Hours and Employment Over the Business Cycle*

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September 12, 2016

Abstract

We show that an estimated business cycle model with benchmark search-and-matching frictions and a neoclassical hours-supply decision cannot account for the cyclical behavior of U.S. hours and employment and their comovement with macroeconomic variables. A parsimonious set of features reconciles the model with the data: non-separable preferences with parametrized wealth effects and costly hours adjustment. The model, estimated with Bayesian methods, offers a structural explanation for the observation that in post-war U.S. recoveries, the covariance between the labor margins is either positive or negative. The contribution of hours per worker to employment and GDP is quantitatively significant, with hours adjustment either enhancing or offsetting employment recoveries.

JEL Codes: C11, E24, E32.

Keywords: Bayesian Estimation, Hours per Worker, Employment.

*First Version: February 15, 2016. For helpful comments, we thank Alejandro Justiniano, Evi Pappa, Federico Ravenna, Morten Ravn, Luca Sala, as well as seminar and conference participants at the 2016 International Association for Applied Econometrics Conference, the EEA-ESEM 2016 Conference, the Kiel Institute for the World Economy, the New York Fed "New Developments in the Macroeconomics of Labor Markets" Conference, and the Saint Louis Federal Reserve.

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1 Introduction

A vast literature addresses the cyclical behavior of the labor market in the context of the Mortensen-Pissarides search and matching model (Mortensen and Pissarides, 1994, and Pissarides, 2000), arguably the benchmark theory of equilibrium unemployment today.[1] Nevertheless, the majority of this literature ignores the distinction between changes in average hours per worker (the intensive margin) versus movements in and out of employment (the extensive margin).[2] Omitting the compositional adjustment of total hours worked is not without loss of generality. Changes in hours per worker are about as large as changes in employment in many OECD countries (Ohanian and Raffo, 2012). In the U.S., the volatility of the intensive margin accounts for approximately one-third of the variability of aggregate hours. Moreover, in specific U.S. business cycle episodes, the two margins covary either positively or negatively, and their relative contribution to aggregate fluctuations is time-varying.[3]

In this paper, we take up the challenge of accounting for and explaining the cyclical behavior of the margins of labor adjustment and their comovement with the rest of the economy. These relations are central for policy prescriptions of quantitative business-cycle models, as labor market responses shape the dynamics of key policy variables, such as the output gap. We first determine under which conditions a business cycle model that features search-and-matching frictions can account for macro data that include both margins of labor adjustment. We then provide a structural assessment of the contribution of the intensive margin to aggregate fluctuations, shedding new light on the sources of labor market dynamics.

Towards this end, we embed search-and-matching frictions and a neoclassical hours-supply decision in a state-of-the-art business cycle model that can successfully account for key macroeconomic time-series, as shown in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007).[4] We estimate the model using Bayesian inference with U.S. data. Our full information approach

[1]See, among others, Andolfatto (1996), den Haan, Ramey, and Watson (2000), Gertler and Trigari (2009), and Shimer (2005).

[2]Some early contributions, including Cho and Cooley (1994), Kydland and Prescott (1991), and Hansen and Sargent (1988), calibrate models in which the supply of total hours adjust along both the intensive and extensive margins, but abstract from search and matching frictions.

[3]Section 2 discusses the data and robustness of these computations. In addition, we document that the positive covariance between hours per worker and employment is a significant contributor to total hours variation.

[4]The model features habit formation, investment adjustment costs, variable capital utilization, and nominal price and wage rigidities. As is common practice in the literature, we assume that hours per worker adjust to equate the marginal rate of substitution between hours and consumption to the value of the marginal product of labor. See, among others, Andolfatto (1996), Arseneau and Chugh (2008), Merz (1995), Ravenna and Walsh (2012), and Trigari (2009). Importantly, wage rigidity does not have a direct impact on on-going worker-employer relations, (and thus on the adjustment of hours per worker). As a result, the setup is not vulnerable to the Barro (1977) critique.

provides an ideal laboratory to study the empirical performance of the model, since it allows us to evaluate the model fit relative to a large set of macro moments, beyond pure labor market outcomes. Moreover, it allows us to encompass most of the views on the sources of business cycles found in the literature, giving disturbances other than the neutral technology shock a fair chance to account for labor market adjustments.

Our analysis yields three main results. First, the benchmark model cannot account for the cyclicality of the margins of labor adjustment. In particular, the model cannot reproduce the positive unconditional covariance between employment and hours per worker, and it generates counterfactual volatilities for both labor margins. Moreover, the model cannot account for the empirical covariance between hours per worker and macroeconomic time series.[5] These results hold regardless of the number of labor-market observables included in the estimation—either total hours alone or hours and employment together—and the shocks that affect labor adjustment.[6] The specific source of amplification for employment fluctuations also is irrelevant. While the estimated benchmark model features wage stickiness, our results are virtually unaffected when we consider an alternative version of the model in which wage adjustment is flexible, and employment volatility stems from a higher value of the flow value of unemployment (similarly to Hagedorn and Manovskii, 2008). The counterfactual behavior of the benchmark model also is not intrinsically linked to a specific value of the Frisch elasticity of labor supply. While our estimates for this elasticity are aligned with microeconometric evidence, the inability of the model to reproduce the margins of labor adjustment persists even when we calibrate the Frisch elasticity to values used in the macroeconomic literature, as such values counterfactually augment the intensive margin's variability.

Second, we show that a parsimonious set of features reconciles the model with the data: non-separable preferences that exhibit a weak short-run wealth effect on hours supply and costly hours' adjustment, which are a reduced-form cost capturing various technological frictions that constrain the ability of firms to adjust hours per worker (for instance, set-up costs and coordination issues). We introduce parametrized wealth effects in households' preferences following Jaimovich and Rebelo (2009), since their specification allows us to study the limiting case of no wealth effects considered by Greenwood, Hercowitz, and Huffman (1988), while preserving the existence of balanced growth in

[5] Gertler, Sala, and Trigari (2008) find that a similar model with only the extensive margin is able to reproduce the joint dynamics of one labor margin and macroeconomic variables. Estimates of a version of our benchmark model with only the extensive margin are consistent with this result.

[6] When we use aggregate hours as the only labor market observable, we either consider a standard bargaining power shock or a shock that affects the hours margin. When we include hours and employment as observables, we consider simultaneously the bargaining power shock and a hours supply shock.

the model.[7] The weakening of wealth effects eliminates the negative comovement between hours per worker and employment in response to TFP and demand shocks, while non-separability increases the comovement between hours per worker and consumption, which in turn helps the model to reproduce the empirical covariance of the intensive margin with output and investment. In addition, the presence of costly hours' adjustment prevents excessive variability in hours per worker, a second key dimension for reproducing the cyclical behavior of both margins of labor adjustment.

Finally, we examine the behavior of hours and employment in post-WWII U.S. recoveries.[8] The estimated model offers a structural interpretation for the observed time-varying comovement between hours per worker and employment. The labor margins co-move positively in response to standard demand and supply shocks, while labor-market shocks—shocks that affect wage bargaining and hours supply—result in negative comovement. The latter directly impact the relative cost of adjusting hours and employment, which induces a negative comovement between the intensive and extensive margins. By contrast, standard aggregate demand and supply shocks result in few incentives for firms to reallocate labor across its margins of adjustment. As a result, hours adjustment and employment comove positively.

A model counterfactual shutting down the intensive margin shows that the contribution of hours per worker to employment and GDP is quantitatively significant. Moreover, adjustment in hours per worker either enhances or offsets employment recoveries. When shocks induce the labor margins to comove positively, lack of hours adjustment unambiguously boosts employment (as firms must adjust labor to meet a given aggregate demand). By contrast, employment can be dampened when hours and employment comove negatively (since firms can no longer substitute from the more costly labor input). This result suggests that policies aimed at increasing flexibility in hours per worker, such as those advocated by the so-called "Hartz reforms" adopted in Germany, may or may not delay employment recoveries, depending on the shocks that affect the labor margins.

While we estimate the model on U.S. data, the results of our paper are broader in scope. First, as documented by Ohanian and Raffo (2012), hours and employment positively comove in several economies (for instance, in the U.K., Canada, and Japan), suggesting that the inability of the benchmark model to account for the margins of labor adjustment is not limited to the U.S. economy. Second, parametrized wealth effects and costly hours' adjustment introduces enough flexibility to allow the model to match a broad array of empirical regularities about hours per

[7] Imbens, Rubin, and Sacerdote (1999) provide microeconomic evidence of weak short-run wealth effects on the labor supply by studying a sample of lottery prize winners.

[8] To avoid the zero lower bound on monetary policy, we exclude the Great Recession for estimation.

worker and employment, including potentially negative ones observed in some European economies.

This paper relates to several strands of the literature. First, since Shimer (2005), a large literature addresses the ability of the search and matching model to replicate the cyclical behavior of vacancies and employment. While the debate has for the most part focused on calibrated versions of the search model, a few recent contributions examine the issue in the context of quantitative, estimated models (Gertler, Sala, and Trigari, 2008, and Justiniano and Michelacci, 2012).[9] In contrast, we document the inability of the model to jointly reproduce the cyclical behavior of hours per worker, employment, and their empirical covariances with macroeconomic time series. In addition, we show how to amend the benchmark model to address these shortcomings and structually evaluate the contribution of the intensive margin to aggregate dynamics.

This paper also relates to the literature addressing the behavior of employment in U.S. cyclical recoveries. In particular, an active strand of research addresses the so-called "jobless recoveries" following the past three U.S. recessions (of 1991, 2001, and 2009), where aggregate employment continued to decline for years following the turning point in aggregate income and output.[10] Our results provide additional insights to the debate by showing that employment growth in jobless recoveries would not have been unambiguously stronger in the absence of hours adjustment.[11]

The rest of the paper is organized as follows. Section 2 reviews the empirical relation of U.S. hours and employment. Section 3 outlines the benchmark model. Section 4 describes the approach for inference and discusses the cyclical behavior of the margins of labor adjustment in the estimated model. Section 5 presents the alternative model featuring parameterized wealth effects and hours adjustment costs. Section 6 studies the performance of the alternative model and discusses the cyclical behavior of hours per worker and employment in post-war U.S. recoveries. Section 7 evaluates the robustness of the results to alternative model specifications. Section 8 concludes.

[9] Christiano, Trabandt, and Walentin (2011) estimate a small-open economy model featuring search and matching frictions and endogenous hours per worker. They focus on the role of shocks and frictions for business cycle dynamics, without addressing the model's capability to capture the margins of labor adjusmtnet. Altug, Kabaca, and Poyraz (2011) show that financial frictions contribute to the dynamics of employment and hours per worker in a small-open economy model calibrated to match features of emerging economies. Balleer, Gehrke, Lechthaler, and Merkl (2016) identify, quantify, and interpret the dynamics of short-time work (i.e., publicly subsidized work time reductions) in Germany.

[10] No consensus has yet emerged regarding the source of jobless recoveries. Some attribute the occurrence of this phenomenon to fundamental changes in the underlying economic structure (e.g., Schreft, Singh, and Hodgson, 2005 and Groshen and Potter, 2003). Others focus on cyclical explanations, such as the intensive margin of labor adjustment in the wake of a short and shallow recession (Bachmann, 2012). Jaimovich and Siu (2012) show that jobless recoveries in the aggregate are accounted for by jobless recoveries in the middle-skill occupations that are disappearing because of job polarization. Gali, Smets, and Wouters (2012) study slower recoveries in an estimated model that abstracts from endogenous fluctuations in hours per worker.

[11] We find no evidence of structural change explaining the contribution of the intensive margin to labor adjustment, as our results are robust to sub-sample estimation.

2 Hours and Employment in the Data

We begin with a review of stylized facts about U.S. hours per worker, employment, and total hours worked. In contrast to previous work, we use measures of total hours worked and employment for the entire economy constructed by the BLS mainly from the Current Employment Statistics (CES) survey.[12] Francis and Ramey (2009) show this economy-wide total hours series is less sensitive to sectoral shifts than nonfarm business sector measures. First, we find that fluctuations in hours per worker account for up to 30 percent of the variation in total hours. Second, hours per worker and employment positively co-move, and their positive covariance is a substantial contributor to the variability of total hours. Third, both the comovement and the relative contribution of the intensive margin varies in specific business cycle episodes such as cyclical recoveries. We also highlight the robustness of these facts across alternative labor data sets and discuss their importance for explaining fluctuations in aggregate hours.

We use quarterly data over the period 1965:1-2007:4, which corresponds to the estimation sample period in section 4. Hours per worker is constructed from the total hours and employment series. Total hours and employment are divided by the civilian non-institutional population to express in per capita terms. All variables are expressed in logs and multiplied by 100. Over the sample period, employment exhibits an upward trend while hours per worker exhibits a downward trend.[13] We consider several alternative detrending methods. Our preferred method removes a linear trend from each series, which corresponds to the series used for estimation in section 4. When hours and employment are linearly detrended, their sum almost perfectly matches the original, demeaned total hours series (their correlation is over 0.99). Thus, the linear filtering appears to account for the low-frequency structural features of employment and hours per worker while preserving the original properties of the total hours series. In addition, we apply a HP filter with smoothing parameters of 1600 and 10^5 and a band pass filter as in Christiano and Fitzgerald (2003).

To assess the contribution of the intensive margin to labor adjustment, we consider two standard decompositions of the variance of total hours. The first decomposition exploits the fact that

$$\text{var}(TH_t) = \text{cov}(TH_t, h_t) + \text{cov}(TH_t, L_t),$$

[12] This data is publicly available from the BLS website at `www.bls.gov/lpc/special_requests/us_total_hrs_emp.xlsx`.

[13] As shown by Kirkland (2000), the decline in average hours per worker recorded by the CES survey can be attributed to the disproportionate increase of nonsupervisory workers in retail trade and services—the two industry divisions in the service-producing sector with the lowest average weekly hours—together with the decline in the percentage of production workers in mining and manufacturing—the two divisions with the highest number of average weekly hours.

where TH_t is total hours worked, h_t is hours per worker, and L_t is employment. Using this decomposition, we compute the shares of the variance attributed to hours per worker and employment as

$$\beta_{cov,h} \equiv \frac{\text{cov}(TH_t, h_t)}{\text{var}(TH_t)}, \quad \beta_{cov,L} \equiv \frac{\text{cov}(TH_t, L_t)}{\text{var}(TH_t)}.$$

In addition, we consider the following alternative decomposition:

$$\text{var}(TH_t) = \text{var}(h_t) + \text{var}(L_t) + 2\text{cov}(h_t, L_t),$$

and define the shares of the variance attributed to hours per worker, employment, and the covariance term respectively as

$$\beta_h \equiv \frac{\text{var}(h_t)}{\text{var}(TH_t)}, \quad \beta_L \equiv \frac{\text{var}(L_t)}{\text{var}(TH_t)}, \quad \beta_{cov} \equiv \frac{2\text{cov}(h_t, L_t)}{\text{var}(TH_t)}.$$

Table 1 displays these variance shares for the alternative detrending methods.[14] While employment accounts for the largest share of variation in total hours, the intensive margin plays a nontrivial role. The first decomposition shows that the covariance between hours per worker and total hours ($\beta_{cov,h}$) accounts for up to one-third of the total variation in TH_t. The second decomposition shows that the positive covariance between hours and employment (β_{cov}) explains approximately one-third of the variability in total hours. Thus, fluctuations in the intensive margin affect total hours both directly and indirectly through employment.

Table 1: Components of the Variance of Total Hours

Filtering	$\left(\frac{\text{cov}(TH_t,h_t)}{\text{var}(TH_t)}\right)$	$\left(\frac{\text{cov}(TH_t,L_t)}{\text{var}(TH_t)}\right)$	$\left(\frac{\text{var}(h_t)}{\text{var}(TH_t)}\right)$	$\left(\frac{\text{var}(L_t)}{\text{var}(TH_t)}\right)$	$\left(\frac{2\text{cov}(h_t,L_t)}{\text{var}(TH_t)}\right)$
			1965:1-2007:4		
Linear	0.33	0.67	0.18	0.51	0.31
HP 1600	0.21	0.79	0.10	0.67	0.23
HP 10^5	0.25	0.75	0.10	0.60	0.30
BP	0.23	0.77	0.10	0.63	0.27

Table A.1 in Appendix A documents the robustness of these results to two alternative data sources. The first uses labor variables from the Current Population Survey (CPS) which are augmented with armed forces data to provide an alternative economy-wide measure, as in Ramey

[14]The shares are similar using a longer data sample from 1965:1-2014:4.

(2012). CPS total hours data exhibit less pronounced low-frequency variation than CES measures, as shown by Frazis and Stewart (2010). Our results are robust to unfiltered and filtered measures of these variables. In addition, the results remain when using the labor market variables of Smets and Wouters (2007), which are widely employed in the DSGE estimation literature. In this case, hours per worker can contribute approximately 50 percent of the variation in total hours.

While Table 1 documents an unconditional positive correlation between hours per worker and employment, the comovement varies in specific episodes. To illustrate this, figure 1 plots total hours, hours per worker, and employment during five recoveries: 1970:1, 1975:1, 1982:4, 1991:1, and 2001:4.[15] For reference, the figure displays the first difference of the natural logarithm of GDP as well (top row). We display labor market variables relative to a linear trend. Hours per worker and employment positively co-move in some recoveries, such as 1982:4, but negatively co-move in other episodes, as in 1991:1.[16] In addition, hours per worker was quantitatively important for aggregate hours in several recoveries. For instance, at the 1982:4 trough, the difference in employment and total hours relative to trend was over two percentage points, whereas four quarters later the gap shrunk to a difference of about one percentage point (see the bottom row, column three). The closing of the gap was due to hours per worker, which was rising on average over the period. Likewise, in the recovery of 2001:4, total hours and hours per worker exhibited a short increase two periods after GDP's trough, while employment steadily declined over the whole episode.

In the subsequent sections, we focus on developing a model consistent with these patterns in the data.

3 The Model

This section outlines a benchmark medium-scale, dynamic stochastic general equilibrium model that features labor-market search and matching frictions and a standard neoclassical hours-supply decision. The model shares salient details that many have found useful for capturing features of the data. These include habit formation, costs of adjusting the flow of investment, variable capital utilization, and nominal price and wage rigidities. We abstract from monetary frictions that would motivate a demand for currency and model a cashless economy following Woodford (2003). Below, variables without a time subscript denote non-stochastic values along the balanced growth path.

[15] The literature comparing employment measures in jobless recoveries suggests preference for CES data measures similar to those used here. See Bachmann (2012) for a review of the literature.

[16] These results hold independently of the detrending procedure, as labor variables exhibit the same trends with alternative filtering methods.

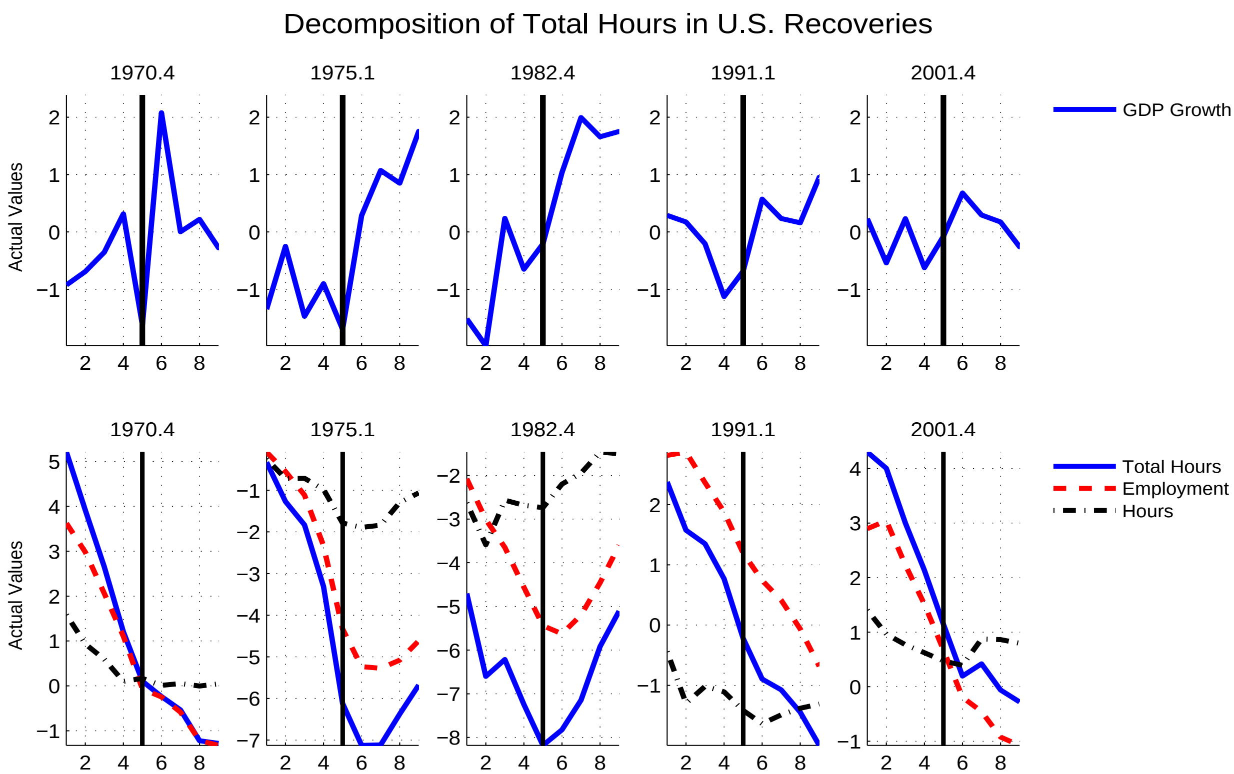

Figure 1. U.S. cyclical recoveries. Solid vertical lines indicate the troughs, using the NBER dates. Labor data are measures for the entire economy.

Household Preferences

The economy is populated by a representative household with a continuum of members along the unit interval. In equilibrium, some family members are unemployed, while others are employed. As is common in the literature, we assume that family members perfectly insure each other against variation in labor income due to changes in employment status, so that there is no *ex post* heterogeneity across individuals in the household (see Andolfatto, 1996, and Merz, 1995).

The representative household maximizes the expected intertemporal utility function

$$W_t \equiv E_t \sum_{s=t}^{\infty} \beta^{s-t} \bar{\beta}_s \left[\log(C_s - h_C C_{s-1}) - \bar{h}_s \int_0^{L_s} \frac{h_{js}^{1+\omega}}{1+\omega} dj \right], \tag{1}$$

where $\beta \in (0,1)$ is the discount factor, C_t is aggregate consumption, h_C is the degree of habit formation, L_t is the number of employed workers, and h_{jt} denotes hours worked by the employed member j. $\bar{\beta}_t$ denotes an exogenous shock to the discount factor, which evolves according to $\log \bar{\beta}_t = \rho_{\bar{\beta}} \log \bar{\beta}_{t-1} + \varepsilon_{\bar{\beta}t}$ with $\varepsilon_{\bar{\beta}t} \overset{iid}{\sim} N\left(0, \sigma_{\bar{\beta}}^2\right)$. $\bar{h}_t$ denotes an exogenous shock to the marginal disutility of hours worked, which evolves according to $\log \bar{h}_t = \rho_{\bar{h}} \log \bar{h}_{t-1} + \varepsilon_{\bar{h}t}$ with $\varepsilon_{\bar{h}t} \overset{iid}{\sim} N\left(0, \sigma_{\bar{h}}^2\right)$ Utility is logarithmic to ensure the existence of a balanced growth path in the presence of non-stationary technological progress.

The consumption basket C_t aggregates differentiated consumption varieties, $C_{\omega t}$, in Dixit-Stiglitz form: $C_t = \left[\int_0^1 C_{\omega t}^{(\bar{\theta}_t - 1)/\bar{\theta}_t} d\omega\right]^{\bar{\theta}_t/(\bar{\theta}_t - 1)}$, where $\bar{\theta}_t > 1$ is the exogenous elasticity of substitution across goods. We assume that $\bar{\theta}_t$ follows the stochastic process $\log \bar{\theta}_t = \rho_{\bar{\theta}} \log \bar{\theta}_{t-1} + (1 - \rho_{\bar{\theta}}) \log \bar{\theta} + \varepsilon_{\bar{\theta}t}$, where $\varepsilon_{\bar{\theta}t} \overset{iid}{\sim} N\left(0, \sigma_{\bar{\theta}}^2\right)$, which, following the literature, we refer to as a price markup shock. The corresponding price index is given by: $P_t = \left[\int_0^1 P_{\omega t}^{1-\bar{\theta}} d\omega\right]^{1/(1-\bar{\theta})}$, where $P_{\omega t}$ is the price of variety ω.

Production

There are two vertically integrated production sectors. In the upstream sector, perfectly competitive firms use capital and labor to produce a homogenous intermediate input. In the downstream sector, monopolistically competitive firms purchase intermediate inputs and produce the differentiated varieties that are sold to consumers. This production structure is common in the search and matching literature featuring nominal rigidities and monopolistic competition, as it simplifies the introduction of labor market frictions in the model; see, for instance, Gertler, Sala, and Trigari

(2008), Ravenna and Walsh (2011), and Trigari (2009).

Intermediate Input Producers

There is a unit mass of perfectly competitive intermediate producers. Production requires capital and labor. Within each firm there is a continuum of jobs; each job is executed by one worker. Capital is perfectly mobile across firms and jobs and there is a competitive rental market in capital. All jobs produce with identical exogenous productivity $\bar{A}_t$. We assume that the growth rate of technology, $\bar{g}_{At} \equiv \bar{A}_t/\bar{A}_{t-1}$, follows the stochastic process: $\log \bar{g}_{At} = \rho_{\bar{g}_A} \log \bar{g}_{At-1} + (1-\rho_{\bar{g}_A}) \log \bar{g}_A + \varepsilon_{\bar{g}_A t}$, where $\varepsilon_{\bar{g}_A t} \overset{iid}{\sim} N\left(0, \sigma^2_{\bar{g}_A}\right)$.

A filled job i in the representative firm j produces $\left(k^i_{jt}\right)^a \left(\bar{A}_t h^i_{jt}\right)^{1-\alpha}$ units of output, where k^i_{jt} is the stock of capital allocated to the job i and h^i_{jt} is the corresponding number of hours worked. Since all jobs produce with identical aggregate productivity $\bar{A}_t$, all existing matches produce the same amount of output using the same capital and hours inputs. Thus, we omit the job-specific index i henceforth. Total producer's output exhibits constant returns to scale in total hours and capital:

$$Y^I_{jt} = K^{\alpha}_{jt} \left(\bar{A}_t L_{jt} h_{jt}\right)^{1-\alpha}, \tag{2}$$

where L_{jt} is the measure of jobs within the firm and $K_{jt} \equiv L_{jt} k_{jt}$.[17]

The relationship between a firm and a worker can be severed for exogenous reasons. We denote by λ the fraction of jobs that are exogenously destroyed in each period.[18] Job creation is subject to matching frictions. To hire a new worker, firms have to post a vacancy, incurring a real cost $\bar{A}_t \kappa_{jt}$, where $\kappa_{jt} \equiv \kappa V^{\tau}_{jt}/(1+\tau)$. This specification implies that total vacancy costs are convex in the number of posted vacancies, V_{jt}, an assumption that is consistent with the evidence in Merz and Yashiv (2007).[19] We let the vacancy cost drift with the level of technology to ensure balanced growth; otherwise, κ_{jt} would become a smaller fraction of labor income as the economy grows. The probability of finding a worker depends on a constant returns to scale matching technology, which converts aggregate unemployed workers U_t and aggregate vacancies V_t into aggregate matches $M_t = \chi U^{\varepsilon}_t V^{1-\varepsilon}_t$, where $0 < \varepsilon < 1$. Each firm meets unemployed workers at a rate $q_t \equiv M_t/V_t$. Finally, as is common practice in the literature, all separated workers are assumed to reenter the

[17] This stems from the fact that $Y^I_{jt} = L_{jt} \left(k_{jt}\right)^a \left(\bar{A}_t h_{jt}\right)^{1-\alpha} = K^{\alpha}_{jt} \left(\bar{A}_t L_{jt} h_{jt}\right)^{1-\alpha}$.

[18] Hall (2005) and Shimer (2005) argue that, in the U.S. data, the separation rate varies little over the business cycle, although part of the literature disputes this position; see Davis, Haltiwanger, and Schuh (1998) and Fujita and Ramey (2009).

[19] Our results are robust to considering convex hiring costs as in Gertler, Sala, and Trigari (2008).

unemployment pool; i.e., we abstract from workers' labor-force participation decisions.[20]

The timing of events in the labor market proceeds as follows. The firm j begins a period with a stock of L_{jt-1} workers, which is immediately reduced by exogenous separations. Then, the firm posts vacancies V_{jt} and selects the total capital stock, K_{jt}.[21] Once the hiring round has been completed, wages and hours per worker are determined, and production occurs.[22] The law of motion of employment is given by:

$$L_{jt} = (1-\lambda)L_{jt-1} + q_t V_{jt}. \tag{3}$$

Following the estimation literature, we allow for nominal wage stickiness; section 7 relaxes this assumption. As in Arseneau and Chugh (2008), we use Rotemberg's (1982) model of a nominal rigidity and assume that firms face a quadratic cost of adjusting the hourly nominal wage rate, w_{jt}^n.[23] The real, per-worker cost of changing the nominal wage between period $t-1$ and t is

$$\Gamma_{w_j t} \equiv \frac{\phi^w \bar{A}_t}{2}\left(\frac{w_{jt}^n}{w_{jt-1}^n}\pi_C^{\iota_w - 1}\pi_{Ct-1}^{-\iota_w} - \bar{g}_A\right)^2,$$

where $\phi^w \geq 0$ is in units of consumption, $\pi_{Ct} \equiv P_t/P_{t-1}$ is the gross CPI inflation rate, and $\iota_w \in [0,1]$ measures the degree to which nominal wage adjustment is indexed to previous price inflation. If $\phi^w = 0$, there is no cost of wage adjustment. Similar to the vacancy cost, the wage adjustment cost is tied to the level of technology $\bar{A}_t$ to ensure balanced growth.

Intermediate input producers sell their output to final producers at a real price φ_t in units of

[20] Campolmi and Gnocchi (2016) incorporate a participation decision in a standard New Keynesian model with matching frictions. They show that the presence of a participation margin moderately increases the volatility of employment fluctuations. As discussed in section 7, since our results do not depend on the specific source of employment volatility in the model, the presence of endogenous labor force participation is not likely to affect our results.

[21] With full capital mobility and price-taker firms in the capital market, it is irrelevant whether producers choose the total stock of capital K_{jt}, or, instead, determine the optimal capital stock for each existing job, k_{jt}. Moreover, as noted by Cahuc, Marque, and Wasmer (2008), the specific timing of the capital decision is immaterial for the equilibrium allocation, since capital can be costlessly adjusted within each firm—firms can always re-optimize K_{jt} within a given a period.

[22] Thus, labor-market matching occurs within a period, which, as noted by Arseneau and Chugh (2012), is empirically descriptive of U.S. labor-market flows at quarterly frequencies.

[23] Alternatively, we could follow Gertler, Sala, and Trigari (2008) and assume staggered (Calvo) nominal wage bargaining. The advantage of assuming a quadratic wage adjustment cost is a more convenient model aggregation. Notice that these alternative sources of wage rigidity are not observationally equivalent, even in a first-order approximation to the model policy functions around a deterministic steady state with zero net inflation. The reason is that, as discussed by Gertler and Trigari (2009), the wage dispersion implied by staggered Nash bargaining generates a spillover effect on the average wage that is absent with convex wage adjustment costs. However, as already shown by Gertler and Trigari (2009), the quantitative importance of such an externality is very modest. Accordingly, the implied model dynamics are remarkably similar across the two alternative specifications (results are available upon request).

consumption. The present discounted value of the stream of profits is given by:

$$\Pi_{jt}^{I} \equiv E_t \left\{ \sum_{t=s}^{\infty} \beta_{s,s+1} \left[\varphi_s Y_{js}^{I} - \frac{w_{js}^{n} h_{js}}{P_s} L_{js} - \Gamma_{w_j s} L_{js} - r_{Ks} K_{js} - \kappa \bar{A}_s \frac{V_{js}^{1+\tau}}{1+\tau} \right] \right\}, \tag{4}$$

where $\beta_{t,t+1} \equiv \beta u_{Ct+1}/u_{Ct}$ is the household stochastic discount factor. Equation (1) implies that the marginal utility of consumption u_{Ct} is defined by

$$u_{Ct} \equiv \frac{\bar{\beta}_t}{C_t - h_C C_{t-1}} - h_C \beta E_t \left(\frac{\bar{\beta}_{t+1}}{C_{t+1} - h_C C_t} \right).$$

The representative producer chooses V_{jt}, L_{jt}, and K_{jt} to maximize (4) subject to (2) and (3). When making these decisions, the firm anticipates that both the hourly wage w_{jt} and hours per worker h_{jt} do not depend on the scale of the firm, so that $\partial w_{jt}^{n}/\partial L_{jt} = \partial h_{jt}/\partial L_{jt} = 0$. As shown below, these results obtain under the standard assumptions of individual Nash wage bargaining and neoclassical determination of hours per worker.

The first-order condition for K_{jt} equates the marginal revenue product of capital to its rental cost:

$$\varphi_t \alpha \left(\frac{K_{jt}}{\bar{A}_t L_{jt} h_{jt}} \right)^{\alpha - 1} = r_{Kt}, \tag{5}$$

implying that the capital-total hours ratio is symmetric across producers, since it only depends on aggregate variables. Let S_{jt}^{f} denote the Lagrange multiplier on the constraints (3), representing the value to the firm of hiring an extra worker. The first-order condition for L_{jt} implies:

$$S_{jt}^{f} = (1-\alpha)\, \varphi_t \left(\frac{K_{jt}}{\bar{A} h_{jt} L_{jt}} \right)^{\alpha} \bar{A}_t h_{jt} - \frac{w_{jt}^{n} h_{jt}}{P_t} - \Gamma_{w_j t} + E_t \beta_{t,t+1} (1-\lambda) S_{jt+1}^{f}. \tag{6}$$

Intuitively, the value of a job to the firm corresponds to the expected, present discounted value of the streams of profits from the match—the difference between the value of the marginal product and the wage payment to the worker minus the cost of adjusting the nominal wage. Finally, the first-order condition for vacancies equates the cost of filling a vacancy to the value of a filled position:

$$\kappa \bar{A}_t \frac{V_{jt}^{\tau}}{q_t} = S_{jt}^{f}. \tag{7}$$

Equation (6) and (7) imply a standard job creation condition:

$$\frac{\kappa \bar{A}_t V_{jt}^{\tau}}{q_t} = (1-\alpha)\, \varphi_t \left(\frac{K_{jt}}{\bar{A} h_{jt} L_{jt}} \right)^{\alpha} \bar{A}_t h_{jt} - \frac{w_{jt}^{n} h_{jt}}{P_t} - \Gamma_{w_j t} + \kappa (1-\lambda) E_t \beta_{t,t+1} \frac{\bar{A}_{t+1} V_{jt+1}^{\tau}}{q_{t+1}}.$$

Forward looking iteration of the job creation equation implies that, at the optimum, the expected discounted value of the stream of profits generated by a match over its expected lifetime is equal to the cost of filling a vacancy, $\kappa \bar{A}_t V_{jt}^{\tau}/q_t$.

Hours Determination

We assume that hours per worker adjust to the point where the worker's marginal cost of working an extra hour is equal to the firm's marginal benefit, as is common practice in the literature. This is tantamount to assuming that h_{jt} maximizes the joint surplus of the firm and the worker.[24] This requires that the worker's marginal rate of substitution between consumption and leisure is equal to the value of the marginal value product of an extra hour worked, leading to the condition:

$$\frac{W_{h_jt}}{u_{Ct}} = (1-\alpha)\,\varphi_t \left(\frac{K_{jt}}{\bar{A} h_{jt} L_{jt}}\right)^{\alpha} \bar{A}_t, \tag{8}$$

where $W_{h_jt} \equiv \partial W_t / \partial h_{jt} = -\bar{\beta}_t \bar{h}_t h_{jt}^{\omega}$. Using the first-order condition for capital, the optimality condition in (8) can be written as

$$\frac{\bar{\beta}_t \bar{h}_t h_{jt}^{\omega}}{u_{Ct}} = (1-\alpha)\,\varphi_t \left(\frac{r_{Kt}}{\varphi_t \alpha}\right)^{\frac{\alpha}{\alpha-1}} \bar{A}_t, \tag{9}$$

which shows that h_{jt} only depends on aggregate conditions, i.e., $h_{jt} = h_t$ is invariant to the scale of the firm. Moreover, hours per worker do not directly depend on the hourly wage w_{jt}.

Wage Bargaining

The nominal wage is the solution to an individual Nash bargaining problem, and the wage payment divides the match surplus between workers and firms. Due to the presence of nominal rigidities, we assume that bargaining occurs over the nominal wage rather than the real wage, as in Arseneau and Chugh (2008), Gertler, Sala, and Trigari (2008), and Thomas (2008). With zero costs of nominal wage adjustment ($\phi^w = 0$), the real wage is identical to the one obtained from bargaining directly over the real wage. This is no longer the case in the presence of wage adjustment costs. As is standard practice in the literature, the wage bargaining is atomistic, implying that the firm and

[24] Alternatively, we could assume that firms have the right to manage hours or consider Nash bargaining over hours per worker. The disadvantage of such theoretical frameworks is twofold. First, the choice of hours is not privately efficient from the perspective of each firm-worker match. Second, wage stickiness would affect fluctuations in hours worked. Consequently, both frameworks are subject to the Barro (1977) critique, given that firms and workers have an ongoing relationship.

the worker take K_{jt} and L_{jt} as given at the bargaining stage. Moreover, both parties account for the fact that $\partial h_t / \partial w_{jt} = 0$, as shown above.

Let $\bar{\eta}_t \in (0,1)$ be the weight given to the worker's individual surplus in Nash bargaining. We assume that $\bar{\eta}_t$ follows the process: $\log \bar{\eta}_t = \rho_{\bar{\eta}} \log \bar{\eta}_{t-1} + (1-\rho_{\bar{\eta}}) \log \bar{\eta} + \varepsilon_{\bar{\eta}t}$, where $\varepsilon_{\bar{\eta}t} \overset{iid}{\sim} N\left(0, \sigma_{\bar{\eta}}^2\right)$. Exogenous fluctuations in the worker's bargaining power are the counterpart of wage-markup shocks typically assumed in the estimation of benchmark New Keynesian models that abstract from search and matching frictions.[25] The firm and the worker maximize the Nash product

$$\left(S_{jt}^f\right)^{1-\bar{\eta}_t} \left(S_{jt}^w\right)^{\bar{\eta}_t},$$

where S_{jt}^f is defined as in (12) and S_{jt}^w denotes the worker surplus:

$$S_{jt}^w = \frac{w_{jt}^n}{P_t} h_t - b\bar{A}_t - \frac{\bar{\beta}_t \bar{h}_t h_t^{1+\omega}}{(1+\omega)\, u_{Ct}} + E_t \left[\beta_{t,t+1} (1-\lambda)\, S_{jt+1}^w \left(1 - \frac{M_{t+1}}{U_{t+1}}\right)\right]. \tag{10}$$

The worker's surplus corresponds to the expected present discounted value of wage payments over the lifetime of the match minus the expected present discounted value of the flow value of unemployment, including unemployment benefits from the government $b\bar{A}_t$ (financed with lump sum taxes), and the utility gain from leisure in terms of consumption.

The first-order condition with respect to w_{jt}^n implies the following sharing rule:

$$\eta_{w_j t} S_{jt}^f = (1 - \eta_{w_j t}) S_{jt}^w, \tag{11}$$

where $\eta_{w_j t}$ is the *effective* bargaining share of workers:

$$\eta_{w_j t} \equiv \frac{\bar{\eta}_t \left(\partial S_{jt}^w / \partial w_{jt}^n\right)}{\bar{\eta}_t \left(\partial S_{jt}^w / \partial w_{jt}^n\right) - (1-\bar{\eta}_t) \left(\partial S_{jt}^f / \partial w_{jt}^n\right)} = \frac{\bar{\eta}_t h_t}{\bar{\eta}_t h_t - (1-\bar{\eta}_t) \left(\partial S_{jt}^f / \partial w_{jt}^n\right)}.$$

(See Appendix B for the expression of $\partial S_{jt}^f / \partial w_{jt}^n$.) As in Gertler and Trigari (2009), the effective bargaining share is time-varying due to the presence of wage adjustment costs. Absent these costs, the bargaining share is exogenous, $\eta_{w_j t} = \bar{\eta}_t$. Importantly, wage rigidity implies that $\eta_{w_j t}$ is countercyclical, amplifying employment fluctuations in response to aggregate shocks as first noted by Gertler and Trigari (2009).

[25] Up to a first-order approximation, wage markup shocks are isomorphic to hours supply shocks in the benchmark New Keynesian model. Such equivalence breaks down in the presence of labor-market search and matching frictions.

It is straightforward to verify that w^n_{jt} does not depend on the scale of the firm. To see this, substitute equation (9) into the definition of the worker's and firm's surplus, S^w_{jt} and S^f_{jt}, and use the first-order condition for capital to eliminate the capital-labor ratio in S^f_t:

$$S^f_{jt} = (1-\alpha)\,\varphi_t \left(\frac{r_{Kt}}{\varphi_t \alpha}\right)^{\frac{\alpha}{\alpha-1}} \bar{A}_t h_t - \frac{w^n_{jt} h_t}{P_t} - \Gamma_{wjt} + E_t \beta_{t,t+1} (1-\lambda)\, S^f_{jt+1}. \tag{12}$$

Since all the intermediate firms produce with identical technology $\bar{A}_t$, there is a symmetric equilibrium in which $K_{jt} = K_t$, $L_{jt} = L_t$, $h_{jt} = h_t$, $V_{jt} = V_t$, and $w^n_{jt} = w^n_t$. In turn, nominal hourly wage inflation, defined by $\pi_{wt} \equiv w^n_t / w^n_{t-1}$ is linked to CPI inflation by $\pi_{wt} = (w_t / w_{t-1})\, \pi_{Ct}$, where $w_t \equiv w^n_t / P_t$ denotes the real hourly wage. Finally, searching workers in period t are equal to the mass of unemployed workers: $U_t = 1 - (1-\lambda)\, L_{t-1}$.

Final Goods Production

A continuum of monopolistically competitive final-sector firms produce differentiated varieties using the intermediate input. The producer ω faces the following demand: $Y^C_{\omega t} = (P_{\omega t}/P_t)^{-\bar{\theta}_t}\, Y^C_t$, where Y^C_t denotes aggregate demand of the final consumption basket, inclusive of sources besides household consumption.[26]

We introduce price-setting frictions by following Rotemberg (1982) and assume that final producers must pay a quadratic price adjustment cost. We also allow for price indexation by assuming that final producers index price changes to past CPI inflation, so that price adjustment costs take the form:

$$\frac{\phi^p}{2} \left(\frac{P_{\omega t}}{P_{\omega t-1}} \pi_C^{\iota_p - 1} \pi_{Ct-1}^{-\iota_p} - 1 \right)^2 P_{\omega t} Y^C_{\omega t},$$

where $\phi^p \geq 0$ determines the size of the adjustment cost (prices are flexible if $\phi^p = 0$) and $\iota_p \in [0, 1]$ is the indexation parameter.

The producer ω maximizes the present discounted value of the expected stream of (real) profits:

$$\Pi^F_{\omega s} = E_t \sum_{s=t}^{\infty} \beta_{s,s+1} \left\{ \frac{P_{\omega s}}{P_s} \left[1 - \frac{\phi^p}{2} \left(\frac{P_{\omega s}}{P_{\omega s-1}} \pi_C^{\iota_p - 1} \pi_{Cs-1}^{-\iota_p} - 1 \right)^2 \right] Y^C_{\omega s} - \varphi_s Y^C_{\omega s} \right\},$$

subject to the demand schedule $Y^C_{\omega t} = (P_{\omega t}/P_t)^{-\bar{\theta}_t}\, Y^C_t$. Let $\pi_{\omega t} \equiv P_{\omega t}/P_{\omega t-1}$. Optimal price setting

[26] Aggregate demand takes the same CES form as the consumption basket, with the same elasticity of substitution $\bar{\theta}_t$ across consumption varieties. This ensures that the consumption price index is also the price index for aggregate demand of the final basket.

implies that the (real) output price $P_{\omega t}/P_t$ is equal to a markup over the real marginal cost φ_t:

$$\frac{P_{\omega t}}{P_t} = \frac{\bar{\theta}_t}{\left(\bar{\theta}_t - 1\right)\Xi_{\omega t}}\varphi_t,$$

where

$$\Xi_{\omega t} \equiv 1 - \frac{\phi^p}{2}\left(\pi_{\omega t}\pi_{Ct-1}^{-\iota_p}\pi_C^{\iota_p - 1} - 1\right)^2 + \frac{\phi^p}{\bar{\theta}_t - 1}\left\{\begin{array}{c} \pi_C^{\iota_p - 1}\left(\pi_{\omega t}\pi_{Ct-1}^{-\iota_p}\pi_C^{\iota_p - 1} - 1\right)\pi_{\omega t}\pi_{Ct-1}^{-\iota_p} \\ -E_t\left[\beta_{t,t+1}\left(\pi_{\omega t+1}\pi_{Ct}^{-\iota_p}\pi_C^{\iota_p - 1} - 1\right)\pi_{Ct+1}^{-1}\pi_{\omega t+1}^2\pi_{Ct}^{-\iota_p}\frac{Y_{\omega t+1}^C}{Y_{\omega t}^C}\right] \end{array}\right\}.$$

There are two sources of endogenous markup variation in the model. First, the cost of adjusting prices gives firms an incentive to change their markups over time in order to smooth price changes across periods. Second, exogenous shocks to the firm market power result in time-varying markups even in the absence of price stickiness. In the symmetric equilibrium, $P_{\omega t} = P_t$ and $\Xi_{\omega t} = \Xi$. As a consequence, $\pi_{\omega t} = \pi_t = \pi_{Ct}$.

Household Budget Constraint and Optimal Intertemporal Decisions

The household enters period t with nominal private bond holdings B_t, earning a gross interest rate i_t. The household also accumulates the physical capital and rents it to intermediate input producers in a competitive capital market. Investment in the physical capital stock, I_{Kt}, requires the use of the same composite of all available varieties as the basket C_t. We introduce convex adjustment costs in physical investment and variable capital utilization. The utilization rate of capital is set by the household. Thus, effective capital rented to firms, K_t, is the product of physical capital, $\tilde{K}_t$, and the utilization rate, u_{Kt}: $K_t = u_{Kt}\tilde{K}_t$. Increases in the utilization rate are costly because higher utilization rates imply faster capital depreciation. We assume a standard convex depreciation function: $\delta_{Kt} = \delta_0 + \delta_1\left(u_{Kt} - 1\right) + \delta_2\left(u_{Kt} - 1\right)^2$. Physical capital, $\tilde{K}_t$, obeys a standard law of motion:

$$\tilde{K}_{t+1} = \left(1 - \delta_{Kt}\right)\tilde{K}_t + \bar{P}_{Kt}\left[1 - \frac{\nu_K}{2}\left(\frac{I_{Kt}}{I_{Kt-1}} - \bar{g}_A\right)^2\right]I_{Kt}, \tag{13}$$

where $\nu_K > 0$ is a scale parameter, and $\bar{P}_{Kt}$ is an investment specific shock. The latter is a source of exogenous variation in the efficiency with which the final good can be transformed into physical capital, and thus into tomorrow's capital input.[27] The investment shock evolves via the process

[27] Justiniano, Primiceri, and Tambalotti (2010) suggests that this variation might stem from technological factors specific to the production of investment goods, but also from disturbances to the process by which these investment goods are turned into productive capital.

$\log \bar{P}_{Kt} = \rho_{\bar{P}_K} \log \bar{P}_{Kt-1} + \varepsilon_{\bar{P}_K t}$, where $\varepsilon_{\bar{P}_K t} \overset{iid}{\sim} N\left(0, \sigma^2_{\bar{P}_K}\right)$.

The per-period household's budget constraint is:

$$P_t C_t + P_t I_{Kt} + B_{t+1} = i_t B_t + w_t^n h_t L_t + r_{Kt} P_t K_t + b \bar{A}_t (1 - L_t) P_t + P_t \Pi_t^I + P_t \int_0^1 \Pi_t^F(i)\, di + T_t^g, \quad (14)$$

where T_t^g is a nominal lump-sum tax from the government.

The household maximizes its expected intertemporal utility subject to (13) and (14). The Euler equation for capital accumulation requires: $\zeta_{Kt} = E_t \left\{ \beta_{t,t+1} \left[r_{t+1} u_{Kt+1} + (1 - \delta_{Kt+1}) \zeta_{Kt+1} \right] \right\}$, where ζ_{Kt} denotes the shadow value of capital (in units of consumption), defined by the first-order condition for investment I_{Kt}:

$$\zeta_{Kt}^{-1} = \left[1 - \frac{\nu_K}{2} \left(\frac{I_{Kt}}{I_{Kt-1}} - 1 \right)^2 - \nu_K \left(\frac{I_{Kt}}{I_{Kt-1}} - 1 \right) \left(\frac{I_{Kt}}{I_{Kt-1}} \right) \right] + \nu_K \beta_{t,t+1} E_t \left[\frac{\zeta_{Kt+1}}{\zeta_{Kt}} \left(\frac{I_{Kt+1}}{I_{Kt}} - 1 \right) \left(\frac{I_{Kt+1}}{I_{Kt}} \right)^2 \right].$$

The optimal condition for capital utilization implies: $r_{Kt} = \zeta_{Kt} [\delta_{K1} + \delta_{K2}(u_{Kt} - 1)]$. Finally, the Euler equation for bond holdings implies: $1 = i_t E_t \left[\beta_{t,t+1} / (1 + \pi_{Ct+1}) \right]$.

The Government

Fiscal policy is fully Ricardian. The government finances its budget deficit with lump-sum taxes each period. Public spending is determined exogenously, $G_t = \bar{g}_t$, where the exogenous government spending shock $\bar{g}_t$ follows the process $\log \bar{g}_t = \rho_{\bar{g}} \log \bar{g}_t + (1 - \rho_{\bar{g}}) \log \bar{g} + \varepsilon_{\bar{g}t}$, with $\varepsilon_{\bar{g}t} \overset{iid}{\sim} N\left(0, \sigma^2_{\bar{g}}\right)$.

The monetary authority sets the nominal interest rate following a feedback rule of the form

$$\frac{i_t}{i} = \left(\frac{i_{t-1}}{i} \right)^{\varrho_i} \left[\left(\frac{\pi_{Ct}}{\pi_C} \right)^{\varrho_\pi} \left(\frac{Y_{gt}}{Y_g} \right)^{\varrho_Y} \right]^{1 - \varrho_i} \left(\frac{Y_{gt}}{Y_{gt-1}} \right)^{\varrho_{dY}} \bar{\imath}_{it}, \quad (15)$$

where i is the steady state of the gross nominal interest rate. The interest rate responds to deviations of inflation and the GDP gap, Y_{gt}, from their long-run targets, as well as to deviations of the growth rate of the GDP gap, Y_{gt}/Y_{gt-1}. Consistent with Woodford (2003), we define Y_{gt} as the deviation of model GDP, $Y_t \equiv C_t + I_{Kt} + G_t$, from its level prevailing under flexible prices and wages and absent inefficient shocks (i.e., absent markup and bargaining power shocks). The monetary policy rule is subject to a shock, $\bar{\imath}_{it}$, which evolves according to $\log \bar{\imath}_{it} = \rho_{\bar{\imath}} \log \bar{\imath}_{it-1} + \varepsilon_{\bar{\imath}t}$, with $\varepsilon_{it} \overset{iid}{\sim} N\left(0, \sigma^2_{\bar{\imath}}\right)$.

Market Clearing

In the symmetric equilibrium, bonds are zero in net supply: $B_t = B_{t+1} = 0$. Thus, combining the household's and government's budget constraints yields the following aggregate resource constraint:

$$Y_t^C \left[1 - \frac{\nu}{2}\left(\pi_{Ct}\pi_C^{\iota_p - 1}\pi_{Ct-1}^{-\iota_p} - 1\right)^2\right] = C_t + I_{Kt} + \kappa_t \bar{A}_t V_t + G_t. \tag{16}$$

Intuitively, total output produced by firms must be equal to the sum of market consumption, investment in physical capital, the costs associated to job creation, the purchase of goods from the government, and the real cost of changing prices. Finally, labor market clearing implies $Y_t^C = Y_t^I$.

The model contains 15 equations that determine 15 endogenous variables: i_t, π_{Ct}, π_{wt}, C_t, L_t, V_t, M_t, h_t, w_t, φ_t, $\tilde{K}_{t+1}$, I_{Kt}, ζ_{Kt}, u_{Kt}, r_{Kt}, and 10 definitions (U_t, S_t^f, S_t^w, q_t, u_{Ct}, δ_{Kt}, κ_t, η_{wt}, Ξ_t, and Y_{gt}). Additionally, the model features 8 exogenous disturbances: $\bar{g}_{At}$, $\bar{\beta}_t$, $\bar{h}_t$, $\bar{\theta}_t$, $\bar{\eta}_t$, $\bar{P}_{Kt}$, $\bar{\imath}_t$, and $\bar{g}_t$.

Model Solution

Consumption, investment, capital, the real wage, and GDP, (together with Y_t^C, S_t^f, S_t^w, and u_{Ct}) fluctuate around a stochastic balanced growth path, since the level of technology has a unit root. We rewrite the model in terms of detrended variables and compute the log-linear approximation around the non-stochastic steady state. The details of these steps can be found in Appendix C, along with the full set of stationarized equilibrium conditions (and their log-linear approximations). We then solve the resulting linear system of rational expectation equations to obtain the transition equations, which are linked to data with an observation equation to form the state-space model used for estimation.

4 Estimation

We estimate the model with U.S. quarterly data from 1965:1 to 2007:4. Details of the data construction and linkages to observables are presented in Appendix A. The sample starting period reflects the initial availability of some wage measures we consider. For the benchmark estimation, we end the estimation prior to the recent zero lower bound episode.[28] Our initial estimation in-

[28] See Hirose and Inoue (2015) for a discussion of how the ZLB can bias estimates of log-linearized model parameters.

cludes seven observables commonly employed in the literature.[29] The seven observables include the log difference of aggregate consumption, investment, GDP, and real wages, the log difference of the GDP deflator, the Federal Funds rate, and the log of economy-wide total hours worked. To avoid stochastic singularity, we include seven structural shocks. To facilitate comparison with the literature (i.e., Christiano, Trabandt, and Walentin, 2011, and Gertler, Sala, and Trigari, 2008), our benchmark specification assumes that shocks to the exogenous component of the worker's bargaining power, $\bar{\eta}_t$, are the only disturbance directly affecting the labor market, i.e., $\bar{h}_t = 1$ for any t.[30]

In addition, we estimate the model including the hours supply shock, $\bar{h}_t$, and one ancillary observable, the log of economy-wide employment.[31] Using information on both margins of labor adjustment helps identify key labor parameters such as the Frisch elasticity. Moreover, the inclusion of the hours supply shock gives the model a better chance to match the dynamics of the labor margins.

We use Bayesian inference methods to construct the parameters' posterior distribution, which is a combination of a prior density for the parameters and the likelihood function, evaluated using the Kalman filter. We take 1.5 million draws from the posterior distribution using the random walk Metropolis-Hastings algorithm. For inference, we discard the first $500,000$ draws and keep one every 50 draws to remove some correlation of the draws.[32]

Prior Distributions

We impose dogmatic priors for some parameters. The household discount factor β is set to 0.99, α is 0.3, and depreciation δ is 0.025. The steady-state price markup is set at 1.1. Steady-state government spending is fixed at 20 percent of GDP, which equals the post-war average for all levels of government spending. Following standard practice in the literature, we use independent evidence for the average quarterly separation rate λ and the elasticity of matches to unemployment, ε. In particular, we choose $\lambda = 0.105$ based on the observation that jobs last on average about two and half years in the U.S. economy (Shimer, 2005). We set ε to be equal to 0.5, the midpoint of

[29] Examples include Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2007), Del Negro, Schorfheide, Smets, and Wouters (2007), Gertler, Sala, and Trigari (2008), and Justiniano, Primiceri, and Tambalotti (2010).

[30] In section 7, we discuss the alternative possibility of focusing on stochastic fluctuations in the disutility of hours worked, $\bar{h}_t$, while keeping constant the worker's bargaining power, i.e., $\bar{\eta}_t = 1$.

[31] This is observationally equivalent to estimating the model using hours per worker and employment as observables, since we abstract from measurement error.

[32] We set the step size to ensure the acceptance rate is in the range of 20 to 40 percent for all variations of the estimated model. Convergence diagnostics include cumulative sum of draws (cumsum) statistics and Geweke's Separated Partial Means (GSPM) test. Results are available from the authors.

the evidence typically cited in the literature and within the range of plausible values (0.5 to 0.7) reported by Petrongolo and Pissarides (2006). Finally, we set the cost of posting a vacancy, κ, and the matching efficiency parameter, χ, to match the quarterly average job finding probability, M/U, and the average probability of filling a vacancy, q. For the U.S., the former is equal to 0.95, while the latter is 0.9 (Shimer, 2005).

Table 2 lists the prior distributions for the remaining parameters in the columns labeled "Priors." Our priors for common New Keynesian parameters are similar to those in Smets and Wouters (2007). We set the price stickiness parameter, ω^p, to a value that would replicate the frequency of price adjustment in a Calvo-type Phillips curve in the absence of strategic price complementarities. For comparability with the literature, we directly estimate the related Calvo parameter ξ^p.[33] In contrast, no direct mapping to a Calvo-type wage Phillips curve exists, even in a linearized setup. Thus, we employ a prior for ϕ^w that permits a broad degree of stickiness. The estimated labor market parameters include the steady-state value of the workers' bargaining power $\bar{\eta}$, the replacement rate b/wh, and the degree of convexity in the cost of posting vacancies τ. The first two have priors similar to those in Gertler, Sala, and Trigari (2008). Finally, the bargaining power, price markup, and investment are normalized to enter with a unitary coefficient in the log-linearized equations that determine wages, inflation, and investment, respectively. The priors for the standard deviations of shocks are chosen to generate similar volatilities between the variables they directly impact and their data counterparts, as is common practice in the literature.

Posterior Estimates

Table 2 reports the posterior estimates of the benchmark model presented in section 3. As previously discussed, we estimate two versions of this model. The first includes seven observables and seven shocks: TFP, investment, preference, government spending, interest rate, price markup, and bargaining shocks. Parameter estimates from this version are listed under the column "7 obs." The second version includes an additional observable, employment, and an additional labor market shock, the hours-supply shock $\bar{h}_t$. Parameter estimates from this version are listed in the column "Benchmark" under the headings "8 obs" in Table 2.

For a discussion of the posterior estimates relative to the literature, see Appendix D.

[33] ξ^p is related to ω^p via the mapping $\omega^p = \left[\left(\bar{\theta} - 1\right)/\bar{\theta}\right] \xi^p/(1-\xi^p)(1-\xi^p\beta)$.

Table 2: Posterior Distributions for Estimated Parameters.

Parameter	Prior				Posterior					
					7 obs		8 obs			
					Benchmark Model		Benchmark Model		Preferred Model	
	Dist.*	Mean	Std.	90% Int.	Mean	90% Int	Mean	90% Int	Mean	90% Int
Preferences										
h_C, habit formation	B	0.5	0.1	[0.34, 0.66]	0.79	[0.73, 0.83]	0.68	[0.63, 0.72]	0.79	[0.73, 0.84]
ω, inverse Frisch	G	2	0.5	[1.25, 2.89]	3.34	[2.49, 4.33]	6.98	[5.83, 8.24]	2.74	[1.94, 3.68]
Frictions and Production										
$100 \log \bar{g}_A$, growth rate	N	0.4	0.03	[0.35, 0.45]	0.41	[0.37, 0.45]	0.40	[0.36, 0.44]	0.41	[0.36, 0.45]
ν_K, investment adj. cost	N	4	1.5	[1.53, 6.47]	4.89	[3.15, 6.93]	6.97	[5.48, 8.54]	7.76	[6.10, 9.50]
ϕ_h, hours adj. cost	N	4	1.5	[1.53, 6.47]	n.e.		n.e.		6.17	[4.53, 7.91]
ς, capital utilization	B	0.5	0.1	[0.34, 0.66]	0.54	[0.45, 0.62]	0.51	[0.43, 0.58]	0.44	[0.36, 0.52]
$\bar{\eta}$, workers bargaining power	B	0.5	0.1	[0.34, 0.66]	0.76	[0.63, 0.86]	0.56	[0.44, 0.68]	0.50	[0.38, 0.62]
$b/(w * h)$, replacement rate	B	0.5	0.1	[0.34, 0.66]	0.59	[0.48, 0.69]	0.56	[0.41, 0.69]	0.47	[0.34, 0.58]
τ, convexity vacancy cost	G	2	0.5	[1.25, 2.89]	1.27	[0.80, 1.83]	2.67	[2.05, 3.38]	2.74	[2.10, 3.48]
$\omega^w/1000$, wage stickiness	N	2	0.4	[1.34, 2.66]	2.86	[2.31, 3.42]	2.53	[2.00, 3.07]	2.59	[2.07, 3.13]
ι_w, wage partial indexation	B	0.5	0.15	[0.25, 0.75]	0.77	[0.61, 0.90]	0.69	[0.54, 0.84]	0.71	[0.56, 0.85]
ξ^p, price stickiness	B	0.66	0.1	[0.49, 0.82]	0.86	[0.83, 0.89]	0.90	[0.87, 0.93]	0.90	[0.87, 0.93]
ι_p, price partial indexation	B	0.5	0.15	[0.25, 0.75]	0.13	[0.06, 0.21]	0.12	[0.05, 0.21]	0.12	[0.05, 0.21]
Monetary policy										
ϱ_π, interest resp. to inflation	N	1.7	0.3	[1.21, 2.19]	1.78	[1.55, 2.05]	1.21	[1.01, 1.43]	1.32	[1.12, 1.53]
ϱ_Y, interest resp. to Y gap	G	0.125	0.1	[0.02, 0.32]	0.05	[0.02, 0.09]	0.10	[0.06, 0.14]	0.07	[0.03, 0.12]
ϱ_{dY}, interest to Y gap growth	N	0.13	0.05	[0.05, 0.21]	0.34	[0.28, 0.40]	0.31	[0.25, 0.36]	0.28	[0.23, 0.34]
ϱ_i, resp. to lagged interest rate	B	0.75	0.1	[0.57, 0.90]	0.76	[0.72, 0.80]	0.73	[0.68, 0.77]	0.75	[0.70, 0.79]
Shocks										
ρ_{g_A}, technology	B	0.5	0.2	[0.17, 0.83]	0.14	[0.05, 0.24]	0.07	[0.02, 0.13]	0.10	[0.03, 0.19]
ρ_β, preference	B	0.5	0.2	[0.17, 0.83]	0.70	[0.59, 0.79]	0.84	[0.78, 0.89]	0.67	[0.52, 0.79]
ρ_{P_K}, investment	B	0.5	0.2	[0.17, 0.83]	0.84	[0.78, 0.90]	0.20	[0.10, 0.30]	0.20	[0.11, 0.30]
ρ_θ, price markup	B	0.5	0.2	[0.17, 0.83]	0.88	[0.81, 0.93]	0.82	[0.74, 0.88]	0.85	[0.77, 0.91]
ρ_η, bargaining	B	0.5	0.2	[0.17, 0.83]	0.37	[0.24, 0.51]	0.16	[0.06, 0.26]	0.16	[0.07, 0.27]
ρ_g, govt cons	B	0.5	0.2	[0.17, 0.83]	0.99	[0.98, 0.99]	0.99	[0.98, 0.99]	0.98	[0.98, 0.99]
$\rho_{\bar{i}}$, monetary shock	B	0.5	0.2	[0.17, 0.83]	0.13	[0.05, 0.22]	0.15	[0.06, 0.25]	0.16	[0.07, 0.26]
ρ_h, hours shock	B	0.5	0.2	[0.17, 0.83]	n.e.		0.97	[0.94, 0.98]	0.97	[0.96, 0.99]
$100\sigma_{g_A}$, technology	IG	0.5	1	[0.01, 0.19]	0.83	[0.75, 0.92]	1.01	[0.92, 1.11]	1.07	[0.97, 1.19]
$100\sigma_\beta$, preference	IG	1	1	[0.01, 0.19]	2.43	[2.00, 2.95]	2.06	[1.78, 2.39]	2.87	[2.30, 3.63]
$100\sigma_{P_K}$, investment	IG	0.1	1	[0.01, 0.19]	0.71	[0.60, 0.83]	1.36	[1.18, 1.56]	1.37	[1.19, 1.57]
$100\sigma_\theta$, price markup	IG	0.1	1	[0.01, 0.19]	0.06	[0.05, 0.07]	0.06	[0.05, 0.08]	0.06	[0.05, 0.07]
$100\sigma_\eta$, bargaining	IG	1	1	[0.01, 0.19]	4.11	[3.36, 4.88]	4.90	[4.28, 5.56]	4.88	[4.27, 5.52]
$100\sigma_g$, govt cons	IG	0.5	1	[0.01, 0.19]	1.47	[1.34, 1.61]	1.53	[1.39, 1.67]	1.57	[1.43, 1.72]
$100\sigma_{\bar{i}}$, monetary shock	IG	0.1	1	[0.01, 0.19]	0.24	[0.21, 0.26]	0.24	[0.22, 0.27]	0.24	[0.21, 0.26]
$100\sigma_{\bar{h}}$, hours supply shock	IG	0.5	1	[0.01, 0.19]	n.e.		3.49	[2.97, 4.05]	3.51	[2.93, 4.17]
Log marginal data density							-1073		-1024	
$2 \ln$(Bayes Factor) vs. Benchmark							0		98	

*Distributions: N: Normal; G: Gamma; B: Beta; IG: Inverse Gamma.

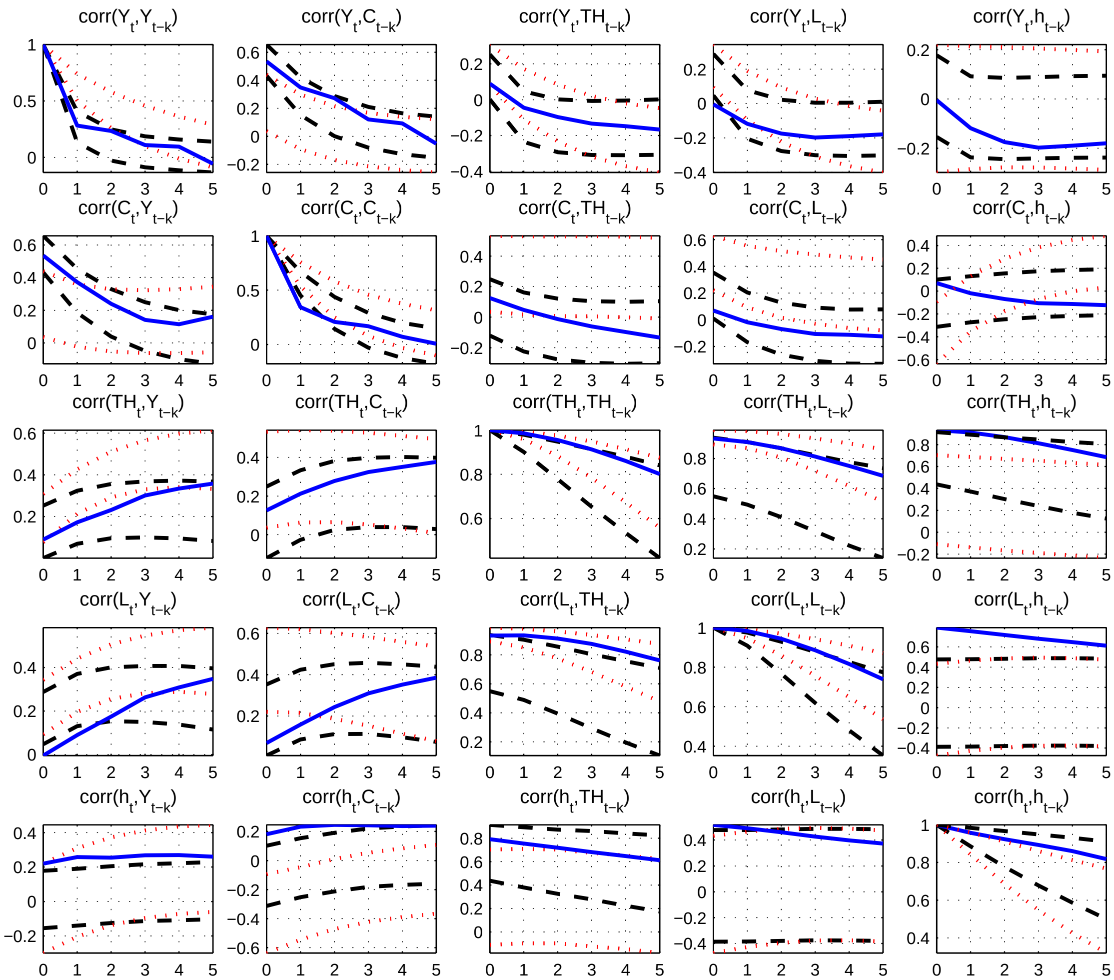

Figure 2. Correlograms from the data (solid lines) and 90 percent posterior intervals from 1) the benchmark model with seven observables (dotted lines) and 2) the benchmark model with eight observables (dashed lines).

Model Fit

To understand how well the benchmark model fits the data, we compare a set of statistics implied by the model to their data counterparts. Figure 2 plots the correlogram for several aggregate macroeconomic and labor market variables in the data (solid lines), as well as the 90-percent posterior intervals implied by both parameter and small sample uncertainty from the seven observable case (dotted lines) and the eight observable case (dashed lines).[34] We discuss the results of each case in turn.

The literature shows that the benchmark model with only the extensive margin and seven

[34]We sample 10,000 draws from the posterior. For each parameter draw, we generate 100 samples of the observable variables from the model with the same length as our dataset, after first discarding 100 initial observations. We compute statistics for each of these samples.

observables—including either total hours or employment—is able to reproduce the joint dynamics of employment and macroeconomic variables (see, for instance, Gertler, Sala, and Trigari, 2008). Estimates of a version of our benchmark model with only the extensive margin are in line with these results (results available upon request). However, when the intensive margin is introduced in the model, its ability to account for the correlations between labor market variables and aggregate macroeconomic series is significantly impaired, as evidenced by comparing the data (solid lines) and model (dotted lines) statistics in figure 2. First, the benchmark model estimated with seven observables does not capture the positive correlation between hours and employment nor the relative contributions of the labor margins to the variance of total hours. In particular, the model assigns an almost exclusive role to employment, as the 90 percent posterior bands for the share of the labor margin to the variance of total hours (β_L) are between 0.64 and 1.21, while the data counterpart is only 0.51. The β_{cov} ranges from -0.35 to 0.25, well short of the positive comovement (0.31) between hours and employment observed in the data. Moreover, the model overstates the correlation between the growth rate of output with total hours or employment at various leads and lags. Even though it correctly reproduces the correlogram between total hours and consumption growth, it does so with a counterfactual comovement of the individual margins with respect to consumption.

Prima facie, the poor performance of the model with seven observables could reflect that the model is estimated with only one labor market observable. However, simply adding information about the labor market by increasing the set of observables to include simultaneously employment (or hours per worker) and total hours does not improve the performance of the model. The dashed lines of figure 2 report the 90 percent posterior correlogram bands for the benchmark model when employment data and an hours supply shock are incorporated in the estimation. The correlation of hours per worker and consumption growth is still too low relative to the data, while the correlation between employment and output growth is instead too high. Despite providing more information about labor market dynamics, the model still fails to deliver the positive correlation between hours and employment, and the β_{cov} ranges from -0.43 to 0.37. In addition, this version of the model tends to overstate the importance of hours per worker relative to the data, as the posterior for β_h ranges from 0.16 to 0.76, whereas its value is 0.18 in the data. All in all, the benchmark model—independently of the shocks considered or the observables included in the estimation—is unable to replicate satisfactorily the correlation structure between the aggregate macroeconomic series and the labor market variables.

The main issue is that hours per worker tends to be too countercyclical in the model.[35] To address the shortcomings of the benchmark model, in the next section we propose two modifications that reconcile the model with the data. First, we introduce preferences with a flexible parametrization of the strength of the short-run wealth effect on hours supply. In addition, we also assume adjustment costs to the intensive margin to help dampen the movement in hours. These two ingredients provide a parsimonious strategy to reproduce the correlation of the labor market variables and the macroeconomic series.

5 Alternative Model

Parametrized Wealth Effects in Labor Supply

We modify the period utility function in equation (1) to encompass an alternative preference specification that features a flexible parameterization of the strength of the short-run wealth effect on the labor supply. We consider the class of preferences first introduced by Jaimovich and Rebelo (2009) (JR henceforth). Following Schmitt-Grohe and Uribe (2007), we modify the original JR specification to allow for internal consumption habit formation. The period utility function of the representative household now is given by:

$$\frac{1}{1-\sigma}\left(C_t - h_C C_{t-1} - \bar{h}_t X_t \int_0^{L_t} \frac{h_{jt}^{1+\omega}}{1+\omega} dj\right)^{1-\sigma} - \frac{1}{1-\sigma}, \tag{17}$$

where $\gamma \in (0,1]$ and $X_t = (C_t - h_C C_{t-1})^{\gamma} X_{t-1}^{1-\gamma}$. The parameter γ governs the magnitude of the wealth elasticity of labor supply. As $\gamma \to 0$, in the absence of habit formation, and abstracting from time variation in the number of employed family members, this is the preference specification considered by Greenwood, Hercowitz, and Huffman (1988). This special case induces a supply of labor that is independent of the marginal utility of consumption. As a result, when γ is small, anticipated changes in income will not affect the current labor supply. As γ increases, the wealth elasticity of labor supply rises. In the polar case in which γ is unity, per-period utility becomes a product of habit-adjusted consumption and a function of hours worked.

[35] Notice that if we assumed that firms have the right to manage (RTM) hours, hours supply considerations (and thus wealth effects) do not affect h_t. Nevertheless, the lack of positive comovement between L_t and h_t persists—under RTM, h_t equates the marginal product of an hour worked to w_t, implying that, with wage rigidities and pre-determined capital, h_t falls when L_t increases, other things equal. In contrast, the comovement between h_t and L_t improves with Nash bargaining over hours per worker, as long as the worker's bargaining share is not constrained to be symmetric to the corresponding share in wage Nash bargaining. This result reflects the additional degree of freedom stemming from the extra bargaining parameter. Results are available upon request.

Notice that the term X_t makes preferences non–time-separable in consumption and hours worked provided that γ is different from one. In this case, the presence of employed and unemployed workers implies that even with full risk-sharing within the household, the specification in equation (17) cannot be obtained by aggregating primitive utility functions for employed and unemployed workers.[36]

A key advantage of JR preferences is that they are compatible with long-run balanced growth provided that $\sigma = 1$, which we assume from now on. Thus, the representative household maximizes the expected intertemporal utility function

$$W_t \equiv E_t \sum_{s=t}^{\infty} \beta^{s-t} \bar{\beta}_s \left[\log \left(C_s - h_C C_{s-1} - \bar{h}_s X_s \int_0^{L_s} \frac{h_{js}^{1+\omega}}{1+\omega} dj \right) \right] \tag{18}$$

subject to the sequence of budget constraints given by equations (13) and (14). This alternative preference specification affects the household's stochastic discount factor, since now the marginal utility of consumption, $u_{Ct} \equiv \partial W_t / \partial C_t$, is given by:

$$\begin{aligned} u_{Ct} = {} & \bar{\beta}_t \Psi_t^{-1} + \gamma \mu_t \left(C_t - h_C C_{t-1} \right)^{\gamma - 1} X_{t-1}^{1-\gamma} - \beta h_C E_t \left(\bar{\beta}_{t+1} \Psi_{t+1}^{-1} \right) \\ & - \gamma \beta h_C E_t \left[\mu_{t+1} \left(C_{t+1} - h_C C_t \right)^{\gamma - 1} X_t^{1-\gamma} \right], \end{aligned} \tag{19}$$

where $\Psi_t \equiv C_t - h_C C_{t-1} - \bar{h}_t X_t \int_0^{L_t} \left[h_{jt}^{1+\omega} / (1+\omega) \right] dj$ and $\mu_t \equiv -\bar{\beta}_t \Psi_t^{-1} L_t \bar{h}_t h_{jt}^{1+\omega} / (1+\omega) + (1-\gamma) \beta E_t \left[\mu_{t+1} \left(C_{t+1} - h_C C_t \right)^{\gamma} X_t^{-\gamma} \right]$. The marginal rate of substitution between consumption and leisure now is defined as:

$$W_{h_j t} \equiv \frac{\partial W_t}{\partial h_{jt}} = -\Psi_t^{-1} \bar{\beta}_t \bar{h}_t h_{jt}^{\omega} X_t. \tag{20}$$

Notice that the marginal rate of substitution between hours and consumption for worker j, $-W_{h_j t} / u_{Ct}$, only depends on aggregate variables, with the exception of hours worked, h_{jt}.

Hours Adjustment Costs

We modify the production function in equation (2) by introducing hours adjustment costs, capturing various frictions that may constrain the ability of firms to adjust hours per worker—for instance, technological constraints due to set-up costs and coordination issues. We maintain the assumption

[36] We have considered an alternative version of the model that features JR preferences for employed workers and a distinct utility function for unemployed family members. We then aggregate across agents, maintaining the assumption of full risk sharing within the household. Details are available upon request.

that each producer is of measure zero relative to the size of the economy.

A filled job in firm j produces

$$(k_{jt})^a \left\{ \bar{A}_t h_{jt} \left[1 - \frac{\phi_h}{2} (h_{jt} - h_j)^2 \right] \right\}^{1-\alpha} \tag{21}$$

units of the intermediate input, where $\phi_h \geqslant 0$ denotes the cost of adjusting hours per worker (in units of the intermediate input), and h_j is the value of hours-per worker along the balanced growth path. Since, as in the benchmark model, all workers produce with identical productivity, we continue to omit the worker-specific index in our notation.

Let $\tilde{h}_{jt}$ denote effective hours used as an input of production:

$$\tilde{h}_{jt} = h_{jt} \left[1 - \frac{\phi_h}{2} (h_{jt} - h_j)^2 \right],$$

such that the job production function can be written more compactly as $(k_{jt})^a \left(\bar{A}_t \tilde{h}_{jt} \right)^{1-\alpha}$. The value of the marginal product of an hour per worker is now given by

$$(1-\alpha) \varphi_t \left(\frac{k_{jt}}{\bar{A} \tilde{h}_{jt}} \right)^\alpha \bar{A}_t \Delta_{\tilde{h}_{jt}},$$

where

$$\Delta_{\tilde{h}_{jt}} \equiv \frac{\partial \tilde{h}_{jt}}{\partial h_{jt}} = \frac{\tilde{h}_{jt}}{h_{jt}} - \phi_h h_{jt} (h_{jt} - h_j).$$

Notice that up to a first-order approximation, $\tilde{h}_{jt} = h_{jt}$.

Hours per Worker

Optimality in hours per worker, h_{jt}, continues to equate the worker's marginal rate of substitution between consumption and leisure to the value of the marginal product of an extra hour worked:

$$-\frac{W_{h_{jt}}}{u_{Ct}} = (1-\alpha) \varphi_t \left(\frac{k_{jt}}{\bar{A} \tilde{h}_{jt}} \right)^\alpha \bar{A}_t \Delta_{\tilde{h}_{jt}},$$

where $W_{h_{jt}} \equiv \partial W_t / \partial h_{jt}$ is now defined by equation (20). Owing to perfectly mobile capital across jobs, the optimal capital allocation for each job continues to equate the value of the marginal product of capital to its marginal cost:

$$\alpha\varphi_t\left(\frac{k_{jt}}{\bar{A}\tilde{h}_{jt}}\right)^{\alpha-1}=r_{Kt}. \tag{22}$$

Therefore, hours per worker satisfy the following optimality condition:

$$\Psi_t^{-1}\bar{\beta}_t\bar{h}_t h_{jt}^{\omega}X_t=(1-\alpha)\,\varphi_t\left(\frac{r_{Kt}}{\alpha\varphi_t}\right)^{\frac{\alpha}{\alpha-1}}\bar{A}_t\Delta_{\tilde{h}_{jt}}. \tag{23}$$

Equation (23) implies that hours per worker, h_{jt}, continue to depend only on aggregate conditions, so that $h_{jt}=h_t$ (and thus $\tilde{h}_{jt}=\tilde{h}_t$).[37] Thus, hours per worker do not depend on firm-level employment, i.e., $\partial h_{jt}/\partial L_{jt}=0$. Notice also that equation (22) implies that $k_{jt}=k_t$. Thus, total output exhibits constant returns to scale in total effective hours, $L_{jt}\tilde{h}_t$, and capital:

$$Y_{jt}^I\equiv\int_0^{L_{jt}}(k_{jt})^a\left(\bar{A}_t\tilde{h}_t\right)^{1-\alpha}dj=K_{jt}^{\alpha}\left(\bar{A}_tL_{jt}\tilde{h}_t\right)^{1-\alpha}, \tag{24}$$

where $K_{jt}=L_{jt}k_t$ is the total amount of capital used by the intermediate input producer j.

As shown in Appendix B, the equilibrium wage differs from what is implied by the sharing rule in equation (11) only because of the different definitions of the value of the marginal product of labor and the flow value of unemployment implied by the parametrized wealth effect on the labor supply. Importantly, the hourly wage remains independent of the scale of the firm, since the firm and worker surplus continue not to depend on firm-level employment, L_{jt}. Overall, our modifications affect three equilibrium conditions—equations (4), (14), and (15) in Table A.3—and three definitions—equations D.4-D.6 in Table A.3 in Appendix C.

6 Hours and Employment in Post-War U.S. Business Cycles

This section contains the econometric analysis of the model with JR preferences and hours adjustment costs, which we reference as our preferred model. We first discuses the prior and posterior distributions of parameters as well as the ability of the model to fit the data. Next, we study the propagation of structural disturbances and present a counterfactual experiment to assess the importance of the intensive margin in U.S. recoveries.

[37] Notice that Ψ_t depends on aggregate employment, L_t. Since the firm is of measure zero relative to the economy, $\partial L_t/\partial L_{jt}=0$.

Estimation and Model Performance

We estimate the model with the same eight observables discussed above. For symmetry, we employ the same prior for hours adjustment costs as for investment adjustment costs, a normal distribution centered at 4 with a standard deviation of 1.5. This prior is diffuse enough to allow positive mass over a wide range of low and high adjustment cost values. We use a dogmatic prior for the parameter governing the strength of the wealth effect in labor supply, setting $\gamma = 0.01$. This value is sufficiently small to approach the limiting case of no wealth effects. In addition, we also have estimated a version of the model with a Beta prior for γ centered at 0.5 with a standard deviation of 0.1. The posterior mean for γ in this case is 0.16, outside the 90 percent prior bands. Lowering the prior mean of γ results in lower posterior estimates and similar transmission mechanisms as our calibrated version. The priors for the remaining parameters are the same as those discussed in Section 4.

Figure 3 plots the correlogram for several aggregate macroeconomic and labor market variables in the data (solid lines), as well as the 90 percent posterior intervals implied by both parameter and small sample uncertainty from this preferred model (dashed lines) and the benchmark model with eight observables (dotted lines). In almost all cases, the correlogram bands for the preferred model encapsulate the data counterparts, whereas the benchmark model often fails to account for the cross-correlation structure of labor variables and macroaggregates. The preferred specification also implies variance decompositions of total hours more united with the data counterparts: β_h ranges from 0.12 to 0.54, β_L from 0.20 to 0.72, and β_{cov} from -0.05 to 0.44.

The inclusion of JR preferences significantly improves the performance of the model through two channels. First, as described in the previous section, JR preferences can reduce the strength of the short-run wealth effect on the labor supply. This mitigates the effect of variations in consumption on the marginal rate of substitution and makes hours per worker more responsive to changes in the value of the marginal product of hours. This also explains the data's preference for large adjustment costs to hours, as they readjust the variability of hours to be comparable to the data. Second, the nonseparable preferences of the JR specification reinforce the comovement between consumption and hours. When the two margins of labor increase, the marginal utility of consumption also rises, prompting households to consume more.

Table 2 reports the log marginal data densities and Bayes factors for the benchmark and preferred models. Bayes factors quantify the relative support of two competing specifications given the

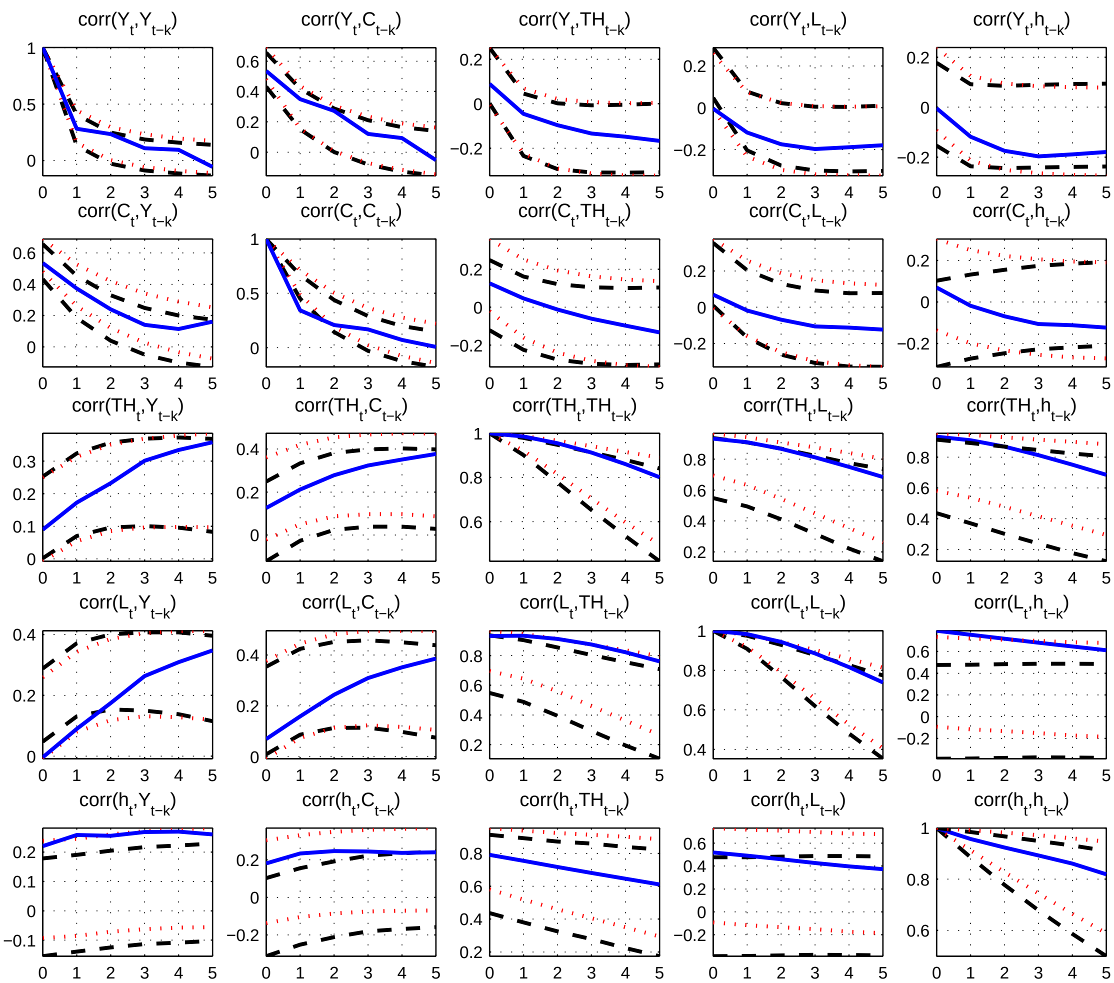

Figure 3. Correlograms from the data (blue solid lines) and 90 percent posterior intervals from 1) the preferred model with JR preferences and hours adjustment costs (red dotted lines) and 2) the benchmark model with eight observables (black dashed lines).

observed data and are calculated from marginal data densities, see Kass and Raftery (1995). Log marginal data densities are computed using Geweke's (1999) modified harmonic mean estimator with a truncation parameter of 0.5.[38] Higher log marginal data density values imply greater fit. Kass and Raftery (1995) suggest that if twice the natural logarithm of the Bayes factor is greater than 2, then there is positive evidence in favor of the first model. Values greater than 10 suggest very strong evidence. The benchmark model has a value substantially larger than 10, suggesting the data have strong preference for the model with JR preferences and hours adjustment costs.

As a final check on the performance of our preferred model, we perform the following counterfactual. First, we use the posterior mean estimates from the benchmark model estimated with seven observables to obtain the model's predicted series for the seven structural shocks (TFP, investment, preference, government spending, interest rate, price markup, and bargaining power) using the two-sided Kalman filter. Next, we use the filtered seven structural shocks to simulate variables from two models: (1) the benchmark seven shock model and (2) the preferred model at its posterior mean estimates. Figure 4 displays the labor market variables generated from the benchmark model (top panel), and the preferred model (bottom panel), as well as the data (dotted-dashed lines in both panels). Since the benchmark model includes total hours as an observable, by construction the two-sided Kalman filter ensures the benchmark model perfectly matches this series. However, the benchmark model matches total hours only with counterfactual employment and hours per worker series. In contrast, the preferred model's implied employment and total hours series track the data well. It is important to note that the preferred model series are generated from the benchmark model's seven structural series. Thus, the preferred model does not perfectly match the total hours series. Nonetheless, it matches this series quite well in the counterfactual while additionally improving the fit of the individual labor margins. This result confirms the preferred model's fit stems from internal propagation, as opposed to being induced entirely from the addition of an hours supply shock.

To conclude, we note that while parametrized wealth effects and hours adjustment costs are key ingredients for the model to reproduce the empirical covariances of labor market variables, hours supply shocks remain a key contributor to the variance of hours per worker. In particular,

[38]Model rankings are invariant to alternative truncation parameter choices. We restrict analysis to the parameter subspace that delivers a unique rational expectations equilibrium and denote this subspace as Θ_D. In addition, we restrict parameters to ensure the steady-state wage lies within the feasible bargaining set. Let $I\{\theta \in \Theta_D\}$ be an indicator function that is one if the parameter vector θ is in the determinacy region and zero otherwise. Then, the joint prior distribution is defined as $p(\theta) = (1/c)\,\tilde{p}(\theta) I\{\theta \in \Theta_D\}$, where $c = \int_{\theta \in \Theta_D} \tilde{p}(\theta) d\theta$ and $\tilde{p}(\theta)$ denotes the joint prior density.

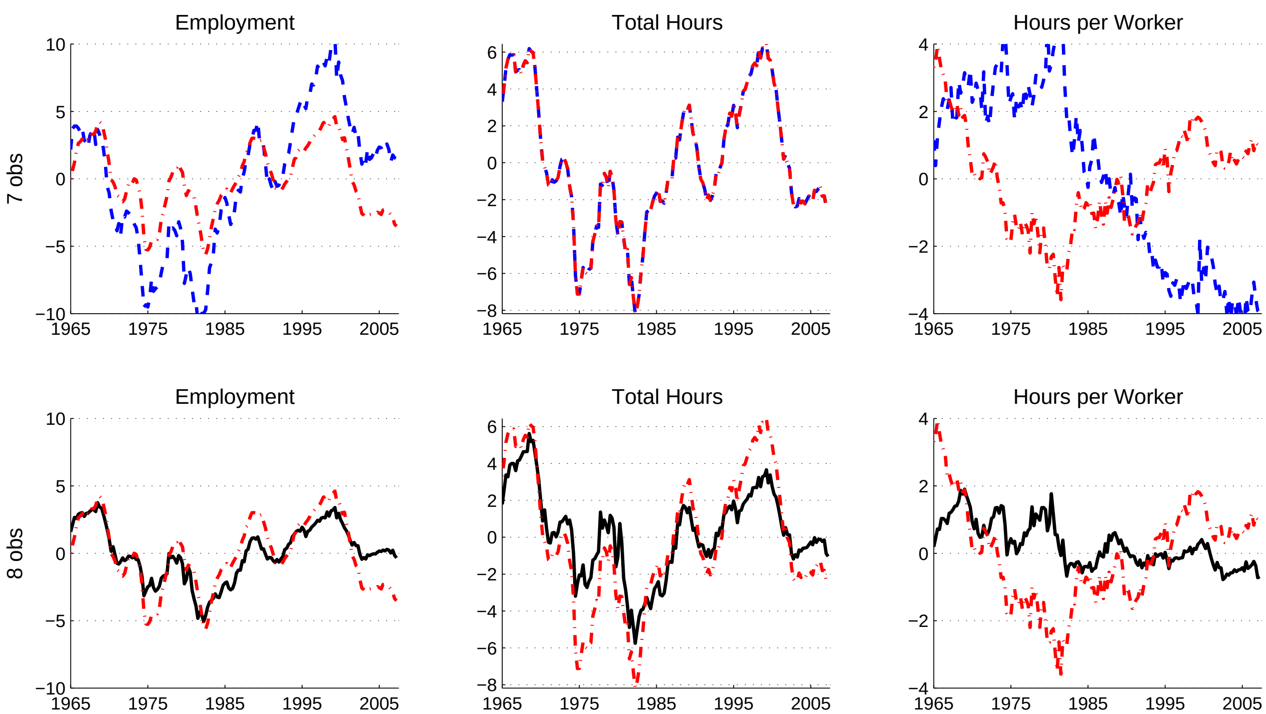

Figure 4. Fitted and counterfactual variables. Blue dashed lines are simulated from the posterior mean estimates of the benchmark model with seven structural shocks. Black solid lines are simulated from the posterior mean estimates of the preferred model using the benchmark model's seven shock series. Red dotted-dashed lines denote the data.

the variance decompositions presented in Appendix E show that $\bar{h}_t$ accounts for between 60 to 80 percent of the volatility of h_t. The remaining part is mainly due to either investment-specific or productivity shocks, depending on the time horizon considered.

A natural question concerns the interpretation of hours supply shocks in the context of the model. One possibility is that $\bar{h}_t$ simply reflects measurement error. To address this issue, we estimate an alternative version of the model that additionally allows for measurement error in each observable. Even in this case, hours supply shocks still remain an important contributor to fluctuations in hours per worker (results available upon request).

A closer look at the model equilibrium conditions presents a simple structural interpretation for the role of $\bar{h}_t$ at business cycle frequencies. Consider the log-linear approximation of the intratemporal condition for optimality in hours with the assumption that steady-state hours per worker are normalized to one:

$$\begin{aligned}
&\hat{\bar{\beta}}_t - \frac{1}{\Psi}\left[\hat{C}_t C - h_C \frac{C}{g_A}\left(\hat{C}_{t-1} - \hat{g}_{At}\right) - \frac{LX}{1+\omega}\left(\hat{L}_t + (1+\omega)\,\hat{h}_t + \hat{X}_t\right)\right] + \hat{h}_t + \hat{X}_t - \hat{u}_{Ct} \\
&= \hat{\varphi}_t + \alpha\left(\hat{u}_{Kt} + \hat{\bar{K}}_t - \hat{g}_{At} - \hat{L}_t - \hat{h}_t\right) - \phi_h \hat{h}_t - \left(\omega + \frac{XL}{(1+\omega)\Psi}\right)\hat{\bar{h}}_t,
\end{aligned}$$

where hats denote log-deviations. The right-hand side of this equation shows that $\bar{h}_t$ acts as a time-varying shifter of the marginal product of one hour worked, consistent with the empirical observation that changes or differences in working hours do not entail the same changes or differences in effective labor input (Pencavel, 2015). Thus, $\bar{h}_t$ captures cyclical fluctuations in unobservable utilization of hours per worker, reflecting variations in unobserved worker effort (see, for instance, Kimball, Fernald, and Basu, 2006).[39]

Aggregate Shocks and the Margins of Labor Adjustment

To further examine the differences in the preferred and benchmark models' transmission channels, we examine the propagation mechanism of individual shocks, focusing on the adjustment of the two labor margins. For the two model specifications, we focus on the dynamics following innovations to aggregate TFP, investment-specific productivity, preference, worker's bargaining power and to the nominal interest rate. In the preferred model, these shocks account for over 85 percent of the

[39] Marchetti and Nucci (2014) document a hump-shaped profile of labor effort at business cycle frequencies. Notice that $\bar{h}_t$ may also capture in reduced-form other unmodeled features of hours adjustment such as overtime hours. A formal assesment of the quantitative importance of this alternative interpretation is precluded by the absence of economy-wide data for overtime hours in the U.S. economy. In addition, Wolters (2016) discusses how low-frequent demographic trends and sectoral shifts can affect hours per worker measurements.

variance of the growth rate of output, consumption, and investment on impact and 10 periods after the shocks. For total hours, the contribution is 80 percent on impact and 60 percent after 10 periods.[40]

Figure 5 reports the 90 percent posterior intervals for the impulse responses of output growth, employment, and hours per worker. Solid lines denote the responses of the benchmark model estimated with eight observables, while dashed lines correspond to the preferred framework. In all cases, responses are computed following a one standard deviation shock. As reported in Table 2, the estimated persistence and standard deviations of innovations are similar across the benchmark and preferred specifications, suggesting that the improved fit can be traced to an improvement in the propagation mechanism rather than to different estimates of the shock processes.

The first column displays the responses following a positive shock to the growth rate of aggregate productivity. Other things equal, price stickiness induces lower labor demand, rather than lower goods prices. However, in the benchmark model, the brunt of the impact adjustment of total hours is on the intensive margin, as higher productivity induces a positive wealth effect that reduces labor supply. By contrast, employment is virtually unaffected initially. The initial decline in hours per worker reduces the flow value of unemployment, leading to wage moderation. As a consequence, the surplus of hiring a worker increases, leading to higher employment after the first period. The relative contribution of the two margins is altered in our preferred model. JR preferences reduce the wealth effect on the labor supply, causing hours per worker to drop less on impact. This, in turn, reduces its effect on the firm's surplus, leading employment to decline on impact as well. Thus, reducing the wealth effect on the labor supply induces positive comovement between the intensive and the extensive margin. A similar mechanism is at work following an increase in the degree of impatience of households—the preference shock $\bar{\beta}_t$ reported in column two of figure 5. In this case, households substitute from investment to consumption. Higher aggregate demand boosts employment in both models. However, in the preferred model, due again to the limited wealth effect, the expansionary demand shock results in an increase in hours per worker (rather than in a fall, as in the benchmark model), and thus implies a positive comovement with employment. The same logic applies to the monetary shock as well (column five), with the exception that the increase in the policy rate translates into reductions in demand, as the real interest rate increases.

[40]Appendix E presents the full details of variance decompositions. Markup shocks account for 21 percent of the variance in total hours at period 10. We do not report the impulse responses following an innovation to the elasticity of substitution across goods because they are qualitatively and quantitatively similar across the preferred and the benchmark model.

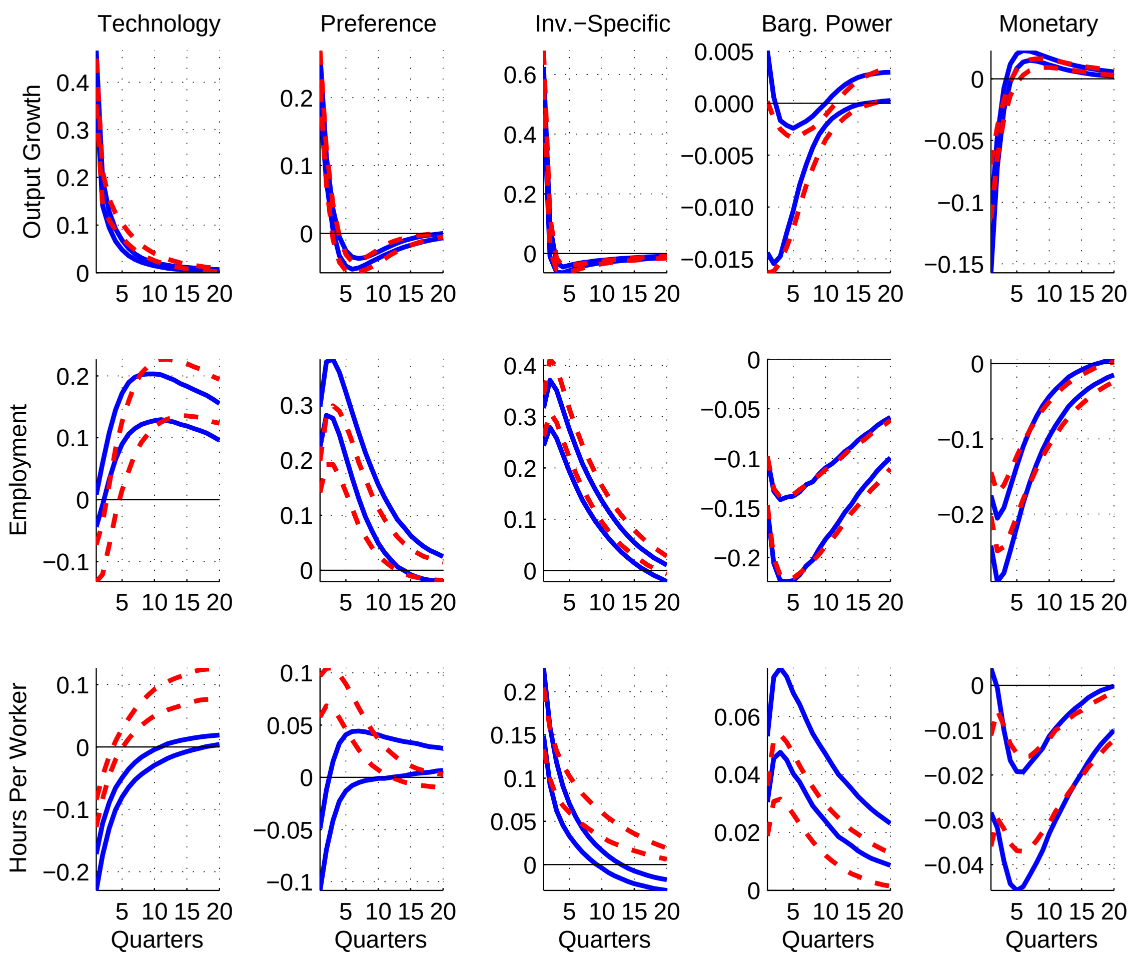

Figure 5. Impulse response following a standard deviation innovation. Bands represent 90 percent confidence intervals. Solid lines denote the responses of the benchmark model estimated with eight observables, while dashed lines correspond to the preferred framework.

Finally, an increase in productivity specific to the production of the investment good displays positive comovement between the labor margins in both specifications (column three of figure 5). In this case, the wealth effect is small, independently of the particular form of preferences assumed because of the low estimated persistence of the shock. The limited persistence implies a short-lived increase in output growth with little effect on permanent income and consumption. As a result, the wealth effect is not large enough to induce a negative comovement between hours per worker and employment on impact.

An exogenous increase in the workers' bargaining power (column four of figure 5) directly affects employment, since workers appropriate a larger share of the surplus through higher wages. Firms have fewer incentives to create jobs and total hours worked adjusts through the relatively cheaper intensive margin. The shock is recessionary as it increases the cost of production, leading output, investment and consumption to decline. The impulse responses are qualitatively similar in the benchmark and preferred models, although hours per worker in the preferred model, insulated by the wealth effect, tends to respond less. The responses of macroaggregates and total hours following an increase in the disutility of hours worked $\bar{h}_t$ (not reported) are comparable to those following the bargaining power shock. In this case, the adjustment of the labor market margins are reversed, with hours per worker declining and employment rising.

Employment and Hours in U.S. Cyclical Recoveries

We now use the preferred model to empirically study the cyclical behavior of hours and employment in U.S. data. We focus on U.S. business cycle recoveries—i.e., the progression of the economy after having hit the trough of a recession—since the topic recently has received attention in policy circles due to the so-called jobless recoveries (see Bernanke, 2003).

Figure 6 plots the historical decomposition of the growth rate of employment, hours per worker, and output using the posterior mean estimates of the preferred model. The historical decompositions display the structural innovations responsible for the time-varying comovement between hours per worker and employment in U.S. recoveries. For instance, employment and hours per worker comove positively in the recoveries of the first part of the sample. Figure 6 shows that the recoveries of 1970, 1975, and 1982 are preceded by negative investment-specific shocks, as well as negative markup shocks in 1975 and 1982 (see Appendix E for the smoothed shocks in the recessions and recoveries we analyze). During the recoveries, these shocks are dampened or reversed, which simultaneously boosts employment and hours per worker. By contrast, the recoveries of

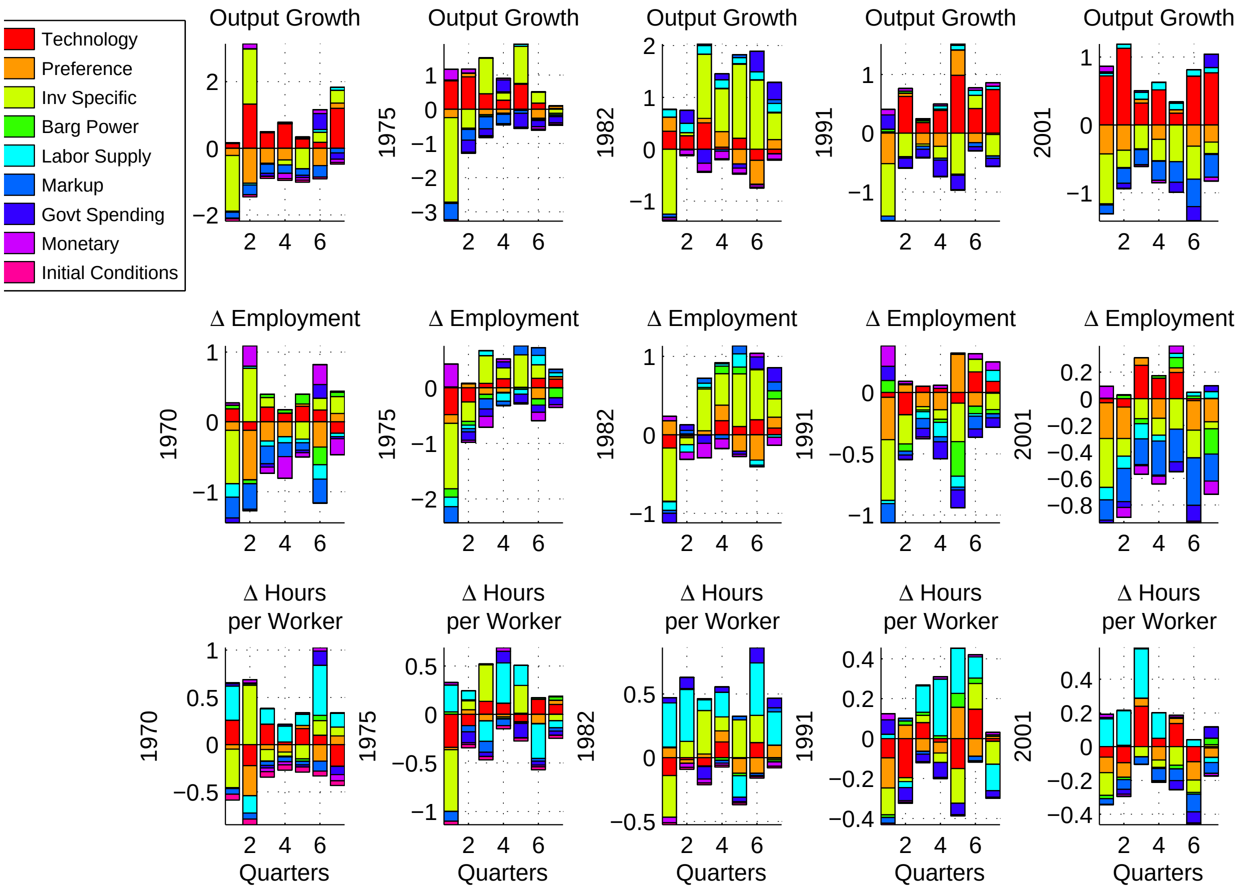

Figure 6. Historical decomposition for US business cycle recoveries.

1991 and 2001 feature negative comovement between employment and hours. In these episodes, the reversion of investment-specific shocks is significantly weaker. Moreover, the recoveries of 1991 and 2001 are characterized by a larger role for labor market disturbances: positive shocks to the workers' bargaining power in 1991 and lower disutility of hours in 2001.[41] In line with the previous discussion, both labor market shocks and the reduced importance of supply shocks break the positive comovement between the margins of labor adjustment during these recoveries.

Our model provides an ideal laboratory to quantify the contribution of the intensive margin for employment outcomes. Toward this goal, we perform the following counterfactual. First, we use the posterior mean estimates of the preferred model and the two-sided Kalman filter to construct smoothed estimates of the structural shocks and model variables. We then construct a counterfactual time series in each recovery where hours are held constant at their steady-state value starting at the trough. In each episode, we initialize the economy using the smoothed estimates and then compare the actual path to the hypothetical one where hours per worker are constant. Our results indicate that the contribution of hours per worker to the employment recovery—i.e., whether hours per worker and employment display substitutability or complementarity—depends upon the structural disturbances that are responsible for labor market fluctuations.

Figure 7 contrasts the actual values of the growth rate of GDP, employment and hours per worker (solid lines) with the model counterfactual values (dashed lines).[42] Figure 7 shows that the contribution of hours adjustment during U.S. cyclical recoveries is significant. Importantly, the direction of this effect can be either positive or negative. In the recoveries of 1970, 1975, 1982, and 2001, employment would have been, on average, half of a percentage point higher in the absence of any adjustment along the intensive margin. In the recovery of 1991, employment would have been 0.4 percentage points lower without hours adjustment.

To understand these results, notice that the channel through which the intensive margin affects employment outcomes ultimately depends on the nature of the shocks driving employment fluctuations. When shocks that induce positive comovement between h_t and L_t drive the recoveries (such as in 1970, 1975, and 1982), employment must increase more when the intensive margin cannot adjust, as firms facing nominal rigidities are forced to adjust their labor force along the extensive margin to meet a given demand. By contrast, when recoveries feature a more prominent role for

[41] The contribution of labor supply shocks in jobeless recoveries is consistent with Aaronson, Rissman, and Sullivan (2004).

[42] Since the growth rate of GDP, employment, and total hours are observables, the smoothed estimates of these variables from the two-sided Kalman filter, as well as hours per worker, perfectly match the data by construction.

labor market shocks, lack of adjustment along the intensive margin can either increase or decrease employment. In 2001, constant hours per worker remove the negative effect of the higher efficiency of hours per worker (lower $\bar{h}_t$) on hiring. As a result, employment is higher in the counterfactual economy. By contrast, the first part of the recovery in 1991 is characterized by complementarity between hours per worker and employment. In this case, a series of negative realizations of bargaining power shocks that precede the recovery keeps employment above its steady-state level. Since a decrease in the bargaining power of workers increases the surplus of the firm, producers shift away from the (relatively more expensive) hours margin, which increases the surplus of the firm and employment even more. In the counterfactual economy with constant hours, this secondary effect is shut down, leading employment to be lower. Over time the contribution of bargaining shocks vanishes, while the contribution of productivity shocks increases, leading employment to be counterfactually higher.

Our results demonstrate that in order to evaluate the contribution of hours per worker to employment, one needs to account for the particular disturbances driving the economy in specific episodes.

7 Sensitivity Analysis

We investigate the robustness of our results under several alternative specifications. The results of these robustness checks are summarized in table 3. For reference, the first two rows report the results of the benchmark and preferred models, previously discussed. To understand how well the model accounts for the labor market variables, we report for each specification the shares of the variance of total hours attributed to hours per worker, employment, and their covariance. In addition, we report log marginal data densities. In all robustness cases, the preferred model implies a higher log marginal data density, signaling greater fit. We discuss each robustness case in turn.

Alternative Shocks

We explore the sensitivity of the results to the inclusion of an alternative structural shock. We estimate the benchmark model with seven observables when the hours supply shock is included as opposed to the bargaining power shock. Hours supply shocks can potentially improve the model's fit with respect to the labor market variables, as they directly affect the intensive labor margin. The total hours variance shares in this case are listed in row "7 obs, $\bar{h}$ shock" of table 2. For comparison,

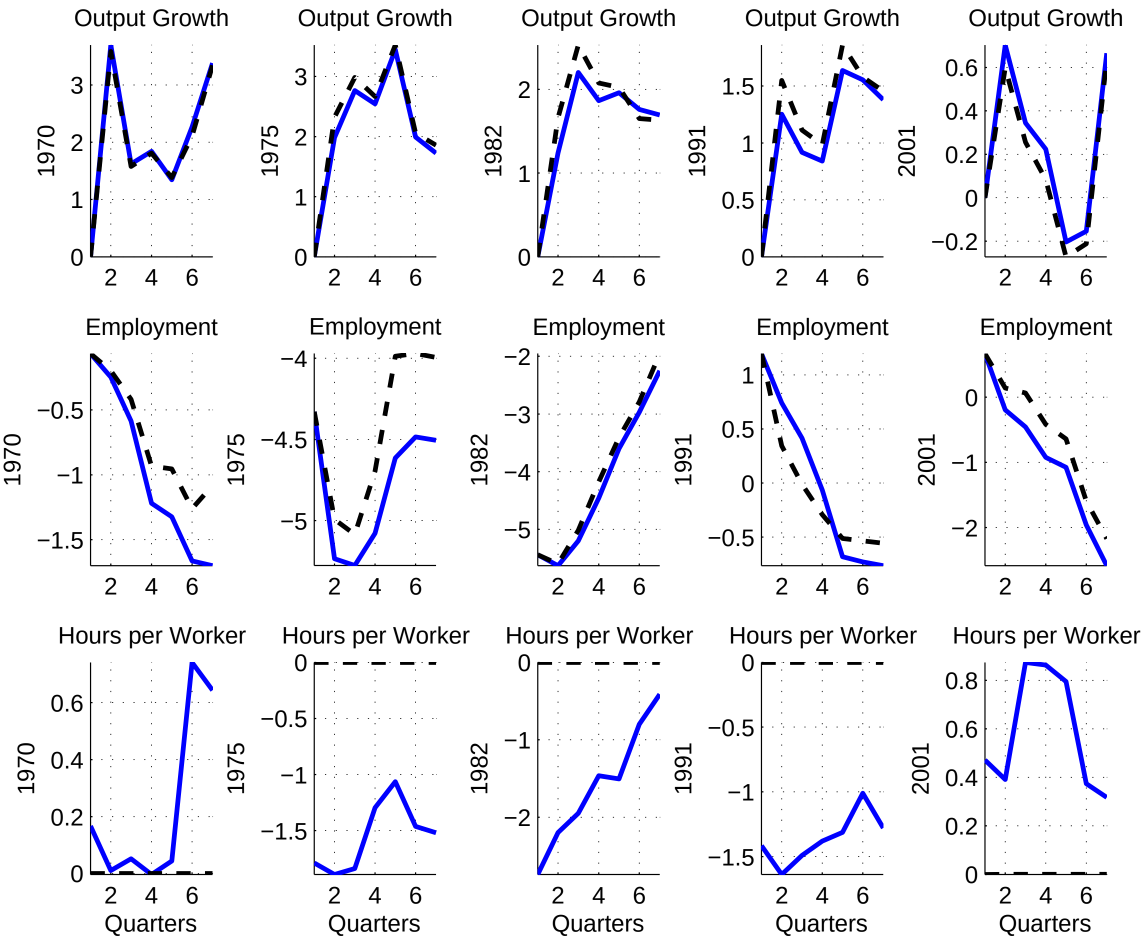

Figure 7. Recoveries relative to GDP trough. Blue solid lines: actual data. Black dotted-dashed lines: Counterfactual with hours per worker constant at his trend level from the trough-on. Red dashed lines: preferred model. Output growth is normalized to zero at the trough.

Table 3: Robustness checks from Alternative Estimated Specifications.

		Log Marginal Data Density	β_h	β_L	β_{cov}
CES Data			**0.18**	**0.51**	**0.31**
	Preferred Model	-1024	[0.13, 0.56]	[0.20, 0.71]	[-0.05, 0.44]
	Benchmark Model	-1073	[0.16, 0.76]	[0.22, 0.89]	[-0.43, 0.37]
	Preferred Model, no wage obs	-869	[0.07, 0.25]	[0.33, 0.62]	[0.26, 0.46]
	Benchmark Model, no wage obs	-881	[0.08, 0.38]	[0.26, 0.69]	[0.12, 0.46]
	Preferred Model, mix wage obs	-1332	[0.06, 0.56]	[0.22, 0.95]	[-0.28, 0.45]
	Benchmark Model, mix wage obs	-1380	[0.09, 0.72]	[0.26, 1.12]	[-0.62, 0.39]
	7 obs, $\bar{\eta}$ shock	-1008	[0.03, 0.22]	[0.64, 1.21]	[-0.35, 0.25]
	7 obs, $\bar{h}$ shock	-1076	[0.18, 0.60]	[0.10, 0.50]	[0.16, 0.44]
CPS Data			**0.07**	**0.78**	**0.15**
	Preferred Model	-1152	[0.05, 0.30]	[0.31, 0.70]	[0.14, 0.45]
	Benchmark Model	-1184	[0.11, 0.47]	[0.26, 0.78]	[-0.07, 0.43]
SW Data			**0.39**	**0.44**	**0.17**
	Preferred Model	-989	[0.14, 0.62]	[0.18, 0.67]	[-0.07, 0.42]
	Benchmark Model	-1051	[0.20, 0.83]	[0.19, 0.80]	[-0.40, 0.36]

Note: Parenthesis denote 90 percent posterior intervals. Log marginal data densities calculated using Geweke's modified harmonic mean estimator; values are comparable conditional on observables, with different sets denoted by horizontal lines.

the estimates from the benchmark model with seven observables is included for reference in row "7 obs, $\bar{\eta}$ shock." While the hours supply shock does ensure the model matches the covariance of employment and hours per worker, it does so with a counterfactually high volatility of hours per worker, as β_h's bands encompass higher values than β_L's bands.

Wage Data

We document the robustness of our results to the wage observable. Using U.S. micro data, Haefke, Sonntag, and Van Rens (2013) document that the wages of newly hired workers, unlike wages in ongoing relationships, are volatile and procyclical. In addition, our benchmark wage observable is not restricted to earnings, as it includes employer contributions to employee-benefits (Justiniano, Primiceri, and Tambalotti, 2013). We address these issues as follows. We first consider a specification where we drop wages from the set of observables and the bargaining power shock. In this case, we further assume that wage adjustment is flexible. Our estimates imply that employment volatility stems from a higher value of the flow value of unemployment.[43] Rows "Preferred Model, no wage obs" and "Benchmark Model, no wage obs" of table 3 displays the total hours variance shares in this case. Without wage stickiness, both models better match the covariance of employment and hours per worker. However, the preferred model still produces better fit—as evidenced by a significantly higher log marginal data density (due to improved model correlations between labor market variables and macroaggregates).

In addition, we estimate a version of the preferred model in which three measures of the wage are simultaneously included in the observables. This strategy has been recently used by several papers in the estimation literature (see for instance Boivin and Giannoni (2006), Gali, Smets, and Wouters (2011), and Justiniano, Primiceri, and Tambalotti (2013)). The first is the measure described in section 4, which is the BLS' hourly compensation for the nonfarm business sector. The second measure is the BLS' average hourly earnings of production and nonsupervisory employees. The third measure is the quality adjusted wage series of Haefke, Sonntag, and Van Rens (2013), which adjusts for individual-level characteristics. We assume that each series represents an imperfect

[43] Chahrour, Chugh, and Potter (2014) estimate a search-based real business cycle model using a broad set of wage indicators, allowing the latent wage series in the model to follow a non-structural ARMA process. Under the estimated process, wages adjust immediately to most shocks.

measure of the model wage according to:

$$\begin{bmatrix} \text{Comp Wage}_t \\ \text{Earn Wage}_t \\ \text{Quality Wage}_t \end{bmatrix} = \begin{bmatrix} \Gamma_1 \\ \Gamma_2 \\ \Gamma_3 \end{bmatrix} (\hat{w}_t - \hat{w}_{t-1} + \hat{g}_{At}) + \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \end{bmatrix}$$

where e_{it} for $i = 1, 2, 3$ denote *iid* observation errors.[44] Rows "Preferred Model, mix wage obs" and "Benchmark Model, mix wage obs" of Table 3 display the total hours variance shares in this case. Again, the preferred model has a better fit, with bands well encompassing the data.

Alternative Labor Market Variables and Subsample Analysis

We check whether our results are sensitive to the labor market measures used for the estimation. We estimate the model using CPS labor market variables, as in Ramey (2012).[45] In this case, neither total hours nor employment are linearly detrended as it is less obvious the series exhibit a deterministic trend; the two variables are demeaned. Parameter estimates in this case are comparable to those in table 2. Log marginal data densities suggest strong preference for the preferred model as well. As shown in table 3, the posterior bands for the model's βs well-encompass their data counterparts. In addition, these results are robust to using the Smets and Wouters (2007) labor market observables for estimation, which are commonly employed in the DSGE estimation literature, as evidenced by the last rows of table 3.

Finally, our analysis of U.S. recoveries is robust to sub-sample estimation conditional on our observables. This experiment allows us to address how structural change in parameter estimates (in particular, those directly affecting labor market dynamics) contributes to the dynamics of hours and employment in post-war U.S. data (the results are available upon request). As is common practice in the literature, we split our original sample at the start of the so-called Great Moderation, estimating from 1965:1 to 1983:4 and 1984:1 to 2007:4.

[44]The priors for the Γ's are normal distributions centered at 1 with a standard deviation of 0.5. The priors for the standard deviations of the wage observation errors are inverse gamma distributions with mean of 0.1 and standard deviation of 1. Specifically, we use the median real wage of new hires corrected for fluctuations in all observable worker characteristics from Haefke, Sonntag, and Van Rens (2013). This series is not available for the full sample period, but the Kalman filter handles missing observations.

[45]See Appendix A for a description of the alternative labor market data.

8 Conclusions

We estimate a benchmark search and matching model augmented with endogenous fluctuations in hours per worker and shocks that affect both margins of labor adjustment. We show that this benchmark model is unable to replicate the correlation structure between aggregate macroeconomic series and the labor market variables. Two proposed modifications reconcile the model with the data: adjustment costs to the intensive margin and a flexible parametrization of the strength of the short-run wealth effect on hours supply, as first introduced by Jaimovich and Rebelo (2009). We use the modified model to structurally assess the contribution of the intensive margin of labor adjustment to aggregate dynamics. We find the contribution of hours adjustment during U.S. cyclical recoveries is significant and can be either positive or negative depending on the innovations in the economy. Our results have implications for the design of labor market policies that affect the flexibility of hours adjustment.

While we estimate the model on U.S. data, our model introduces enough flexibility to allow the model to match a broad array of empirical covariances between hours per worker and employment, including potentially negative ones as observed in some European economies. Discerning the role of the intensive margin for other countries, as well the introduction and study of country-specific labor market policies, are important avenues for future research.

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