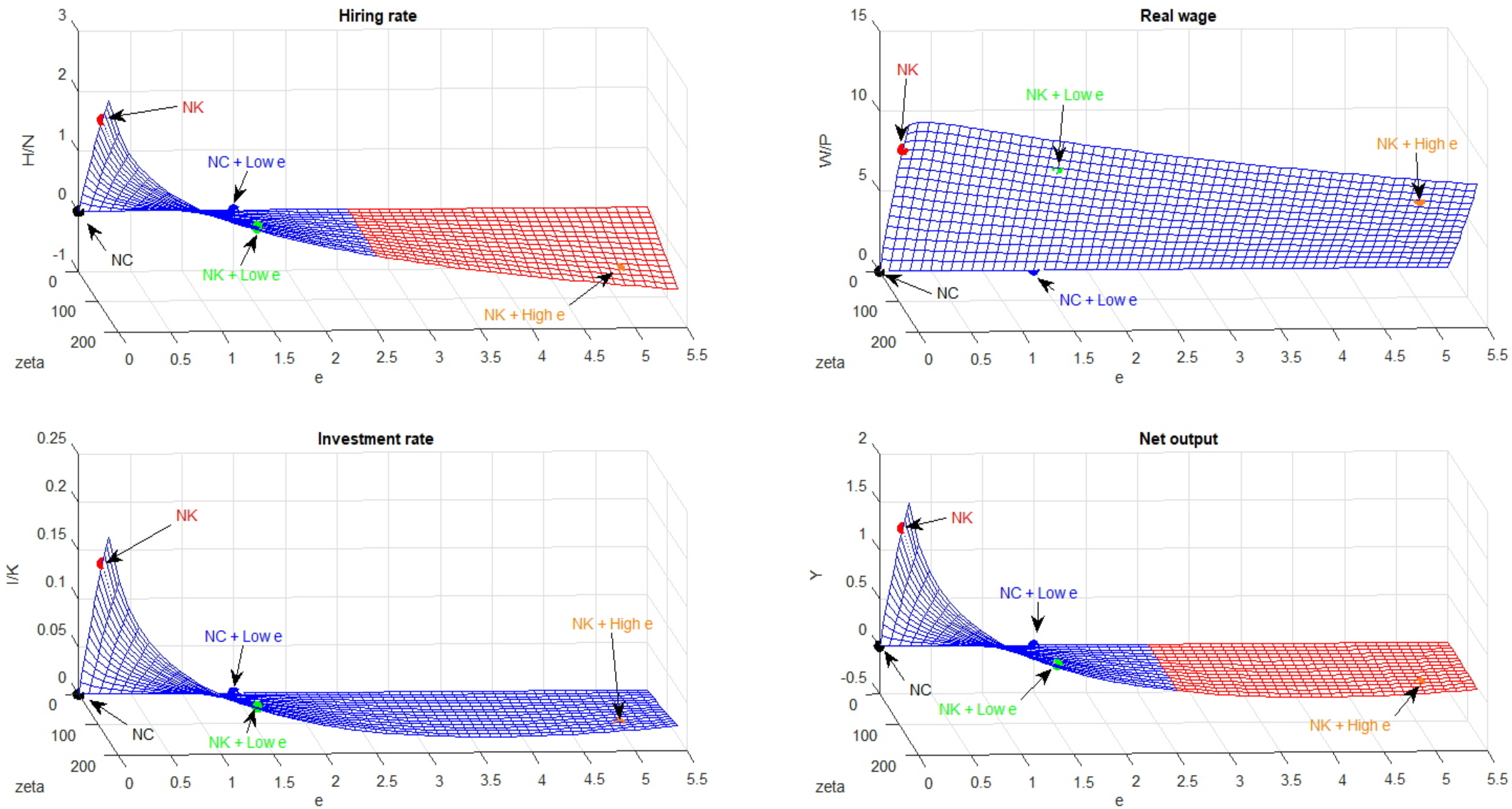
Note: The values in the tables are comparable changes upon impact of the shock.

Figure 1: Impulse Responses on Impact of a Technology Shock



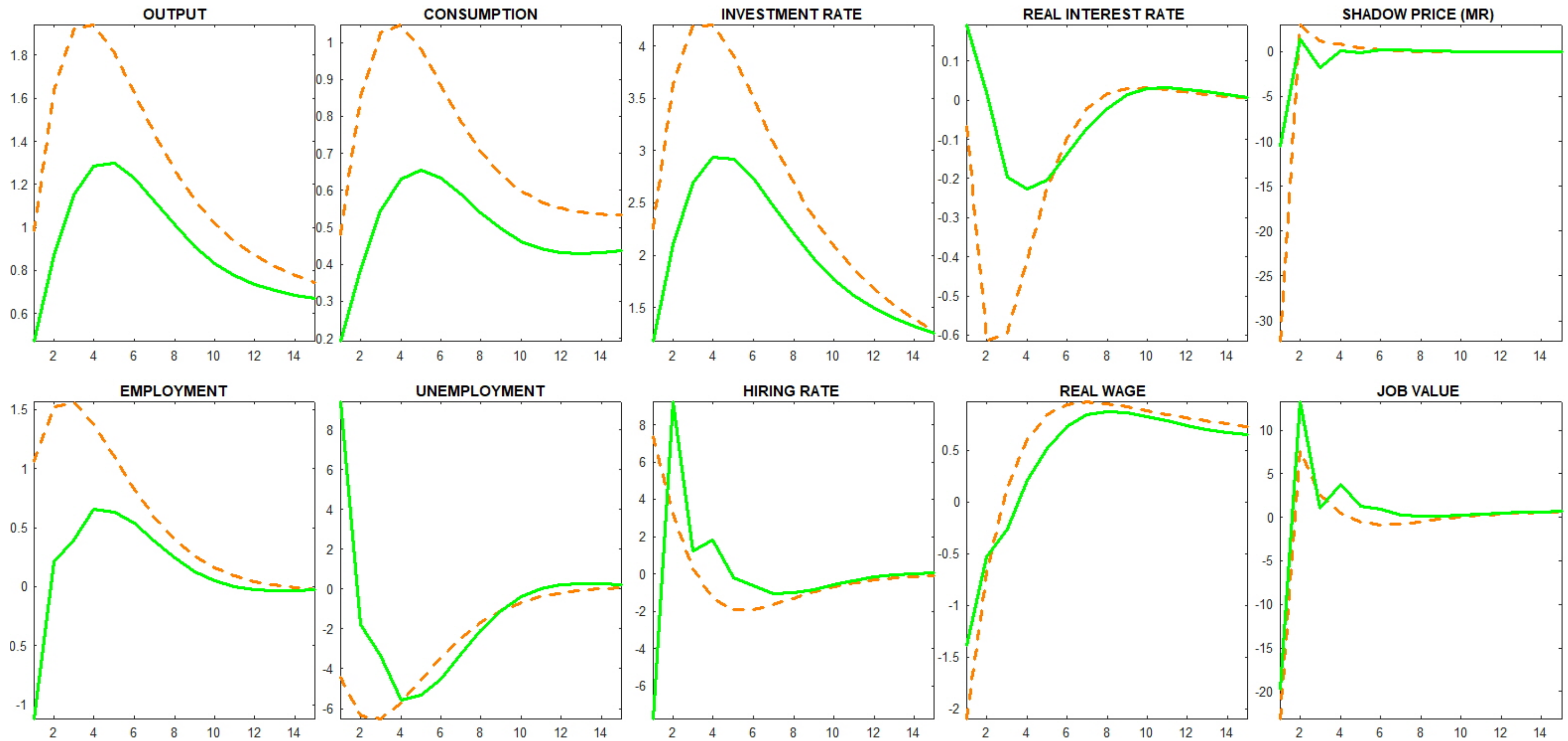
Notes: The figure shows impulse responses on the impact of a 1% positive technology shock for various parameterizations of the model where we allow price rigidities, ζ, and hiring frictions, e, to vary. The real wage and output are expressed in percent deviations from steady state, hiring and investment rates in percentage points deviations.

Figure 2: Impulse Responses on Impact of a Monetary Policy Shock



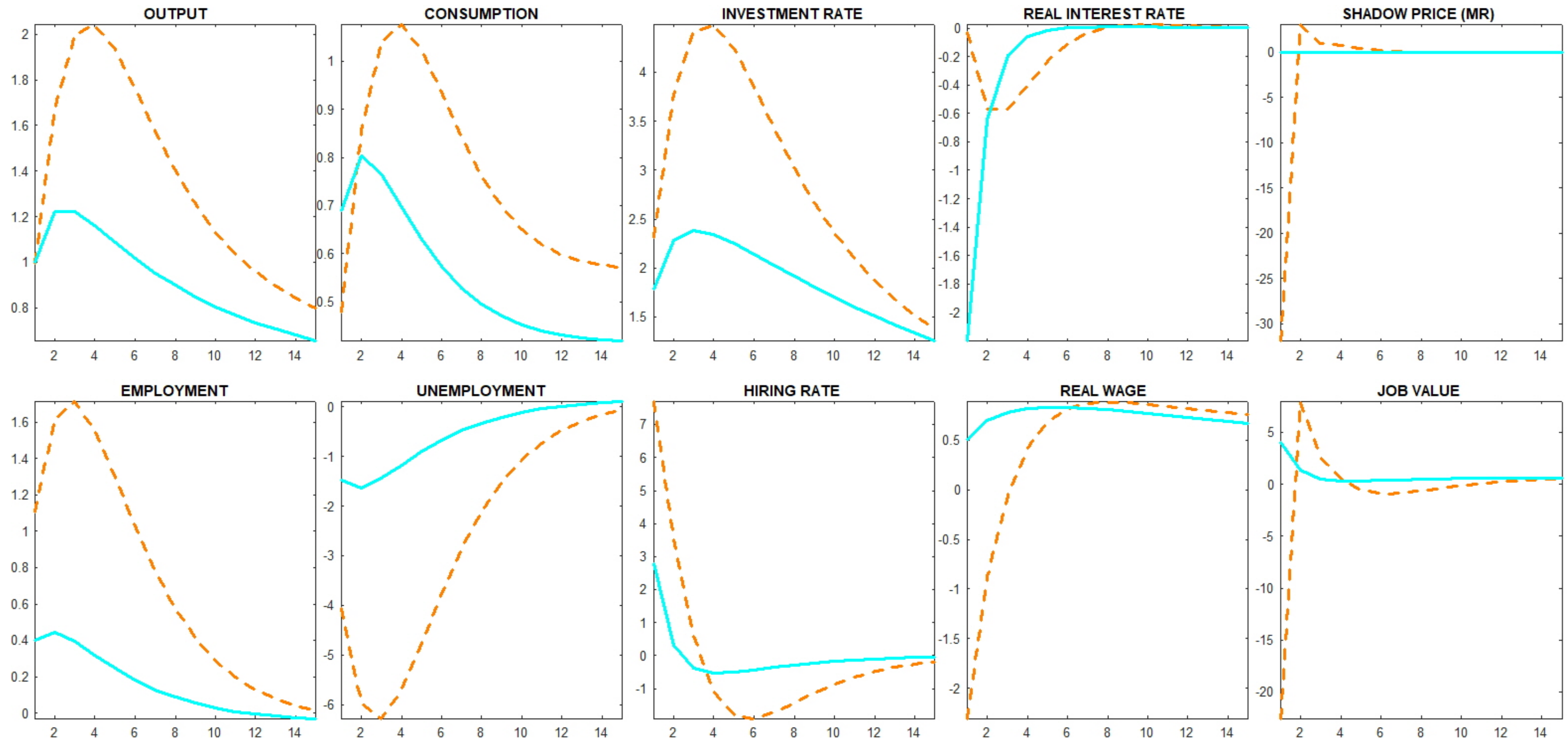
Notes: The figure shows impulse responses on the impact of a 25 basis points expansionary monetary shock for various parameterizations of the model where we allow price rigidities, ζ, and hiring frictions, e, to vary. The real wage and output are expressed in percent deviations from steady state, hiring and investment rates in percentage points deviations.

Figure 3: Impulse Responses to a Technology Shock: Extended Model with "Low" vs. "High" Scales of Hiring Costs



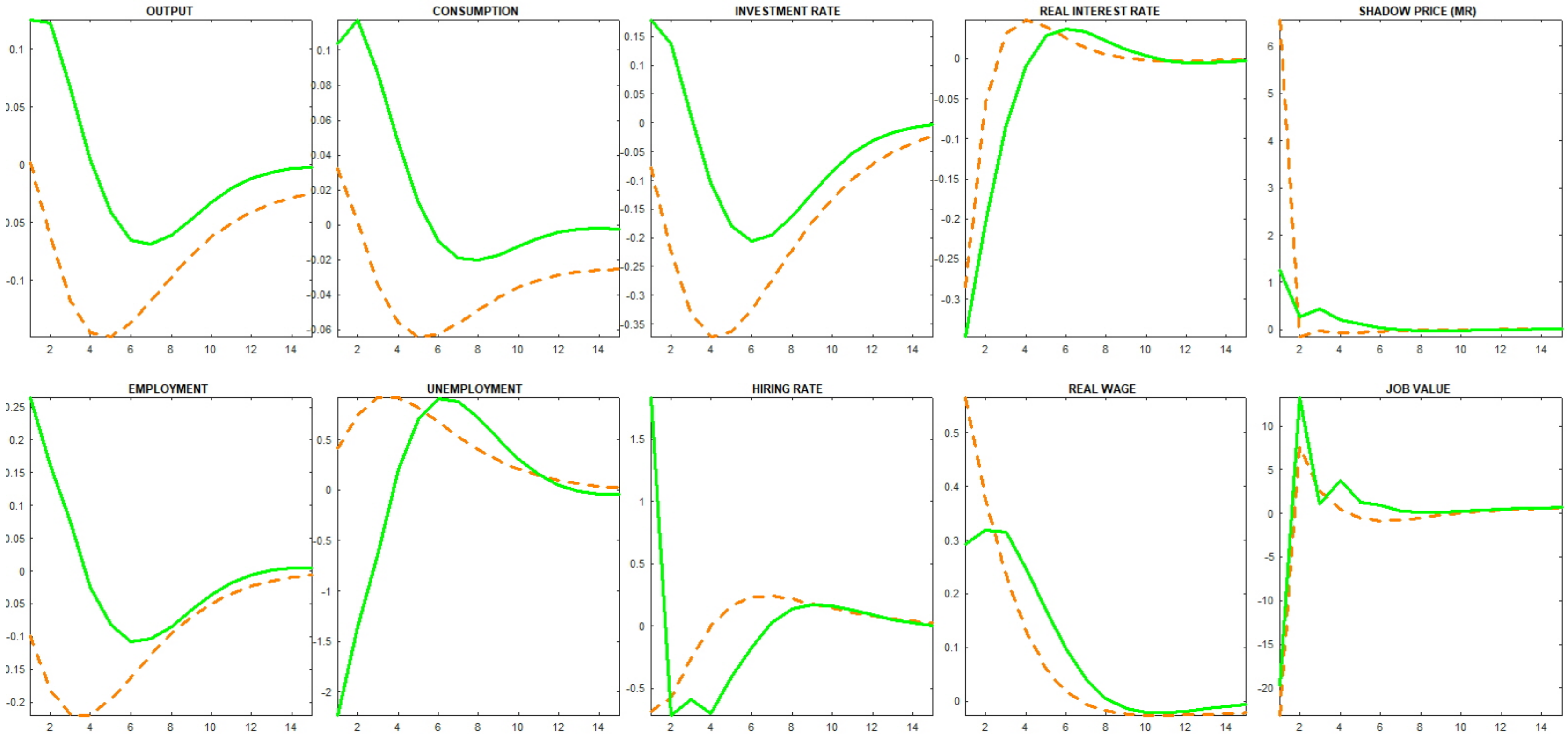
Notes: impulse responses to a 1% positive technology shock obtained for two different parameterizations: "high" hiring costs (orange broken line; e =5) and " low" frictions (solid green line; e =1.2). All variables are expressed in % deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

Figure 4: Impulse Responses to a Technology Shock: Extended Model with Rigid vs. Flexible Prices



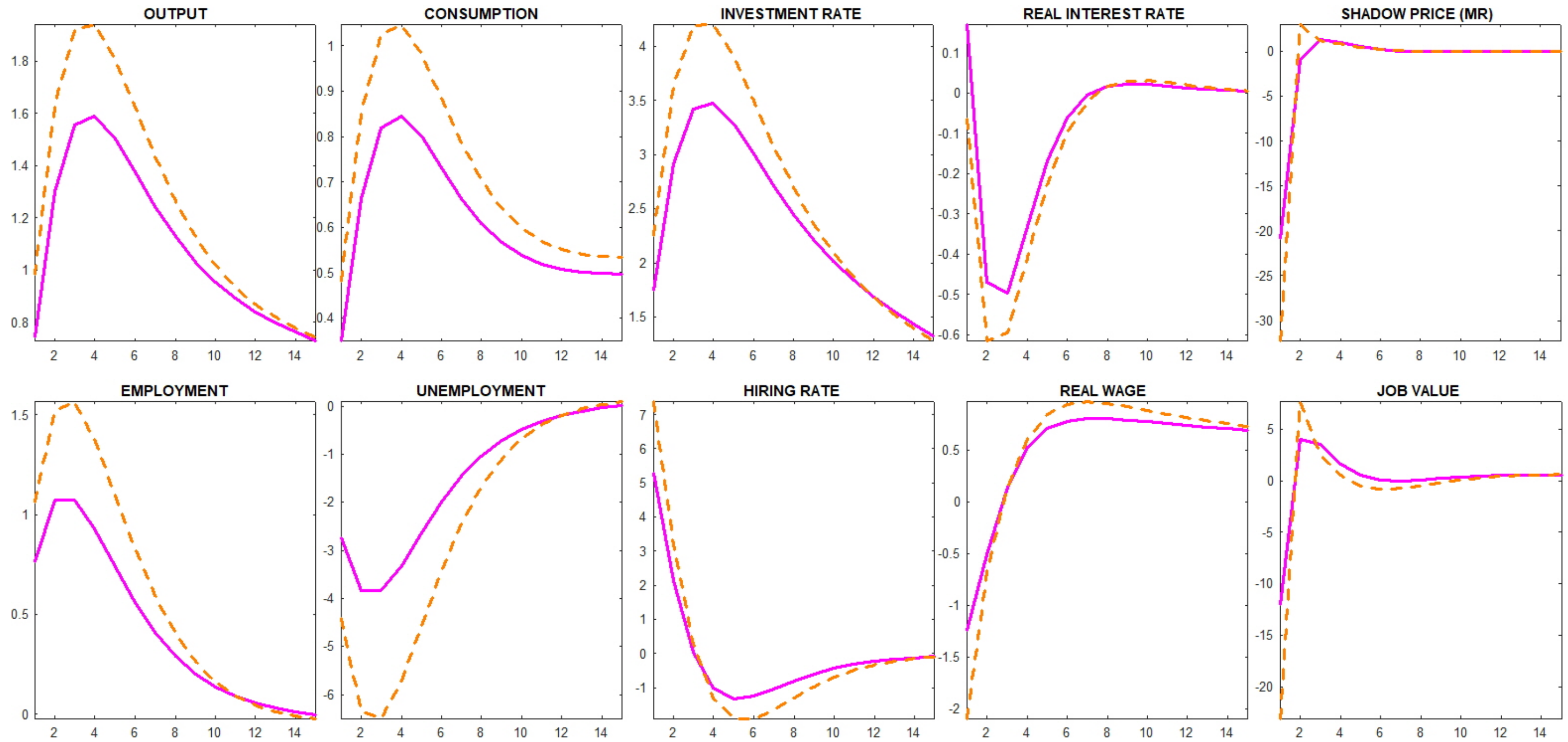
Notes: impulse responses to a 1% positive technology shock obtained for two different parameterizations: The rigid price model with hiring costs (NK + L Frictions, orange broken line; ζ=120 and e =5) and the flexible price model with hiring costs (NC + L Frictions, solid light blue line; $\zeta \simeq 0$ and e =5). All variables are expressed in % deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

Figure 5: Impulse Responses to a Monetary Policy Shock: Extended Model with “Low” vs. “High” Scales of Hiring Costs



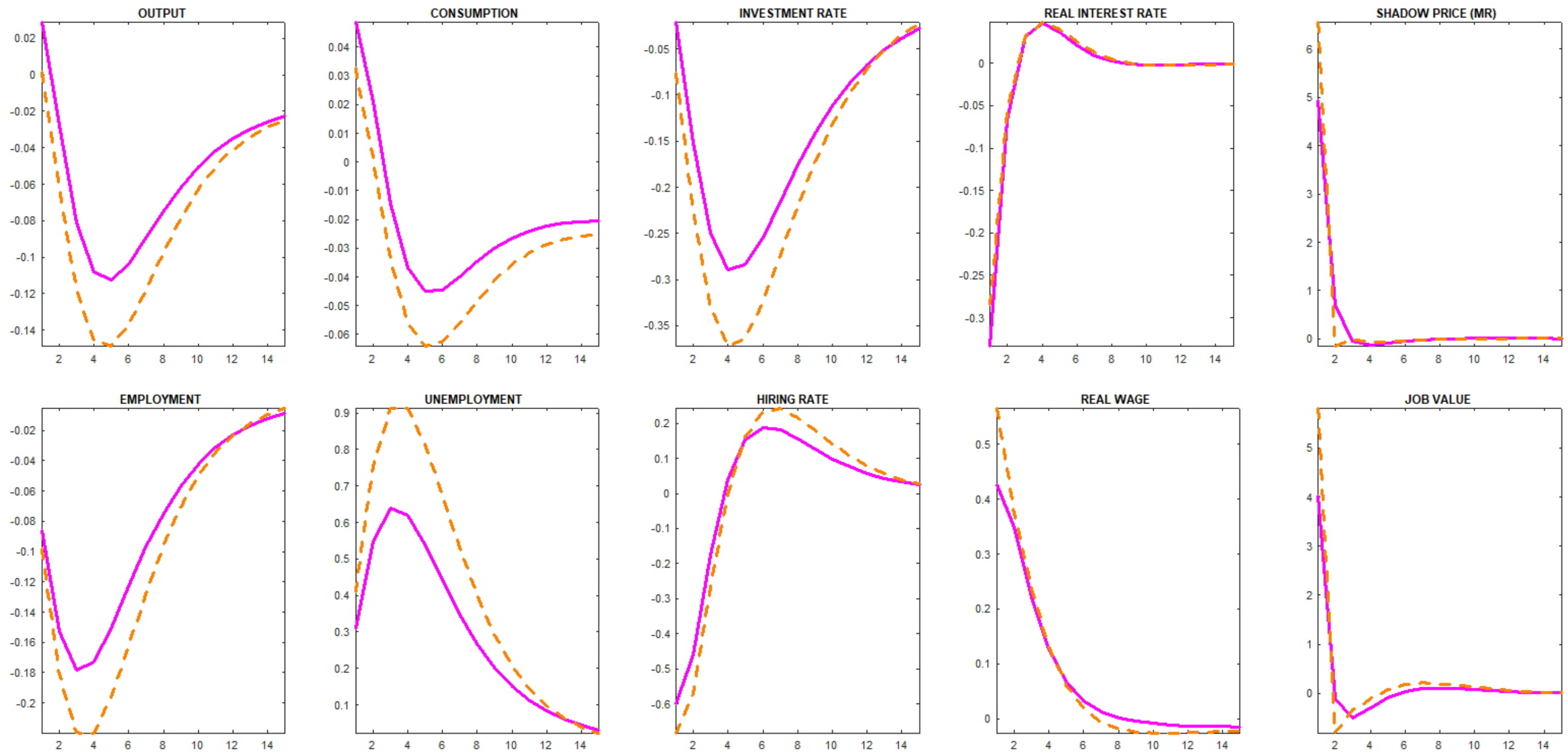
Notes: impulse responses to a 25 basis point expansionary monetary policy shock obtained for two different parameterizations: “high” hiring costs (orange broken line; e =5) and “low” frictions (solid green line; e =1.2). All variables are expressed in % deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

Figure 6: Impulse Responses to a Technology Shock, Vacancy Costs Only vs Vacancy and Hiring Costs



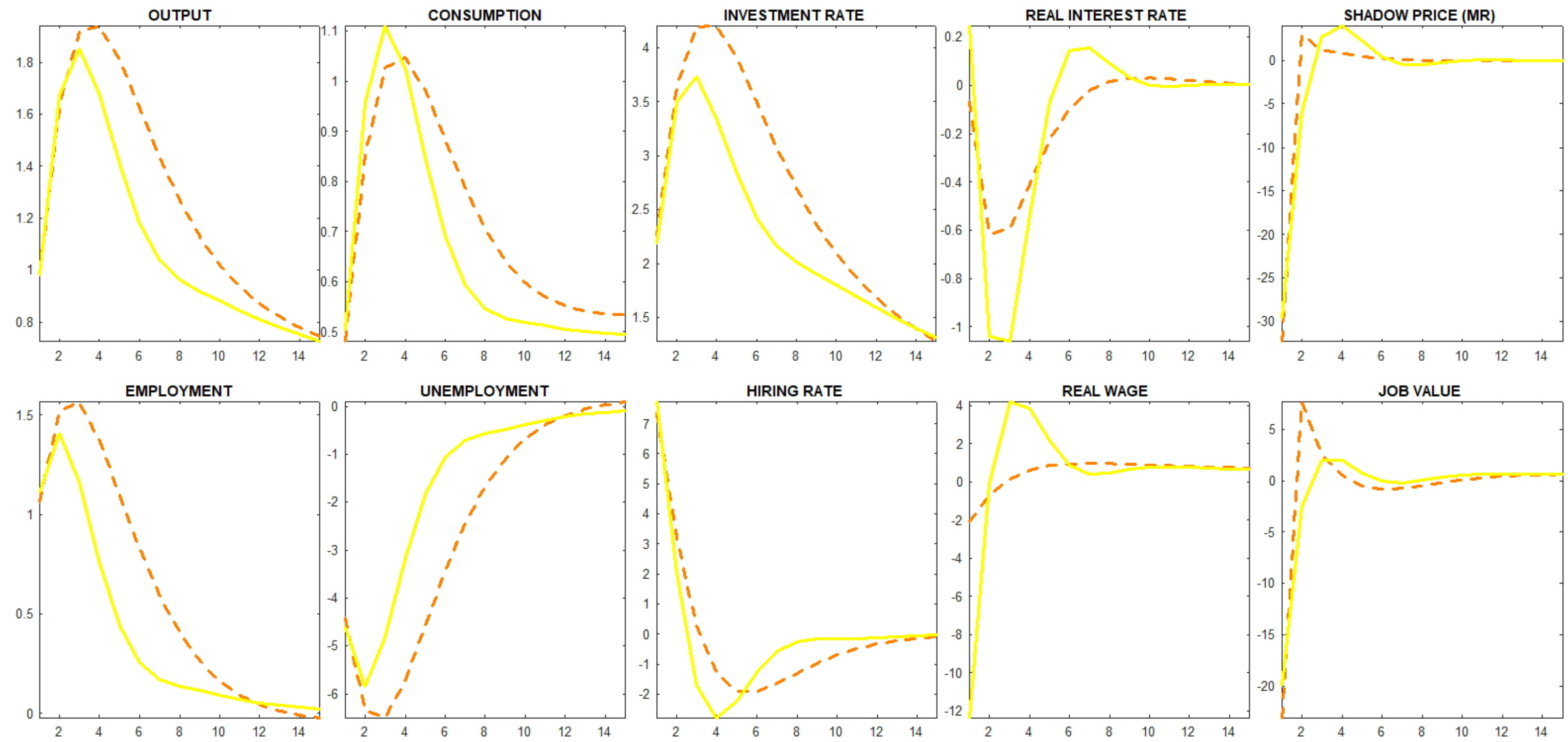
Notes: Impulse responses to a 1% positive technology shock obtained for two different parameterizations of η^q both with "high" hiring costs e =5. The orange (dashed) line uses the benchmark $\eta^q = 0.49$, implying the co-existence of both vacancy and hiring costs; and the purple (solid) line uses $\eta^q = 2$, implying vacancy costs only. All variables are expressed in % deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

Figure 7: Impulse Responses to a Monetary Policy Shock,Vacancy Costs Only vs Vacancy and Hiring Costs



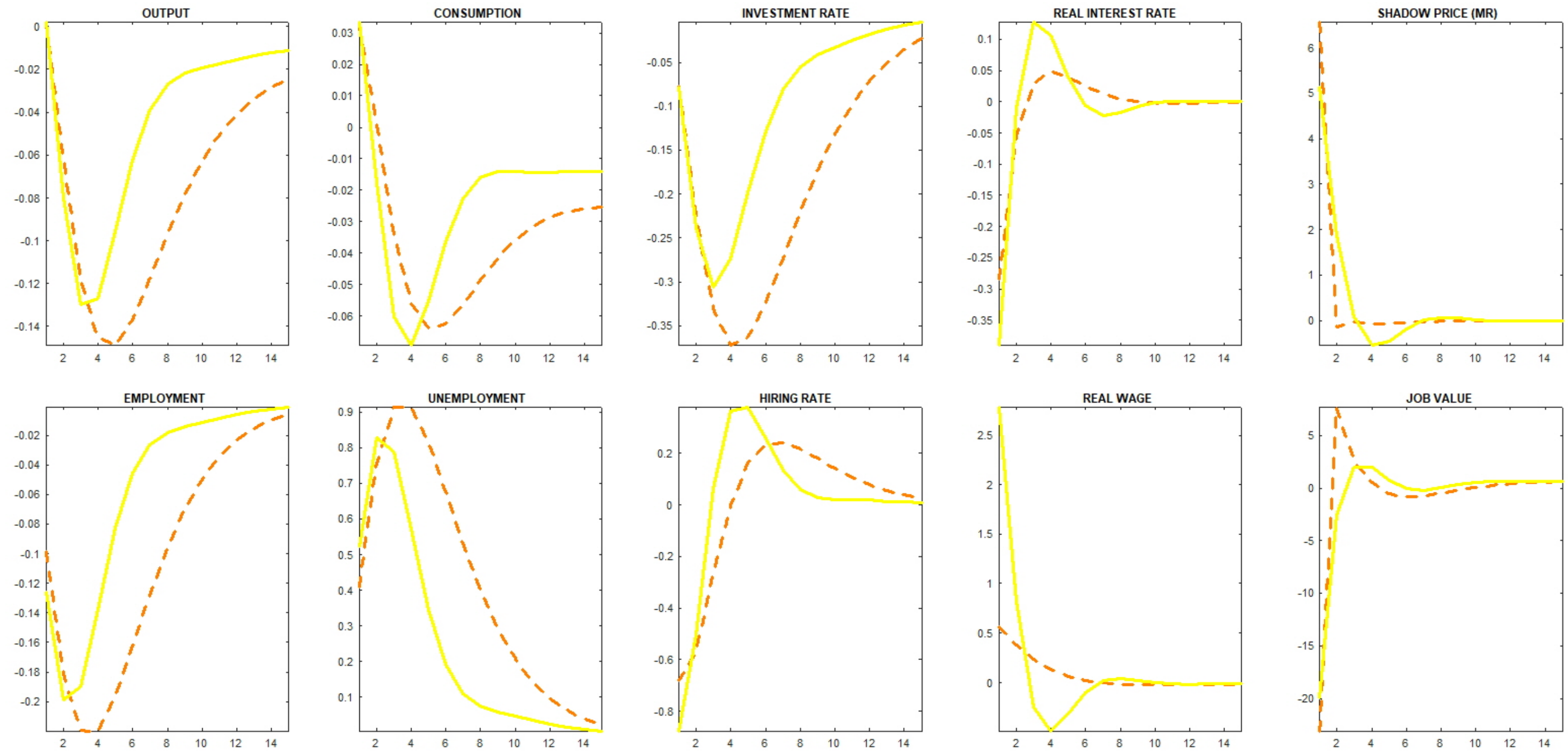
Notes: Impulse responses to a 25 basis points monetary policy expansion shock obtained for two different parameterizations of η^qboth with "high" hiring costs e =5. The orange (dashed) line uses the benchmark $\eta^q = 0.49$ implying the co-existence of both vacancy and hiring costs; and the purple (solid) li ne uses $\eta^q = 2$, implying vacancy costs only.. All variables are expressed in % deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

Figure 8: Impulse Responses to a Technology Shock: Low vs. High Wage Indexation ω



Notes: impulse responses to a 1% positive technology shock obtained for two different parameterizations: high wage indexation (orange broken line; $\omega = 0.87$) and low wage indexation (solid yellow line; $\omega = 0.1$). All variables are expressed in % deviations, except hiring, investment and real rates, which are expressed in percentage points deviations

Figure 9: Impulse Responses to a Monetary Policy Shock: Low vs.High Wage Indexation ω



Notes: impulse responses to a 25 basis points monetary expansion shock obtained for two different parameterizations: high wage indexation (orange broken line; $\omega = 0.87$) and low wage indexation (solid yellow line; $\omega = 0.1$). All variables are expressed in % deviations, except hiring, investment and real rates, which are expressed in percentage points deviations