

The Importance of Hiring Frictions in Business Cycles

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Abstract

The paper shows that there is an important direct role for hiring frictions in business cycles. This runs counter to key models in several strands of the macroeconomic literature, which imply that hiring frictions are not important per-se, but only insofar as they allow for wage rigidity. As wages are major costs for firms, while hiring costs are small, much attention has been given to wage cyclicalities, including issues of rigidity, while hiring costs were seen mostly as a factor operating to mitigate worker flows dynamics. We show that while hiring costs are indeed small, they interact with price frictions to offset, and possibly reverse, their effects. This confluence of frictions has significant implications for business cycle modelling.

Our results stem from two assumptions, for which we present micro and macro evidence: first, hiring costs include internal costs of hiring, such as training costs, and not just vacancy posting costs. Second, hiring involves mostly disruption to production within the firm, rather than third-party payments for hiring services.

Under these assumptions, the interaction between price frictions and hiring frictions reverses standard business cycle results, with dramatic implications for technology and monetary policy shocks. The mechanism produces strong amplification of labor market outcomes conditional on technology shocks, even under a pro-cyclical opportunity cost of work.

Keywords: hiring frictions; business cycles; interactions with price frictions.

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1 Introduction

Is there a direct role for hiring frictions in business cycles and are they important? Can they explain volatile labor market outcomes? This paper suggests that the answer to these questions is positive. This view runs counter to key models in major strands of the macroeconomic literature, which give negative answers.

Consider two benchmark literatures as a point of departure. First, labor market frictions in the tradition of Diamond, Mortensen, and Pissarides, 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 paradigm to account for the cyclical behavior of the labor market. These models typically abstract from price frictions, emphasized by the canonical New Keynesian approach.

Second, when labor market frictions, as modelled in Diamond, Mortensen, and Pissarides, have been explicitly incorporated within New Keynesian 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 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).

The contribution of this paper is to show that there is a *direct* role of hiring frictions in business cycle dynamics. Hence, hiring frictions matter *per se*, and not just because they allow for (privately-efficient) wage rigidity. The intuition for our mechanism is the following. The prevalent view states that wages are the key costs for firms, while hiring costs are small. Hence much attention is given to wage cyclicality, including issues of rigidity, while hiring costs are seen as a factor mitigating worker flows dynamics. 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. These effects operate through a shadow price, defined below, which responds to technology and monetary policy shocks. These changes alter the firm's incentives to hire in a significant way, leading to changes in employment, and, as a result, in the entire general equilibrium of the economy.

Our model relies on two essential ingredients, for which there is strong empirical macro- and micro-based evidence. The first is the explicit modelling of internal costs of hiring, such as training costs. These are different from the canonical vacancy posting costs, which depend on external market conditions. Empirical evidence reviewed in Section 2.2 below indicates that external costs of hiring are dwarfed by the magnitude of internal costs. The second key ingredient is that hiring costs are output costs, that is, they entail disruption to production. A sizable literature reviewed below has provided microeconomic evidence that hiring costs are mainly a loss in production stemming from the diversion of activities from production to hiring rather than payments for third-party services. We note that papers in the literature either have

made none of these two assumptions, or when they assumed the first, they did not also assume the second.

Our model is general enough to reproduce key results in the literature as special cases: for instance, we can recover the result obtained in the Diamond-Mortensen-Pissarides literature, whereby hiring frictions mitigate responses, hence precluding any significant effects of frictions in explaining volatile labor market variables. But this result only arises in the special case where price frictions are shut down or restricted to be quantitatively negligible. We can also recover the result obtained in the New-Keynesian literature, whereby hiring frictions do not matter much, per se. But this result only arises in the special case where hiring costs derive only from vacancies or, more generally, whenever internal hiring costs are assumed to be implausibly small. As we depart from these knife-edge assumptions, the interaction of price frictions and hiring frictions produces a host of interesting results. 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 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 (which equals marginal revenues and marginal costs). In the textbook 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. 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 New Keynesian 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, diverting resources from production into recruiting is less valuable at times when sales are more profitable.

While there is a widespread agreement that, if anything, the importance of labor market frictions in business cycle models is to make room for privately efficient wage rigidities to matter, the role of wage rigidities itself in enhancing the volatility of labor market outcomes is not unquestionable. Chodorow-Reich and Karabarbounis (2016) have shown that in the presence of a procyclical opportunity cost of work, leading models of the labor market, including models with endogenously rigid wages, fail to generate amplification, irrespective of the level of the opportunity cost. Using detailed microdata they provide solid evidence that the opportunity cost of work is indeed procyclical. We show that the amplification of labor market outcomes generated in our model is robust to the procyclicality of the opportunity cost of work.

We note that the key feature that induces amplification in our model is the countercyclical-

ity of marginal hiring costs conditional on technology shocks. This propagation mechanism is radically different from the one that takes place in DMP models, where vacancy posting costs are the sole source of frictions in the labor market. Indeed, in a DMP set-up the marginal cost of hiring is procyclical. Namely, in good times aggregate vacancies rise, which implies that vacancies become harder to fill, and the cost of hiring increases. This canonical propagation mechanism, which hinders the ability of search and matching models to account for the cyclicity of labor market outcomes, fades away when one accounts for the relative importance of internal costs of hiring.

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 New Keynesian 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 the modelling of hiring costs in the literature and provides the background for our formulation. Section 3 presents the baseline model with a minimal set of assumptions. Section 4 discusses calibration and explains the mechanism illustrating impulse responses. Section 5 explores the robustness of the mechanisms to the use of a richer macroeconomic general equilibrium model, including the introduction of different forms of hiring frictions and different parameterizations of the Taylor rule. Moreover, it elaborates on how alternative formulations of hiring costs affect the propagation of shocks. Section 6 concludes.

2 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 adopted in the literature and the related empirical evidence, so as to place our modelling in context. Three distinctions regarding the hiring cost function matter for the current paper. One relates to the arguments – are the costs related to actual hires, or related to aggregate labor market conditions, such as vacancy filling rates? A second is whether these costs are pecuniary costs paid to other firms for the provision of hiring services, or rather production costs entailing a loss of output within the firm. A third pertains to the shape of the function.

¹Starting 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).

The traditional DMP 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.

Cost of hires or cost of vacancies? Vacancy costs have been referred to as external costs of hiring as they depend on aggregate labor market conditions, i.e. 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.² 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). A host of papers has estimated and/or used actual hiring costs. 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 Groeshny (2016), Coles and Mortensen (2016), and Christiano, Eichenbaum and Trabandt (2016).

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), Mühlemann and Leiser (2015, Tables 1, 2, and 4), and Blatter et al (2016, Table 1) 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

²There is an old macroeconomic literature on this topic (including investment, as well as hiring), which features the internal costs of hiring. Such models were proposed in the 1960s and 1970s. Key papers include the following. Lucas (1967) and Mortensen (1973) derived firm optimal behavior with convex adjustment costs for n factors of production. In Mortensen's summary of Lucas (footnote 4 on p. 659), he 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 ($-f_x$) 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. The discussion here continues this strand and empirically substantiates it.

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. 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.

Pecuniary costs paid to other agents vs output costs. In much of the 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 the direct costs of training, measured as expenses related to course material and external teachers salaries. This forgone cost of production is measured as the opportunity cost of work incurred by co-workers, managers, and the new hires themselves, in connection with recruitment or training activities. 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. In a micro study, 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 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. 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.

Functional form. Those cited papers which have used structural estimation (Yashiv (2000, 2016, 2017), 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.

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 (NC) 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.³

Introducing price frictions into the otherwise frictionless model yields the New Keynesian (NK) 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 and from variation of hours worked on the intensive margin.⁴ 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:

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

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:

$$P_t C_t + P_t I_t + \frac{B_{t+1}}{R_t} = W_t N_t + X_t^K K_{t-1} + B_t + \Omega_t - T_t, \quad (2)$$

³With 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)).

⁴As shown in Rogerson and Shimer (2011), 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.

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:

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

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:

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

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

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

an equation characterizing optimal investment decisions:

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

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,

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

where V_t^N is the Lagrange multiplier associated with the employment law of motion. It represents the marginal value to the household of having an unemployed worker turning employed at the beginning of the period. Eq.(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 eq.(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,⁵ plus a continuation value.

⁵A worker unemployed at the beginning of the period would still be employed at the end of the period with probability x_t , in which case the household would get a net payoff of V_t^N . The term $1 - x_t$ at the denominator is a rescaling coming from the relation between beginning- and end-of-period unemployment $U_{0,t} = \frac{U_t}{1 - x_t}$.

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 R_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:

$$P_t = \left(\int_0^1 P_{t,i}^{1-\epsilon} di \right)^{1/(1-\epsilon)}, \quad (8)$$

and the demand for the intermediate good i is:

$$Y_{t,i} = \left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon} Y_t. \quad (9)$$

3.2.2 Hiring Frictions

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

$$Y_{t,i} = f_{t,i} (1 - \tilde{g}_{t,i}), \quad (10)$$

where $f(A_t, N_{t,i}, K_{t,i}) = A_t N_{t,i}^\alpha K_{t,i}^{1-\alpha}$, 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 $\ln A_t = \rho_a \ln A_{t-1} + e_t^a$, 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. The explicit functional form for these costs follows previous work by Merz and Yashiv (2007), Gertler Sala

and Trigari (2008), 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, $\frac{H_{t,i}}{N_{t,i}}$, in line with estimates by Yashiv (2016, 2017):

$$\tilde{g}_{t,i} = \frac{e}{2} \left(\frac{H_{t,i}}{N_{t,i}} \right)^2, \quad (11)$$

where $e > 0$ is a scale parameter. The modeling of hiring frictions in eq.(11) is consistent with the substantial macroeconomic and microeconomic evidence reviewed in Section 2.⁶

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 will restrict attention to internal costs of hiring only, excluding vacancy costs. We will therefore interpret hiring costs as training costs and other costs that are related to the hiring rate. 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:

$$\max_{\{P_{t+s,i}, H_{t+s,i}, \tilde{K}_{t+s,i}\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \begin{aligned} & \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s}}{P_{t+s}} N_{t+s,i} - \frac{X_{t+s}^K}{P_{t+s}} \tilde{K}_{t+s,i} \\ & - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \end{aligned} \right\}, \quad (12)$$

substituting for $Y_{t+s,i}$ using the demand function (9), and subject to the law of motion for labor (13),

$$N_{t,i} = (1 - \delta_N) N_{t-1,i} + H_{t,i}, \quad 0 < \delta_N < 1, \quad (13)$$

⁶We 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 verified 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.(10) so as to minimize deviations from the literature.

and the constraint that output must equal demand:

$$\left(\frac{P_{t,i}}{P_t}\right)^{-\epsilon} Y_t = f_{it}(1 - \tilde{g}_{it}), \quad (14)$$

which is obtained by combining equations (9) and (10).

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

$$\pi_t(1 + \pi_t) = \frac{1 - \epsilon}{\zeta} + \frac{\epsilon}{\zeta} \Psi_t + E_t \Lambda_{t,t+1} (1 + \pi_{t+1}) \pi_{t+1} \frac{Y_{t+1}}{Y_t}, \quad (15)$$

where Ψ_t is the Lagrange multiplier associated with the constraint (14), and which we have called 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 (15) specifies that inflation depends on the marginal cost as well as expected future inflation.

The first-order conditions with respect to H_t , N_t and \check{K}_t , are:

$$Q_t^N = \Psi_t (f_{N,t} - g_{N,t}) - \frac{W_t}{P_t} + (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N, \quad (16)$$

$$Q_t^N = \Psi_t g_{H,t}, \quad (17)$$

$$\frac{X_t^K}{P_t} = \Psi_t (f_{K,t} - g_{K,t}), \quad (18)$$

where Q_t^N is the Lagrange multiplier associated with the employment law of motion, and $g_{X,t}$, $f_{X,t}$ denote the derivatives of the functions f_t and $g_t \equiv \tilde{g}_t f_t$ with respect to variable X . One can label Q_t^N as Tobin's Q for labor or the value of labor. We notice that the value of a marginal job in equation (16) can be expressed as the sum of current-period profits –the marginal revenue product $\Psi_t (f_{N,t} - g_{N,t})$ less the real wage– and a continuation value. In equation (17), 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 (18) is equated to the marginal revenue product of capital $\Psi_t (f_{K,t} - g_{K,t})$.

Solving the F.O.C. for employment in equation (16) for Ψ_t , and eliminating Q_t^N using (17) we get:

$$\Psi_t = \frac{\frac{W_t}{P_t}}{f_{N,t} - g_{N,t}} + \frac{\Psi_t g_{H,t} - (1 - \delta_N) E_t \Lambda_{t,t+1} \Psi_{t+1} g_{H,t+1}}{f_{N,t} - g_{N,t}}, \quad (19)$$

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 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.

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 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:⁷

$$W_t = \arg \max \left\{ \left(V_t^N \right)^\gamma \left(Q_t^N \right)^{1-\gamma} \right\}. \quad (20)$$

The solution to this problem is a standard wage equation:

$$\frac{W_t}{P_t} = \gamma \Psi_t (f_{N,t} - g_{N,t}) + (1 - \gamma) \left[\chi C_t N_t^\varphi + \frac{x_t}{1 - x_t} \frac{\gamma}{1 - \gamma} Q_t^N \right]. \quad (21)$$

3.4 The Monetary and Fiscal Authorities and Market Clearing

We assume that the government runs a balanced budget:

$$T_t = B_t - \frac{B_{t+1}}{R_t}, \quad (22)$$

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

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*} \right)^{\rho_r} \left[\left(\frac{1 + \pi_t}{1 + \pi^*} \right)^{r_\pi} \left(\frac{Y_t}{Y^*} \right)^{r_y} \right]^{1-\rho_r} \tilde{\zeta}_t, \quad (23)$$

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 $\tilde{\zeta}_t$ captures a monetary policy shock, which is assumed to follow the autoregressive process $\ln \tilde{\zeta}_t = \rho_\zeta \ln \tilde{\zeta}_{t-1} + e_t^\zeta$, with $e_t^\zeta \sim N(0, \sigma_\zeta)$.

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

$$(f_t - g_t) \left[1 - \frac{\zeta}{2} \pi_t^2 \right] = C_t + I_t. \quad (24)$$

⁷We have solved a version of the model that allows for intrafirm bargaining as in Bruggemann, Gautier and Menzio (2018). We found that intrafirm bargaining amplifies the mechanism discussed in the following sections (see Faccini and Yashiv (2017)). For the sake of simplicity and comparability with the medium-scale model presented in Section (5), we simplify along this dimension.

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 Empirical Implementation

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 both 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.

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.

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, $\frac{s_H}{f-s_N}$, 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 produced by the BLS designed to account also for workers who are marginally attached to the labor force (U-6), consistently with our measure of the separation rate. 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. The calibration target for marginal hiring costs in point (i) above implies a ratio of marginal hiring costs over steady state wages $\frac{\Psi \cdot g_{Ht}}{W/P}$ around 30%, i.e., less than one month of wages.⁸ We focus on marginal hiring costs, while the empirical literature typically reports numbers for average hiring costs. The latter, computed as g_t/H_t , are close to two weeks of wages in our calibration. This calibration of hiring costs is intentionally conservative in the sense that average and marginal costs are at the lower bound of the spectrum of estimates reported in the literature. For instance, the widely-cited study of Silva and Toledo (2009) reports that average training costs are about 55% of quarterly wages,⁹ while our average is 15%.

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.¹⁰ 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

We show how the impulse responses obtained on the impact of technology and monetary policy shocks change across different parameterizations of hiring and price frictions. This is convenient to illustrate the interaction produced by these two frictions, and to provide intuition. Specifically, 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

⁸The 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 (11) is mild.

⁹This 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.

¹⁰Our value for ζ is obtained by matching the same slope of the linearized Phillips Curve as in Galí: $\frac{\epsilon-1}{\zeta} = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$, 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 . While Galí (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.

version of the model.¹¹

Impulse responses to technology shocks and to monetary policy shocks upon impact are reported in Figures 1 and 2, respectively.

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, just 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 NK model embodying price frictions together with hiring frictions as calibrated in Table 1, Section 4.1 (green 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 NC model with no frictions obtained by setting $\zeta \simeq 0$ and $e \simeq 0$ (black point); (v) finally, we add a NK model with a higher intensity of hiring frictions, corresponding to the estimate in Silva and Toledo (2009), $e = 5$ and $\zeta = 120$ (orange point).¹²

We emphasize that while we indicate five points in this space, corresponding to the models under review, these serve as reference points and the graphs offer a “bigger picture”.

Technology Shocks

We begin by noting that in the case where both price and hiring frictions are shut down, the model delivers the standard NC 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 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 Rogerson and Shimer (2011) 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.

¹¹The very simple model presented here lacks propagation and hence some key differences in the impulse responses across restricted versions 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.

¹²We set the parameter e close to zero and not exactly equal to zero for ease of exposition. Notice that for $e = 0$ there is no unemployment, and in the frictionless labor market equilibrium the restriction $n_t + u_t = 1$ must be lifted to analyze business cycle dynamics. So the model has a discontinuity at $e = 0$. Labelling the model with $e \simeq 0$ as “New Classical” is therefore a slight abuse of terminology. Yet, solving the model with a totally frictionless labor market for different values of ζ , would show the same qualitative pattern reported in Figures 3 and 4 below. Hence we abstract from this minor complication for illustrative purposes.

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 this 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, 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.

To understand the mechanism, consider the optimal hiring condition, obtained by merging the FOCs for hiring and employment in equations (16) and (17), eliminating Q_t^N :

$$\Psi_t (f_{N,t} - g_{N,t}) - \frac{W_t}{P_t} + (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N = \Psi_t g_{H,t}. \quad (25)$$

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 shock operates in the standard way, by generating amplification in profits through the marginal product of labor (see the black point). 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 (25), the partial effect of changes in shadow price on job creation is ambiguous. To resolve this ambiguity, note that

$$\frac{\partial (\Psi_t g_{H,t})}{\partial \Psi_t} = g_{H,t} = e \frac{H_t}{N_t} \frac{f_t}{N_t} = \frac{Q_t^N}{\Psi_t}, \quad (26)$$

where the second equality follows from substituting the explicit functional form for \tilde{g}_t in eq.(11) and the third equality follows from the FOC in eq.(17), which implies that $Q_t^N = g_{H,t} \Psi_t$.

This expression 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 small 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).

But as the scale of hiring frictions increases, the fall in marginal hiring costs makes employment fall by less (green point). Eventually, beyond a certain threshold the response of employment turns positive and for sufficiently large values of e may even be stronger than in the NC case (orange point). What drives amplification then, 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 intuitive explanation why hiring frictions offset the standard New-Keynesian propagation channel is the following. In the textbook NK model, 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. Because hiring involves a forgone cost of production, a fall in the shadow price with the productivity shock implies that it becomes more profitable to allocate resources to hiring.

The increase in employment in the NK model with hiring frictions induces a stronger increase in investment and 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. Hiring frictions, by sustaining employment, also raise the opportunity cost of work, $\chi C_t N_t^\varphi$ in equation (21). This increase in the workers' threat point in wage negotiations endogenously leads to a lower fall in their wages.

The importance of hiring frictions in the transmission of technology shocks highlighted here is at odds with the results obtained by standard NK modelling (see, for example, Galí (2011)), whereby the propagation of shocks is virtually unaffected by labor market frictions. The main reason for this discrepancy lies in the assumption that the costs of hiring are exclusively related to vacancy posting. Calibration, such as that based on the measure of vacancy costs reported by Silva and Toledo (2009), implies that hiring costs are slightly above a tenth of a percentage point of GDP, about ten times less than in our benchmark low-hiring friction calibration, which is instead based on a broader definition of costs. In the space of Figure 1, this standard calibration would correspond to a value of e close to the origin. Moreover, the standard NK model features vacancy posting costs as pecuniary, hence the mechanism above does not apply. In the next Section we will elaborate more formally on the role of pecuniary costs and output costs, and show that vacancy posting costs lead to a mitigation of the mechanism presented here, even if hiring costs are expressed as output costs.

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.

The reason why hiring frictions offset the standard New-Keynesian 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 forgoing production, the marginal cost of hiring increases (RHS of equation (25)), dampening the incentives for job creation. Intuitively, diverting resources from production into recruiting is less convenient at times where sales are more profitable.

As shown by eq.(26), the marginal cost of hiring becomes more sensitive to changes in the shadow price as the scale of the hiring costs 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, and that the irrelevance results obtained by either Rogerson and Shimer (2011) and Galí (2011) can be supported as some special outcomes of the general framework presented here, which are based on very restrictive assumptions.

5 The Medium Scale 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 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 á la Christiano, Eichenbaum and Evans (2005), 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.

Beyond providing robustness, this section highlights the role of the mechanism discussed above as an additional one to wage rigidity, in providing amplification to labor market outcomes. Indeed, we will show that in our framework, wage rigidity does not generate sufficient amplification when calibrated to match the autocorrelation of real wages in US data. We also elaborate on the direct role of pecuniary and output costs of hiring, as well as on the role of external and internal hiring costs for the propagation mechanism discussed above. Finally, we discuss the results in the light of the empirical literature.

5.1 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

$$H_t = \frac{U_{0,t} V_t}{\left(U_{0,t}^l + V_t^l \right)^{\frac{1}{l}}}, \quad (27)$$

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:

$$\tilde{g}_{t,i} = \frac{e}{2} q_t^{-\eta^q} \left(\frac{H_{t,i}}{N_{t,i}} \right)^2, \quad (28)$$

where $q_t = \frac{H_t}{V_t}$ and H_t, V_t are aggregates.¹³

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 (11), 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

¹³The function can also be written as

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

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 (28) 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 Hall (2005) type wage norm:

$$\frac{W_t}{P_t} = \omega \frac{W_{t-1}}{P_{t-1}} + (1 - \omega) \frac{W_t^{NASH}}{P_t}, \quad (29)$$

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

$$\frac{W_t^{NASH}}{P_t} = \arg \max \left\{ \left(V_t^N \right)^\gamma \left(Q_t^N \right)^{1-\gamma} \right\}. \quad (30)$$

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 low friction benchmark, the parameter e governing the intensity 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 0.2. To inspect the mechanism, we will also report impulse responses for a “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 as reported by Shimer (2005) for US 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. 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 Results

We discuss the results and explain the mechanisms. We do so through varying the values of key parameters with respect to the benchmark calibration of Table 2.

5.2.1 The Interaction of Hiring Frictions and Price Frictions

Technology shocks. Figure 3 reports impulse responses for a 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 lower calibration of the scale of hiring costs is not sufficient to turn the response of employment from negative to positive on the impact of the technology shock. A larger friction parameterization (higher e) instead can. 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. Figure 3a shows this differential effect.

Figure 3a

The ensuing decline in hiring costs (manifested in the fall – see Figure 3 – in job values Q_t^N , which equal $\Psi_t g_{H,t}$) raises the hiring rate, while in the low e case the hiring rate falls. Strikingly, at the higher scale of hiring costs (higher e), and in the presence of price frictions, a technology shock implies a much stronger expansionary response 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. Hiring frictions interacting with price frictions increase the countercyclicality of marginal hiring costs.

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, which has sparked a large literature since Shimer (2005).

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). We label the rigid price model as NK+L Frictions, and the flexible price model as NC + L Frictions.

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. 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. Moreover, 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 indeed 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 a 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 Figure 5a, an effect which strengthens as e rises.

Figure 5a

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 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.

5.2.2 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 New Keynesian 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

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

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 . For values of η^q less than 2, 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.

5.2.3 Output Costs vs. Pecuniary Costs of Hiring

So far we have assumed that the hiring costs specified in eq.(28) are expressed in units of (for-gone) 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 (10) is simply $Y_{i,t} = f(A_t, N_{t,i}, \check{K}_{t,i})$, and the maximization problem of the firm becomes

$$\begin{aligned} \max_{P_{t+s,i}, H_{t+s,i}, \check{K}_{t+s,i}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s} N_{t+s,i}}{P_{t+s}} - \frac{X_{t+s}^K}{P_{t+s}} \check{K}_{t+s,i} \right. \\ \left. - g(A_{t+s,i}, H_{t+s,i}, N_{t+s,i}, \check{K}_{t+s,i}) - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \right\} \quad (31) \end{aligned}$$

subject to the technology constraint (14), the law of motion for employment (13) and the demand function (9).

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 New Keynesian 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 (Galí, 2011).

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 not 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.

5.2.4 The Role of Wages

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

$$\frac{W_t}{P_t} = \omega \frac{W_{t-1}}{P_{t-1}} + (1 - \omega) \left[\gamma \Psi_t (f_{N,t} - g_{N,t}) + (1 - \gamma) \left[\frac{\chi N_t^\varphi}{P_t \lambda_t} + \frac{x_t}{1 - x_t} \frac{\gamma}{1 - \gamma} Q_t^N \right] \right]. \quad (32)$$

where

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

The optimal hiring equation given by:

$$Q_t^N = \Psi_t (f_{N,t} - g_{N,t}) - \frac{W_t}{P_t} + (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N, \quad (33)$$

Combining (32) and (33) yields an expression for the job value Q_t^N . This value represents marginal costs, which are equal to the expected marginal profits of the worker to the firm.

$$\begin{aligned}
Q_t^N &= \Psi_t g_{H,t} \\
&= \Xi_t (1 - \gamma(1 - \omega)) \Psi_t (f_{N,t} - g_{N,t}) \\
&\quad - \Xi_t \left[\omega \frac{W_{t-1}}{P_{t-1}} + (1 - \omega) (1 - \gamma) \frac{\chi_t N_t^\varphi}{\lambda_t P_t} \right] \\
&\quad + \Xi_t (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N
\end{aligned} \tag{34}$$

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 (33) and (34) 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 $\frac{\chi_t N_t^\varphi}{P_t \lambda_t}$, as discussed above. By equation (34) this term is expected to play an offsetting role to increases in productivity $f_{N,t}$, as $\frac{\partial Q_t^N}{\partial \frac{\chi_t N_t^\varphi}{P_t \lambda_t}} = -\Xi_t (1 - \omega) (1 - \gamma) < 0$. This is in line with the logic laid down by Chodorow-Reich and Karabarbounis (2016). 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 on the different terms in equation (34).

Table 3

The table shows the differences across different specifications of the values of ζ, e , and 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 bigger movements are in marginal hiring costs, $\Psi_t g_{H,t}$, and in adjusted net marginal productivity $\Xi_t (\Psi_t (f_{N,t} - g_{N,t}) (1 - \gamma(1 - \omega)))$, 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). Hence the basic amplification of the model is not dependent on exogenous wage rigidity, but there is some contributing effect after the initial impact.

5.2.5 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.

5.3 The Results in the Context of the Empirical Literature

Our theoretical investigation has related to a grid of values in the joint space of price frictions and hiring frictions. It supports the full variety of results obtained in the empirical VAR and DSGE studies. This variety includes contradictory findings. Our model is able to account for them, when predicating the outcomes on values of e and ζ .

Technology Shocks. The New Classical model posits a key role for technology shocks in generating business cycles, with positive shocks leading to employment and output expansion; see, for example, Section 4 in King and Rebelo (1999). The seminal work by Galí (1999), which sparked a debate in the literature, was the first to identify a negative response of employment to total factor productivity (TFP) shocks. While Galí (2004) and others have provided more evidence in this direction, VAR analysis in Uhlig (2004), Christiano, Eichenbaum and Vigfusson (2004), Mertens and Ravn (2011), Alexopoulos (2011), and Sims (2011) found opposite results, pointing to a positive response of employment.

In a recent survey paper, Ramey (2016) lists almost 20 specifications of DSGE models and their results (see her Table 9). Four studies find that TFP shocks explain sizeable fractions of output fluctuations (in the range of 40% to 75%), six studies document little effect (less than 10% explained), and the rest range from 12% to 30%. In discussing the findings of these models and of the related VAR results, Ramey points to their contrasting findings. For example, in models without price rigidity, positive TFP shocks invariably raise hours of work and in models with price rigidity they invariably lower hours of work. In the latter case, technology shocks are unlikely to be an important source of economic fluctuations, as they cannot generate the positive co-movement between employment and output, which is characteristic of the business cycle. The current paper has shown that our modelling of hiring frictions does not constrain the sign of the response of hiring to technology shocks. This would give technology shocks a channel to matter for economic fluctuations, even in a DSGE model with price rigidities.

Monetary Policy Shocks. The standard, expansionary effects of a decrease in interest rates are consistent with a multitude of results in the VAR literature, which rely on a variety of identification schemes. Yet, the findings in Faust, Swanson and Wright (2004), Uhlig (2005), and Amir and Uhlig (2016) are consistent with the view that monetary policy produces small real effects or even no real effects. Table 1 in Ramey (2016) lists 11 specifications of DSGE models and their results. Only two studies find that these shocks explain sizeable fractions of output fluctuations, while the others document small effects (less than 10% explained). Moreover, Ramey (2016) argues that relaxing the conventional assumption in VARs whereby prices and output cannot respond to the interest rate contemporaneously, leads to “puzzling” results, whereby an expansionary monetary policy shock seems to have significant *contractionary* effects. These results emerge using a variety of agnostic identification schemes. Similarly, the empirical evidence presented by Nekarda and Ramey (2013) on mark-ups being pro-cyclical conditional on monetary policy shocks, also appears as a “puzzle,” when interpreted within the confines of a textbook New-Keynesian model. Yet even these results, would not appear “puzzling” when seen through the lenses of our model. Indeed, they can be supported by a combination of sufficiently strong, yet plausible, hiring and price frictions.

6 Conclusions

This paper shows that hiring frictions matter in a significant way for business cycles, not only through wage setting mechanisms. Using a grid of plausible parameterizations, we have

shown that hiring frictions are as important as price frictions for the propagation of shocks in New-Keynesian models. Hence, we conclude that New Keynesian modelling needs to recognize the importance of hiring frictions in the transmissions of shocks. At the same time, search and matching DMP modelling needs to recognize the importance of price frictions. The interactions of frictions are key.

Our model emphasizes the importance of internal output costs of hiring, which appears to be the most empirically relevant source of hiring frictions in the micro-data. By changing the notion of hiring costs we were able to reverse the conclusions obtained in the literature, which found a negligible direct role for hiring frictions in business cycle models. Thus, we have shown that the precise nature of hiring frictions is key for the transmission of 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.¹⁴ 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 literature 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, the precise degree of price rigidity is less relevant, if not irrelevant, in the propagation of shocks to real variables. For higher, yet not implausible values of frictions costs, the conventional New Keynesian propagation mechanism is even turned upside-down. Therefore, the Macro literature needs a correct assessment of hiring costs in conjunction with price frictions to gauge the propagation of shocks at business cycle frequencies. We leave this important task for future research.

¹⁴See, for example, the recent sectorial study of price frictions in De Graeve and Walentin (2015) and the references therein.

References

- [1] Alexopoulos, M. (2011). "Read All About It! What Happens Following a Technology Shock," **American Economic Review** 101, 1144-1179.
- [2] Alexopoulos, M. and T. Tombe (2012). "Management Matters," **Journal of Monetary Economics** 59, 269-285.
- [3] Amir A. P. and H. Uhlig (2015). "Sign Restrictions in Bayesian FAVARs with an Application to Monetary Policy Shocks," NBER Working paper 21738.
- [4] Andolfatto, D. (1996). "Business Cycles and Labor-Market Search," **American Economic Review** 86,1 112-132.
- [5] Bartel, A. P. (1995). "Training, Wage Growth and Job Performance: Evidence from a Company Database," **Journal of Labor Economics**, 13, 3, 401-425.
- [6] Bartel, A.P., N. D. Beaulieu, C.S. Phibbs, and P.W. Stone (2014). "Human Capital and Productivity in a Team Environment: Evidence from the Healthcare Sector," **American Economic Journal: Applied Economics** 6(2): 231–259
- [7] Basu, S. and J. Fernald (1997). "Returns to Scale in US Production: Estimates and Implications," **Journal of Political Economy**, 105(2), 249-83.
- [8] Blanchard, O. and J. Galí (2010). "Labor Markets and Monetary Policy: A New Keynesian Model with Unemployment," **American Economic Journal: Macroeconomics** 2(2), 1-30.
- [9] Blatter M., S. Muehlemann, S. Schenker, and S.C. Wolterd (2016). "Hiring Costs for Skilled Workers and the Supply of Firm-Provided Training," **Oxford Economic Papers**, 68, 1, 238-257.
- [10] Brugemann, B., P. Gautier, and G. Menzio (2018). "Intra Firm Bargaining and Shapley Values," **Review of Economic Studies**, forthcoming.
- [11] Burnside, C. (1996). "Production Function Regressions, Returns to Scale, and Externalities," **Journal of Monetary Economics** 37, 177-201.
- [12] Cahuc, P., F. Marque, and E. Wasmer (2008). "A Theory Of Wages And Labor Demand With Intra-Firm Bargaining And Matching Frictions," **International Economic Review** 49(3), 943-72.
- [13] Chetty, R., A. Guren, D. Manoli, and A. Weber (2013). "Does Indivisible Labor Explain the Difference between Micro and Macro Elasticities? A Meta-Analysis of Extensive Margin Elasticities," **NBER Macroeconomics Annual 2012**, Volume 27: 1-56.
- [14] Chodorow-Reich, G., and L. Karabarbounis (2016). "The Cyclicalty of the Opportunity Cost of Employment," **Journal of Political Economy** 124,6,1563 – 1618.

- [15] Christiano, L.J., Eichenbaum, M., Evans, C.L.(2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," **Journal of Political Economy** 113 (1), 1–45.
- [16] Christiano, L. J., M.S. Eichenbaum, and M. Trabandt (2016). "Unemployment and Business Cycles," **Econometrica** 84, 4, 1523–1569.
- [17] Christiano, L. J., M.S. Eichenbaum, and R. Vigfusson (2004). "The Response of Hours to a Technology Shock: Evidence Based on Direct Measures of Technology," **Journal of the European Economic Association** 2(2-3), 381-395.
- [18] Christiano, L. J., M. Trabandt, and K.Walentin (2011). "Introducing Financial Frictions and Unemployment Into a Small Open Economy Model," **Journal of Economic Dynamics and Control** 35,1999–2041.
- [19] Christoffel, K. and T. Linzert (2010). "The Role of Real Wage Rigidity and Labor Market Frictions for Inflation Persistence," **Journal of Money, Credit and Banking** 42(7), 1435-1446.
- [20] Cochrane, J.H. (2005). **Asset Pricing**, Revised Edition, Princeton University Press.
- [21] Cochrane, J.H. (2008). "Financial Markets and the Real Economy, " Chapter 7 in R.Mehra (Ed.) **Handbook of the Equity Risk Premium** 237-325, North-Holland. Amsterdam.
- [22] Coles, M. and D. Mortensen (2016). "Equilibrium Labor Turnover, Firm Growth and Unemployment," **Econometrica** 84, 347-363.
- [23] Cooper, R., J.Haltiwanger, and J.L. Willis (2015). " Dynamics of Labor Demand: Evidence from plant-level observations and aggregate implications" **Research in Economics** 69, 37–50.
- [24] Costain, J. and M. Reiter (2008). "Business Cycles, Unemployment Insurance, and the Calibration of Matching Models," **Journal of Economic Dynamics and Control** 32 (4),1120-55.
- [25] Davis, S. J. and J.Haltiwanger (1999). "Gross Job Flows," in Chapter 41 in O.Ashenfelter and D. Card (eds.) **Handbook of Labor Economics** Vol. 3, 2711-2805, North Holland, Amsterdam.
- [26] Davis, S. J. and J.Haltiwanger (2014). "Labor Market Fluidity and Economic Performance," **Federal Reserve Bank of Kansas City, Jackson Hole Economic Policy Symposium**.
- [27] Davis, S. J., J.Haltiwanger, and S.Schuh (1996). **Job Creation and Destruction**, MIT Press, Cambridge.
- [28] De Graeve. F, and K. Walentin (2015). "Refining Stylized Facts from Factor Models of Inflation," **Journal of Applied Econometrics** 30, 1192-1209.
- [29] Den Haan W.J. , G. Ramey, and J.Watson (2000). "Job Destruction and Propagation of Shocks," **American Economic Review** 90 , 482–498.

- [30] Faust, J., E. T. Swanson, and J. H. Wright (2004). "Identifying VARs Based on High Frequency Futures Data," **Journal of Monetary Economics** 51, 6, 1107–113.
- [31] Faccini, R. and E. Yashiv (2017). "The Importance of Hiring Frictions in Business Cycles" CFM-DP2017-36, November.
- [32] Furlanetto, F. and N. Groshenny (2016). "Mismatch Shocks and Unemployment During the Great Recession," **Journal of Applied Econometrics** 31, 7, 1197-1214.
- [33] Galí J. (1999). "Technology, Employment, and the Business Cycle: Do Technology Shocks Explain Aggregate Fluctuations?," **American Economic Review** 89(1), 249-271.
- [34] Galí J. (2004). "On the Role of Technology Shocks as a Source of Business Cycles: Some New Evidence," **Journal of the European Economic Association** 2(2–3), 372–380.
- [35] Galí, J. (2011). "Monetary Policy and Unemployment," Chapter 10 in B.M. Friedman and M. Woodford (eds.) **Handbook of Monetary Economics Vol. 3A**, 487-546, North Holland, Amsterdam.
- [36] Galí, J. (2015). **Monetary Policy, Inflation and the Business Cycle: An Introduction to the New Keynesian Framework**, 2nd edition. Princeton University Press, Princeton.
- [37] Garibaldi, P. and E. R. Moen (2009). "Industry Dynamics and Search in the Labor Market," working paper.
- [38] Gertler, M., L. Sala, and A. Trigari (2008). "An Estimated Monetary DSGE Model With Unemployment and Staggered Nominal Wage Bargaining," **Journal of Money, Credit and Banking** 40, 1, 713-64.
- [39] Gertler, M. and A. Trigari (2009). "Unemployment Fluctuations with Staggered Nash Wage Bargaining," **Journal of Political Economy** 117, 1, 38-86
- [40] Giannoni, M.P. and M. Woodford (2005). "Optimal Inflation-Targeting Rules," Chapter 3 in B.S. Bernanke and M. Woodford (eds.) **The Inflation Targeting Debate**, 93-162, University of Chicago Press, Chicago.
- [41] Hall, R. E. (2005) "Employment Fluctuations with Equilibrium Wage Stickiness," **American Economic Review**, 95(1), 50-65.
- [42] Khan, A. and J. Thomas (2008). "Idiosyncratic Shocks and the Role of Nonconvexities in Plant and Aggregate Investment Dynamics," **Econometrica** 76, 2, 395-436.
- [43] King, R.G. and S.T. Rebelo (1999). "Resuscitating Real Business Cycles," in J. B. Taylor & M. Woodford (ed.s), **Handbook of Macroeconomics**, volume 1, chapter 14, 927-1007 Elsevier.
- [44] King, R.G. and J. Thomas (2006). "Partial Adjustment Without Apology," **International Economic Review** 47, 3, 779-809.

- [45] Krause, M.U., D. Lopez-Salido and T.A. Lubik (2008). "Inflation Dynamics with Search Frictions: A Structural Econometric Analysis," **Journal of Monetary Economics** 55, 892–916.
- [46] Krueger, A. and C. Rouse (1998). "The Effect of Workplace Education on Earnings, Turnover and Job Performance", **Journal of Labor Economics**, 16, 1, 61-94.
- [47] Lucas, R. E (1967). "Optimal Investment Policy and the Flexible Accelerator," **International Economic Review** 8, 78-85.
- [48] Lucas, R.E. and E. C. Prescott (1971). "Investment Under Uncertainty," **Econometrica** 39, 5, 659-681.
- [49] Manning, A (2011). "Imperfect Competition in the Labor Market," in O.Ashenfelter and D.Card (eds.) **Handbook of Labor Economics Vol 4B**, North Holland, Amsterdam
- [50] Mertens, K. and M.O. Ravn (2011). "Technology-Hours Redux: Tax Changes and the Measurement of Technology Shocks" in R.Clarida and F. Giavazzi (eds.) **NBER International Seminar on Macroeconomics 2010**. Chapter 2, 41-76, University of Chicago Press.
- [51] Merz, M. and E. Yashiv (2007). "Labor and the Market Value of the Firm," **American Economic Review** 97, 1, 419-31.
- [52] Mortensen, D.T. (1973). "Generalized Costs of Adjustment and Dynamic Factor Demand Theory," **Econometrica** 41, 4, 657-665.
- [53] Mühlemann, S. and M.S. Leiser (2015). "Ten Facts You Need To Know About Hiring" IZA DP No. 9363.
- [54] Nekarda, C. and V. Ramey (2013). "The Cyclical Behavior of the Price-Cost Markup," NBER Working Paper No. 19099.
- [55] Pissarides, C.A. (2000). **Equilibrium Unemployment Theory**, The MIT Press, 2nd edition, Cambridge, MA.
- [56] Pissarides, C.A. (2009). "The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?," **Econometrica**, 77(5), 1339-1369.
- [57] Ramey, V. (2016). "Macroeconomic Shocks and Their Propagation," in J.B. Taylor and H.Uhlig (eds). **Handbook of Macroeconomics, vol. 2A**, Chapter 2, 71-162. North-Holland, Amsterdam.
- [58] Rogerson, R. and R. Shimer (2011). "Search in Macroeconomic Models of the Labor Market," in O.Ashenfelter and D.Card (eds.) **Handbook of Labor Economics Vol 4A**, North Holland, Amsterdam.
- [59] Rotemberg, J. (1982). "Monopolistic Price Adjustment and Aggregate Output," **Review of Economic Studies** 49, 517-31.

- [60] Sala, L., U. Söderstrom, and A. Trigari (2013). "Structural and Cyclical Forces in the Labor Market during the Great Recession: Cross-Country Evidence" in F. Giavazzi and K.D. West (eds.) **NBER International Seminar on Macroeconomics 2012**, Chapter 8, 345- 404, University of Chicago Press.
- [61] Sbordone, A.M. (2005). "Do Expected Future Marginal Costs Drive Inflation Dynamics?" **Journal of Monetary Economics** 52, 1183–1197.
- [62] Shimer, R. (2005). "The Cyclical Behavior of Equilibrium Unemployment and Vacancies," **American Economic Review** 95, 1, 25-49.
- [63] Silva, J., and M. Toledo (2009). "Labor Turnover Costs and the Cyclical Behavior of Vacancies and Unemployment," **Macroeconomic Dynamics** 13 (S1), 76-96.
- [64] Sims, E.R. (2011). "Permanent and Transitory Technology Shocks and the Behavior of Hours: A Challenge for DSGE Models," University of Notre Dame, mimeo.
- [65] Smets, F. and R. Wouters, (2007). "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," **American Economic Review** 97(3), 586-606.
- [66] Treadway, A.B. (1971). "The Rational Multivariate Flexible Accelerator," **Econometrica** 39, 5, 845-855.
- [67] Uhlig, H. (2004). "Do Technology Shocks Lead to a Fall in Total Hours Worked?" **Journal of the European Economic Association** 2(2-3), 361-371.
- [68] Uhlig, H. (2005). "What Are The Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure," **Journal of Monetary Economics** 52 (2) 381–419.
- [69] Walsh, C. (2005). "Labor Market Search, Sticky Prices, and Interest Rate Rules," **Review of Economic Dynamics** 8, 829-849.
- [70] Woodford, M. (2003). **Interest and Prices: Foundations of a Theory of Monetary Policy**. Princeton University Press, Princeton.
- [71] Woodford, M. (2005). 'Firm-Specific Capital and the New Keynesian Phillips Curve," **International Journal of Central Banking** 1,2,1-46.
- [72] Yashiv, E. (2000). "The Determinants of Equilibrium Unemployment," **American Economic Review** 90,5,1297-1322.
- [73] Yashiv, E. (2016). "Capital Values and Job Values," **Review of Economic Dynamics**, 19, 1, 190-209.
- [74] Yashiv, E. (2017). "Hiring and Investment Interactions Over the Business Cycle," working paper.

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:

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

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

$$K_{t,j} = (1 - \delta_K) K_{t-1,j} + \left[1 - S \left(\frac{I_{t,j}}{I_{t-1,j}} \right) \right] I_{t,j}, \quad 0 \leq \delta_K \leq 1, \quad (35)$$

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:

$$\lambda_t = \frac{1}{P_t (C_t - \vartheta C_{t-1})}, \quad \frac{1}{R_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}, \quad (36)$$

$$Q_t^K = E_t \Lambda_{t,t+1} \left[\frac{X_{t+1}^K}{P_{t+1}} + (1 - \delta_K) Q_{t+1}^K \right] \quad (37)$$

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

$$V_t^N = \frac{W_t}{P_t} - \frac{\chi N_t^\varphi}{\lambda_t P_t} - \frac{x_t}{1 - x_t} V_t^N + E_t \Lambda_{t,t+1} (1 - \delta_N) V_{t+1}^N, \quad (38)$$

and

$$Q_t^K \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right] + E_t \Lambda_{t,t+1} Q_{t+1}^K S' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 = 1, \quad (39)$$

where the Euler equation (36), the value of capital (6), and the value of a marginal job to the household (38) correspond to equations (5), (18) 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:

$$\begin{aligned} \max_{\{P_{t+s,i}, H_{t+s,i}, \check{K}_{t+s,i}\}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s,i}}{P_{t+s}} N_{t+s,i} - \frac{R_{t+s}^K}{P_{t+s}} \check{K}_{t+s,i} \right. \\ \left. - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{(1 + \pi_{t+s-1})^\psi (1 + \bar{\pi})^{1-\psi} P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \right\} \end{aligned} \quad (40)$$

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 (9) and subject to the law of motion for employment (13) and the constraint that output equals demand:

$$\left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon} Y_t = f(A_t, N_{t,i}, \check{K}_{t,i}) - g(A_t, H_{t,i}, N_{t,i}, \check{K}_{t,i}). \quad (41)$$

The friction cost function in the above constraint is given by

$$g(A_t, H_{t,i}, N_{t,i}, \check{K}_{t,i}) = \frac{e}{2} q_t^{-\eta^q} \left(\frac{H_{t,i}}{N_{t,i}} \right)^2 f_{t,i}, \quad (42)$$

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 eq.(27).

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 $H_{t,i}$, $N_{t,i}$, $\check{K}_{t,i}$ and $P_{t,i}$ are:

$$Q_t^N = \Psi_t g_{H,t}, \quad (43)$$

$$Q_t^N = \Psi_t (f_{N,t} - g_{N,t}) - \frac{W_t}{P_t} + (1 - \delta_N) E_t \Lambda_{t,t+1} Q_{t+1}^N, \quad (44)$$

$$\frac{X_t^K}{P_t} = \Psi_t (f_{K,t} - g_{K,t}) \quad (45)$$

and

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

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

$$\begin{aligned} & \left(\frac{1 + \pi_t}{(1 + \pi_{t-1})^\psi (1 + \bar{\pi})^{1-\psi}} - 1 \right) \frac{1 + \pi_t}{(1 + \pi_{t-1})^\psi (1 + \bar{\pi})^{1-\psi}} = \frac{1 - \epsilon}{\zeta} + \frac{\epsilon}{\zeta} \Psi_t \\ & + E_t \frac{1}{R_t / (1 + \pi_{t+1})} \left[\left(\frac{1 + \pi_{t+1}}{(1 + \pi_t)^\psi (1 + \bar{\pi})^{1-\psi}} - 1 \right) \frac{1 + \pi_{t+1}}{(1 + \pi_t)^\psi (1 + \bar{\pi})^{1-\psi}} \frac{Y_{t+1}}{Y_t} \right]. \quad (46) \end{aligned}$$

Merging the FOCs for capital of households and firms (37) and (45) we get:

$$Q_t^K = E_t \Lambda_{t,t+1} \left[\Psi_{t+1} (f_{K,t+1} - g_{K,t+1}) + (1 - \delta_K) Q_{t+1}^K \right] \quad (47)$$

Wage norm

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

$$\frac{W_t}{P_t} = \omega \frac{W_{t-1}}{P_{t-1}} + (1 - \omega) \frac{W_t^{NASH}}{P_t}, \quad (48)$$

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

$$\frac{W_t^{NASH}}{P_t} = \arg \max \left\{ \left(V_t^N \right)^\gamma \left(Q_t^N \right)^{1-\gamma} \right\}, \quad (49)$$

which yields

$$\frac{W_t^{NASH}}{P_t} = \gamma \Psi_t (f_{N,t} - g_{N,t}) + (1 - \gamma) \left[\chi N_t^\varphi (C_t - \vartheta C_{t-1}) + \frac{x_t}{1 - x_t} \frac{\gamma}{1 - \gamma} Q_t^N \right]. \quad (50)$$

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

$$Y_{t,i} = \left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon} Y_t. \quad (51)$$

The Monetary and Fiscal Authorities and Market Clearing

The model is closed by assuming that the government runs a balanced budget, as per eq. (22), the monetary authority follows the Taylor rule in eq.(23), the goods market clears as per eq.(24) and the capital market clears, $\check{K}_t = K_{t-1}$.

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 $\omega = 0.87$, as in Chistoffel and Linzert (2010), 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. 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. Parameter values and calibration targets for the extended model are reported in Table 2.

8 Tables

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

<i>Description</i>	<i>Parameter</i>	<i>Value</i>
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
<i>Panel B: Steady State Values</i>		
<i>Definition</i>	<i>Expression</i>	<i>Value</i>
Total adjustment cost/ output	$g / (f - g)$	0.013
Marginal hiring cost	$g_H / [(f - g) / N]$	0.20
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

<i>Description</i>	<i>Parameter</i>	<i>Value</i>
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	$\bar{\pi}$	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_ζ	0
<i>Panel B: Steady State Values</i>		
<i>Definition</i>	<i>Expression</i>	<i>Value</i>
Total adjustment cost/ output	$g / (f - g)$	0.011
Marginal hiring cost	$g_H / [(f - g) / N]$	0.18
Opportunity cost of work/ marginal revenue prod.	$\frac{\chi^{CN\varphi}}{mc(f_N - g_N)}$	0.72
Unemployment rate	u	0.106

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

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

a. TFP Shock

model	ω	ζ	e	$\Delta \Psi_t g_{H,t}$	$\Delta \left[\Xi_t \left(\frac{\Psi_t(f_{N,t} - g_{N,t})}{(1 - \gamma(1 - \omega))} \right) \right]$	$\Delta \Xi_t \omega \frac{W_{t-1}}{P_{t-1}}$	$\Delta \left[\frac{\Xi_t(1 - \omega)}{(1 - \gamma) \frac{\chi_{N,t}^{\varphi}}{\lambda_t P_t}} \right]$	$\Delta \left[\frac{\Xi_t(1 - \delta_N)}{E_t\Lambda_{t+1}Q_{t+1}^N} \right]$
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

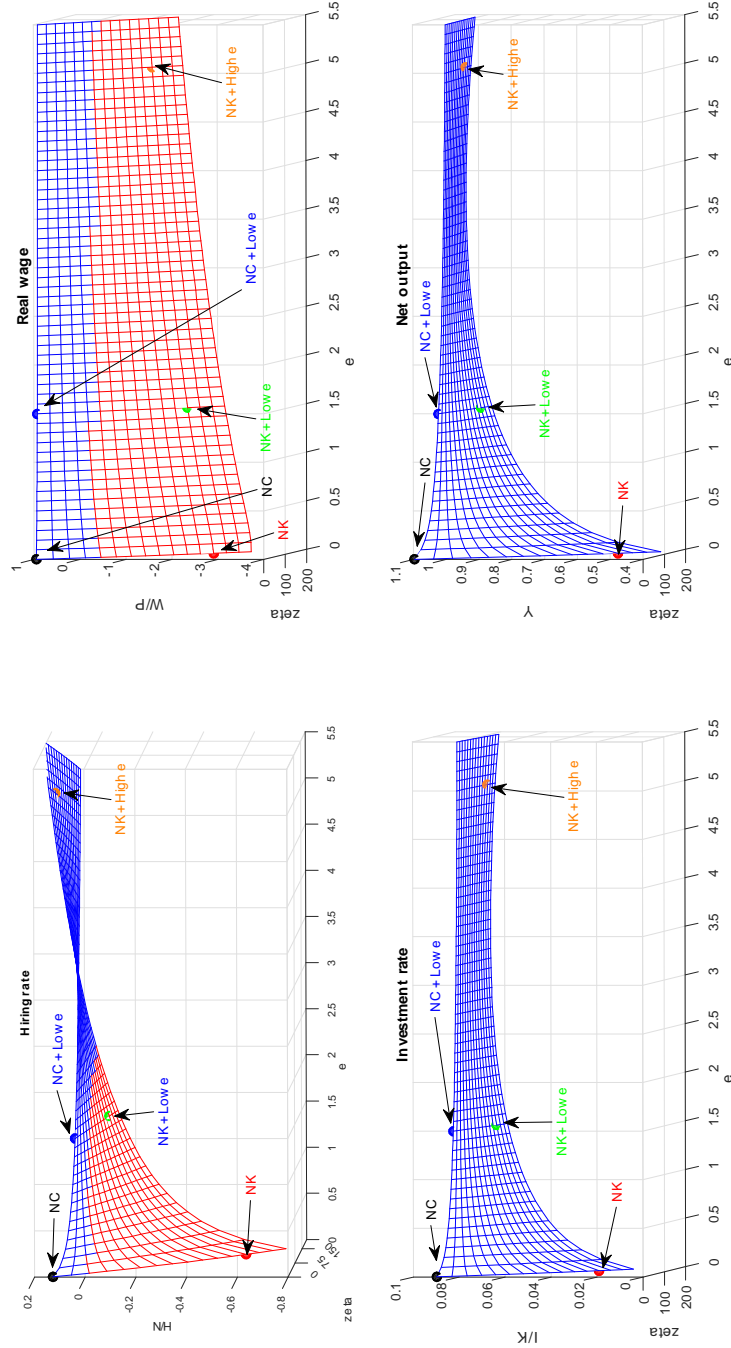
b. Monetary Policy shock

model	ω	ζ	e	$\Delta \Psi_t g_{H,t}$	$\Delta \left[\Xi_t \left(\frac{\Psi_t (f_{N,t} - g_{N,t})}{(1 - \gamma(1 - \omega))} \right) \right]$	$\Delta \Xi_t \omega \frac{W_{t-1}}{P_{t-1}}$	$\Delta \left[\frac{\Xi_t(1 - \omega)}{(1 - \gamma) \frac{\chi N_t^\varphi}{\lambda_t P_t}} \right]$	$\Delta \left[\frac{\Xi_t(1 - \delta_N)}{E_t \Lambda_{t,t+1} Q_{t+1}^N} \right]$
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 are comparable changes upon impact in the value of each variable in the top row .

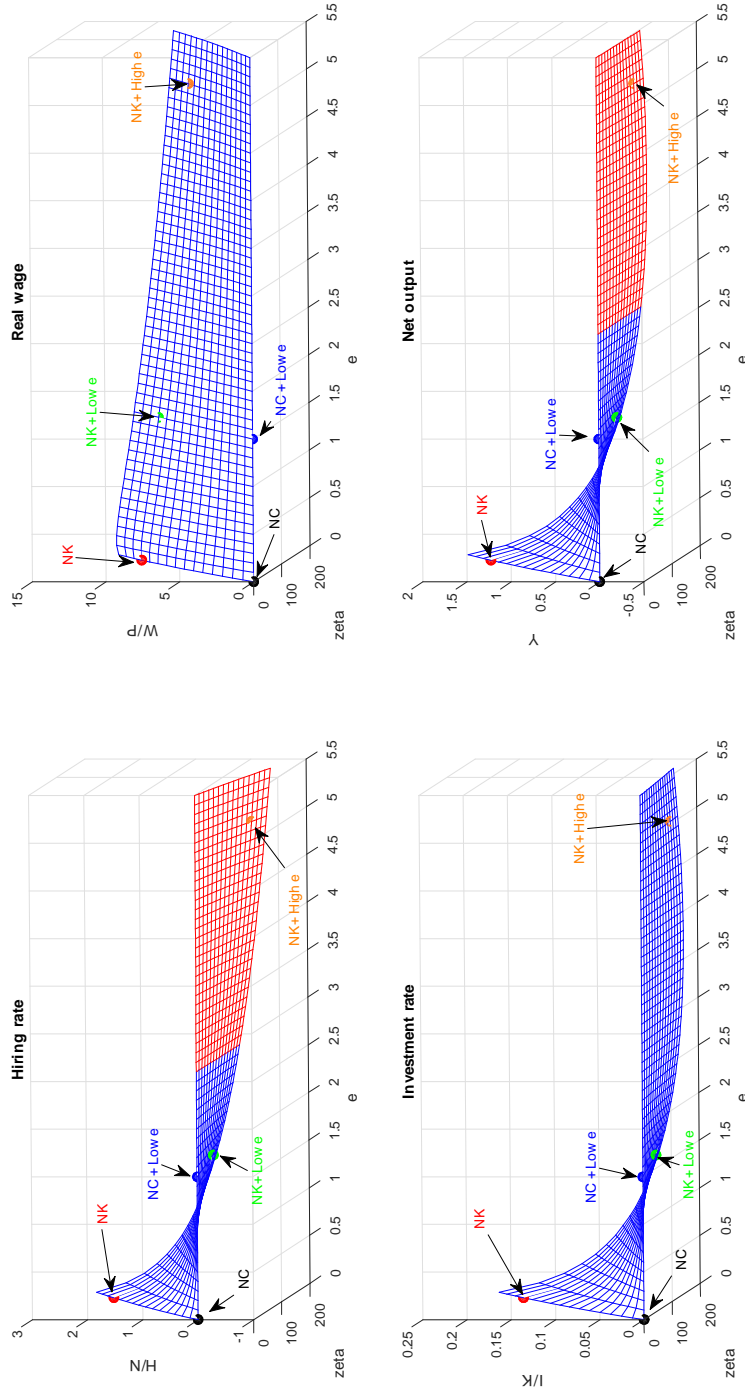
9 Figures

Figure 1: Impulse Responses on Impact of a Technology Shock



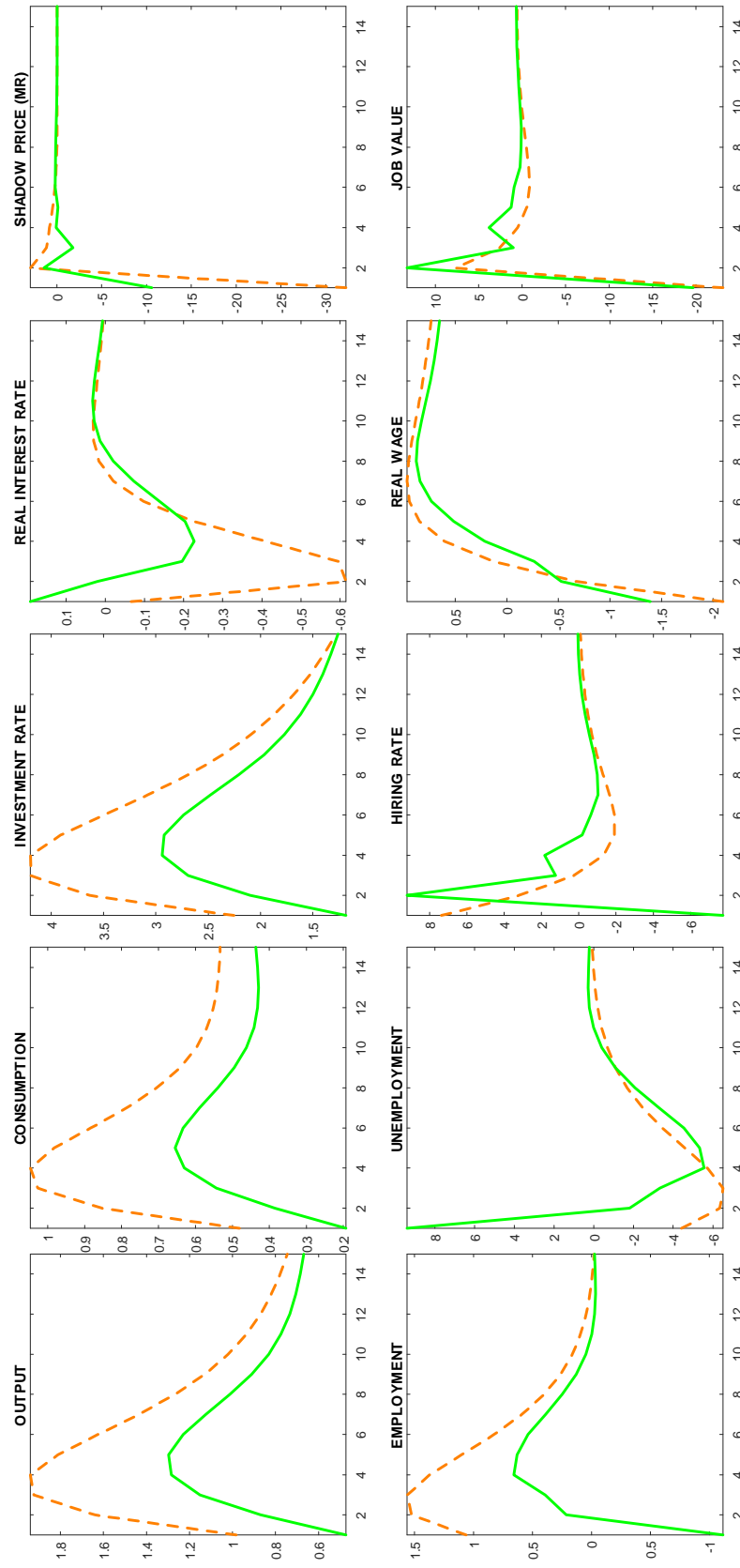
Notes: The figure shows impulse responses on the impact of a 1% positive technology shock for various parameterizations of the model where we allow price rigidities, ζ , and hiring frictions, e , to vary. The real wage and output are expressed in percent deviations from steady state, hiring and investment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

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



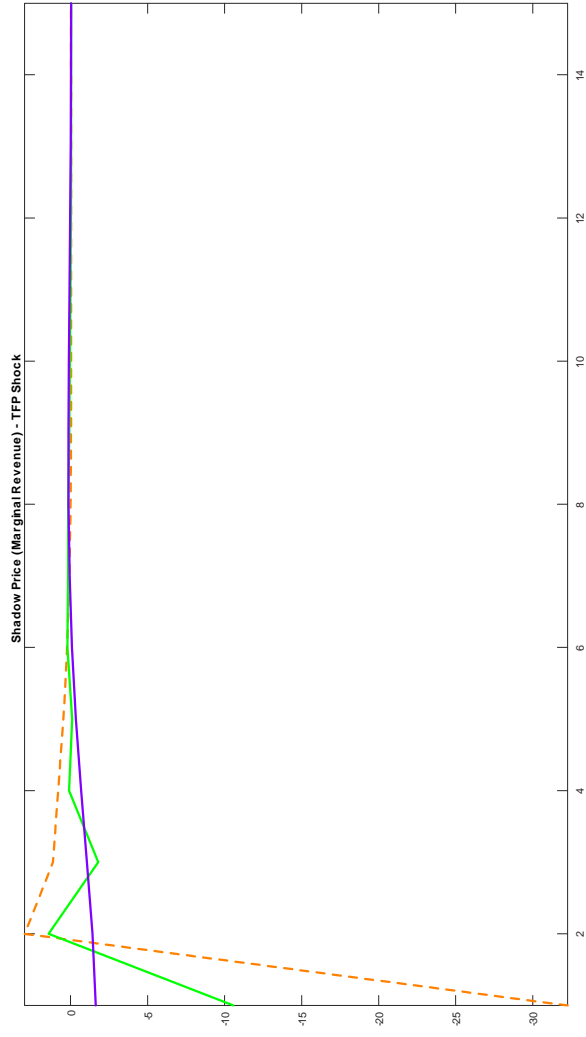
Notes: The figure shows impulse responses on the impact of an 25 basis points expansionary monetary shock for various parameterizations of the model where we allow price rigidities, ζ , and hiring frictions, e , to vary. The real wage and output are expressed in percent deviations from steady state,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



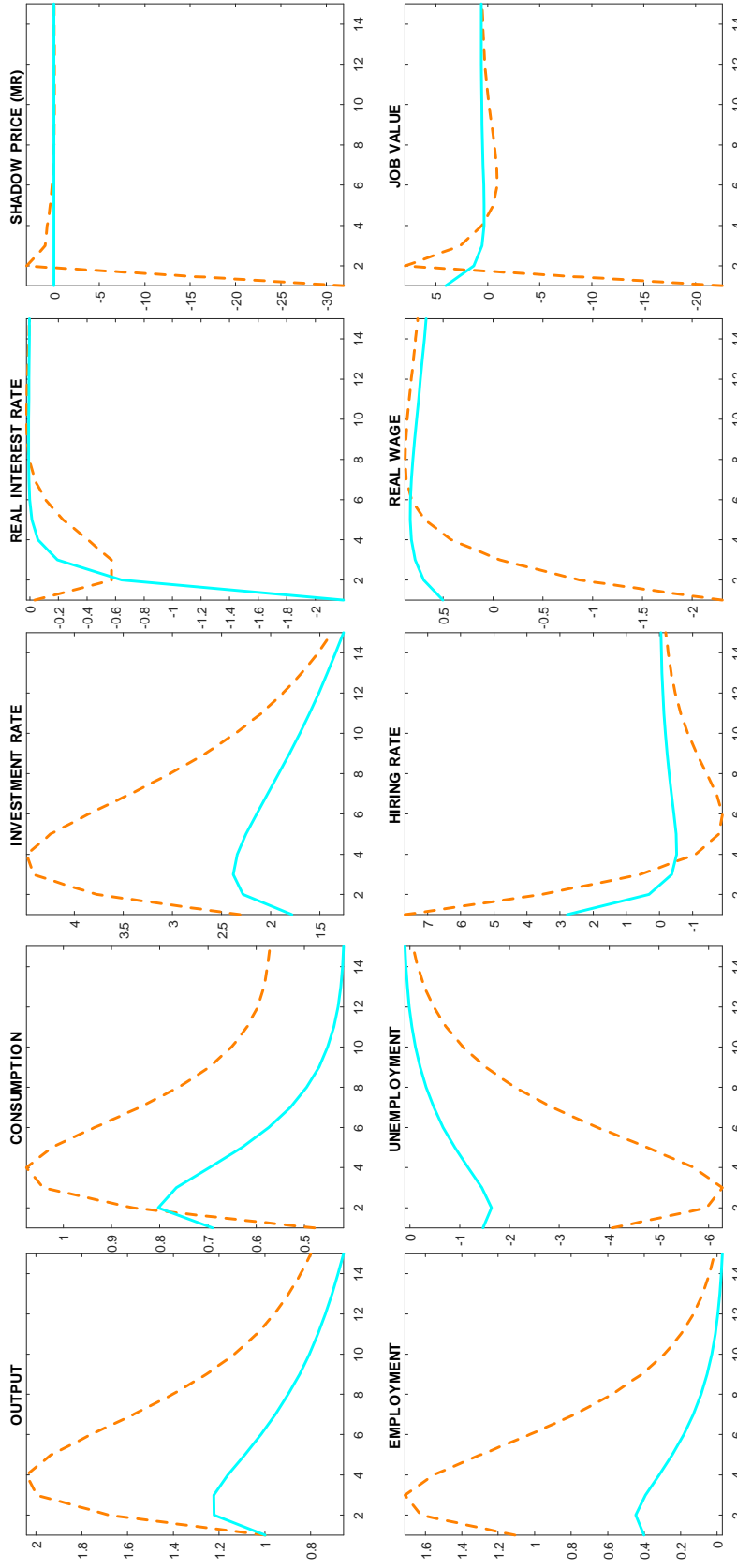
Notes: impulse responses to a 1% positive technology shock obtained for two different parameterizations: “high” hiring costs (orange broken line; $\ell = 5$) and “low” frictions (solid green line; $\ell = 1.2$). All variables are expressed in % deviations, except hiring, investment, and real rates, which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

Figure 3a: Impulse Responses of the Shadow Price to a Technology Shock, Three Scales of Hiring Costs



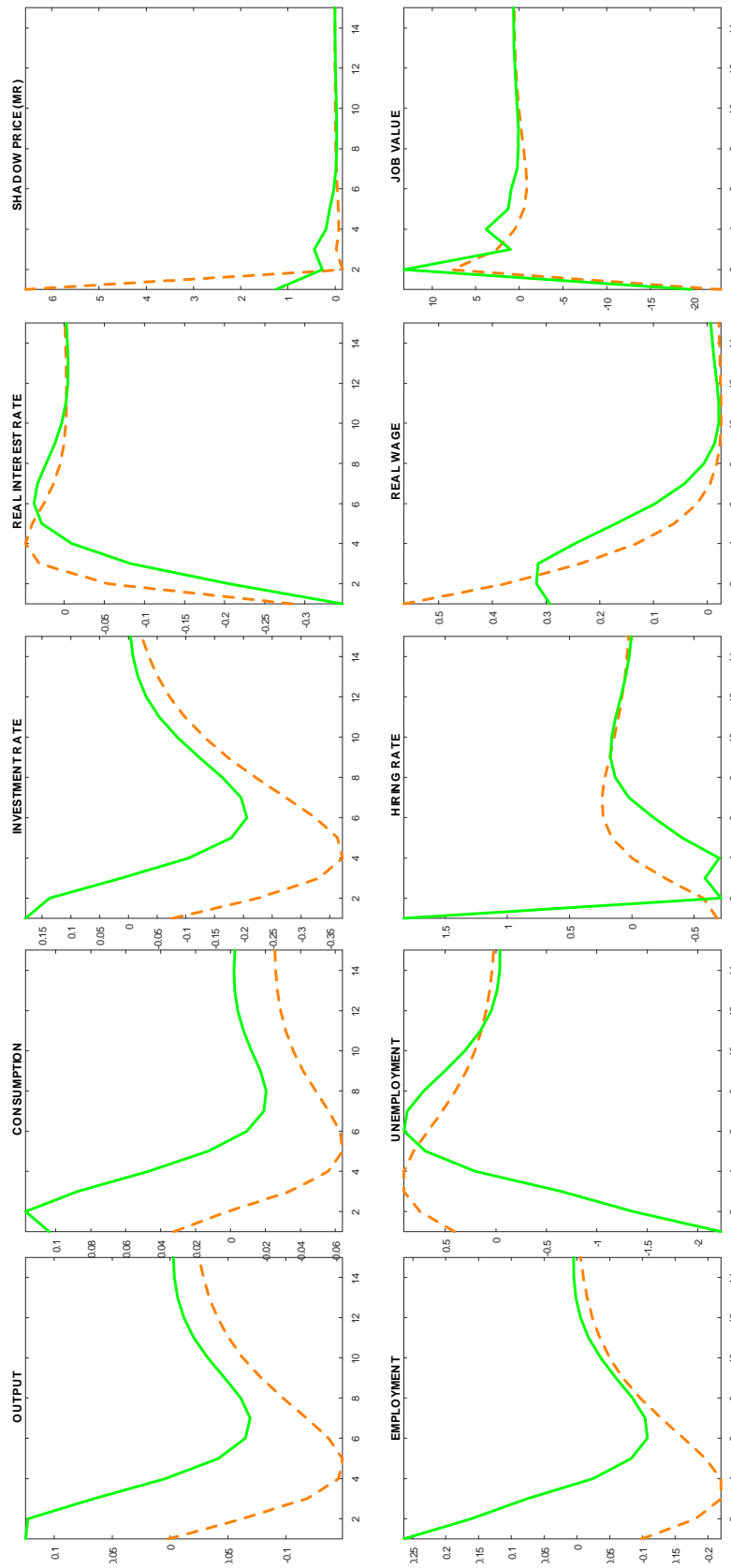
Notes: impulse responses to a 1% positive technology shock obtained for three different parameterizations: “high” hiring costs (orange broken line; $\epsilon = 5$), “low” frictions (solid green line; $\epsilon = 1.2$), and no hiring costs (solid purple line, $\epsilon = 10^{-6}$). Expressed in % deviations..

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



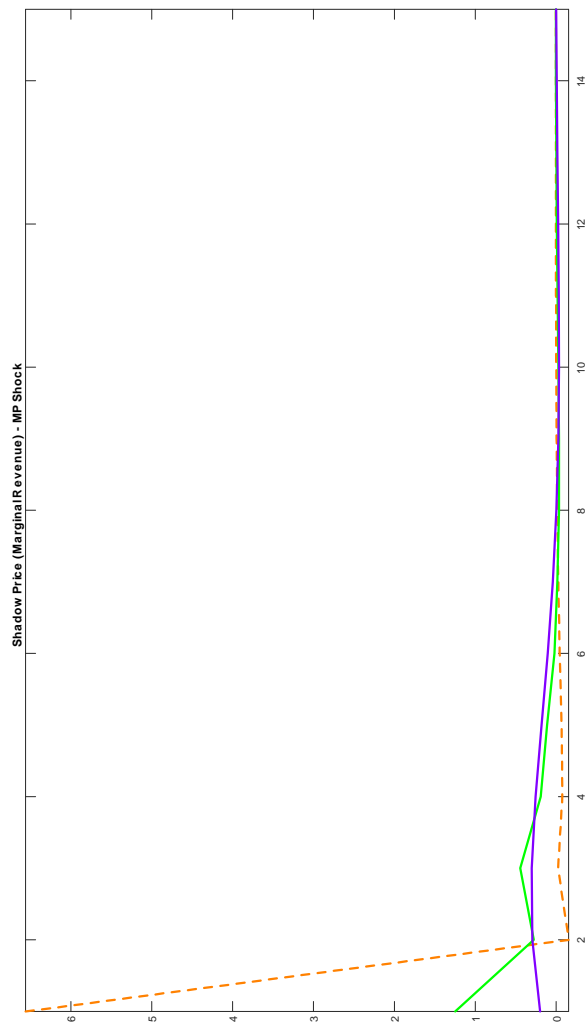
Notes: impulse responses to a 1% positive technology shock obtained for two different parameterizations: The rigid price model with hiring costs (NC + L Frictions, orange broken line; $\bar{\zeta} = 120$ and $e = 5$) and the flexible price model with hiring costs (NK + L Frictions, solid light blue line; $\bar{\zeta} \simeq 0$ 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



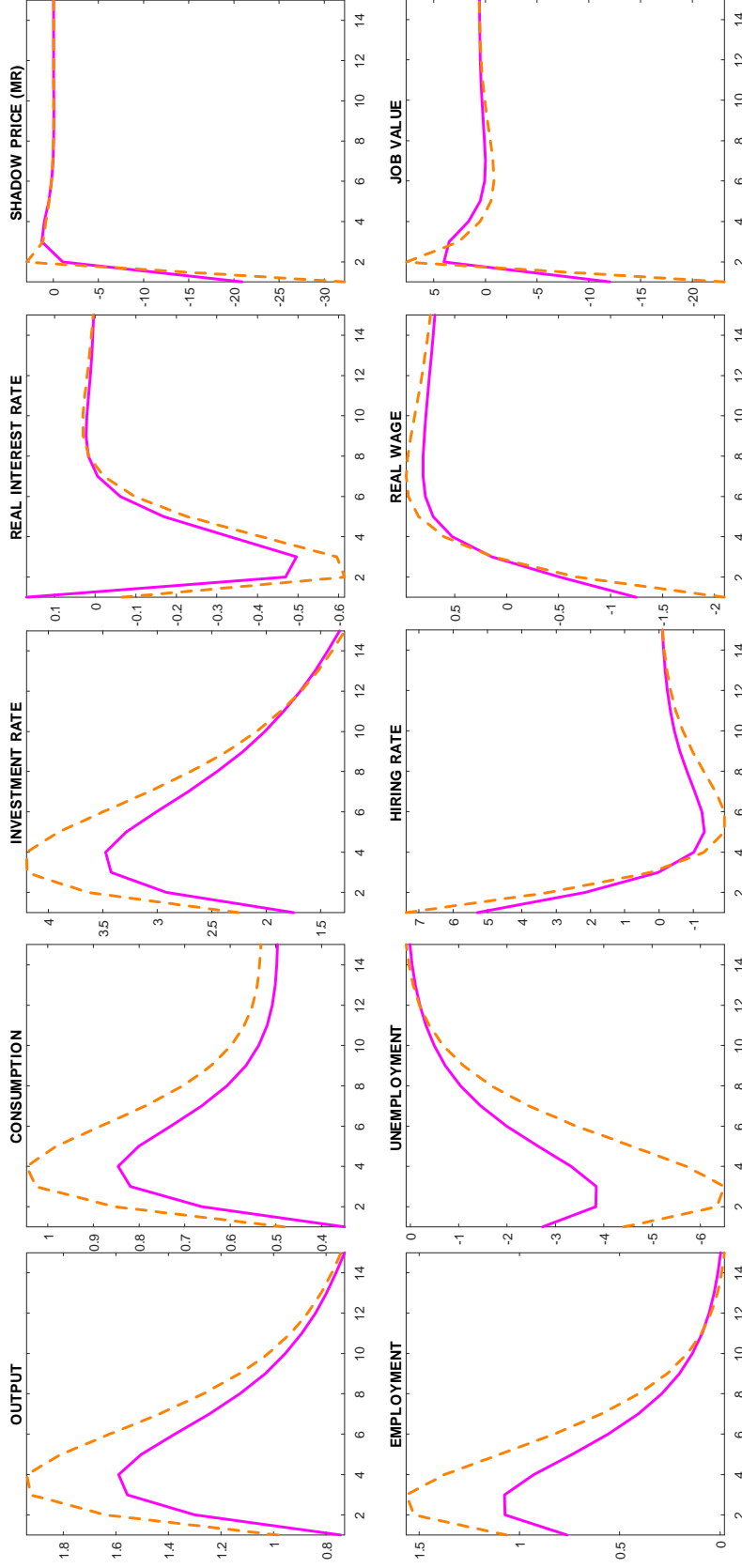
Notes: impulse responses to a 25 basis point expansionary monetary policy shock obtained for two different parameterizations: “high” hiring costs (orange broken line; $e = 5$) and “low” frictions (solid green line; $e = 1.2$). All variables are expressed in % deviations, except hiring, investment, and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

Figure 5a: Impulse Responses of the Shadow Price to a Monetary Policy Shock, Three Scales of Hiring Costs



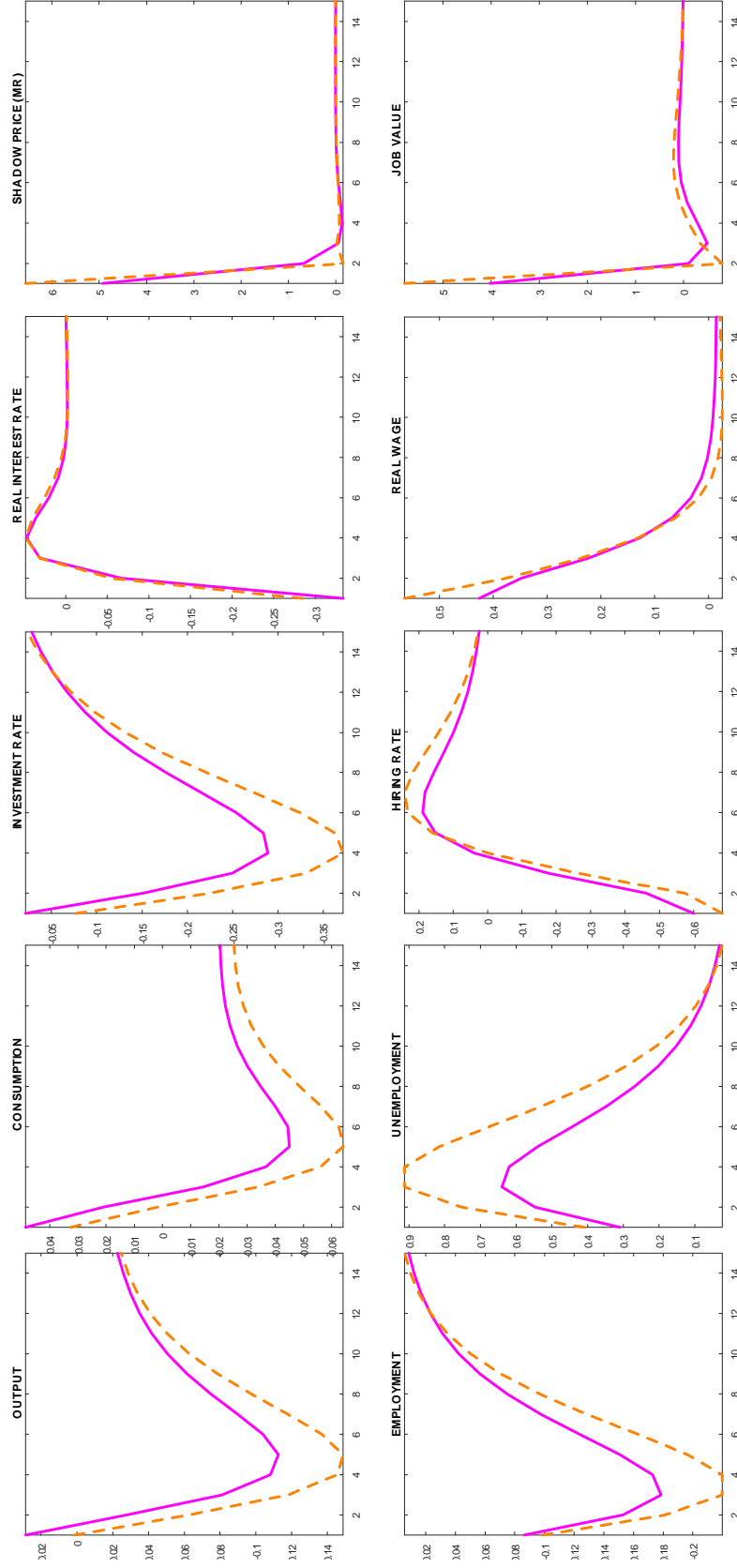
Notes: impulse responses to a 25bp expansionary monetary shock obtained for three different parameterizations: “high” hiring costs (orange broken line; $e = 5$), “low” frictions (solid green line; $e = 1.2$), and no hiring costs (solid purple line, $e = 10^{-6}$). Expressed in % deviations..

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



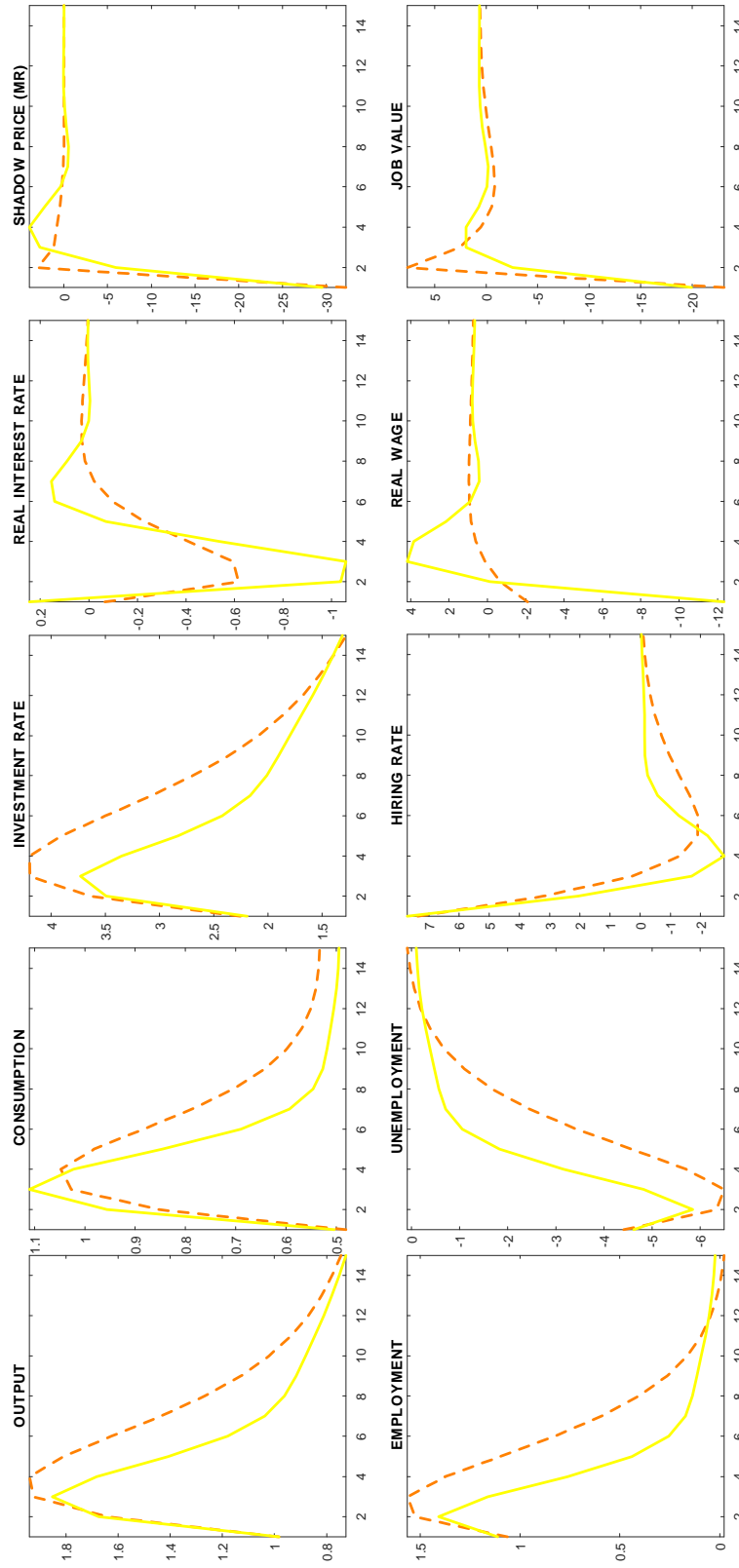
Notes: Impulse responses to a 1% positive technology shock obtained for two different parameterizations of η^η both with "high" hiring costs $e = 5$. The orange (dashed) line uses the benchmark $\eta^\eta = 0.49$; and the purple (solid) line uses $\eta^\eta = 2$. All variables are expressed in % deviations, 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 Costs Only and Hiring Costs



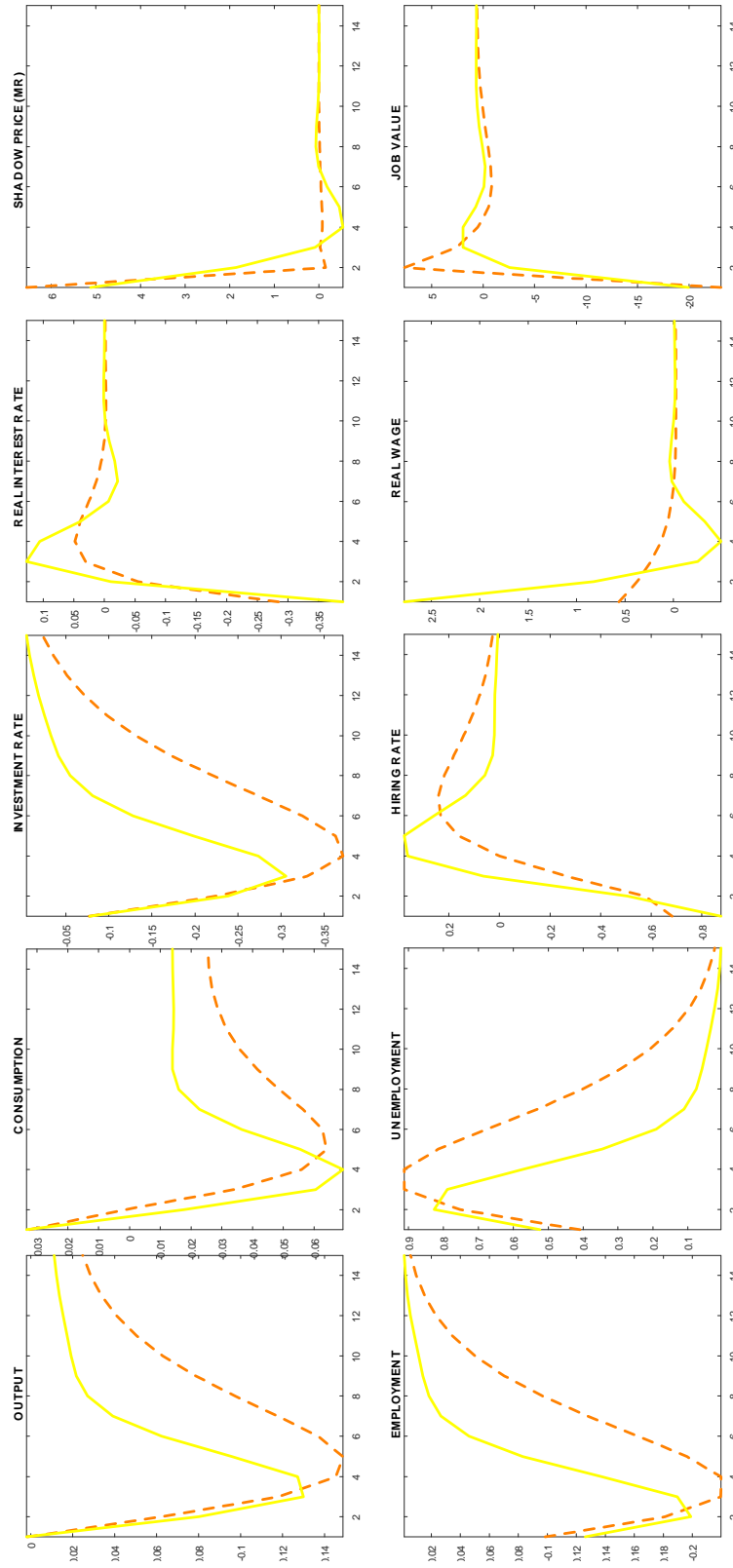
Notes: Impulse responses to a 25 basis points monetary policy expansion shock obtained for two different parameterizations of η^q both with “high” hiring costs $e = 5$. The orange (dashed) line uses the benchmark $\eta^q = 0.49$; and the purple (solid) line uses $\eta^q = 2$. All variables are expressed 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