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The importance of hiring frictions in business cycles

Renato Faccini
Research Department, Danmarks Nationalbank and CFM(LSE)

Eran Yashiv
The Eitan Berglas School of Economics, Tel Aviv University, CFM(LSE), and CEPR

Hiring is a costly activity reflecting firms' investment in their workers. Microdata show that hiring costs involve production disruption. Thus, cyclical fluctuations in the value of output, induced by price frictions, have consequences for the optimal allocation of hiring activities. We outline a mechanism based on cyclical markup fluctuations, placing emphasis on hiring frictions interacting with price frictions. This mechanism generates strong propagation and amplification of all key macroeconomic variables in response to technology shocks and mutes the traditional transmission of monetary policy shocks. A local projection analysis of aggregate U.S. data shows that the empirical results, including the cyclicality of markups, are consistent with the model's impulse response functions.

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JEL classification. E22, E24, E32, E52.

1. Introduction

Hiring is a costly activity reflecting firms' investment in their workers. We use microdata to show that most of the costs of hiring are nonpecuniary, 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

Renato Faccini: rmmf@nationalbanken.dk
Eran Yashiv: yashiv@tauex.tau.ac.il

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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 markup, 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 aforecited 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 rises.

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 coauthors.[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 modeling 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 (2012); 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 similar empirical findings in the literature, which we review in Section 7. Our model provides a rationale for them.

Hence, the mechanism we propose explains some puzzling empirical results, particularly on monetary policy, while keeping the elements of price frictions and wage rigidity. Indeed these elements play important roles; it is the addition of hiring frictions that yields new results, due to the interaction or confluence of frictions. The empirical analysis also provides evidence for the mechanism, which operates through the cyclicality of the shadow value of output. Because the latter equals the inverse of the markup,

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

it can therefore be observed in the data. The model implies a positive comovement of markups, output and employment conditional on both technology and monetary policy shocks. We show that the empirical impulse responses are consistent with that.

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 of the Online Supplementary Material (Faccini and Yashiv (2022)) 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 modeling of hiring frictions is key for the mechanism, we start with a brief review of the different modeling 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 modeling 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, that is, 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 modeled 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.

2.1.1 *Pecuniary costs paid to other agents versus 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 U.S. 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 coworkers, 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.

2.1.2 *Cost of hires versus 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 modeled as a function of aggregate labor market conditions, that is, 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 modeled as a function of firm-level conditions, namely the ratio of new hires to the workforce of the firm, that is, the gross hiring rate (see, e.g., Yashiv (2000), Merz and Yashiv (2007), Gertler, Sala, and Trigari (2008), Gertler and Trigari (2009), Christiano, Trabandt, and Walentin (2011), Sala, Söderstrom, 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, Muehlemann, Schenker, and Wolterd (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 the Bayesian estimation of a DSGE model of Sweden, conclude that "employment adjustment costs are a function of hiring rates, not vacancy posting rates." Sala, Söderstrom, and Trigari (2013) estimate external and internal costs for a number of countries, usually finding that internal costs account for most of the costs of hiring.

2.1.3 *Functional form* Those cited papers, which have used structural estimation (Yashiv (2000, 2016, 2019), 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 modeled 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, e.g., Galí (2011)). Frictions in the labor market have been found to be important, but only *indirectly*. They create a match surplus, allowing for a 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 subsection, 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 decisions and their linkages to financial markets. See Cochrane (2005, Chapter 20) and Cochrane (2008) for overviews and discussions.

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 data sets, 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 nonpecuniary 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 firms, of which 42%, did not provide any relevant information since they did not recruit any worker in the last 3 years. We reduce the sample further by focusing on firms with at least five employees. This leaves us with a sample size of 1699 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 nonpecuniary, output costs in the panel below. The latter are reported in two categories: one is a category of unambiguous output costs; the second is an "ambiguous" category, where we put 24% of interview costs and the costs of reduced productivity, as explained below. Subsequently, we report an alternative breakdown, which distinguishes between the costs incurred before a match is formed (prematch) and after it is formed (postmatch). Finally, in the bottom panel, we report the relative importance of output versus pecuniary costs and post match versus prematch costs.

The first entry in the panel of pecuniary costs (row A) 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 (row B) 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 (row C) 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 1088 euros, which is about 50% of the monthly wage of a newly-hired skilled worker.

TABLE 1. Hiring costs decomposition in the German cross-section.

Pecuniary costs (Euros)	
A) Advertisement costs	368
B) External consultancy costs	373
C) Direct training costs	347
D) Total pecuniary cost (A + B + C)	1088
Output costs (Euros)	
E) Interview costs	295
F) Indirect training costs	231
G) Disruption costs: managers	1610
H) Disruption costs: skilled workers	1976
I) Disruption costs: unskilled workers	82
J) Total output costs (E + F + G + H + I + J)	4194
Ambiguous costs (Euros)	
K) Interview costs	93
L) Reduced productivity costs	1019
M) Total ambiguous (K + L)	1112
Prematch (external) versus post-match (internal) costs	
N) Prematch costs (A + B + E + K)	1129
O) Post-match costs (C + F + G + H + I + L)	5265
Relative importance of hiring costs (%)	
P) Share of output cost {(J/(D + J + M)), ((J + M)/(D + J + M))}	66%, 83%
Q) Share of post-match costs (O/(D + J + M))	82%

Moving to the list of output costs, the first entry (row E) 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 data sets contain heterogenous firms with various sizes of HR departments, including small firms, with few, if any, HR personnel. Interviews may be conducted by HR workers but also by "regular" non-HR workers. For the Swiss data, we have a breakdown of interview costs, which allows us to cap any HR interview costs at 24% of total interview costs. Hence, we place 24% of these costs in row K of the "ambiguous" category and 76% in row E. We are making here an implicit assumption, whereby workers are reallocated between interviewing and producing.

Row F relates to the fact that 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. Row

F measures this 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.[3]

The next three entries (rows G, H, and I) 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 finding of relatively large disruption costs for managers and skilled workers (rows G and H) are in line with the conclusion of the review of the hiring costs literature in Manning (2011) whereby (p. 982) "some general features do emerge... The bulk of these costs are the costs associated with training newly-hired workers and raising them to the productivity of an experienced worker." Cooper, Haltiwanger, and Willis (2015) also point to the importance of disruption costs in the empirical modelling of adjustment costs, concluding (p. 49) that "...the principle cost of labor adjustment is the disruption of the production process."

Row L in Table 1 measures the average productivity shortfall of newly hired workers, relative to their productivity at the end of the training.[4] The results indicate that total output costs, including ambiguous costs (summing up rows J and M) amount to 5306 euros, which is equivalent to around 2.5 months of the average wage of a newly hired worker. Omitting ambiguous costs (i.e., taking row J alone) output costs amount to 4194 euros, or about 2 months of the average wage of a newly hired worker. Overall, total hiring costs, pecuniary and output costs, are equal to 3 months of wages. Of this total, 83% are output costs and the remaining 17% are pecuniary; leaving out ambiguous costs, output costs are 66% of the total.

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 prematch and post-match turns out to be very similar to the decomposition of costs between pecuniary and output. Namely, 82% of costs are incurred after a match is formed, and 18% are incurred before the match is set up.

[3]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 $\bar{y}$ are defined in footnote 4 below. 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.

[4]The interpretation of these costs as output costs is consistent with our modeling, where the production function takes as input a measure N_t of employed workers, without explicitly making a distinction between newly hired and incumbents. The adjustment cost function $g(\frac{H_t}{N_t})$ captures all of the reasons why a firm produces less when hiring. A possible reason is that the newly hired are less productive.

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 $[1 - \frac{\bar{y}}{y_e}] * w_n * T$.

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. Focusing on those establishments that had recruited a positive number of new workers in the past 3 years reduces the sample size to 4265 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 2934 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 in the same way as above.[6] The results indicate that the shares of output costs and post-

TABLE 2. Hiring costs decomposition in the Swiss cross-section.

Pecuniary costs (Swiss francs)	
A) Advertisement costs	1340
B) External consultancy costs	1110
C) Direct training costs	618
D) Total pecuniary cost (A + B + C)	3068
Output costs (Swiss francs)	
E) Interview costs	1531
F) Indirect training costs	500
G) Disruption costs: managers	1964
H) Disruption costs: skilled workers	2697
I) Disruption costs: unskilled workers	135
J) Total output costs (E + F + G + H + I + J)	6827
Ambiguous costs (Swiss francs)	
K) Interview costs	484
L) Reduced productivity costs	3486
M) Total ambiguous (K + L)	3970
Pre-match (external) versus post-match (internal) costs (Swiss francs)	
N) Prematch costs (A + B + E + K)	4465
O) Post-match costs (C + F + G + H + I + L)	9400
Relative importance of hiring costs (%)	
P) Share of output cost {(J/(D + J + M)), ((J + M)/(D + J + M))}	49%, 78%
Q) Share of post-match costs (O/(D + J + M))	68%

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

[6]We note a few differences with respect to the German data set: 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 data sets, 69.1% and 70.5% out of the productivity of a skilled worker, respectively. We thus make the assumption that productivity at the end of the period has the same value in the two data sets. 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

match costs are slightly below the values obtained using German data, but the bottom line remains the same: a substantial fraction, if not most of the costs of hiring, are output costs, and are incurred after a match is formed.

3.3 *Implications for the modeling 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 modeling 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 margin.[8] The household enjoys utility from the aggregate consumption index C_t, reflecting the assumption of full-consumption sharing among the

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 Galí (2010)).

[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

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:

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

subject to the budget constraint (2), and the laws of motion for employment, in equation (3), and capital, in equation (1). The parameter $\beta \in (0,1)$ denotes the discount factor, φ is the inverse Frisch elasticity of labor supply, and χ is a scale parameter governing the disutility of work.[9]

margins of variation. For a data analysis of the connections between employment to employment flows and nominal wage growth, see Moscarini and Postel-Vinay (2017); for a theory of how on-the-job search affects real marginal costs (and inflation), see Moscarini and Postel-Vinay (2019).

[9]Preferences should not be interpreted as specified on the intensive margin, but rather on the extensive margin, akin to the modeling in Galí (2011). This means that $-\chi N_{t+j}^{\varphi}$ should be interpreted as the marginal disutility to the household of having one more worker employed. Thus, the model we define as New Classical (NC), differs from the traditional NC benchmark insofar as we interpret the disutility of labor supply to be specified on the extensive, rather than intensive, margin.

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

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

an equation characterizing optimal investment decisions:

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

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 reemployment value for unemployed workers,[10] 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.[11]

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 $\frac{\zeta}{2}(\frac{P_{t+s,i}}{P_{t+s-1,i}} - 1)^2 Y_{t+s}$, where ζ is a parameter that governs the degree of price rigidity, and Y_t denotes aggregate output. The latter

[10] 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_t. The term $1 - x_t$ at the denominator is a rescaling coming from the relation between beginning- and end-of-period unemployment $U_{0,t} = \frac{U_t}{1 - x_t}$.

[11] Assuming constant unemployment benefits, instead of a time-varying opportunity cost of work, preserves the qualitative features discussed here and would amplify the response of unemployment to technology shocks. The reason is that a procyclical cost of work reduces the procyclicality of profits, thus dampening labor market fluctuations.

is produced by final good firms as a bundle of all the intermediate goods in the economy, and is sold to the households in perfect competition. Specifically, this aggregate output good, which is used for consumption and investment, is a Dixit–Stiglitz aggregator of all the differentiated goods produced in the economy, $Y_t = (\int_0^1 Y_{t,i}{}^{(\epsilon-1)/\epsilon} di)^{\epsilon/(\epsilon-1)}$, where ϵ denotes the elasticity of substitution across goods. The price index associated with this composite output good is $P_t = (\int_0^1 P_{t,i}{}^{1-\epsilon} di)^{1/(1-\epsilon)}$, 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

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

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 $\ln A_t = \rho_a \ln A_{t-1} + e_t^a$, with $e_t^a \sim N(0, \sigma_a)$.

The term $\tilde{g}_{t,i}$ denotes the fraction of output that is lost due to hiring activities. Hiring costs are therefore modeled 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 modeling 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, Söderstrom, and Trigari (2013), and Furlanetto and Groshenny (2016) and goes back in spirit to Lucas and Prescott (1971). All of these studies assume that these costs are a quadratic function of the hiring rate, that is, 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.[12]

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

[12]We could have alternatively assumed a production function given by $f_{i,t} = a_t[N_{i,t} - g(\frac{H_{i,t}}{N_{i,t}})]^{\alpha} K_{i,t}^{1-\alpha}$, 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 equation (9) so as to minimize deviations from the literature.

aggregate cost function is given by $c(\frac{h}{n})f$. 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:

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

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:

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

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:

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

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.[13]

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

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

$$Q^N_t = \Psi_t g_{H,t}, \tag{16}$$

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

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

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 $\Psi_t(f_{N,t} - g_{N,t})$ 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 $\Psi_t(f_{K,t} - g_{K,t})$.

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, Söderstrom, and Trigari (2013), Furlanetto and Groshenny (2016), and Christiano, Eichenbaum, and Trabandt (2016).[14]

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:[15]

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

[14]This assumption is typically made for modeling convenience; however, if a part of these costs are non sunk, then they would show up as lower starting wages, reducing amplification in these models and in ours.

[15]We have solved a version of the model that allows for intrafirm bargaining as in Brügemann, 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:

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

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, that is, $\pi_t = \frac{P_t - P_{t-1}}{P_t}$, 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 nonstochastic 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

TABLE 3. Calibrated parameters and steady-state values, baseline model.

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	0.44
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/ net output	$g/(f-g)$	0.013
Marginal hiring cost/ net output per worker	$g_H/[(f-g)/N]$	0.20
Marginal hiring cost/ wage	$\Psi g_H/(\frac{W}{P})$	0.30
Average hiring cost/wage	$\frac{g}{H}\Psi/(\frac{W}{P})$	0.17
Opportunity cost of work/ marginal revenue prod.	$\frac{\chi C N^\varphi}{mc(f_N-g_N)}$	0.70
Unemployment rate	u	0.111

time equals one quarter. We start by discussing the parameter values that affect the stationary equilibrium. The values are shown in Table 3.

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 U.S. 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, Guren, Manoli, and Weber (2013), pointing to Frisch elasticities around 0.25 on the extensive margin.[16] The elasticity of substitution in demand ϵ is set to the conventional value of 11, implying a steady-state markup of 10%, consistent with estimates presented in Burnside (1996) and Basu and Fernald (1997). Finally, the scale parameter χ in the utility function is normalized to equal 1 and the elasticity of

[16]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. Selecting a different, but reasonable, value of φ, leaving all other parameters unchanged, does not change the implications of our model in any meaningful way. Rerunning our model with new values reveals that increasing hiring frictions in the New Keynesian model continues to reverse the sign of the response of hiring to both technology and monetary shocks.

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 11.1%. The unemployment rate in our model includes the officially unemployed, as well as workers out of the labor force but available for work, beyond the latter pool. We rely on Cairó, Fujita, and Morales-Jiménez (2022), who use the Current Population Survey (CPS) matched records between 1976Q1 and 2016Q4 to compute transition rates between the states of employment (E), unemployment (U), and out of the labor force (N). They subsequently use these rates within a model of labor market dynamics and report the ensuing steady state values. From their Table 3 and its discussion, we deduce the relevant rate, namely available workers without a job as a fraction of an expanded pool of the Labor Force. This rate is 11.1%.[17] We also note that the calibration implies a ratio of the opportunity cost of work to the marginal revenue product of labor of 0.70, 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.[18,19]

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).

[17] Cairó, Fujita, and Morales-Jiménez (2022) estimate the following pools of workers in steady state: $N_t = 0.037$, the relevant part of the "out of the labor force" pool; $U_t = 0.04$, the official pool of unemployment; and $E_t = 0.613$, employment, all expressed as a fraction of the population. Hence, the relevant rate for our unemployment measure is given by $\frac{N_t+U_t}{N_t+U_t+E_t} = 0.111$.

[18] This estimate of training costs is somewhat lower than the one we obtained using Swiss and German data in Section 3. These surveys were used to disentangle the relative importance of pecuniary and non pecuniary costs and inform the modeling. Because we calibrate the model to the U.S., we make use of the survey by Silva and Toledo for the precise estimate of hiring costs. In the analysis below, we look at a wide range of values.

[19] 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. It follows that total costs of hiring are not much higher than training costs alone.

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 (2011) calibration.[20] 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.

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. Hence, each figure has one horizontal axis showing values of ζ, one horizontal axis showing values of e, and a vertical axis showing the response upon impact.

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

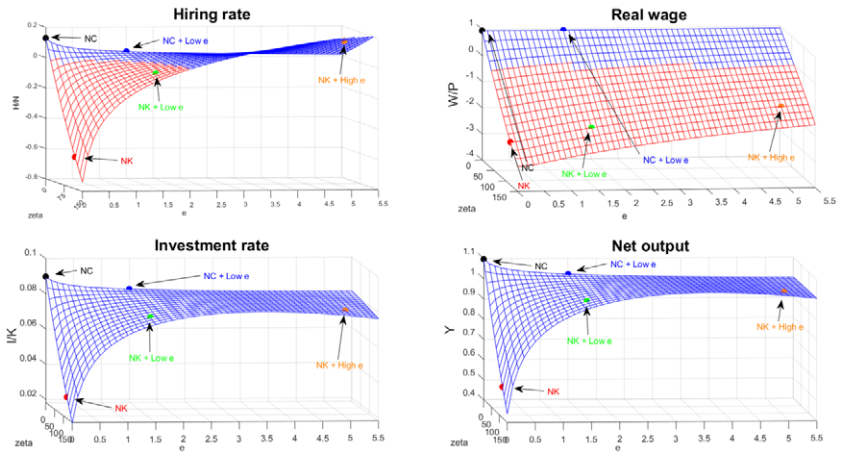


FIGURE 1. Impulse responses on impact of a positive technology shock. *Note*: The figure shows impulse responses on the impact of a 1% expansionary technology shock for various parameterizations of the model where we allow price rigidities, ζ, and hiring frictions, e, to vary. Output and the real wage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

[20] 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 Galí (2011) assumes Calvo pricing frictions, with $\theta_p = 0.75$, we adopt Rotemberg pricing frictions, which implies that in our specification prices are effectively reset every quarter.

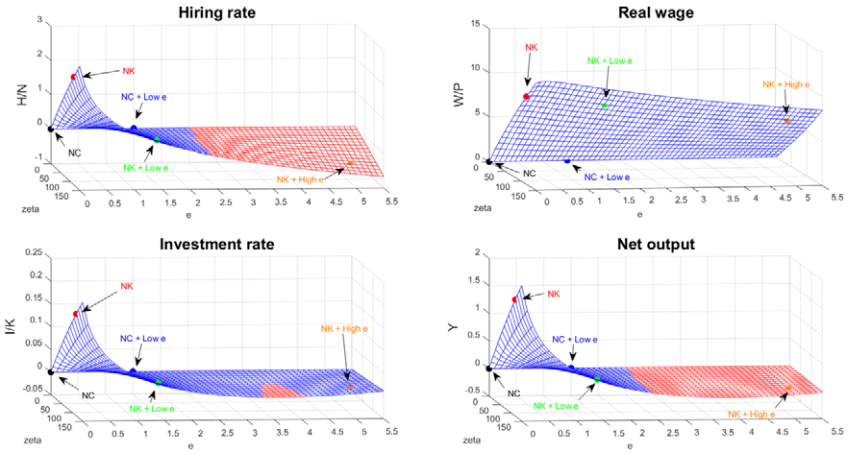


FIGURE 2. Impulse responses on impact of an expansionary monetary policy shock. *Note*: The figure shows impulse responses on the impact of a 25-basis point expansionary interest rate shock for various parameterizations of the model where we allow price rigidities, ζ, and hiring frictions, e, to vary. The real wage and output are expressed in percent deviations from steady state, hiring and investment rates in percentage points deviations.

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 7 weeks of wages, somewhat above the estimate implied by the evidence in Silva and Toledo (2009) for the U.S. economy. 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.[21]

For expositional convenience, we mark 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 $e \simeq 0$; (ii) the NC model with hiring costs; this is obtained by setting a level of price frictions close to zero, that is, $\zeta \simeq 0$, while maintaining hiring frictions as in the baseline calibration; (iii) the standard NK model obtained by maintaining a high degree of price frictions, that is, $\zeta = 120$, but setting hiring costs close to zero, that is, $e \simeq 0$ (NK point); (iv) the NK model embodying price frictions together with hiring frictions as calibrated in Table 3 (NK + low e); (v) finally, a NK model with a higher scale of hiring frictions, corresponding to the estimate in Silva and Toledo (2009), $e = 5$ and $\zeta = 120$(NK + high e).[22]

[21]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).

[22]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.

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."

5.2.1 *Technology shocks* To see the mechanism, it is useful to go through the five model variants reference points. Starting from the NC case, 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 Figure 1). Adding hiring frictions to this frictionless benchmark, results in relatively small changes, which reflect the moderate size of hiring frictions. The responses appear somewhat smoothed by the presence of hiring frictions, recovering the conclusions of DMP-based analyses that hiring frictions operate as an adjustment cost, thereby exacerbating the difficulties of the standard NC model to account for the cyclical behavior of the labor market.

Adding price frictions to the NC model, 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 and output increase less relative to the case with no price rigidities. 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 for employment to fall.

Adding hiring frictions to the NK model, that is, moving from the NK 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 NK+low e 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 (NK+high e 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:

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

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 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

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

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 (NK 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 (NK+low e 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 (NK+high e 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 versus external costs, and on pecuniary versus output costs, and show how the mechanism presented here is affected by changing the hiring costs formulations.

5.2.2 *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. In the NK benchmark instead, 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, the effects of monetary shocks are small (low e, NK+low e point). For higher, but still reasonable levels of hiring frictions (NK+high e 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.[23]

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. So for in-

[23]These results are reminiscent 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 signaling device, hindering the transmission of the shocks to real variables.

stance, in the case of relatively high price and hiring frictions, an expansionary monetary policy shock leads to a contraction of output and employment only on impact. One may wonder whether the mechanism can propagate beyond the quarter of impact and whether the results are robust to the inclusion of a richer set of assumptions, embracing for instance the conventional modeling of a matching function and of vacancy posting costs. 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 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 the key new elements of the model and the key results; full elaboration (the whole model, calibration, and some more impulse responses) is given in Appendix A of the Online Supplementary Material (Faccini and Yashiv (2021)). We then discuss four issues: the role of external labor market conditions; the role of pecuniary costs; the role of wage rigidity; 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:

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

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:

$$\max_{\{P_{t+s,i}, H_{t+s,i}, K_{t+s,i}\}} E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left\{ \frac{P_{t+s,i}}{P_{t+s}} Y_{t+s,i} - \frac{W_{t+s,i}}{P_{t+s}} N_{t+s,i} - \frac{X_{t+s}^K}{P_{t+s}} K_{t+s,i} \right. \tag{28}$$

$$-\frac{\zeta}{2}\left(\frac{P_{t+s,i}}{(1+\pi_{t+s-1})^{\psi}(1+\bar{\pi})^{1-\psi}P_{t+s-1,i}}-1\right)^{2}Y_{t+s}\Bigg\},$$

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:

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

where $V_{t,i}$ denotes vacancies. To ensure comparability with a literature that has modeled hiring costs predominantly as vacancy posting costs, we follow Sala, Söderstrom, 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:

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

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

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

which yields

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

6.2 *Results: 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 (delineated in Appendix A of the Online Supplementary Material, Table AI). 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).

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

Figure 3 shows that the response of employment in the relatively low calibration of the scale of hiring costs remains negative, as in the standard NK model. Under the relatively higher friction parameterization ($e = 5$) 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 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 markup, is a dominant dynamic in our mechanism.

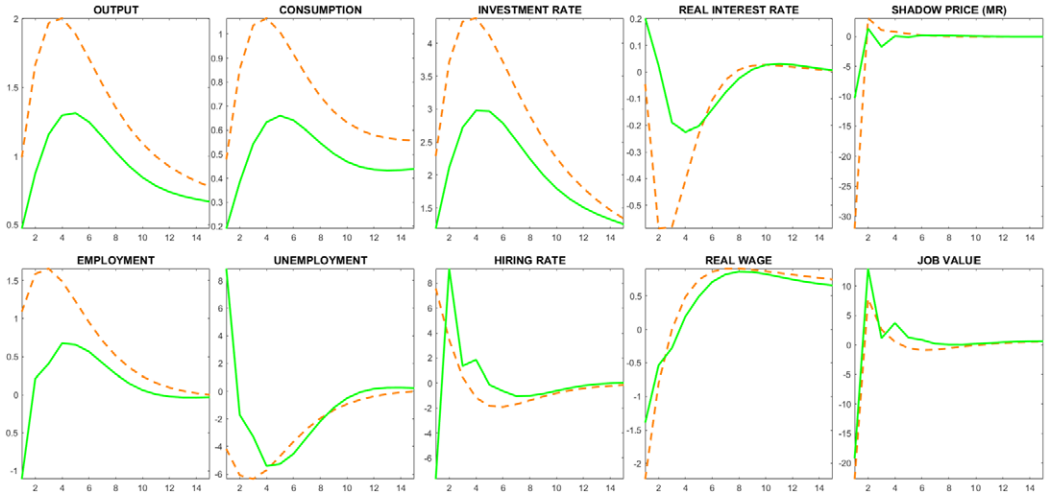


FIGURE 3. Impulse responses to a positive technology shock: extended model with "low" versus "high" scale of hiring costs. *Note*: Impulse responses to a 1% positive technology shock obtained for two different parameterizations: "high" hiring costs (dashed line; $e = 5$) and "low" costs (solid line; $e = 1.2$). All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations. Output is specified net of hiring costs.

The mechanism inherent in Figure 3 is as follows. The positive technology shock, under conventional price rigidity, generates a fall in the marginal cost, and hence an increase in the markup. The ensuing decline in hiring costs, $\Psi_t g_{H,t}$, 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 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.[24]

A complementary and insightful approach to identify and visualize the effect of the interaction between price frictions and hiring frictions is to show how price frictions affect the transmission of technology shocks in a model with hiring frictions. The natural focus, in this context, is on the behavior of unemployment. We do so in Figure 4, where we compare the impulse responses obtained under the same "high" hiring friction case

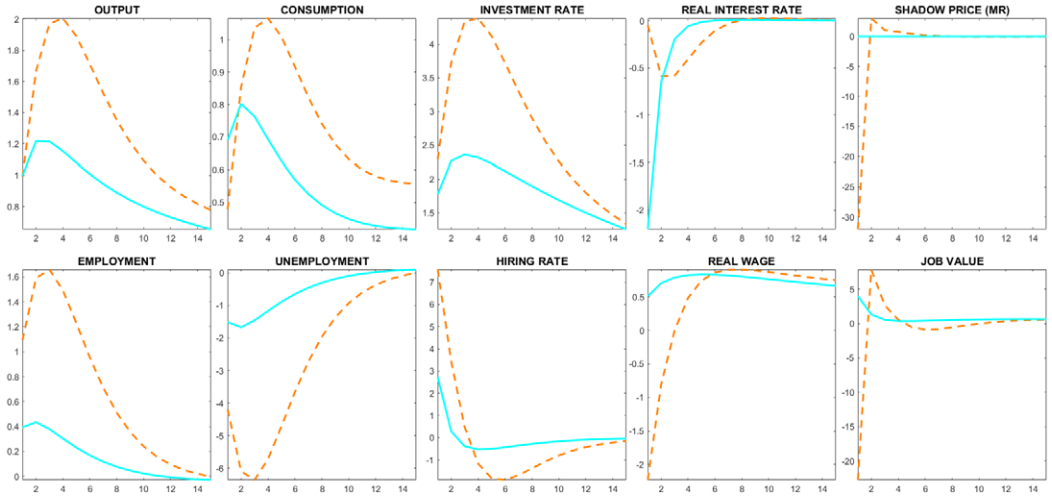


FIGURE 4. Impulse responses to a positive technology shock: extended model with rigid versus flexible prices. *Note*: Impulse responses to a 1 percent positive technology shock obtained for two different parameterizations: The rigid price model with hiring costs (NK+L Frictions, dashed line; $\zeta = 120$ and $e = 5$) and the flexible price model with hiring costs. All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations. Output is specified net of hiring costs.

[24]The fall in real wages on the impact of the shock is not an essential feature of the model but depends on the parameterization. Faccini and Melosi (2022) present an estimated version of this model that preserves the propagation mechanism explored here, and get that real wages are procyclical conditional on technology shocks.

reported in Figure 4 (traced out by the dashed lines), with the otherwise identical model where we shut down price frictions, that is, we set $\zeta \simeq 0$.

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

6.2.2 *Monetary policy shocks* Figure 5 reports impulse responses for an expansionary monetary policy shock obtained under the same "low" and "high" parameterizations of friction costs.

The impulse response analysis reveals that at the lower level of friction costs (solid 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 (dashed line), monetary policy shocks still produce real effects, but in the opposite direction. Again a key role is played by the response of the shadow price Ψ_t as shown in the top row of Figure 5, an effect which strengthens as e rises.

These results are consistent with those that were obtained with the simple model of Section 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 dashed line, which corresponds to the survey evidence of hiring costs reported in Silva and Toledo (2009), is a perfectly reasonable parameterization, and is labeled in Figures 3 and 5 as "high" friction cost purely for comparative reasons. So, the bottom line of the analysis presented in this 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 useful feature of the shadow value Ψ_t is that it is the inverse of markups, and hence is observable in the data. In Section 7, we will provide evidence in favor of the mechanism, by showing that the conditional empirical responses of markups and other key macroeconomic aggregates are in line with the model.

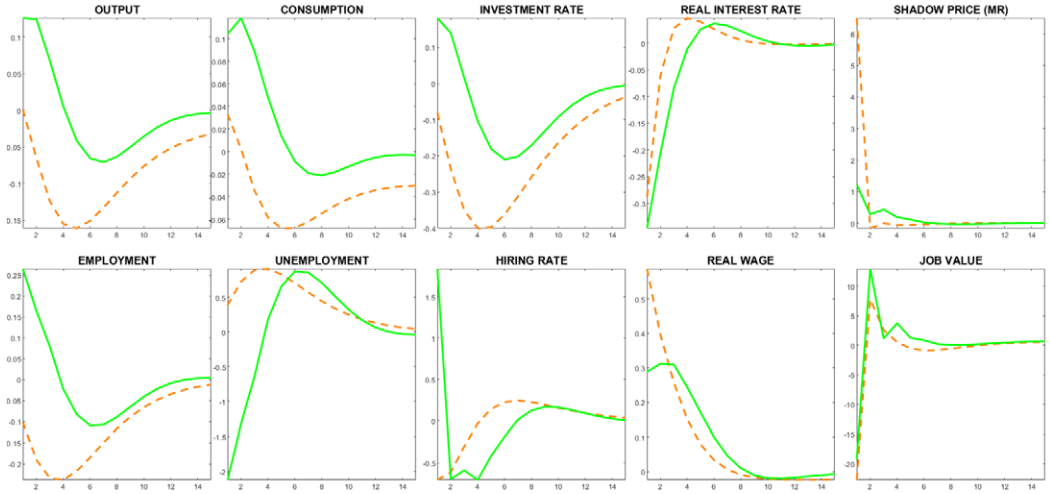


FIGURE 5. Impulse responses to an expansionary monetary policy shock: extended model with "low" versus "high" scale of hiring costs. *Note*: Impulse responses to a 25 basis point expansionary monetary policy shock obtained for two different parameterizations: "high" hiring costs (dashed line; $e = 5$) and "low" costs (solid line; $e = 1.2$). All variables are expressed in percent deviations, except hiring, investment, and real rates, which are expressed in percentage points deviations. Output is specified net of hiring costs.

6.3 *Variations on the extended model*

We use this enlarged framework to examine important variations. The discussion below is based on the results of the extended model, fully elaborated in Appendix A of the Online Supplementary Material.

6.3.1 *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.[25] 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, that is, 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.

6.3.2 *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), that is, 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, that is, 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.

6.3.3 *The role of wage rigidity* The parameter governing wage inertia, ω, is set to equal 0.87 in order to match the autocorrelation of real wages in the U.S. data. There is a burgeoning literature investigating whether the appropriate target for wage cyclicality should include all workers, or only the newly hired. Gertler, Huckfeldt, and Trigari (2020) revisit the seemingly contradictory findings of low cyclicality of aggregate wages and high cyclicality of wages of new hires. They use a unique data set—rich, high-frequency panel data from the Survey of Income and Program Participation (SIPP). This data set allows to separately estimate the wage cyclicality of new hires from unemployment versus that of workers making job-to-job transitions. They find that there is substantial

[25]Indeed, we cannot compare impulse responses for the case of high frictions in the models with pecuniary and output hiring costs, since in the former model the conditions for determinacy are not satisfied. Indeed, with pecuniary costs indeterminacy starts to arise even for moderate values of e.

cyclical variation in wages due to workers moving to better job matches during expansions. After controlling for these composition effects, that is, procyclical upgrading of job match quality, the wages of new hires are no more cyclical than those of existing workers. Hence, they conclude that the sluggish behavior of wages for existing workers is a better guide to the cyclicality of wages than is the high measured cyclicality of new hires wages unadjusted for composition effects.

We note that the mechanism studied in this paper, whereby increasing hiring frictions in a New Keynesian model reverses the responses of hiring and employment to technology and monetary policy shocks, is at work both under flexible wages (Figures 1 and 2) and wage rigidity (Figures 3 and 5). The role of wage rigidity, in the extended model, is to increase propagation in the responses to both technology and monetary policy shocks. This is shown in the Appendix of the Online Supplementary Material of the paper, Figures A3 and A4, where we compare IRFs to technology and monetary policy shocks obtained under high wage rigidity (inertia parameter $\omega = 0.87$), and low wage rigidity ($\omega = 0.10$).

6.3.4 *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 7 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 1 and 2 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 implement a local projections (LP) methodology to generate data-based IRFs, using technology and monetary policy shocks. We then compare these data-based results to the predictions of the model discussed above. The methodology and data used are elaborated in Appendix B of the Online Supplementary Material.

We are thus able to show the data behavior of key variables in our model in response to shocks, including output (f_t), labor market quantities (employment (n_t) and unemployment (u_t)), and markups ($\frac{1}{\Psi_t}$), which play an important role in our mechanism. Note that in what follows we present IRF plots of these variables, whereby the markup $\frac{1}{\Psi_t}$ is the inverse of the shadow value Ψ_t. The IRFs of the latter are shown in Figures 3–5 above.

In what follows, we specify the predicted variables (s_{t+h}), the shocks series used (ε_t), and the controls ($\mathbf{X}_t$). For the markup, we use a series computed by Nekarda and Ramey (2020) based on a Cobb–Douglas production function, consistent with our model's formulation. This is the inverse of the labor share based on labor compensation, to be denoted lmu-CD. Detrending is done by (i) using a fourth-order polynomial trend function or (ii) working with log first differences. We compute Newey–West HAC standard errors.

7.1 *Monetary policy shocks*

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

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

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

$$R_t = a + bZ_t + \mathbf{c}' \mathbf{X}_t + v_t. \tag{38}$$

In this equation a is a constant, R_t is the rate on the 1-year constant-maturity Treasury, Z_t is the instrument, which is the monetary policy shock $\varepsilon_t^{\text{MP}}$, there is an error term v_t, and b and 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 $\varepsilon_t^{\text{MP}}$.

We run equations (37)–(38); the instrument Z_t is the monetary policy shock following Romer and Romer (2004). This shock series is widely used (see, e.g., the extensive discussion in Ramey (2016)). Using an updated data series for the period 1969Q1–2007Q4, computed by Wieland and Yang (2020), we have almost four decades of observations.[26]

In terms of control variables ($\mathbf{X}_t$), we present two specifications in the main text and six more, for robustness, in Appendix B of the Online Supplementary Material. Table 4 delineates the controls, presenting the two alternative specifications. Both rows use two lags of each control.

TABLE 4. Control variables in monetary policy shock projections.

1	$\varepsilon_{t-j}^{\text{MP}}$, f_{t-j}, CPI_{t-j}, FFR_{t-j}
2	controls in (1) + R_{t-j}, EBP_{t-j}, MN factor2$_{t-j}$, mark − up$_{t-j}$, SW factors$_{t-j}$; see note (b)

Note: (a) Time index j=1,2; (b) See Appendix B of the Online Supplementary Material for presentation of the factors.

[26]When using the control variable EBP_t the sample is limited to start in 1973Q1. Having to use quarterly markup series, we work at the quarterly frequency. We note that comparing impulse responses for expansionary monetary policy shocks across subsamples, produces different results, with the fall in employment and GDP and the increase in unemployment being far more persistent in the post-1997 period.

Specification 1 is a parsimonious one and includes a minimal set of controls—the shock itself ($\varepsilon_t^{\text{MP}}$), GDP ($f$), the CPI, and the Fed Funds Rate (FFR). These variables are the key ones needed to control for when looking at monetary policy. Specification 2 is an expanded "maximal" set, adding to the first specification the markup itself, credit and bond markets variables (the 1-year treasury rate (R) and the excess bond premium (EBP) computed by Gilchrist and Zakrajšek (2012)), a factor capturing term spreads, computed by McCracken and Ng (2016) in their analysis of FRED data (denoted MN2), and four factors computed from FRED data by Stock and Watson (2018).[27] Appendix B of the Online Supplementary Material offers details and presents variations on this vector of controls, including intermediate cases between these two extreme specifications.

In all cases, we run the IRFs of the following variables, in response to the monetary policy shock:

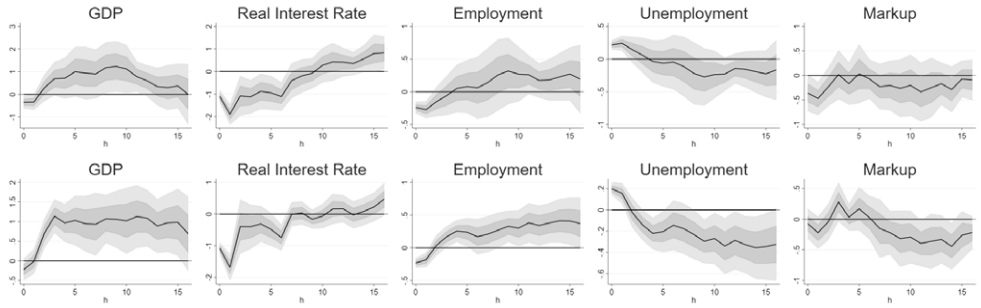
$$s_{t+h} \in \{f_{t+h}, n_{t+h}, u_{t+h}, r_{t+h}, \text{mark} - \text{up}_{t+h}\}. \tag{39}$$

Figure 6 reports these specifications using a fourth-order polynomial trend function and first differences, showing that the precise method of detrending does not matter for the results. We report the estimates of the IRFs of GDP, employment, unemployment, the real rate of interest, and the markup with 68% and 95% confidence bands. All of 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.

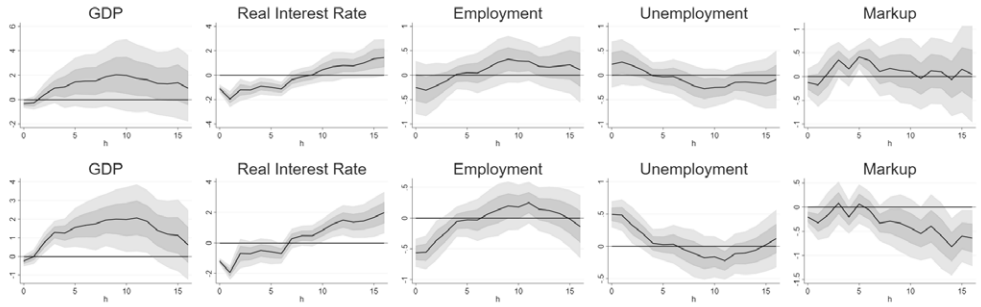
While there are variations in the results across control variables in the various specifications of Figure 6 and of Figure B-1 in Appendix B of the Online Supplementary Material, they convey the same general pattern: a monetary expansion leads initially to a lower real interest rate, lower markup, lower employment and output, and higher unemployment. Subsequently, the effect turns expansionary. Essentially, these local projections IRFs of the data accord with an intermediate case of the model IRFs shown in Figure 5 above (i.e., lie between the solid and the dashed lines). Ramey (2016) gets similar results. In her review of the literature, she discusses the problematics associated with the sign and time pattern of the effects of monetary policy shocks (pp. 91–111). A key issue at the heart of her discussion is the role played by the "recursiveness assumption" in VARs, used by many authors, whereby output and prices are unaffected by the monetary policy shock or the monetary aggregates within the period. Thus output and prices are not allowed to respond to changes in the federal funds rate within the period. She notes that this assumption is at odds with some estimated New Keynesian DSGE models. When she runs monetary policy shocks using Local Projections with the Jorda methodology, relaxing the contentious assumption in question, she obtains the result that contractionary monetary policy shocks have significant expansionary effects. These results are plotted in Figure 2B on page 104.

Ramey (2016) subsequently gets similar results using a proxy SVAR methodology (see her Figure 2C on p. 105). Our model can rationalize these findings, and our Local Projections results in Figure 6 confirm them.

[27] Essentially principal components (factors) computed from a large set of macro variables. See Stock and Watson (2018, p. 942).



a. Fourth-order time trend specifications



b. First difference specifications

FIGURE 6. Impulse response functions to an expansionary monetary policy shock. *Note*: (a) The rows correspond to the two specifications of Table 4. (b) In panel a, we use a fourth-order polynomial time trend and in panel b first differences. (c) F statistics (using HAC Newey–West standard errors, with bandwidth parameter of 12) in the first stage (equation (39)) are for panel a, 110.4 and 155.2; and for panel b, 75.1 and 132.

7.2 *Technology shocks*

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

$$s_{t+h} = c_h^s + \lambda_h^s \varepsilon_t^{\text{TFP}} + \Gamma_h^{s'} \mathbf{X}_t + e_{t+h}^s \tag{40}$$

In terms of control variables ($\mathbf{X}_t$), we present two specifications in the main text and six more, for robustness, in Appendix B of the Online Supplementary Material. Table 5 sums up the controls, presenting the two alternative specifications. All rows use two lags of each control.

We use TFP shocks computed by John Fernald (see Fernald (2012)) for the period 1969Q1–2016Q4. Specification 1 is a parsimonious, minimal one and includes as con-

TABLE 5. Control variables in TFP shock projections.

1	$\varepsilon_{t-j}^{\text{TFP}}$, f_{t-j}, MN factor1$_{t-j}$
2	controls in (1) + mark − up$_{t-j}$, ln R&D$_{t-j}$, LFPR$_{t-j}$, femaleLFPR$_{t-j}$, 55 + LFPR$_{t-j}$, R_{t-j}, r_{t-j}

Note: Time index $j = 1, 2$.

trols the shock itself ($\varepsilon_t^{\text{TFP}}$), GDP ($f$), and a factor capturing real activity, computed by McCracken and Ng (2016) in their analysis of FRED data, to be denoted MN1. Specification 2 is an expanded "maximal" set, adding to the first specification the markup itself, variables that may affect TFP (R&D and labor force participation rates (total, of women, and of workers aged above 55)), and bond markets variables (the 1-year treasury rate (R) and the real rate (r)). Appendix B of the Online Supplementary Material offers details and presents variations on this vector of controls.

Figure 7 reports these specifications using a fourth-order polynomial trend function and first differences. We report the estimates of the IRFs of GDP, employment, unemployment, and the markup with 68% and 95% confidence bands. Our theoretical model predicts that, in the presence of a reasonable amount of hiring frictions, an expansionary TFP shock will lead to a higher markup, higher employment and output and lower unemployment, despite the presence of price rigidities. Figure 7 and Figure B-2 in Appendix B of the Online Supplementary Material bear out these predictions.

How do our findings compare to the literature? About two decades ago, there was a (fierce) debate on the effects of technology shocks on employment. In her review, Ramey (2016) discusses it and developments since then (see pp. 136–141 and the results from sixteen studies in Tables 8 and 9 in her paper). The debate pertained to identification assumptions and concerned alternative measures for employment and for technology shocks. Our model predictions, shown in Figure 3, fit the standard New Keynesian results when using a relatively low e value and fit New Classical type of results when using a relatively high e value. The discussion in Section 5.2 above explains the mechanism involved, describing the conditions whereby each case would hold true. Note that both kinds of results are to be found in the empirical literature. Our LP analysis of U.S. data, reported in Figure 7, fits the higher e specification, and thus accords with some studies in this empirical literature, like Christiano, Eichenbaum, and Vigfusson (2003) and Mertens and Ravn (2011).

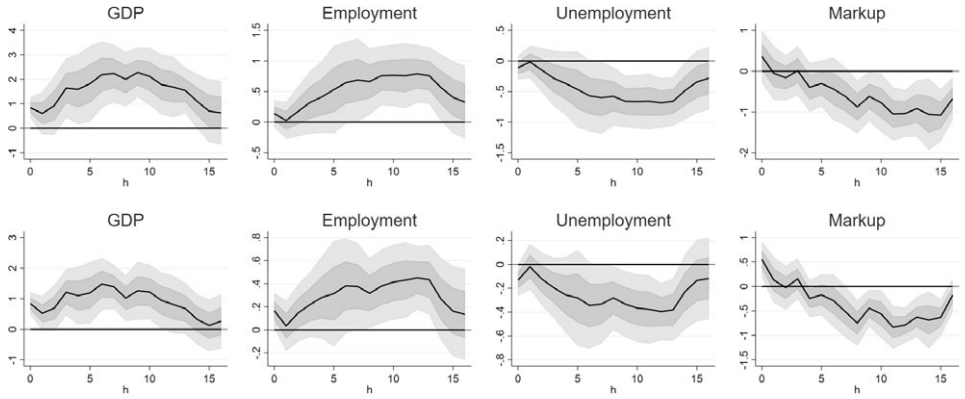
7.3 *LP versus SVAR estimates*

Note that Figures 6 and 7 of the Local Projection (LP) results make use of a markup series computed by Nekarda and Ramey (2020) based on a Cobb–Douglas production function specification (see their discussion on pp. 327–329). The figures report results that are consistent with our model predictions.

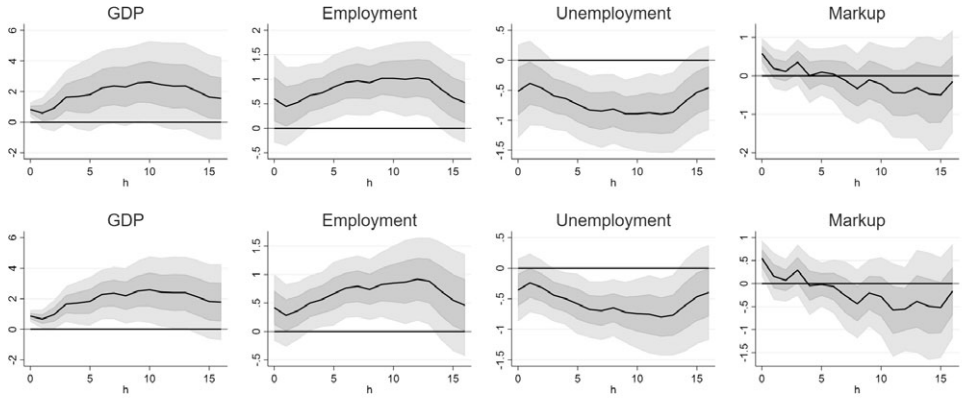
Comparing our model results to the findings of Nekarda and Ramey (2020), who use a SVAR formulation (discussed on pp. 340–345 and shown in Figures 5(a) and 5(c) and in Table 2 of their paper), we get the following:

(i) Our results for the relatively high hiring costs case (high e) indicate procyclical markups for both TFP and monetary policy shocks, as these authors also find.

(ii) They show that monetary policy shocks are initially contractionary when markups are based on the afore-mentioned Cobb–Douglas specification, as our high e formulation also implies. Similar results are presented by Ramey (2016), who notes that, without the assumption in VARs, whereby prices and output cannot



a. Fourth-order time trend specifications



b. First difference specifications

FIGURE 7. Impulse response functions to a positive TFP shock. *Note*: (a) The rows correspond to the two specifications of Table 5. (b) In panel a, we use a fourth-order polynomial time trend and in panel b first differences.

respond to the interest rate contemporaneously, this is the result in IRF analysis. We note that our model rationalizes these findings, and the empirical evidence for them is shown in our Figure 6.

(iii) Turning to the low e results, our model's NK case, we get procyclical markups for TFP shocks as Nekarda and Ramey (2020) do, and moderately countercyclical markups with output expansion for monetary policy shocks. As seen in their Figure 5(a), the latter findings accord with the standard NK view, but not with their own findings.

(iv) It should be noted that both our LP analysis and the SVAR analysis of Nekarda and Ramey (2020) are conditioned on control variables, and so there may arise some differences even when using the very same markup series.

8. Conclusions

We have provided microeconomic evidence whereby 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 microdata 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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