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The Importance of Hiring Frictions in Business Cycles

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Abstract

Hiring is a costly activity reflecting firms' investment in their workers. Micro-data shows that hiring costs involve production disruption. Thus, cyclical fluctuations in the value of output, induced by price rigidities, have consequences for the optimal allocation of hiring activities.

This mechanism generates strong propagation and amplification of all key macroeconomic variables in response to technology shocks and mutes traditional transmission of monetary policy shocks. A LP analysis of U.S. data, shows that the empirical results are consistent with the model's IRFs.

We outline a new mechanism, with hiring frictions as important as price frictions for the propagation of shocks.

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

JEL codes: E22, E24, E32, E52

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1 Introduction

Hiring is a costly activity reflecting firms' investment in their workers. We use micro-data to show that most of the costs of hiring are non-pecuniary, involving production disruption rather than the purchase of hiring-related services from other firms. If hiring costs are output costs, then the optimal allocation of these resources over the business cycle must reflect fluctuations in the (forgone) value of production. Namely, firms have an incentive to time the accumulation of their stock of workers to periods when the value of production is relatively low, and postpone hiring when this value is relatively high. In this paper, we show that such optimal intertemporal allocation engenders an important role for hiring frictions in business cycles.

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

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

The mechanism we explore works as follows. Consider an expansionary TFP shock, which increases productivity and, everything else equal, output supply. If prices are sticky, they cannot drop and stimulate aggregate demand enough to restore equilibrium in the output market. This generates excess supply and hence a fall in the shadow value of output. In the textbook business cycle model with price frictions (the New Keynesian model), where the only use of labor is to produce output for sales, employment unambiguously falls to clear the market. In our model instead, workers can be used either to produce or to hire new workers. Because hiring involves a forgone cost of production, the fall in the afore-cited shadow value implies that it is more profitable to allocate resources to hiring. As a result, the firm substitutes future hiring for current hiring. The stronger the fall in the shadow value, 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 value rises. In the textbook model, employment unambiguously increases to restore the equilibrium. In our model instead, the rise in the shadow value increases the cost of the marginal hire, dampening the incentives for hiring. Intuitively, putting resources into recruiting is less valuable at times when sales are more profitable. As a result, the firm substitutes current hiring for future hiring. For plausible values of hiring costs, employment may fall on the impact of an expansionary monetary policy shock, and subsequently rise.

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

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

To confront our theoretical mechanism with U.S. data, we produce empirical impulse responses for both technology and monetary policy shocks using Jordà (2005) local projections, taking an agnostic approach to the effects of the shocks. The effects of technology shocks are identified using the time series for these shocks computed by Fernald (2004); the effects of monetary policy shocks are identified using an extended Romer and Romer (2004) shocks series. We show that the dynamic responses produced by our proposed mechanism are consistent with those obtained in the empirical model, with positive technology shocks producing expansionary effects on employment, and expansionary monetary policy shocks leading to an initial contraction in employment and output, followed by an expansion. The latter results follow

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

similar findings in the literature, which we review in Section 7. Our model provides a rationale for them.

The paper is organized as follows. Section 2 reviews two issues in the literature: the formulation of hiring costs and the role of these costs in business cycles. Section 3 provides our empirical evidence on the nature of hiring costs. Section 4 presents the baseline model with a minimal set of assumptions, which is inspired by our empirical findings. Section 5 explores the mechanism using calibration and impulse response analysis. Section 6 discusses the results obtained from further exploration, using a richer macroeconomic general equilibrium model that caters for different forms of hiring frictions, and different parameterizations of the Taylor rule. While the main text is brief, an Appendix elaborates on the details. Section 7 provides empirical impulse responses to both technology and monetary policy shocks, which are interpreted in the light of the theoretical model. Section 8 concludes.

2 Literature

Because our modelling of hiring frictions is key for the mechanism, we start with a brief review of the different modelling approaches to hiring costs adopted in the literature and the related empirical evidence. We then review the role of hiring costs in the current business cycle literature.

2.1 The Modelling of Hiring Frictions

Three distinctions regarding the hiring cost function matter for the current paper. One pertains to the nature of these costs – are the costs pecuniary, i.e., paid to other firms for the provision of hiring services, or rather production costs entailing a loss of output within the firm? A second relates to the arguments of the function – are these costs related to actual hires, or related to aggregate labor market conditions, such as vacancy filling rates? A third pertains to the shape of the function.

The traditional search and matching literature relates to vacancy costs, in the form of pecuniary costs, affected by market conditions, 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.

Pecuniary costs paid to other agents vs output costs. In much of the macroeconomic literature that makes use of models with monopolistic competition, hiring costs are expressed in units of the final composite good, and contribute to aggregate GDP (see, inter-alia, 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. Not all hiring costs though, need to give rise to third-party payments for hiring-related services. Hiring costs involve output costs, to the extent that resources are diverted from productive activities to recruitment, or newly hired workers need to receive training before they can achieve the same productivity of the workers they are meant to replace. The existing empirical evidence supports the view that hiring costs involve disruption to production, but does not quantify the relative importance of output and pecuniary costs.

For instance, 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 reduces plant-level production. These results suggest that hiring disrupts the production process, generating a loss of output. In addition, the literature review presented by Silva and Toledo (2009) measures hiring costs as the opportunity cost of work incurred by co-workers, managers, and the new hires themselves, in connection with recruitment or training activities. In this study, hiring can therefore be thought of as the forgone cost of production. In the next Section we provide direct micro evidence on hiring costs and show that output costs account for the lion's share of the total costs of hiring.

Cost of hires vs cost of vacancies Vacancy costs are meant to capture the cost of recruitment, which is incurred before a match is formed, and encompasses the cost of advertising vacancies, interviewing, and screening. These costs have been referred to as external costs of hiring as they are modelled as a function of aggregate labor market conditions, i.e., the ratio of aggregate vacancies to aggregate job seekers as in the tradition of Diamond, Mortensen and Pissarides. Costs of actual hires have been defined in the literature as internal costs as they are modelled as a function of firm-level conditions, namely the ratio of new hires to the workforce of the firm, i.e. the gross hiring rate (see, for example, Yashiv (2000), Merz and Yashiv (2007), Gertler, Sala, and Trigari (2008), Gertler and Trigari (2009), Christiano, Trabandt and Walentin (2011), Sala, Soderstrom, and Trigari (2013), Yashiv (2016), Furlanetto and Groshenny (2016), Coles and Mortensen (2016), and Christiano, Eichenbaum and Trabandt (2016)). The underlying idea is that internal costs capture costs incurred after a match is formed, and consist of training costs, including the time costs associated with learning how to operate capital. Costs may also be incurred in the implementation of new organizational structures within the firm and the introduction of new production techniques; for the latter, see Alexopoulos (2011) and Alexopoulos and Tombe (2012).

In a review of the microeconomic evidence, Manning (2011, p.982) writes that: "the bulk of these [hiring] costs are the costs associated with training newly-hired workers and raising them to the productivity of an experienced worker. The costs of recruiting activity are much smaller." Other reviews of the hiring costs literature, provided by Silva and Toledo (2009, Table 1), Blatter et al (2016, Table 1), and Mühlemann and Leiser (2018, in particular Tables 1 and 2), share the conclusions that internal costs are far more important than external costs. For instance, according to Silva and Toledo (2009), training costs are about ten times as large as recruiting costs. Our own analysis in the next section reaffirms these conclusions.

The bottom line of these microeconomic studies aligns well with conclusions based on macro estimates. Christiano, Trabandt, and Walentin (2011), using Bayesian estimation of a DSGE model of Sweden, conclude that "employment adjustment costs are a function of hiring rates, not vacancy posting rates." Sala, Soderstrom, and Trigari (2012) estimate external and internal costs for a number of countries, usually finding that internal costs account for most of the costs of hiring.

Functional form. Those cited papers which have used structural estimation (Yashiv (2000, 2016, 2018), Merz and Yashiv (2007), and Christiano, Trabandt, and Walentin (2011)) point to convex formulations as fitting the data better than linear ones. Blatter et al (2016, page 4) offer citations of additional studies indicating convexity of hiring costs. One can also rely on the theoretical justifications of King and Thomas (2006) and Khan and Thomas (2008) for convexity. Note, though, that for the mechanism presented in this paper to operate qualitatively the precise degree of convexity in costs does not matter.[2]

2.2 Hiring Frictions in Business Cycle Models

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

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

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

[2]This convex, output costs approach naturally links the hiring problem with a strand of the Macro-Finance literature on firms investment and/or hiring decisions and their linkages to financial markets. See Cochrane (2005, Chapter 20, and 2008) for overviews and discussions.

Pecuniary costs (€)	
A) Advertisement costs	368
B) External consultancy costs	373
C) Direct training costs	347
D) Total pecuniary cost (A+B+C)	1,088
Output costs (€)	
E) Interview costs	388
F) Reduced productivity costs	1,019
G) Indirect training costs	231
H) Disruption costs: managers	1,610
I) Disruption costs: skilled workers	1,976
L) Disruption costs: unskilled workers	82
M) Total output costs (E+F+G+H+I+L)	5,307
Pre-match (external) vs post-match (internal) costs (€)	
N) Pre-match costs (A+B+E)	1,129
O) Post-match costs (C+F+G+H+I+L)	5,265
Relative importance of hiring costs (%)	
N) Share of output cost (M/(D+M))	82.9%
Q) Share of post-match costs (O/(N+O))	82.3%

Table 1: Hiring Costs Decomposition in the German Cross-Section

3 Hiring Costs in Micro Data

The objective of this section is to document and quantify various sources of hiring costs. The analysis makes use of two datasets, which are surveys of representative panels of establishments in Germany and in Switzerland, respectively. Both surveys were specifically designed to measure the various components of hiring costs, distinguishing in particular between pecuniary and non-pecuniary components. They contain, to the best of our knowledge, the most detailed information available on this matter. While the surveys measure training costs for both apprentices and skilled workers, we focus exclusively on the latter, since the system of apprenticeship is a very peculiar feature of the German and Swiss labor markets, with little external validity. A skilled worker is defined as any person who has completed vocational training and is not a member of the management staff.

3.1 German Data

We make use of the survey on the "costs and benefits of the training, recruitment and continuing training of skilled workers," conducted by the Federal Institute for Vocational Education and Training (BIBB-CBS) over the years 2012-2013. The survey samples firms from the administrative register at the Federal Employment Office, and is meant to be representative of the German firms with at least one employee, after appropriate weighting. The original sample contains responses from 3,945 firms, of which 42%, did not provide any relevant information since they did not recruit any worker in the last three years. We reduce the sample further by focussing on firms with at least five employees. This leaves us with a sample size of 1,699 firms.

Table 1 reports a breakdown of the average cost of hiring across various categories, measured in Euros. We report pecuniary costs in the top panel, followed by non-pecuniary (output) costs in the panel below. We then report an alternative breakdown, which distinguishes between the costs incurred before a match is formed (pre-match) and after it is formed (post-match). Finally, in the bottom panel we report the relative importance of output vs. pecuniary costs and post match vs. pre-match.

The first entry in the panel of pecuniary costs refers to the average advertising cost associated with filling a vacancy with a new skilled worker. The question explicitly mentions sources of costs related to advertising in print and online media, the costs of making enquiries with the Employment Office, internal job descriptions, posters, etc. The second entry refers to the average expense per hired skilled worker, related to the provision of hiring services from external consultants and agents, like head hunters. The last entry refers to the direct costs of training events for the new hires, including payment of course fees, travel, and overnight accommodation costs. All of these costs amount to an average of 1,088 Euros, which is 50% of the monthly wage of a newly-hired skilled worker.

Moving to the list of output costs, the first entry includes interview costs. These are measured as the interview time in hours needed to fill a skilled worker vacancy, multiplied by the wage of the workers involved in the interview process (distinguishing between three categories of workers, team managers, skilled, and unskilled workers, and summing up, taking into account their respective wages). Taking the wage as a proxy for productivity, this entry measures the amount of output forgone by diverting work time from production to interviews. The second entry in Table 1 measures the average productivity shortfall of newly hired workers, relative to their productivity at the end of the training.[3] Indeed, during the training period the newly hired adapt to the new work environment, as they gradually learn how to effectively discharge their responsibilities. In these first months of employment their productivity is thus lower than at the end of the training. But there are also times when newly hired workers have to attend training courses, in which case they are completely unable to produce. The third entry measures these indirect time cost of training, which can be interpreted as the cost of diverting the effort of the newly hired workers from production to training.[4]

Finally, the last three entries separately measure the disruption in production involved with the training of a skilled worker for three categories of workers – managers, skilled and unskilled. This is computed as the product of the time spent in the training of the newly hired times the wage of each category of worker.

The results indicate that total output costs amount to 5,307 Euros, which is equivalent to 2.5 months of the average wage of a newly hired worker. So overall, total hiring costs, pecuniary

[3]To compute the costs due to reduced productivity, we exploit information on the productivity of a trainee, relative to that of an experienced skilled worker, at the beginning and at the end of the training period. Denote these two relative productivities by y_b and y_e, respectively, and the average productivity during induction by $\bar{y} = \frac{y_e + y_b}{2}$. In addition, let w_n denote the monthly wage of a newly hired skilled worker and T denote the time of the training, measured in months. The reduced productivity cost is computed as $\left[1 - \frac{\bar{y}}{y_e}\right] * w_n * T$.

[4]To avoid double-counting, the indirect cost of training is computed as $\frac{\bar{y}}{y_e} * w_n^d * T^d$, where w_n^d is the daily wage of a newly hired skilled worker, T^d is the number of induction days, and y_e and $\bar{y}$ have been defined in the previous footnote. Indeed, the shortfall of productivity relative to a worker who has just finished training has already been imputed in the entry "reduced productivity costs" in Table 1.

Pecuniary costs (Swiss Francs)	
A) Advertisement costs	1,340
B) External consultancy costs	1,110
C) Direct training costs	618
D) Total pecuniary cost (A+B+C)	3,068
Output costs (Swiss Francs)	
E) Interview costs	2,015
F) Reduced productivity costs	3,486
G) Indirect training costs	500
H) Disruption costs: managers	1,964
I) Disruption costs: skilled workers	2,697
L) Disruption costs: unskilled workers	135
M) Total output costs (E+F+G+H+I+L)	10,797
Pre-match (external) vs post-match (internal) costs (Swiss Francs)	
N) Pre-match costs (A+B+E)	4,465
O) Post-match costs (C+F+G+H+I+L)	9,400
Relative importance of hiring costs (%)	
N) Share of output cost (M/(D+M))	78%
Q) Share of post-match costs (O/(N+O))	68%

Table 2: Hiring Costs Decomposition in the Swiss Cross-Section

and output costs, are equal to three months of wages.

Of this total, 82.9% are output costs and the remaining 17.1% are pecuniary. Another useful decomposition of these costs involves the distinction between the costs that are incurred before a match is formed and those that are incurred after its formation. As illustrated in Table 1, most of the costs incurred after a match is formed are output costs, whereas most of the costs incurred before a match is formed are pecuniary. Hence, the decomposition of hiring costs into pre-match and post-match turns out to be very similar to the decomposition of costs between pecuniary and output. Namely, 82.3% of costs are incurred after a match is formed, and 17.7% are incurred before the match is set up.

3.2 Swiss Data

We make use of data from the Swiss Costs and Benefits Survey conducted by the Swiss Federal Statistical Office and the Centre for Research in Economics of Education at the University of Bern in 2009.[5] The original sample has 12,634 observations. Focussing on those establishments that had recruited a positive number of new workers in the past three years reduces the sample size to 4,265 observations. We also drop all observations with missing values on the specific occupation of the workers involved in recruitment and training activities, as they do not allow for a precise calculations of hiring costs. This leaves a sample size of 2,934 establishments.

The survey asks questions that are very similar to those in the German survey reviewed above, hence we simply report our computations for the Swiss data in Table 2.[6] The results

[5]We thank Samuel Mühlemann for his advice regarding these data.

[6]We note a few differences with respect to the German dataset: the Swiss data report only the average productivity of a newly hired worker relative to an average skilled worker. They do not report an end-of-period measure of this relative productivity. Both are needed to compute the productivity shortfall over the training period, as explained in footnote 2. It turns out that average productivity has very similar values in the German and Swiss datasets, 69.1% and 70.5%, respectively. We thus make the assumption that productivity at the end of the period

indicate that the shares of output costs and post-match costs are slightly below the values obtained using German data, but the bottom line remains the same: most of the costs of hiring are output costs, and are incurred after a match is formed.

3.3 Implications for the Modelling of Hiring Costs

In the next Section we model hiring costs in a way that accords with the evidence above. Most importantly, hiring costs will be specified as output costs, which implies that aggregate hiring costs take away from GDP rather than add to GDP. In addition, we specify hiring costs to depend on the firm-level hiring rate, rather than aggregate labor market tightness, used in the traditional approach to modelling post-match costs of hiring, and reviewed in Section 2. In Section 6 below we explore the implications of replacing output costs by pecuniary costs, and internal costs (function of the hiring rate) with external costs (function of labor market tightness).

4 The Model

The model features two frictions: price adjustment costs and costs of hiring workers. Absent both frictions, the model boils down to the benchmark New Classical model with labor and capital. Following the Real Business Cycle tradition, capital is included because it plays a key role in producing a positive response of employment to productivity shocks.[7] Introducing price frictions into the otherwise frictionless model yields the New Keynesian benchmark, and introducing hiring frictions into the NK benchmark allows us to analyze how the interplay between these frictions affects the propagation of technology and monetary policy shocks.

In this section, and in order to focus on the above interplay, our modeling strategy deliberately abstracts from all other frictions and features that are prevalent in general equilibrium models and which are typically introduced to enhance propagation and improve statistical fit, namely, habits in consumption, investment adjustment costs, exogenous wage rigidities, etc. In Section 6 below we examine the robustness of our results with respect to such modifications.

4.1 Households

The representative household comprises a unit measure of workers who, at the end of each time period, can be either employed or unemployed: $N_t + U_t = 1$. We therefore abstract from participation decisions, on the job search and from variation of hours worked on the intensive

has the same value in the two datasets. We believe that this is reasonable, given that in these two countries the systems of training are very similar, and indeed the average duration of training is 4 and 4.3 months in the German and Swiss surveys, respectively. To compute reduced productivity costs in the same way as we did for the German data, we would also need information on the wage of a newly hired skilled worker. This information is not available in the Swiss data, so we use the wage of an average skilled worker instead.

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

margin.[8] The household enjoys utility from the aggregate consumption index C_t, reflecting the assumption of full-consumption sharing among the household's members. In addition, the household derives disutility from the fraction of household members who are employed, N_t. It can save by either purchasing zero-coupon government bonds, at the discounted value $\frac{B_{t+1}}{R_t}$, or by investing in physical capital, K_t. The latter evolves according to the law of motion:

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

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

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

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

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

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

where δ_N is the separation rate.

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

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

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

The solution to the intertemporal problem of the household yields the standard Euler equa-

[8] Rogerson and Shimer (2011) have shown that most of the fluctuations in US total hours worked at business cycle frequencies are driven by the extensive margin, so our model deliberately abstracts from other margins of variation. For a theory of how on-the-job search affects real marginal costs (and inflation) see Moscarini and Postel-Vinay (2019).

tion:

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

an equation characterizing optimal investment decisions:

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

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

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

where V^N_t 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. Equation (6) equalizes the cost of one unit of capital to the discounted value of the expected rental rate plus the continuation value of future undepreciated capital. The value of a job, V^N_t in equation (7), is equal to the real wage, net of the opportunity cost of work, $\chi N^\varphi_t C_t$, and the re-employment value for unemployed workers,[9] plus a continuation value. It is worth noting that relative to the DMP model, where the opportunity cost of work is assumed to be constant, deriving the net value of employment from a standard problem of the households implies that this opportunity cost equals the marginal rate of substitution between consumption and leisure.

4.2 Firms

4.2.1 Intermediate and Final Good Firms

We assume two types of firms: intermediate good producers and final good producers. Both firms have a unit measure. Intermediate firms, indexed by i, produce a differentiated good $Y_{t,i}$ using labor and capital as inputs of production. At the beginning of each period, capital is rented from the households at the competitive rental rate X^K_t, 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 differ-

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

entiated goods produced in the economy, $Y_t = \left(\int_0^1 Y_{t,i}{}^{(\epsilon-1)/\epsilon} di\right)^{\epsilon/(\epsilon-1)}$, where ϵ denotes the elasticity of substitution across goods. The price index associated with this composite output good is $P_t = \left(\int_0^1 P_{t,i}{}^{1-\epsilon} di\right)^{1/(1-\epsilon)}$, and the demand for the intermediate good i is:

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

4.2.2 Hiring Frictions

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

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

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

The term $\tilde{g}_{t,i}$ denotes the fraction of output that is lost due to hiring activities. Hiring costs are therefore modelled as output costs, in line with the micro evidence presented in Section 3. The formulation proposed here assumes that hiring costs are internal, following the standard approach to modelling post-match costs of hiring. Indeed, the explicit functional form for these costs follows previous work by Merz and Yashiv (2007), Gertler Sala and Trigari (2008), Gertler and Trigari (2009), Christiano, Trabandt, and Walentin (2011), Sala, Soderstrom, and Trigari (2013), and Furlanetto and Groshenny (2016) and goes back in spirit to Lucas and Prescott (1971). All these studies assume that these costs are a quadratic function of the hiring rate, i.e. the ratio of new gross hires to the workforce, $\frac{H_{t,i}}{N_{t,i}}$:

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

where $e > 0$ is a scale parameter.[10]

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

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

one gets $c\left(\frac{h}{n}\right)\frac{f}{n}$; as n workers do it then the aggregate cost function is given by $c\left(\frac{h}{n}\right)f$. In the simple model presented here we restrict attention to internal costs of hiring only, excluding vacancy costs. We interpret hiring costs as those associated with investment activities, such as training costs. In Section 6 we discuss the implications of including 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. Section (3) has demonstrated that this is an empirically valid assumption.

4.2.3 Optimal Behavior

Intermediate firms maximize current and expected discounted profits:

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

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

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

and the constraint that output must equal demand:

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

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

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

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

where Ψ_t is the Lagrange multiplier associated with constraint (13), and which we have called the shadow price or value of output. It represents the real marginal revenue, which in equilibrium equals the real marginal cost and will play an important role in the transmission of shocks. Equation (14) specifies that inflation depends on this real marginal cost as well as expected future inflation.[11]

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

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

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

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

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

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

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

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

which shows that the marginal revenue Ψ_t is equalized to the real marginal cost (on the RHS). The first term on the RHS is the wage component of the real marginal cost, expressed as the ratio of real wages to the net marginal product of labor. The second term shows that with frictions in the labor market, the real marginal cost also depends on expected changes in the real marginal costs of hiring. So, for instance, an expected increase in marginal hiring costs $E_t \Lambda_{t,t+1} \Psi_{t+1} g_{H,t+1}$ translates into a lower current real marginal cost, reflecting the savings of future recruitment costs that can be achieved by recruiting in the current period. The dynamics of Ψ_t given by equation (18) play a big role in the mechanism below.

4.3 Wage Bargaining

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

Wages are therefore assumed to maximize a geometric average of the household's and the firm's surplus weighted by the parameter γ, which denotes the bargaining power of the households:[12]

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

[12]We have solved a version of the model that allows for intrafirm bargaining as in Brugemann, Gautier and Menzio (2019). We found that intrafirm bargaining amplifies the mechanism discussed in the following sections (see Faccini and Yashiv (2017) for specific results). For the sake of simplicity and comparability with the richer model presented in Section 6, we simplify along this dimension.

The solution to this problem is a standard wage equation:

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

4.4 The Monetary and Fiscal Authorities and Market Clearing

We assume that the government runs a balanced budget:

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

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

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

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

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

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

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

5 The Mechanism

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

5.1 Calibration

Parameter values are set so that the steady-state equilibrium of our model matches key averages of the U.S. economy over the years 1976-2018, assuming that one period of time equals one quarter. We start by discussing the parameter values that affect the stationary equilibrium. The values are shown in Table 3.

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

Table 3: Calibrated Parameters and Steady State Values, Baseline Model

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.

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.[13] 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

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

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

Following our discussions in Sections 2 and 3, hiring costs are to be interpreted in terms of training costs as well as all other sources of forgone output associated with hiring. This calibration of hiring costs is intentionally conservative in the sense that the costs are at the lower bound of the spectrum of estimates reported in the literature. Thus, our calibration engenders the following moderate costs: in terms of total costs, $\frac{g}{f-g}$, we get 1.3% of output; in terms of average costs, we get that they are 17% of quarterly wages ($\frac{\frac{g}{H}\Psi}{\frac{W}{P}} \simeq 2$ weeks of wages) while Silva and Toledo (2009) show that training costs in the U.S. are equivalent to 55% of quarterly wages.[14]

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.[15] 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.

5.2 Exploring the Mechanism

In order to explore the mechanism we look at the effect upon impact of technology shocks and of monetary policy shocks. We do so across different parameterizations of hiring and price frictions, in order to illustrate the interaction produced by these two frictions and to provide intuition.

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

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

In Figures 1 and 2 we plot the response of four variables to each shock: 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 3. In Section 6 below we discuss the results of the impulse responses obtained over the full horizon in a richer version of the model.[16]

Figures 1 and 2

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

For expositional convenience, we mark with colored points in the figure five reference points, which correspond to the following five model variants: (i) the NC model with no frictions obtained by setting $\zeta \simeq 0$ and $e \simeq 0$ (black point); (ii) the NC model with hiring costs; this is obtained by setting a level of price frictions close to zero, i.e. $\zeta \simeq 0$, while maintaining hiring frictions as in the baseline calibration (blue point); (iii) the standard NK model obtained by maintaining a high degree of price frictions, i.e. $\zeta = 120$, but setting hiring costs close to zero, i.e. $e \simeq 0$ (red point); (iv) the NK model embodying price frictions together with hiring frictions as calibrated in Table 3 (green point); (v) finally, a NK model with a higher scale of hiring frictions, corresponding to the estimate in Silva and Toledo (2009), $e = 5$ and $\zeta = 120$ (orange point).[17]

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

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

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

[17]When shutting down price and hiring frictions we set $\zeta \simeq 0$ and/or $e \simeq 0$. This is close to zero and not exactly equal to zero for ease of exposition, as at 0 there are discontinuities. Solving the model using exactly 0 shows the same qualitative pattern reported in Figures 1 and 2. Hence we abstract from this minor complication for illustrative purposes.

frictions. The responses appear somewhat smoothed by the presence of hiring frictions, recovering the conclusions of DMP-based analyses that hiring frictions operate as an adjustment cost, thereby exacerbating the difficulties of the standard NC model to account for the cyclical behavior of the labor market.

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

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

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

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

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

To resolve this ambiguity, note that

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

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

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

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

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

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

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

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

Monetary Policy Shocks Turning to monetary policy shocks in Figure 2, the impulse responses show that in the absence of price frictions, monetary policy is neutral, independently of labor market frictions (compare the black and blue points). In the NK benchmark instead (red point), the monetary policy shock has real effects, which lead to an increase in employment, investment, output and real wages. Most importantly, increasing hiring frictions (higher e) in the presence of price frictions offsets the expansionary effects of monetary policy shocks. At the lower bound of estimates for hiring costs (low e, green point), the effects of monetary shocks are small. For higher, but still reasonable levels of hiring frictions (orange point), employment and output can even fall on the impact of an expansionary shock. In between these two points, there is an area of frictions costs for which these key macroeconomic aggregates virtually do not respond to monetary policy shocks.[18]

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

As shown by equation (25), the marginal cost of hiring becomes more sensitive to changes in the shadow price as the scale of the hiring cost function increases. Hence, if hiring frictions are strong enough, employment may even fall on the impact of an expansionary monetary policy shock, reducing in turn both 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.

6 Further Explorations

The model laid-out in Section 4 is relatively simple and abstracts from various features that are prevalent in medium-scale general equilibrium models. The simplicity of that model is necessary to obtain monotone effects of hiring and price frictions, which are visible in Figures 1 and 2, helping with the exposition of the forces at work. However, a drawback of such simplicity is that the effects of the mechanism explained in the previous Section are quantitatively meaningful only on the impact of the shock. One may wonder whether the results discussed above are robust to the inclusion of a richer set of assumptions, embracing for instance the conventional modelling of a matching function and of vacancy posting costs, and whether they can propagate beyond the quarter of impact. Hence we add these elements to the simple model of Section 4 together with a set of features that are common in larger scale general equilibrium models, such as investment adjustment costs, external habits in consumption, wage rigidity, trend inflation and indexation to past inflation. The results we get indicate that the mechanism explored above is indeed robust to these modifications, and that its propagation can extend well beyond

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

the quarter of impact. Moreover, we find that the amplification to technology shocks can be quantitatively strong.

As these additional elements of a DSGE model are well known, in what follows we present only briefly the key new elements of the model; full elaboration (the whole model, calibration, and impulse responses) is given in Appendix A. We then discuss three issues: the role of external labor market conditions; the role of pecuniary costs; and the specifications of the Taylor rule.

6.1 Key New Elements of the Extended Model

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:

$$\max_{\left\{C_{t+s,j}, I_{t+s,j}, B_{t+s+1,j}\right\}_{s=0}^{\infty}} E_t \sum_{s=0}^{\infty} \beta^s \left[\ln\left(C_{t+s,j} - \vartheta C_{t+s-1}\right) - \frac{\chi}{1+\varphi} N_{t+s,j}^{1+\varphi} \right], \tag{26}$$

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

$$K_{t,j} = (1-\delta_K) K_{t-1,j} + \left[1 - S\left(\frac{I_{t,j}}{I_{t-1,j}}\right)\right] I_{t,j}, \quad 0 \le \delta_K \le 1, \tag{27}$$

where S is the investment adjustment cost function. It is assumed that $S(1) = S'(1) = 0$, and $S''(1) \equiv \phi > 0$.

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.

Intermediate firms maximize the following expression:

$$\begin{aligned} \max_{\left\{P_{t+s,i}, H_{t+s,i}, \check{K}_{t+s,i}\right\}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \Bigg\{ & \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s,i}}{P_{t+s}} N_{t+s,i} - \frac{X^K_{t+s}}{P_{t+s}} K_{t+s,i} \\ & - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{(1+\pi_{t+s-1})^{\psi} (1+\bar{\pi})^{1-\psi} P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \Bigg\} \end{aligned} \tag{28}$$

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

$$\left(\frac{P_{t,i}}{P_t}\right)^{-\epsilon} Y_t = f(A_t, N_{t,i}, K_{t,i}) \left[1 - \tilde{g}(V_{t,i}, H_{t,i}, N_{t,i})\right], \tag{29}$$

where $V_{t,i}$ denotes vacancies. 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:

$$\widetilde{g}_{t,i} = \frac{e}{2}\left(\frac{V_{t,i}}{N_{t,i}}\right)^{\eta^q}\left(\frac{H_{t,i}}{N_{t,i}}\right)^{2-\eta^q} \tag{30}$$

where $\eta^q \in [0,2]$ is a parameter.

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

$$H_t = \frac{U_{0,t}V_t}{\left(U_{0,t}^l + V_t^l\right)^{\frac{1}{l}}}, \tag{31}$$

where $U_{0,t}$ and V_t are aggregates 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 $q_t = \frac{H_t}{V_t}$.

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

$$\frac{W_t}{P_t} = \omega\frac{W_{t-1}}{P_{t-1}} + (1-\omega)\frac{W_t}{P_t}^{NASH}, \tag{32}$$

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

$$\frac{W_t}{P_t}^{NASH} = \arg\max\left\{\left(V_t^N\right)^{\gamma}\left(Q_t^N\right)^{1-\gamma}\right\}, \tag{33}$$

which yields

$$\frac{W_t}{P_t}^{NASH} = \gamma\Psi_t\left(f_{N,t} - g_{N,t}\right) + (1-\gamma)\left[\chi N_t^{\varphi}\left(C_t - \vartheta C_{t-1}\right) + \frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}Q_t^N\right]. \tag{34}$$

6.2 Explorations with the Extended Model

We use this enlarged framework to carry out further explorations. The discussion below is based on the results of this extended model, which are fully elaborated in Appendix A.

6.2.1 The Role of Pecuniary Costs

First, we study how the propagation of technology and monetary policy shocks would change had we assumed that the costs of hiring were expressed in units of the numeraire good rather than intermediate firm output. The main implication of assuming pecuniary costs is that the first order condition for hiring becomes:

$$Q_t^N = g_{H,t}, \tag{35}$$

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

This model with pecuniary costs does not generate reversals of the NK outcomes, unlike the model with output-costs. The role of hiring frictions in this case is to smooth impulse responses, with negligible effects if frictions are calibrated to reflect only vacancy costs. Hence, we recover the results obtained by Galí (2011) on the irrelevance of hiring frictions. This stems from a particular restriction on the parameter space of our model, one that is at odds with the evidence presented in Section 3.

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

6.2.2 The Role of External Conditions

As a second exploration, we investigate how the propagation of our mechanism is affected by the split of hiring costs between (external) vacancy posting costs and (internal) cost of hires, maintaining the assumption that both costs are expressed in units of intermediate output goods. We find that the offset to the standard NK propagation produced by our mechanism is diluted as hiring costs become more dependent on vacancy posting. To understand why the mechanism presented in Section 5.2 is weakened in this case, note that in the case of $\eta^q = 2$ in equation (30), i.e., full dependence on vacancy posting costs, the FOC with respect to hiring becomes

$$Q_t^N = \Psi_t g_{H,t} = \Psi_t e \frac{1}{q_t} \frac{V_t}{N_t} \frac{f(z_t, N_t, K_t)}{N_t}, \tag{36}$$

where q_t is the vacancy filling rate, which depends negatively on the ratio of aggregate vacancies to job seekers (tightness). 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, thereby offsetting the initial effect of Ψ_t. We find that as we reduce the fraction of hiring costs that are external, i.e. as we decrease the value of η^q, 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.

6.2.3 Taylor Rule Specifications

Finally, we explore whether the propagation mechanism relies on specific parameterizations of the Taylor rule. Indeed, 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 carried out the following robustness exercise. We take as a benchmark the version of the extended model where average hiring costs are set to be equal to seven weeks of wages.

Under this parameterization an expansionary technology shock produces an increase in employment and an expansionary monetary policy shock produces a contraction in output. To show that these 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 their calibrated values. Our results reveal that the sign of the impulse responses on impact, as well as one and two years after the shock are not affected by the Taylor rule.

7 Empirical Impulse Responses

In this section we show how U.S. macro evidence compares to the impulse responses generated by the model. We present IRFs of the data, using technology and monetary policy shocks. We then compare these data-based results to the predictions of the model discussed above. The data used are elaborated in Appendix B.

7.1 Methodology

We implement a local projections (LP) methodology to generate data-based IRFs. This methodology was suggested by Jordà (2005). Subsequently, several authors, including Jordà, Schularick, and Taylor (2018), have shown how to use this method with a LP-IV estimator, employing the shocks as instruments. Stock and Watson (2018) delineate and discuss the conditions of relevance and exogeneity under which external instrument methods produce valid inference on structural impulse response functions. The basic LP regression is the following:

$$s_{t+h} = c_h^s + \lambda_h^s \varepsilon_t + \mathbf{\Gamma}_h^{s'} \mathbf{X}_t + e_{t+h}^s. \tag{37}$$

Equation (37) can be understood as follows. On the LHS s_{t+h} is a predicted variable at horizon h. The forecasting horizon is denoted h. On the RHS the shock is denoted ε_t. Each regression has a constant (c_h^s) and an error term (e_{t+h}^s). $\mathbf{X}_t$ is a vector of control variables. The estimated coefficients are λ_h^s and the vector $\mathbf{\Gamma}_h^s$, respectively. A plot of the λ_h^s traces out the effect of the shock ε_t on the variable s_{t+h}, i.e., the impulse response function (IRF) of the variable to the shock. We compute Newey-West HAC standard errors.

The rationale for this methodology is that it is a direct forecasting method, as distinct from iterated forecasting, and puts fewer restrictions on the IRFs relative to VARs. Here we implement it for the TFP shock.

For the monetary policy shock we use the LP-IV method. The following equation is run at second stage:

$$s_{t+h} = c_h^s + \lambda_h^s \widehat{R}_t + \mathbf{\Gamma}_h^{s'} \mathbf{X}_t + e_{t+h}^s \tag{38}$$

where the fitted interest rate $\widehat{R}_t$ emerges from the first stage where one estimates:

$$R_t = a + bZ_t + \mathbf{c}'\mathbf{X}_t + v_t \tag{39}$$

In this equation a is a constant, R_t is the rate on the one year constant-maturity Treasury, Z_t is the instrument, which is the monetary policy shock ε_t^{MP}, there is an error term v_t, and b and $\mathbf{c}$ are coefficients. Stock and Watson (2018) use this formulation to estimate the response of four key U.S. macroeconomic variables to a monetary policy shock ε_t^{MP}. In discussing and implementing this formulation, they suggest including in $\mathbf{X}_t$ lagged values of s_t and of Z_t, inter-alia, as a way to satisfy the exogeneity conditions for the instrument (see their pages 925 and 941).

Estimation of equations (37)-(39) requires detrending non-stationary series and the choice of control variables ($\mathbf{X}_t$). In what follows we specify the predicted variables (s_{t+h}), the shocks series used (ε_t), and the controls ($\mathbf{X}_t$). We discuss alternative specifications separately for monetary policy shocks and for technology shocks. Detrending consists of (i) using a linear-quadratic trend, or (ii) working with log first differences.

7.2 Monetary Policy Shocks

We run equations (38)-(39); the instrument Z_t is the monetary policy shock following Romer and Romer (2004). This shock series is widely used (see, for example, the extensive discussion in Ramey (2016)). Using an updated monthly data series for the period March 1969– December 2007, computed by Wieland and Yang (2017), we have almost four decades of observations, grouped into months.

In terms of control variables ($\mathbf{X}_t$), we present three specifications. One follows Ramey (2016), a second follows Stock and Watson (2018), and the third specification is our own. Table

1	Ramey 2016: $\varepsilon^{MP}_{t-i}, IP_{t-i}, u_{t-i}, CPI_{t-i}, P^{COM}_{t-i}, FFR_{t-i}$; see note b
2	Stock and Watson (2018): $\varepsilon^{MP}_{t-j}, R_{t-j}, IP_{t-j}, CPI_{t-j}, EBP_{t-j}$,factors$_{t-j}$; see note c
3	ε^{MP}_{t-j}, dependent var$_{t-j}$, $IP_{t-j}, r_{t-j}, MNfactor1_{t-j}, CPI_{t-j}$

Table 4: Control Variables in Monetary Policy Shock Projections. Notes: a) Time indices i=1,2 and j=1,2,3,4. b) Ramey (2016) discusses these specifications on pages 104-106, including Figure 2B. c) Stock and Watson (2018) discuss these specifications on pages 940-943, including Table 1.

4 presents these alternative specifications. The controls include real variables – industrial production (IP), unemployment (u), and the real rate of interest (r); nominal variables – the Fed Funds Rate (FFR), the CPI, and an index of commodity prices (CPI and P^{COM}, respectively); credit and bond markets variables – the one year treasury rate (R) and the excess bond premium (EBP) computed by Gilchrist and Zakrajšek (2012). Stock and Watson (2018) use four factors they compute from the FRED data set. In our specification we make use of the factors computed by McCracken and Ng (2016) in their analysis of FRED data, to be denoted MN (see details in Appendix B). In all cases we run the IRFs of the following variables, in response to the monetary policy shock:

$$s_{t+h} \in \{IP_{t+h}, n_{t+h}, u_{t+h}, r_{t+h}\}. \tag{40}$$

The specification used by Ramey (2016; see pp. 104-110), row 1 of Table 4 here, takes as controls two lags of the shocks, of two real variables (industrial production and unemployment), and of the three nominal variables cited above. The specification used by Stock and Watson (2018; see their Table 1 and the discussion on pages 940-943), row 2 of Table 4 here, uses as controls four lags of the shock, of their predicted variables (R, IP, CPI, EBP), and of their factors. Our specification, row 3 of Table 4, uses four lags of the shocks, of the dependent variable, of three real variables ($IP, r, MNfactor1$) and of the CPI.

Figure 3 reports these specifications using a linear-quadratic time trend, while Appendix B reports the first differences version, showing that the precise method of detrending does not matter for the results. We report the estimates of the IRFs of industrial production, employment, unemployment, and the real rate of interest with 68% and 95% confidence bands. All the specifications we consider satisfy the criterion for exogeneity of the instruments, as our F statistic in the first stage (using HAC standard errors) is well above 10, as shown in the figure notes.

Figure 3

While there are variations in the results across control variables in the various specifications, they convey the same general pattern: a monetary expansion leads initially to a lower real interest rate, lower employment and output (industrial production), and higher unemployment. Similar plots (for a monetary contraction) are presented by Ramey (2016; see her Figure 2B on page 104), who notes that relaxing the conventional assumption in VARs, whereby prices and output cannot respond to the interest rate contemporaneously, leads to “puzzling” results,

1	$\varepsilon^{TFP}_{t-j}, f_{t-j}, r_{t-j}, MNfactor1_{t-j}, MNfactor2_{t-j}, R_{t-j}, \pi_{t-j}, EBP_{t-j}, T10Y3M_{t-j}$
2	$\varepsilon^{TFP}_{t-j}, f_{t-j}, r_{t-j}, MNfactor1_{t-j}$
3	$\varepsilon^{TFP}_{t-j}, MNfactor2_{t-j}, R_{t-j}, \pi_{t-j}, EBP_{t-j}, T10Y3M_{t-j}$

Table 5: Control Variables in TFP Shock Projections. Note: Time index j=1,2,3,4.

whereby contractionary monetary policy seems to have significant expansionary effects. Our model can rationalize these findings.

7.3 Technology Shocks

We run the TFP shocks with quarterly data in one stage as follows.

$$s_{t+h} = c^s_h + \lambda^s_h \varepsilon^{TFP}_t + \Gamma^{s'}_h \mathbf{X}_t + e^s_{t+h} \tag{41}$$

We use TFP shocks computed by John Fernald (see Fernald (2014)) for the period 1969Q1-2018Q2. In terms of control variables ($\mathbf{X}_t$), we present three specifications in Table 5. The controls here include lagged shocks, real variables (GDP, the real rate of interest, MN factor 1), inflation and the one year Treasury rate, and credit market variables that were found in the literature to have substantial forecasting power. They include those described for Table 4, as well as the 10 year–3 months treasury spread ($T10Y3M$) and MN factor 2, which captures term spreads. We use quarterly data, including the McCracken and Ng (2016) factors based on FRED data. Row 1 is a comprehensive specification, while rows 2 and 3 are more parsimonious, with shocks and real variables only in Row 2 and shocks and nominal and credit variables only in Row 3. All rows use four lags of each control.

Figure 4 reports these specifications using a linear-quadratic time trend, while Appendix B shows that the results are robust to taking first differences. We report the estimates of the IRFs of GDP, employment, and unemployment with 68% and 95% confidence bands.

Figure 4

Our theoretical model predicts that, in the presence of a reasonable amount of hiring frictions, an expansionary TFP shock will lead to higher employment and output and lower unemployment, despite the presence of price rigidities. Figure 4 bears out these predictions.

8 Conclusions

We have provided microeconomic evidence that most of the costs of hiring are output costs, rather than payments to third parties for the provision of hiring services. We have then shown that because hiring frictions involve forgone output, the optimal intertemporal allocation of hiring activities over the cycle is directly affected by fluctuations in the value of output. This mechanism implies that hiring frictions matter in a significant way for business cycles, and not only through wage setting mechanisms. Indeed, the interaction between price and hiring frictions has key implications for the transmission of both technology and monetary policy shocks.

Our analysis of hiring costs using micro data is a first attempt of providing estimates on the importance of the various types of these costs. Currently, the scarcity of research on this topic is striking, particularly when compared to the vast literature that has measured the frequency of price adjustments. Indeed, most of the empirical research in this field has focused on measuring price rigidities under the prevalent belief that this is a necessary statistic to gauge the strength of the New-Keynesian mechanism. On the other hand, the empirical macroeconomic literature, related to business cycles, has neglected the measurement of hiring frictions, under the belief that these frictions are small, and not so important for our understanding of the business cycle. Our results indicate that if hiring frictions are more than tiny, though still moderate, they are of key importance. As a result, the standard propagation of New Keynesian models could be turned upside down, with positive technology shocks leading to an increase in employment, and expansionary monetary policy shocks leading to an initial contraction in economic activity, followed by an expansion. We have shown that an agnostic approach to the estimation of technology and monetary policy shocks is consistent with these theoretical impulse responses.

To sum up, we have shown that it is important to gain a better understanding of the nature of the hiring costs that we incorporate in macro models as they can potentially matter a lot in shaping business cycle fluctuations. This is a largely understudied topic in the existing literature that we believe merits much more attention.

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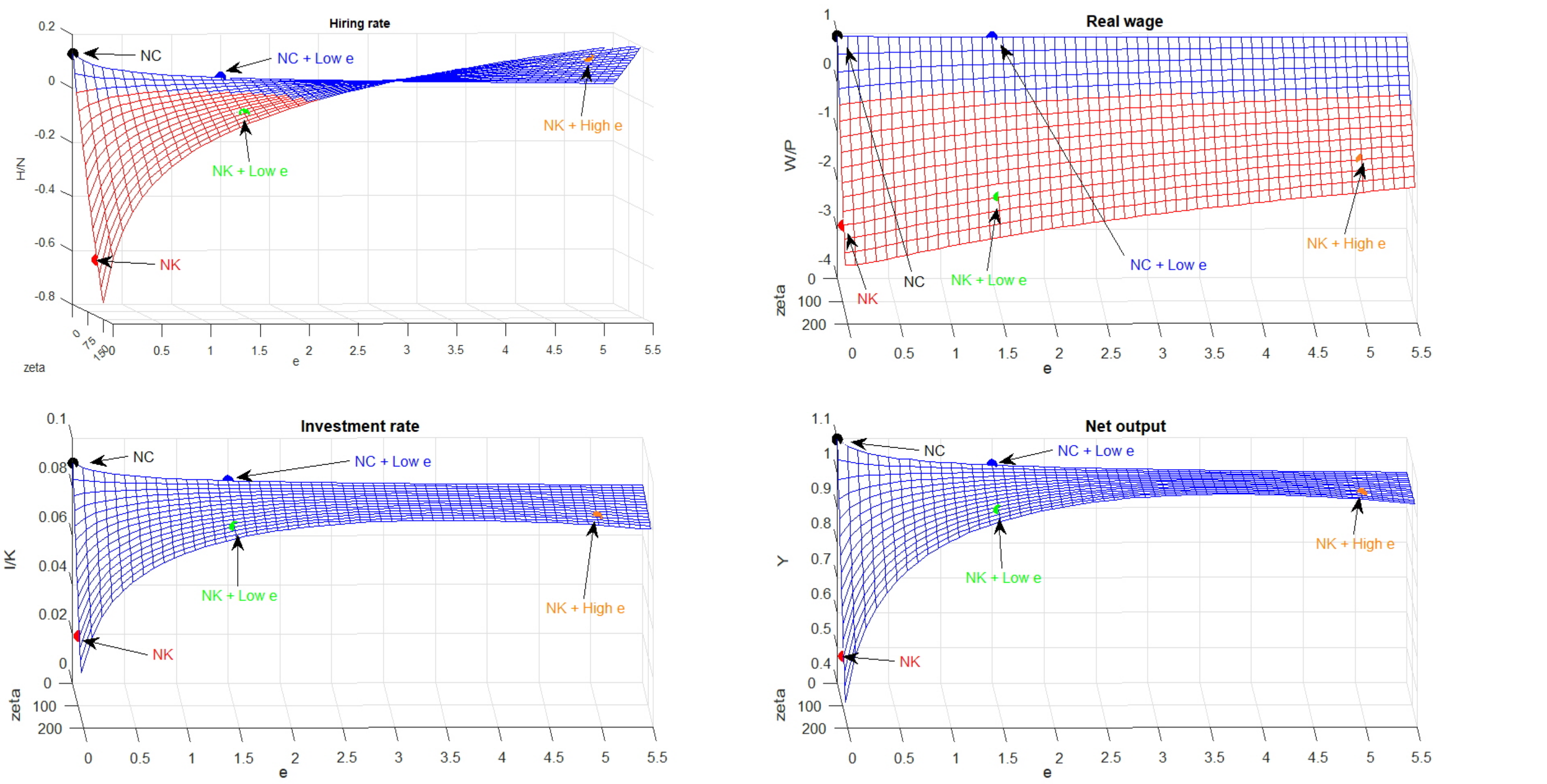

Figure 1: Impulse Responses on Impact of a Positive Technology Shock. Notes: The figure shows impulse responses on the impact of a 1 percent expansionary technology shock for various parameterizations of the model where we allow price rigidities, ζ, and hiring frictions, e, to vary. The real wage and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

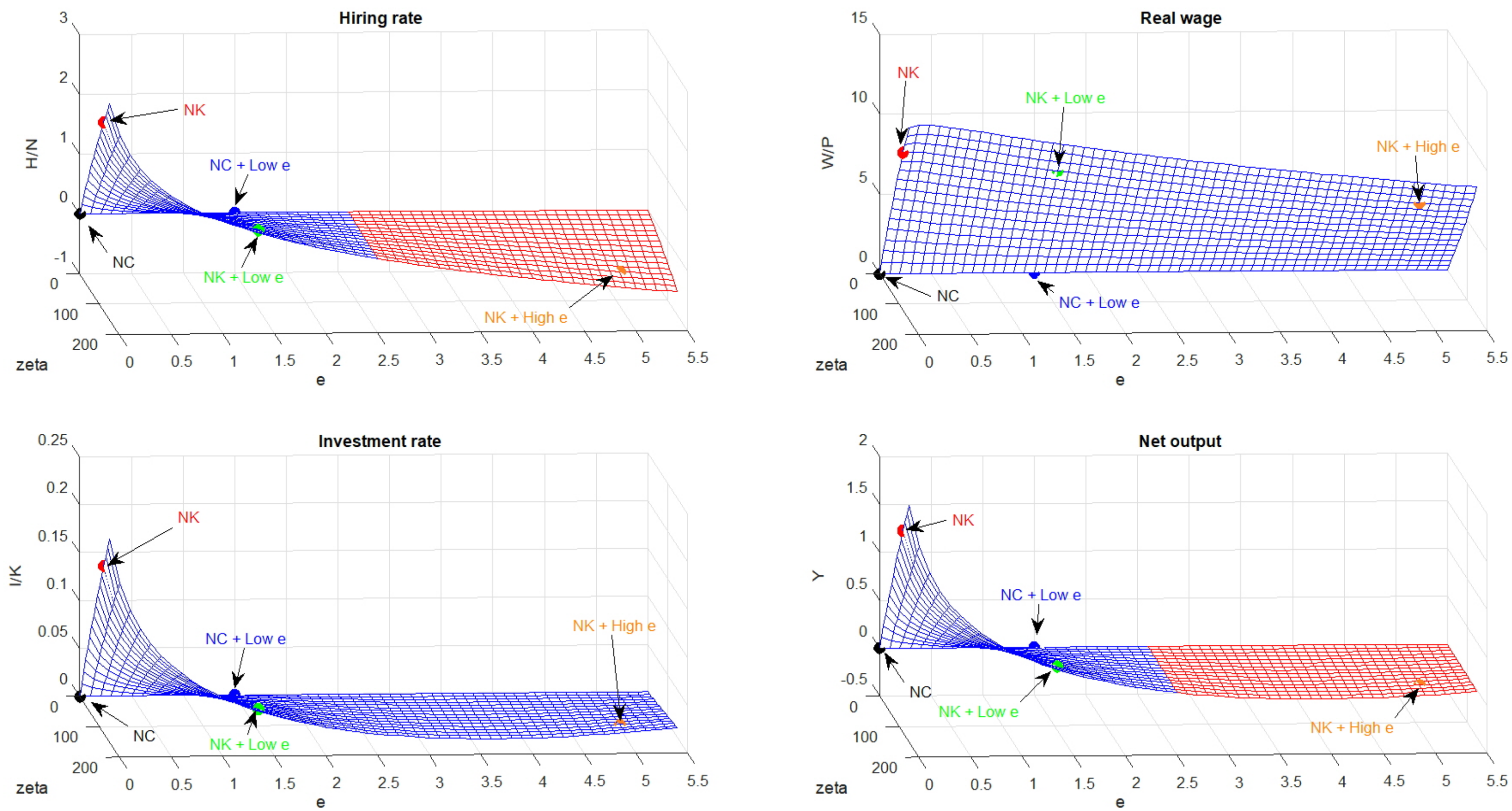

Figure 2: Impulse Responses on Impact of an Expansionary Monetary Policy Shock. Notes: The figure shows impulse responses on the impact of a 25 basis point expansionary interest rate shock for various parameterizations of the model where we allow price rigidities, ζ, and hiring frictions, e, to vary. The real wage and output are expressed in percent deviations from steady state, hiring and investment rates in percentage points deviations.

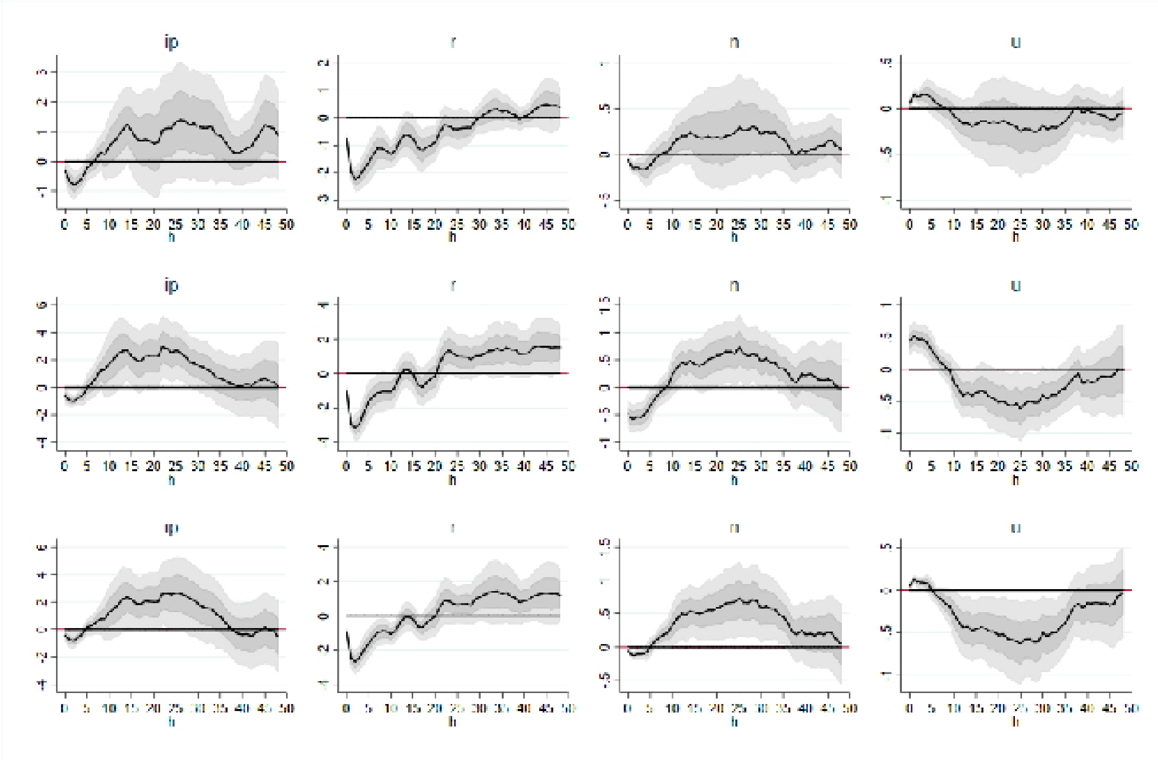

Figure 3: Impulse Reponse Functions to an Expansionary Monetary Policy Shock. Notes: a) The rows correspond to the three specifications of Table 4. b) Rows 2 and 3 use a linear-quadratic time trend. Row 1, following Ramey (2016), does not use a detrending procedure. c) F statistics (using HAC Newey-West standard errors, with bandwidth parameter of 12) in the first stage (eq.39) are for row 1, 105.4, for row 2, 37.5, and for row 3, 42.7.

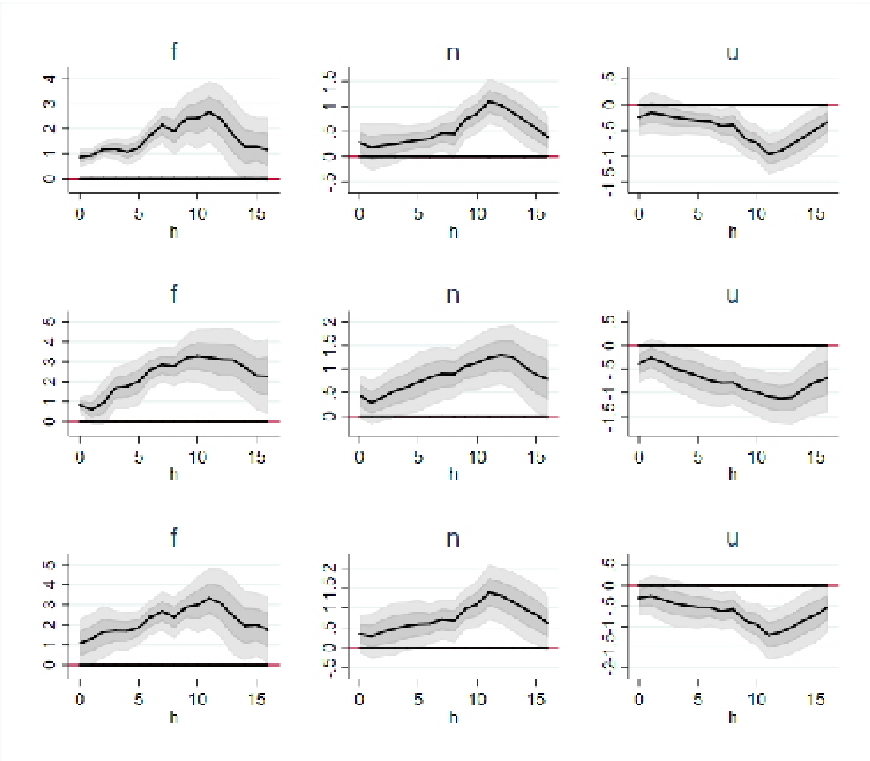

Figure 4: Impulse Reponse Functions to a Positive TFP Shock. Notes: a) The rows correspond to the three specifications of Table 5. b) We use a linear-quadratic time trend.

Appendices

A The Extended Model (for online publication)

In this Appendix we fully elaborate on the extended model and on the further explorations of its mechanism.

Sub-Section A.1 presents the extended model, which is essentially a medium-scale general equilibrium model, catering for a richer framework.

Sub-Section A.2 presents the full impulse response functions of this extended model, revisiting the mechanism discussed above.

Two sub-sections then examine the role of our formulation of hiring costs: in sub-section A.3 we look at output costs vs pecuniary costs and in sub-section A.4 we look at internal vs external costs. Finally, sub-Section A.5 reports on the robustness of the results to variations in the Taylor rule.

A.1 The Extended Model

The model augments the simple set-up of Section 4 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.

A.1.1 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:

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

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

$$K_{t,j} = (1-\delta_K) K_{t-1,j} + \left[1 - S\left(\frac{I_{t,j}}{I_{t-1,j}}\right)\right] I_{t,j}, \quad 0 \leq \delta_K \leq 1, \tag{42}$$

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

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

$$\frac{1}{R_t} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t}, \tag{43}$$

$$Q_t^K = E_t \Lambda_{t,t+1} \left[\frac{X_{t+1}^K}{P_{t+1}} + (1-\delta_K) Q_{t+1}^K \right] \tag{44}$$

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

$$V_t^N = \frac{W_t}{P_t} - \frac{\chi N_t^{\varphi}}{\lambda_t P_t} - \frac{x_t}{1-x_t} V_t^N + E_t \Lambda_{t,t+1} (1-\delta_N) V_{t+1}^N, \tag{45}$$

and

$$Q_t^K \left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - S'\left(\frac{I_t}{I_{t-1}}\right) \frac{I_t}{I_{t-1}} \right] + E_t \Lambda_{t,t+1} Q_{t+1}^K S'\left(\frac{I_{t+1}}{I_t}\right) \left(\frac{I_{t+1}}{I_t}\right)^2 = 1, \tag{46}$$

where the Euler equation (43), the value of capital (44), and the value of a marginal job to the household (45) correspond to equations (5), (17) and (7) in the simple model of Section 4, respectively.

A.1.2 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:

$$\begin{aligned} \max_{\{P_{t+s,i}, H_{t+s,i}, K_{t+s,i}\}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \Bigg\{ & \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s,i}}{P_{t+s}} N_{t+s,i} - \frac{X_{t+s}^K}{P_{t+s}} K_{t+s,i} \\ & - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{(1+\pi_{t+s-1})^{\psi} (1+\bar{\pi})^{1-\psi} P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \Bigg\} \end{aligned} \tag{47}$$

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

$$\left(\frac{P_{t,i}}{P_t}\right)^{-\epsilon} Y_t = f(A_t, N_{t,i}, K_{t,i}) \left[1 - \tilde{g}(V_{t,i}, H_{t,i}, N_{t,i})\right]. \tag{48}$$

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:

$$\tilde{g}_{t,i} = \frac{e}{2}\left(\frac{V_{t,i}}{N_{t,i}}\right)^{\eta^q}\left(\frac{H_{t,i}}{N_{t,i}}\right)^{2-\eta^q}. \tag{49}$$

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

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

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

It can be easily shown that equation (49) implies that an increase in the vacancy filling rate q_t decreases the marginal cost of hiring.[19] For intermediate values of $\eta^q \in (0,2)$, the specification in (49) allows for both hiring rates and vacancy rates to matter for the costs of hiring in different proportions.

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

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

$$Q_t^N = \Psi_t g_{H,t}, \tag{50}$$

$$Q_t^N = \Psi_t\left(f_{N,t} - g_{N,t}\right) - \frac{W_t}{P_t} + (1-\delta_N)E_t\Lambda_{t,t+1}Q_{t+1}^N, \tag{51}$$

$$\frac{X_t^K}{P_t} = \Psi_t\left(f_{K,t} - g_{K,t}\right) \tag{52}$$

and

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

[19] Equation (49) can be rewritten as $\tilde{g}_{t,i} = \frac{e}{2}q_t^{-\eta^q}\left(\frac{H_{t,i}}{N_{t,i}}\right)^2$, which implies that $g_{H,t,i} = \frac{\partial}{\partial H_{t,i}}\tilde{g}_{t,i}f_{t,i} = eq_t^{-\eta^q}\frac{H_{t,i}}{N_{t,i}^2}f_{t,i}$.

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

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

$$+E_t\frac{1}{R_t/(1+\pi_{t+1})}\left[\left(\frac{1+\pi_{t+1}}{(1+\pi_t)^{\psi}(1+\bar{\pi})^{1-\psi}}-1\right)\frac{1+\pi_{t+1}}{(1+\pi_t)^{\psi}(1+\bar{\pi})^{1-\psi}}\frac{Y_{t+1}}{Y_t}\right]. \quad (53)$$

Merging the FOCs for capital of households and firms (44) and (52) we get:

$$Q_t^K = E_t\Lambda_{t,t+1}\left[\Psi_{t+1}\left(f_{K,t+1}-g_{K,t+1}\right)+(1-\delta_K)Q_{t+1}^K\right] \quad (54)$$

A.1.3 Matching

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

$$H_t=\frac{U_{0,t}V_t}{\left(U_{0,t}^l+V_t^l\right)^{\frac{1}{l}}}, \quad (55)$$

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 $q_t=\frac{H_t}{V_t}$.

A.1.4 Wage Norm

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

$$\frac{W_t}{P_t}=\omega\frac{W_{t-1}}{P_{t-1}}+(1-\omega)\frac{W_t}{P_t}^{NASH}, \quad (56)$$

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

$$\frac{W_t}{P_t}^{NASH}=\arg\max\left\{\left(V_t^N\right)^{\gamma}\left(Q_t^N\right)^{1-\gamma}\right\}, \quad (57)$$

which yields

$$\frac{W_t}{P_t}^{NASH}=\gamma\Psi_t\left(f_{N,t}-g_{N,t}\right)+(1-\gamma)\left[\chi N_t^{\varphi}\left(C_t-\vartheta C_{t-1}\right)+\frac{x_t}{1-x_t}\frac{\gamma}{1-\gamma}Q_t^N\right]. \quad (58)$$

A.1.5 Final Good Firms

Final firms maximize

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

subject to

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

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

$$Y_{t,i} = \left(\frac{P_{t,i}}{P_t} \right)^{-\epsilon} Y_t. \tag{59}$$

A.1.6 The Monetary and Fiscal Authorities and Market Clearing

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

A.1.7 Calibration

The model is calibrated following the same steps as in Sub-Section 5.1. 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 5.1. All other parameter values that are common to the simple model are set to the same value reported in Table 3. As for the new parameters, the investment adjustment cost parameter ϕ is set to 2.5, and the habit parameter to $\vartheta = 0.8$, reflecting the estimate by Christiano, Eichenbaum and Trabandt (2016). The parameter governing trend inflation is set to $\bar{\pi} = 0.783\%$, which corresponds to the average of the US GDP deflator over the calibration period. Given that, the value of the discount factor β, is set so as to match a 1% nominal rate of interest. We set the degree of indexation to a moderate value of $\psi = 0.5$, and the parameter governing wage rigidity to $\omega = 0.87$, in order to match the persistence of the US real wage data. Finally, we set the elasticity of the hiring friction function η^q to 0.49, which is value estimated by Sala, Soderstrom, and Trigari (2013) for the US economy. 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. In the relatively low friction benchmark, the parameter e governing the scale of hiring frictions is set following the same strategy as in Section 5.1: the value of e is set to 1.2 so as to target a ratio of marginal hiring costs to productivity of 0.20. To inspect the mechanism, we will also report impulse responses for a relatively high frictions benchmark, where the scale of the hiring costs function is raised to 5, in order to match the empirical evidence in Silva and Toledo (2009), where average hiring costs are equal to 55% of quarterly wages.

Parameter values and calibration targets for the extended model are reported in Table A-1.

Table A-1

A.2 The Mechanism Revisited

We discuss the results of the extended model and revisit the mechanisms discussed above. We do so, again, through variation of the values of key parameters with respect to the benchmark calibration of Table A-1. The figures now give the full impulse response functions over 15 quarters for ten key variables. The top row in each figure shows five main macroeconomic variables – output, consumption, investment (in rates out of capital), the real rate of interest, and Ψ_t, the shadow price. The bottom row in each figure shows five main macro/labor variables – employment and unemployment rates, hiring (in rates out of employment), the real wage, and the value of the job (Q_t^N).

A.2.1 Technology Shocks

Figure A-1 reports impulse responses for a positive technology shock obtained under the benchmark parameterization with small friction costs (low e, the green solid line), and an alternative parameterization with a higher, but still reasonable, friction cost (higher e, the orange broken line).

Figure A-1

Figure A-1 shows that the response of employment in the relatively low calibration of the scale of hiring costs remains negative, as in the standard NK model. Under the relatively higher friction parameterization (e) the response turns positive. In the latter case, the shadow price Ψ_t, a key driver in our mechanism, falls considerably more upon impact. Note that this latter change is in addition to the effect discussed in Sub-Section 5.2, whereby the sensitivity of marginal hiring costs,$\Psi_t g_{H,t}$, depends on e via $g_{H,t}$. Here the value of e matters for the movement in Ψ_t itself, as seen in the top row of the figure, whereby a higher value of e engenders a higher fall in Ψ_t. The path of Ψ_t, the shadow price, which is also the inverse of the mark-up, is a dominant dynamic in our mechanism.

The mechanism inherent in Figure A-1 is as follows. The positive technology shock, under conventional price rigidity, generates a fall in the marginal cost and hence an increase in the mark-up. The ensuing decline in hiring costs (manifested in the fall in job values Q_t^N, which equal $\Psi_t g_{H,t}$) raises the hiring rate in the high e case. Strikingly, at a higher scale of hiring costs (higher value of e), and in the presence of price frictions, a technology shock implies much stronger expansionary responses of employment, investment, output and consumption, which increase over the impulse response horizon, showing persistent, hump-shaped dynamics. This counterintuitive result, whereby, at a higher scale of frictions, technology shocks are magnified in terms of the response of real variables in a NK model, is in accordance with the discussion of the mechanism presented in Sub-Section 5.2. The key point is that hiring frictions interact with price frictions to increase the countercyclicality of marginal hiring costs. Thus, following a positive technology shock, hiring costs decline with the fall in the shadow price Ψ_t, which is stronger the higher is e, as shown in the figure.

A complementary and insightful approach to identify and visualize the effect of the interaction between price frictions and hiring frictions is to show how price frictions affect the transmission of technology shocks in a model with hiring frictions. The natural focus, in this context, is on the behavior of unemployment. We do so in Figure A-2, where we compare the impulse responses obtained under the same "high" hiring friction case reported in Figure A-1 (traced out by the orange broken lines), with the otherwise identical model where we shut down price frictions, i.e. we set $\zeta \simeq 0$ (this is traced out by the light blue solid lines).

Figure A-2

Because the latter is effectively a rich specification of the DMP model with capital, Figure A-2 allows us to pin down the effects of introducing price frictions into this DMP benchmark. As a result, any difference between the two models is due to the endogenous response of the shadow value of output, Ψ_t. The figure reveals that the mechanism produces strong amplification of unemployment to the underlying TFP shock, with an impact elasticity around 4 and a peak elasticity around 6 in the presence of both hiring frictions and price frictions. This compares with an impact – and peak – elasticity around $1\frac{1}{2}$ under flexible prices. In addition, the hump-shaped impulse response of unemployment to technology shocks is much more pronounced in the presence of price stickiness. Hence, introducing price frictions into a model with hiring frictions generates both volatility and endogenous persistence in the response of unemployment to technology shocks. The mechanism, once again, is the one discussed in Sub-Section 5.2, which operates through the countercyclicality of the shadow price and hiring costs induced by price rigidities.

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

Monetary policy shocks. Figure A-3 reports impulse responses for an expansionary monetary policy shock obtained under the same "low" and "high" parameterizations of friction costs.

Figure A-3

The impulse response analysis reveals that at the lower level of friction costs (green line), an expansionary monetary policy shock produces real effects, increasing output, consumption, employment, investment, and real wages. At the higher level of friction costs instead (orange line), monetary policy shocks still produce real effects, but in the opposite direction. Again a key role is played by the response of the shadow price Ψ_t as shown in the top row of FigureA-3, an effect which strengthens as e rises.

These results are consistent with those that were obtained with the simple model of Section 4, 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 A-1 and A-3 as "high" friction cost purely for comparative reasons. So the bottom line of the analysis presented in this subsection, 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.

A.3 Output Costs vs. Pecuniary Costs of Hiring

So far we have assumed that the hiring costs specified in equation (49) are expressed in units of (forgone) output. Alternatively we could have assumed, following the convention in the literature, that hiring costs are pecuniary, meaning that they are specified in units of the composite good. In this case the production function (9) is simply $Y_{t,i} = f(A_t, N_{t,i}, K_{t,i})$, and the maximization problem of the firm becomes

$$\max_{P_{t+s,i}, H_{t+s,i}, \breve{K}_{t+s,i}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s} N_{t+s,i}}{P_{t+s}} - \frac{X^K_{t+s}}{P_{t+s}} K_{t+s,i} - g_{t,i} - \frac{\zeta}{2} \left(\frac{P_{t+s,i}}{P_{t+s-1,i}} - 1 \right)^2 Y_{t+s} \right\},$$

where $g_{t,i} = \tilde{g}_{t,i} Y_{t,i}$, subject to the demand function (8), the law of motion for employment (12), and the technology constraint (13).

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

$$Q^N_t = g_{H,t},$$

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

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

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

A.4 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 A-4 and A-5 for technology shocks and monetary policy shocks, respectively.

Figures A-4 and A-5

The figures show that the offset to the standard NK propagation produced by our mechanism is considerably diluted in the case where hiring costs depend only on vacancy posting. Indeed, the amplification in the response of labor market variables to technology shocks is very much reduced. To understand why the mechanism presented in Section 5.2 is weakened in the case of $\eta^q = 2$ consider the FOC for hiring, where now

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

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

A.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 A-3 and A-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 A-1.

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.

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

Table A1: Calibrated Parameters and Steady State Values, Extended Model

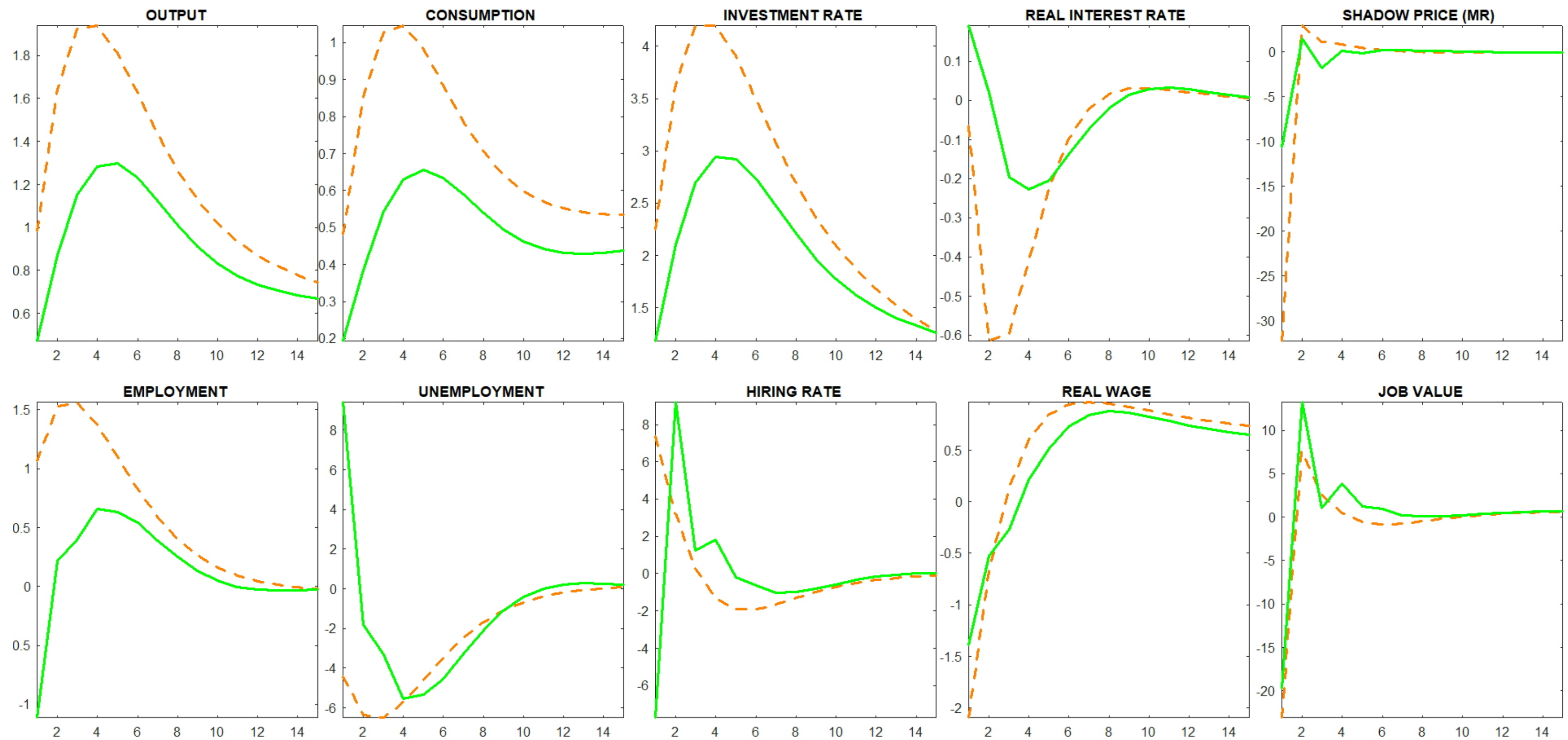

Figure A1: Impulse Responses to a Positive Technology Shock: Extended Model with "Low" vs. "High" Scales of Hiring Costs. Notes: impulse responses to a 1 percent positive technology shock obtained for two different parameterizations: "high" hiring costs (orange broken line; e=5) and " low" frictions (solid green line; e=1.2). All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

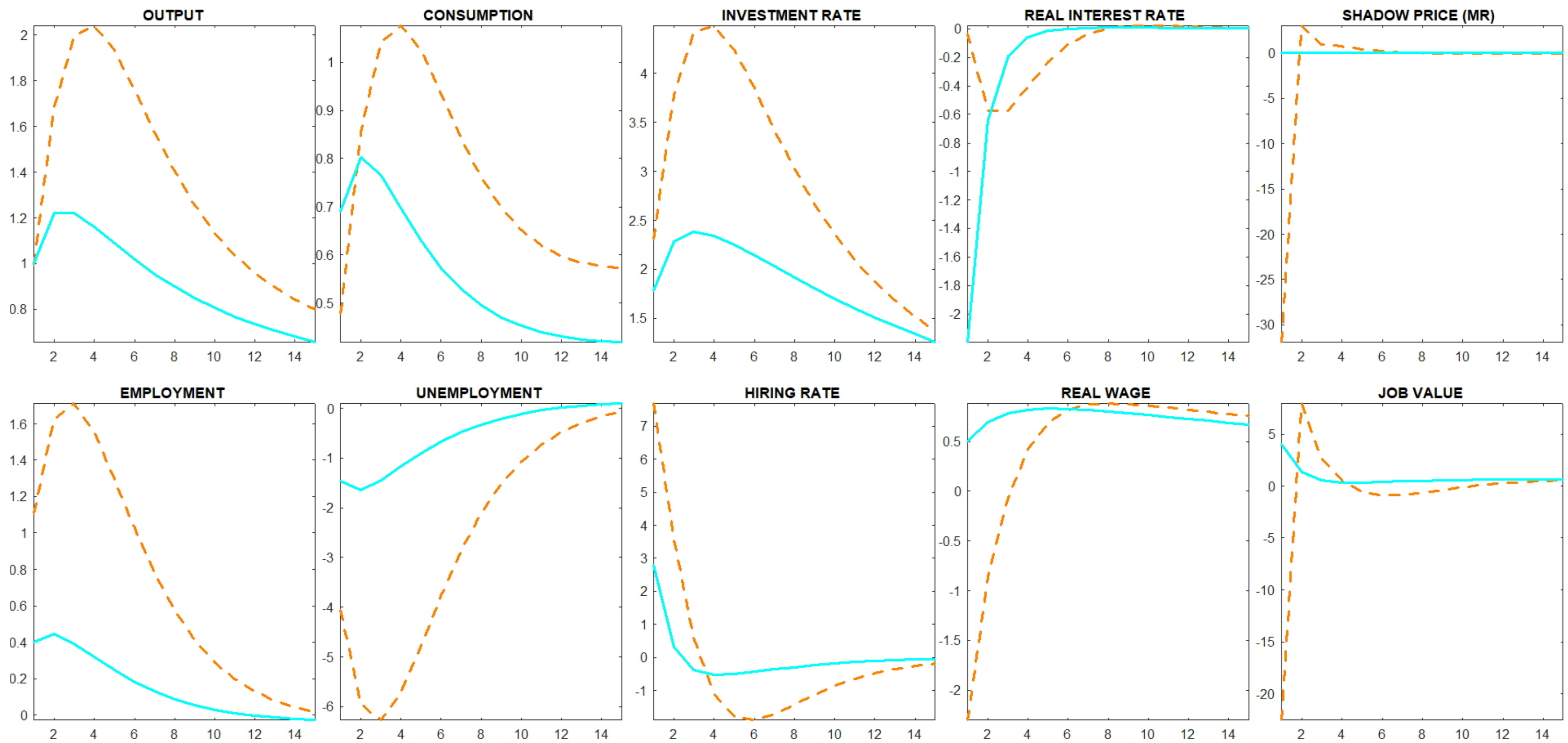

Figure A2: Impulse Responses to a Positive Technology Shock: Extended Model with Rigid vs. Flexible Prices. Notes: impulse responses to a 1 percent positive technology shock obtained for two different parameterizations: The rigid price model with hiring costs (NK + L Frictions, orange broken line; $\zeta = 120$ and e=5) and the flexible price model with hiring costs (NC + L Frictions, solid light blue line; $\zeta \simeq 0$ and e=5). All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

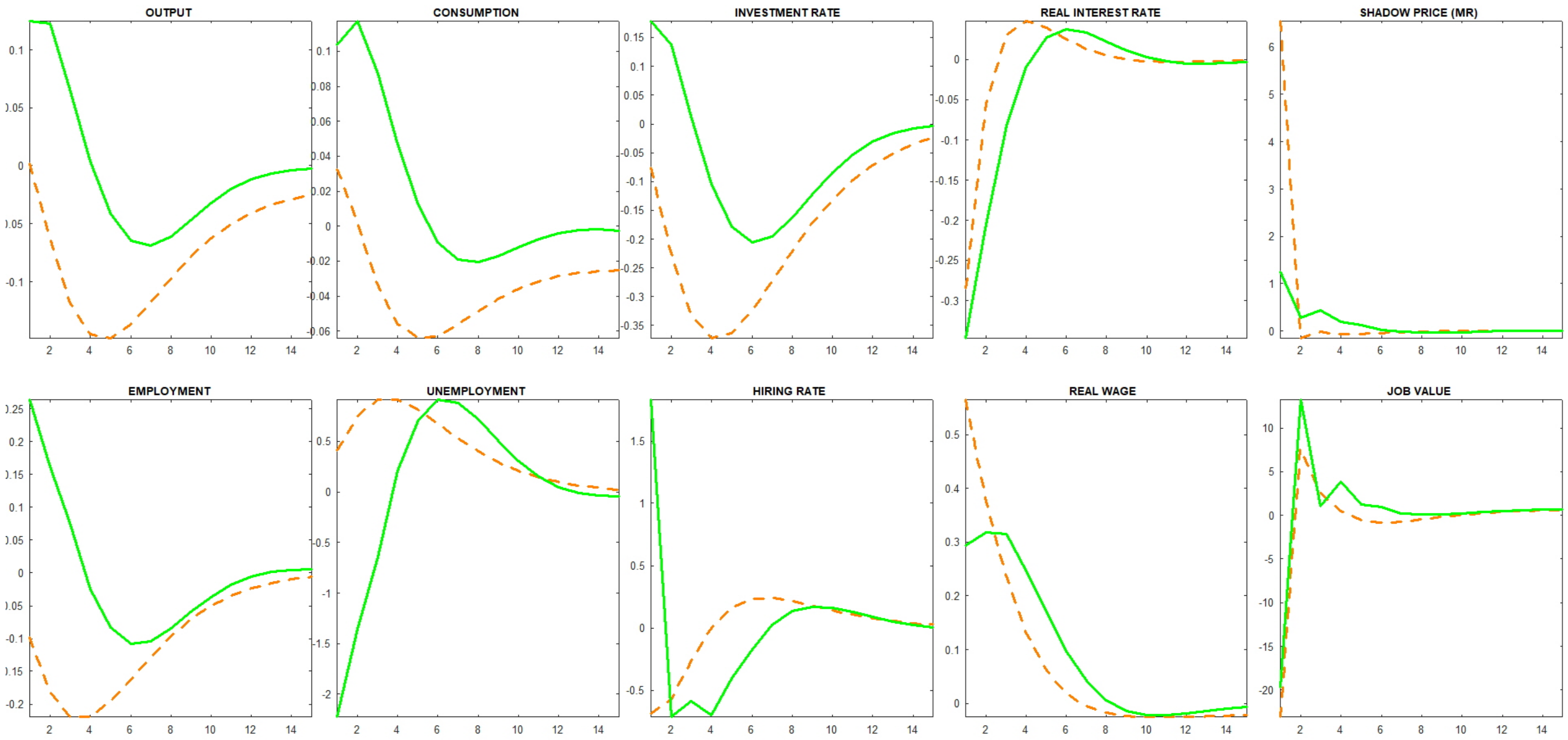

Figure A3: Impulse Responses to an Expansionary Monetary Policy Shock: Extended Model with "Low" vs. "High" Scales of Hiring Costs. Notes: impulse responses to a 25 basis point expansionary monetary policy shock obtained for two different parameterizations: "high" hiring costs (orange broken line; e=5) and "low" frictions (solid green line; e=1.2). All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

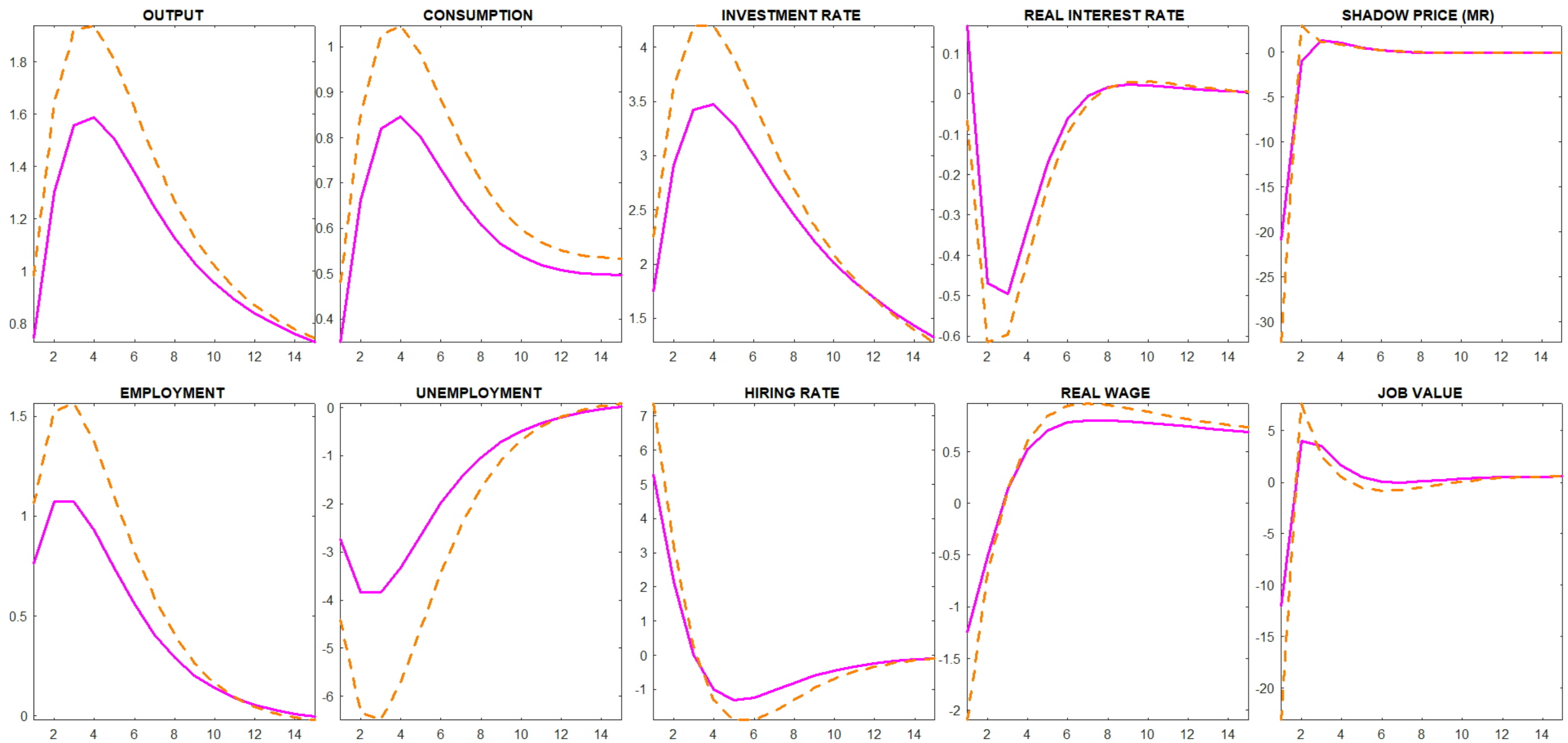

Figure A4: Impulse Responses to a Positive Technology Shock, Vacancy Costs Only vs Vacancy and Hiring Costs. Notes: Impulse responses to a 1 percent positive technology shock obtained for two different parameterizations of etaq both with "high" hiring costs e=5. The orange (dashed) line uses the benchmark $\eta^q = 0.49$, implying the co-existence of both vacancy and hiring costs; and the purple (solid) line uses $\eta^q = 2$, implying vacancy costs only. All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

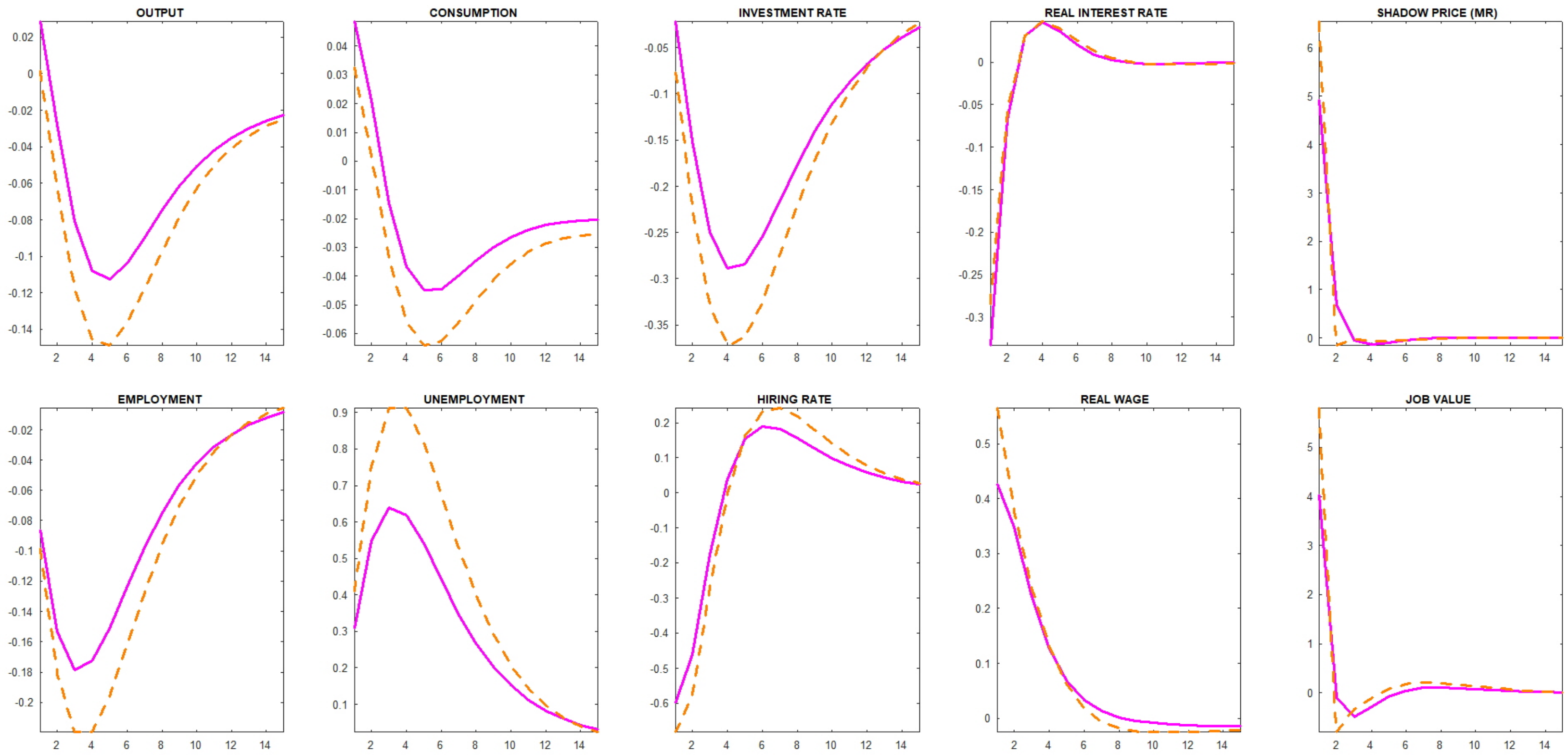

Figure A5: Impulse Responses to an Expansionary Monetary Policy Shock, Vacancy Costs Only vs Vacancy and Hiring Costs. Notes: Impulse responses to a 25 basis points monetary policy expansion shock obtained for two different parameterizations of etaq both with "high" hiring costs e=5. The orange (dashed) line uses the benchmark $\eta^q = 0.49$ implying the co-existence of both vacancy and hiring costs; and the purple (solid) li ne uses $\eta^q = 2$, implying vacancy costs only. All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations.

B Local Projections Analysis

B.1 Monthly Data for MP shocks

All of the variables used are in logs. When a variable x is a rate it is formulated as $\ln(1+x) \simeq x$. The following table presents the details; sources are from FRED unless noted otherwise.

	symbol	definitions	source (FRED)
real	IP_t	Industrial Production index	INDPRO
	n_t	Employment rate (civilian)	CE16OV and CLF16OV
	u_t	Civilian Unemployment rate	UNRATE
	w_t	Real Wages (non-farm)	COMPRNFB
	MN factor 1_t	Macro Factor 1; See note a	MN
prices, inflation			
	CPI_t	CPI	CPIAUCSL
	P_t^{COM}	Commodity (non-energy) Price Index	World Bank
	π_t	$LCPI_t - LCPI_{t-1}$	CPIAUCSL
financial	R_t	One-year constant maturity Treasury rate	GS1
	FFR_t	Effective Federal Funds rate	FEDFUNDS
	r_t	Real Interest rate; See note b	FEDFUNDS and CPIAUCSL
	EBP_t	Excess Bond Premium	Gilchrist and Zakrajšek (2012)
	$T10Y3M_t$	10-Yr $-$3-Month Spread, Treasury	T10Y3M
MP shocks	ε_t^{MP}	Romer-Romer shocks; See note c	Romer and Romer (2004); Wieland and Yang (2017)

Table B1: Monthly Data Used for MP Shocks. Notes: a) We take factors from McCracken and Ng (2016), to be denoted MN. The interpretation of MN factor 1, discussed on their pages 577-8, is "activity, employment". b) We compute the real rate as the log of the ratio of the gross Federal Funds Rate rate to the gross CPI rate of inflation. c) The Romer and Romer shock series is from Wieland and Yang (2017).

B.2 Results for MP Shocks First Differences Specifications

Figure B1 shows the IRFs to an expansionary monetary policy shock specified in Table 4 using first differences for all variables which are not rates.

Figure B1

B.3 Quarterly Data for TFP Shocks

All of the variables used are in logs. When a variable x is a rate it is formulated as $\ln(1+x) \simeq x$. Table B2 presents the details.

symbol	definitions	source (FRED)
f_t	Real GDP (non-farm, business)	OUTNFB
n_t	Employment rate (civilian, CPS)	CE16OV and CLF16OV
u_t	Unemployment rate	UNRATE
w_t	Real Wages per hour (non-farm, business)	COMPRNFB
r_t	Real Interest Rate; See note b	FEDFUNDS and CPIAUCSL
R_t	One year constant maturity Treasury rate	GS1
EBP_t	Gilchrist-Zakrajšek Excess Bond Premium	Fed
$T10Y3M_t$	10-Yr – 3-Month Spread, Treasury	T10Y3M
MN factor 1_t	Macro Factor 1; See note a	MN
MN factor 2_t	Macro Factor 2; See note a	MN
ε_t^{TFP}	TFP Shock	Fernald (2014)

Table B2: Quarterly Data Used for TFP Shocks. Notes: a) We take factors from McCracken and Ng (2016), to be denoted MN. The interpretation of the two MN factors we use, discussed on their pages 577-8, is as follows: "activity, employment" for Macro Factor 1, and "term spreads, inventories" for Macro Factor 2. b) We compute the real rate as the log of the ratio of the gross Federal Funds Rate rate to the gross CPI rate of inflation.

B.4 Results for TFP Shocks First Differences Specifications

Figure B2 shows the IRFs to an expansionary TFP shock specified in Table 5 using first differences.

Figure B2

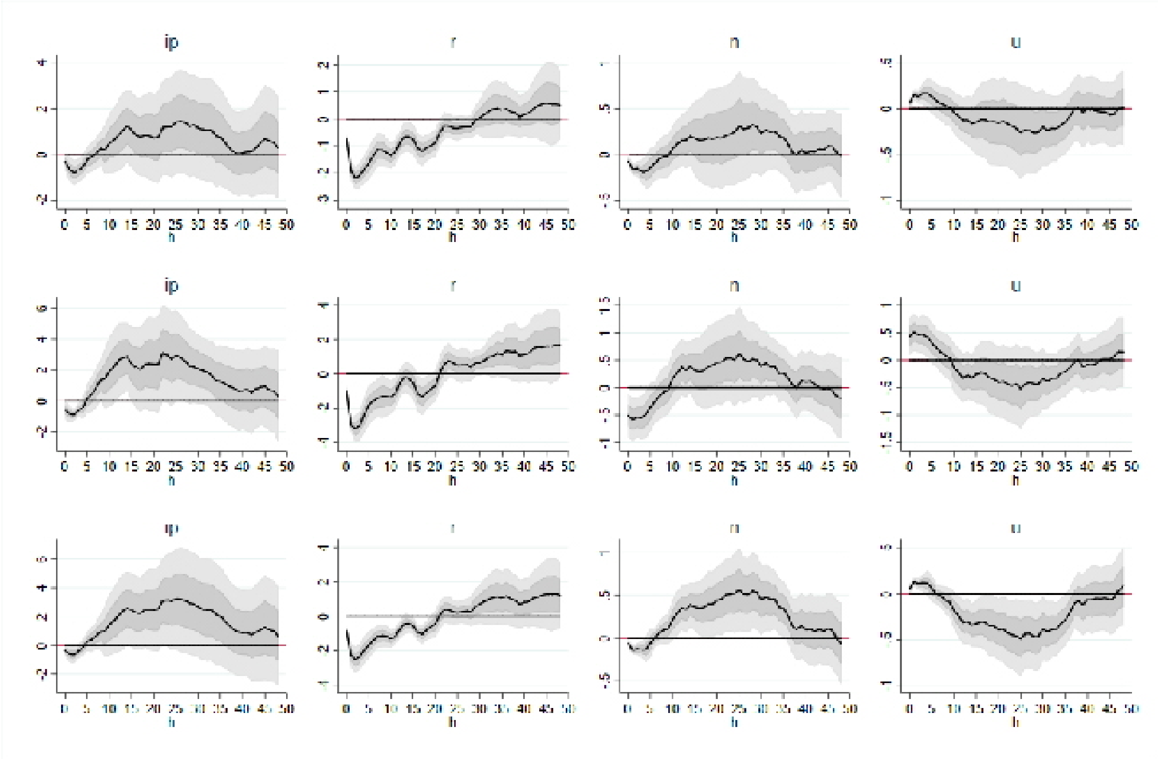

Figure B1: Impulse Reponse Functions to an Expansionary Monetary Policy Shock. Notes: a) The rows correspond to the three specifications of Table 4. b) First differencing of variables which are not rates are used throughout. c) F statistics (using HAC Newey-West standard errors, with bandwith parameter of 12) in the first stage (equation (39)) are for row 1, 119.4, for row 2, 35.1, and for row 3, 51.3.

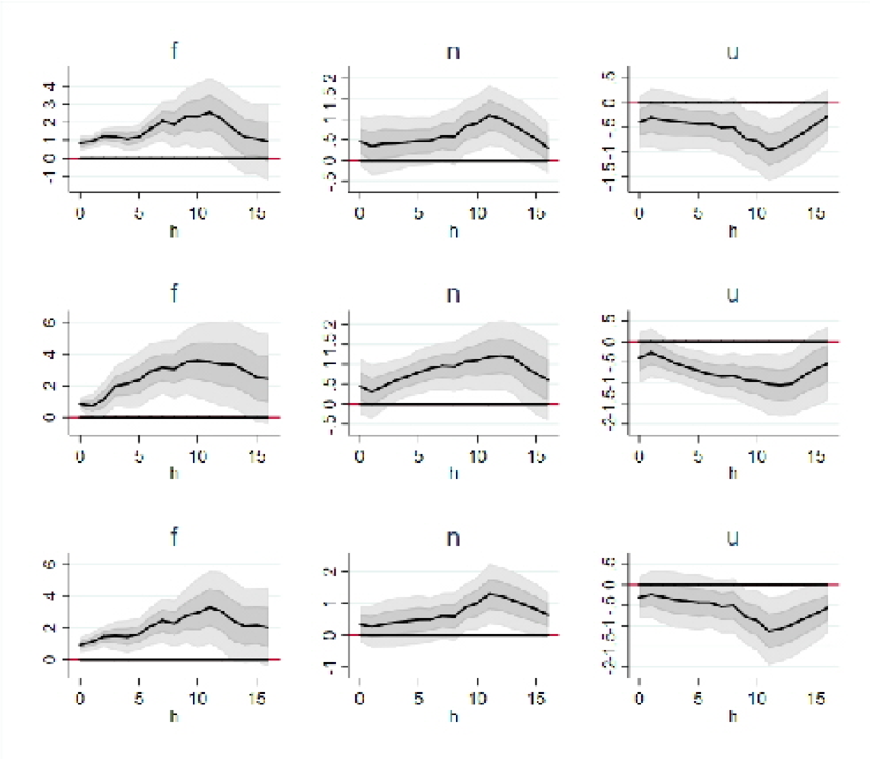

Figure B2: Impulse Reponse Functions to a Positive TFP Shock. Notes: a) The rows correspond to the three specifications of Table 5. b) First differencing of variables which are not rates are used throughout.