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JEL Classification: E30, E50, E60

Keywords: Effort, Hours, labor adjustment, Labor market deregulation, labor productivity

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Labor adjustment and productivity in the OECD*

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1 Introduction

This paper argues that the cyclicality of labor productivity – output per hour – is related to the different nature of labor adjustment across countries. Figure 1 shows that countries with lower employment volatility are characterized by more procyclical labor productivity, that is, by a higher correlation between the cyclical components of output and labor productivity. The aim of our investigation is to explain this new stylized fact.

[insert Figure 1 here]

The sample period here is 1984q1 to 2019q4. The key message from Figure 1 is robust to alternative filtering methods including the HP filter (Hodrick and Prescott, 1997), band pass filter (Christiano and Fitzgerald, 2003), Hamilton filter (Hamilton, 2018), or fourth difference filter.[1] It is also robust to restricting the sample to the Great Recession, defined in Christiano et al. (2015) as the period from 2008q3 until 2013q2. The latter finding is interesting for two reasons.

First, a natural candidate explanation for the pattern in Figure 1 is that technology shocks are the dominant source of business cycle fluctuations in countries with highly procyclical productivity, while demand shocks are more important in countries where the cyclicality of labor productivity is low. This is consistent with employment being rather stable in the former group of countries, and more variable in the latter. However, the Great Recession was a large shock that hit several countries simultaneously and, arguably, in similar ways. This suggests that the large cross-country variation in business cycle moments shown in Figure 1 can be traced to structural differences across economies, which in turn led to differences in shock transmission, rather than the shock mix itself being idiosyncratic.

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[1] See the online appendix for a robustness analysis. There, we also show that there is a negative (albeit less tight) correlation between unemployment volatility and labor productivity cyclicality.

Second, the Great Recession is widely believed to have been driven by deficient demand, see for instance Christiano et al. (2015). In a demand-driven recession, a drop in labor productivity is difficult to explain with standard business cycle models in the absence of variable factor utilization. With unchanged technology, we expect firms to cut back their labor input as demand for their products declines. Labor productivity goes down only if labor falls by less than output. With capital fixed in the short run, this means that labor is utilized less intensively – i.e. effort falls – during the downturn. Variable capital utilization as in Christiano et al. (2005) could, as an alternative model feature, generate procyclical labor productivity without the necessity to endogenize labor effort. However, Lewis et al. (2019) show that effort clearly outperforms capital utilization in terms of explaining the Euro Area business cycle.

In this paper, our aim is thus to develop a model that can replicate the evidence in Figure 1 without relying on cross-country differences in the relative importance of technology versus demand shocks. Rather, we focus on differences in labor market adjustment, coupled with variable labor utilization, as the key candidate explanation. In particular, we attribute the procyclicality of labor productivity to variations in effort, which in turn result from a reluctance of firms to adjust the workforce. This idea of labor hoarding dates back to Okun (1963) and Oi (1962); for an overview article, see Biddle (2014).[2]

Employment protection remains restrictive in many countries, especially in the Euro Area (Deutsche Bundesbank, 2019). The OECD's employment protection legislation (EPL) index from 2019 ranges from 0.09 in the US to 3.61 in the Netherlands.[3] There is large variation in redundancy pay across countries; Lazear (1990) reports severance

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[2] Further contributions to this large literature include Hall (1987), Rotemberg and Summers (1990), Bernanke and Parkinson (1991), Burnside et al. (1993), Basu (1996), Sbordone (1996), Basu and Kimball (1997), Basu and Fernald (2001) and Gordon (2011).

[3] Numbers refer to 'Annual strictness of employment protection – individual and collective dismissals (regular contracts)'. *Source*: OECD Employment Protection Legislation Database, `http://oe.cd/epl`.

pay between zero and over 15 months of a worker's wage, with an overall value of 3.5. More recent data from the World Bank's Doing Business Report 2017 range from zero in the US to 27 weeks of salary in South Korea, and yet higher numbers for non-OECD countries.[4]

High costs of laying off employees in times of low demand discourage labor adjustment along the extensive margin. Already Nickell (1979) found that hours fluctuations were higher and employment fluctuations lower after the 1966 Redundancy Payments Act increased the cost of dismissal in the UK. In a sample of 20 OECD countries over the period 1975-1997, Nunziata (2003) shows that stricter employment protection and looser working time regulations were associated with a lower variability of employment over the cycle. This finding is confirmed in more recent data by Gnocchi et al. (2015).

Today, around one half of the adjustment in total hours worked in the Euro Area is through changes in hours per employee rather than changes in employment (Dossche et al., 2019). Short-time work (STW) schemes and working time accounts, used extensively e.g. in Germany, make hours worked more flexible.[5] Lydon et al. (2019) show that the STW take-up rate among firms is positively related to greater firing costs and more stringent employment protection.

Our final crucial model ingredient is variable labor utilization, or effort. Labor effort cannot be observed directly. However, several indirect measures suggest that it is procyclical: workplace accidents (Fairris, 1998; Boone and van Ours, 2002), sick leave (Leigh, 1985; Schön, 2015), indicators of bad health outcomes (Ruhm, 2000). Firms report that they pay more for labor in recessions than is strictly necessary (Fay and Medoff, 1985). The American Time Use Survey indicates that 'non-work at work' is, on the whole, coun-

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[4] *Source*: World Economic Forum Global Competitiveness Index, `https://tcdata360.worldbank.org/indicators/redun.cost`.

[5] STW schemes can save jobs by acting as automatic stabilizers during downturns, see Balleer et al. (2016), Brey and Hertweck (2020). The use of working time accounts expanded strongly in the Great Recession (Burda and Hunt, 2011; Herzog-Stein et al., 2018).

tercyclical (Burda et al., 2020). Finally, self-reported work effort appears to be procyclical (Lewis and van Dijcke, 2020).[6]

This paper develops a business cycle model with capital and three labor margins: employment, hours per worker and effort per hour.[7] Importantly, firms face employment adjustment costs, which use up part of their output. Workers are expected to provide a certain amount of effective labor; they choose the combination of hours and effort per hour that minimizes their disutility from working (Bils and Cho, 1994). We show that, in a model with labor effort, greater employment adjustment frictions imply more procyclical labor productivity along with more stable employment, consistent with the observed cross-country heterogeneity. The constant-effort model fails to replicate the pattern in the data. As a consequence, labor market deregulation – a reduction in firms' employment adjustment costs – reduces the cyclicality of labor productivity by more when effort can vary than in the case where effort is constant. Variable effort is thus relevant for evaluating the effect of such a reform. More fundamentally, we argue that the cyclicality of labor productivity is not a reliable indicator of which type of shock – technology or demand – drives the business cycle, see also Shea (1999).

Related literature. Consistent with our cross-country evidence presented above, Mitra (2020) shows that the cyclicality of labor productivity declined more in US states and industries that experienced a larger drop in union density.

Ohanian (2010) shows that during the Great Recession, labor input fell strongly in the US, whereas labor productivity declined only by a small amount. Meanwhile, many European countries saw large drops in labor productivity, but not in employment. These

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[6] A couple of papers find evidence of countercyclical effort in a single firm (Lazear et al., 2016; Senney and Dunn, 2019), suggesting that the 'shirking model' of Shapiro and Stiglitz (1984) might play a role at the micro level. Given the body of evidence summarized above, we will maintain the assumption that effort is procyclical at the macro level.

[7] As we show in the online appendix, replacing employment volatility with unemployment volatility does not alter our key empirical message, suggesting that the participation margin does not play a large role for the stylized fact shown in Figure 1.

findings are in line with the evidence in our Figure 1. Viewed through the lens of a real business cycle (RBC) model, the European experience is consistent with adverse technology shocks, while the US experience is not. In this paper, we present empirical evidence for more countries and for a longer time span. More importantly, though, we seek a model that can generate the pattern of Figure 1, keeping the underlying shock structure the same. This is the key difference between our paper and Ohanian (2010), who instead takes the model as given.

Perri and Quadrini (2018) explore the role of a financial shock as a driver of the Great Recession. They show that endogenous utilization and cross-country differences in labor adjustment costs are required to replicate the heterogeneous responses of labor productivity and employment in European countries versus the US. We would go further and argue that these two features are important in order to account adequately for business cycle fluctuations more generally, not only during that particular episode.

Llosa et al. (2014) show that a model with firing costs can explain cross-country differences in the relative importance of the intensive labor margin, i.e. changes in hours per worker, in total hours adjustment. The intensive margin of labor adjustment is more important for countries with greater firing costs. We show that introducing variable labor utilization (endogenous effort) helps to also match the procyclical nature of labor productivity observed in most OECD countries.

The US experience. The change in US labor productivity from pro- to countercyclical after 1984 has received a fair amount of attention.[8] Different explanations for this change have been put forward. Barnichon (2010) points to a greater volatility of technology shocks relative to non-technology shocks in the more recent period. McGrattan and Prescott (2012) extend the standard RBC model with intangible capital, i.e. accumu-

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[8] See inter alia Galí and Gambetti (2009), Ohanian and Raffo (2012), Fernald and Wang (2016). Based on data that go back to the 1960s, US labor productivity used to be procyclical (Stock and Watson, 1999).

lated know-how from investing in research and development, brands, and organizations. Insofar as it counts as an expense rather than being capitalized, it is not included in GDP. This leads to an underestimation of output movements. If labor input is correctly measured, the correlation of output and labor productivity falls as a consequence; productivity becomes less procyclical. Garin et al. (2018) propose a model of labor reallocation across sectors and show that a decline in the importance of aggregate shocks relative to reallocative shocks can account for the change in the cyclicality of US labor productivity. Following a reallocative shock, employment declines in adversely affected sectors as workers move to sectors with improved productivity, causing aggregate labor productivity to rise. Sectoral heterogeneity also plays a role in vom Lehn and Winberry (2019), who suggest that shocks to investment hubs have become more important after 1984, resulting in less sectoral comovement and less cyclical labor productivity. Schaal (2017) introduces idiosyncratic volatility shocks in a search-and-matching model. Greater volatility drives unproductive firms out of the market so that employment decreases, whereas aggregate productivity increases.

Galí and van Rens (2020) and Mitra (2020) instead propose a factor utilization margin, more specifically: variable labor effort. They argue that lower hiring and firing costs since 1984 in the US can explain why firms use the effort margin less to adjust effective labor input, but instead hire and fire workers more quickly, so that measured productivity becomes less procyclical. van Zandweghe (2010) also favors an explanation of the US productivity cyclicality sign switch based on structural changes in the labor market.

Arguably, most of the proposed structural changes to explain the fall in the cyclicality of US labor productivity (intangible capital, allocative shocks, investment hubs, idiosyncratic volatility shocks) have also occurred in other industrialized countries. This raises the question why labor productivity has remained procyclical in other large industrialized economies, such as the Euro Area or Japan. Moreover, as discussed above, labor markets function very differently across countries due to institutional differences (such as firing costs and working-time regulations). This suggests that an explanation based on differences in the functioning of labor markets may be more promising to understand the cross-country differences we observe in the cyclicality of labor productivity.

Outline. The rest of the paper is structured as follows. Section 2 presents the model and explains our calibration strategy. Section 3 presents the dynamic effects of technology and demand shocks, and discusses the implications of allowing for variable labor effort. We also show how the size of the effort margin affects the cyclicality of labor productivity. We then consider the effects of reducing labor market rigidities when effort can vary, and contrast them with those of the constant-effort model. In Section 4, we introduce sticky prices in the model and investigate to what extent our results change. Other model modifications are discussed in a robustness analysis in Section 5. Section 6 concludes.

2 Model

Our model has three labor margins, employment, hours and effort, the latter modelled as in Bils and Cho (1994). Hours and effort are chosen efficiently. Employment adjustment costs shift the burden of adjustment away from the extensive margin and towards the two intensive margins.[9]

2.1 Households

A household is a large family composed of a $[0, 1]$ continuum of infinitely-lived, ex-ante identical members, a fraction n_t of whom are employed at time t. Matching with firms is random, costless and time-independent (Danthine and Kurmann, 2004). Per employed member, h_t denotes hours worked and e_t is effort per hour. All household members

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[9] For simplicity, we assume quadratic employment adjustment costs in our baseline model. Our findings are unchanged if we instead assume (asymmetric) firing costs. See the online appendix.

consume the average per capita consumption, c_t. There are no unemployment benefits; for simplicity we normalize the benefit from home production or leisure to zero. The household chooses paths for consumption, capital k_t and employment to maximize lifetime utility,

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln c_t - \frac{A}{1+\eta} n_t^{1+\eta} - \frac{B}{1+\gamma} n_t h_t^{1+\gamma} - \frac{C}{1+\tau} n_t h_t e_t^{1+\tau} \right\}, \tag{1}$$

subject to the budget constraint,

$$c_t + k_{t+1} - (1-\delta)k_t + \frac{\phi_k}{2}(k_{t+1} - k_t)^2 \leq w_t h_t n_t + r_t k_t + D_t, \tag{2}$$

where $\beta \in (0,1)$ is the household's subjective discount factor, $\delta \in (0,1)$ is the capital depreciation rate, and $\phi_k \geq 0$ scales capital adjustment costs.[10] The elasticities $\eta, \gamma, \tau \geq 0$ capture the curvature of labor disutility in employment, hours and effort, respectively. The parameters A, B and C are non-negative weights on, respectively, employment, hours and effort in labor disutility. Futhermore, w_t is the wage rate per hour, r_t is the rental rate on capital, and D_t are dividends. All variables are expressed in units of the consumption good.

Effort affects utility only if the household member is employed and works non-zero hours. Hours matter for utility only if the member is employed. Employment is the only margin that matters *per se* as it has a utility cost that is independent of hours (and effort). According to (1), therefore, higher hours or effort have an additional negative effect on utility over and above the disutility of employment. The choice of hours and effort is explained below.

The household's equilibrium conditions satisfy:

$$1 + \phi_k(k_{t+1} - k_t) = \mathrm{E}_t \left\{ \beta_{t,t+1} \left[(1-\delta) + \phi_k(k_{t+2} - k_{t+1}) + r_{t+1} \right] \right\}, \tag{3}$$

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[10] The choice of hours and effort provision is discussed in the intratemporal household problem described in Subsection 2.3 below.

$$\left(An_t^{\eta} + \frac{B}{1+\gamma}h_t^{1+\gamma} + \frac{C}{1+\tau}h_t e_t^{1+\tau}\right) c_t = w_t h_t, \tag{4}$$

where $\beta_{t-1,t} = \beta c_{t-1}/c_t$ is the household's stochastic discount factor, (3) is the optimality condition for capital, and (4) equates the marginal rate of substitution between employment and consumption on the left hand side to the wage per employee, $w_t h_t$, on the right hand side.

2.2 Firms

Firms choose optimally their inputs capital k_t and employment n_t to maximize the expected discounted stream of profits,

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_{0,t} \left\{ y_t - w_t h_t n_t - r_t k_t \right\}, \tag{5}$$

subject to a production technology that incorporates employment adjustment costs g_t,

$$y_t = z_t k_t^{\alpha} H_t^{1-\alpha} - g_t, \tag{6}$$

where z_t denotes exogenous total factor productivity and $\alpha \in (0,1)$ is the capital share. The production technology is thus a Cobb-Douglas function of capital and total effective hours, the latter defined as $H_t \equiv e_t h_t n_t$. We use $\beta_{0,t}$ for discounting in the firm's problem, given that the households own the firms, see the dividends D_t in the household's budget constraint (2).

As in Cacciatore et al. (2017), we regard the employment adjustment cost as a pure loss and not as a transfer to workers. Llosa et al. (2014) and (Hopenhayn and Rogerson, 1993), model g_t as a firing cost. Instead, our employment adjustment cost is approximated as a quadratic function,

$$g_t = g(n_t, n_{t-1}) = \frac{\phi_n}{2}(n_t - n_{t-1})^2, \tag{7}$$

such that the first derivative with respect to its first argument is $g_{1t} \equiv \partial g_t / \partial n_t = \phi_n(n_t - n_{t-1})$. Notice also that $g_{2t} \equiv \partial g_t / \partial n_{t-1} = -\phi_n(n_t - n_{t-1}) = -g_{1t}$. In steady state, the employment adjustment cost (7) is zero.

The firm's first order conditions with respect to capital and employment are, respectively,

$$\alpha \frac{y_t + g_t}{k_t} = r_t, \tag{8}$$

$$(1-\alpha)\frac{y_t + g_t}{n_t} = w_t h_t + g_{1t} - \mathrm{E}_t\{\beta_{t,t+1} g_{1t+1}\}, \tag{9}$$

where we have used the relation $g_{2t} = -g_{1t}$. The left hand side of (8) is the firm's marginal product of capital, $\alpha z_t k_t^{\alpha-1} H_t^{1-\alpha}$. At the optimum, this has to be equated with the marginal cost of capital, i.e. the rental rate r_t. In (9), the marginal product of employment, $(1-\alpha) z_t k_t^{\alpha} H_t^{-\alpha}$, has to equal the marginal cost of employment, which has three components. First, an additional employee who works h_t hours costs the firm $w_t h_t$ in wage payments. Second, the change in the firm's workforce gives rise to the adjustment cost g_{1t} in the current period. Third, since next period's employment adjustment cost depends on current employment, g_{1t+1} also enters the first order condition.

Firms' current profits can be written as:

$$D_t = y_t - w_t h_t n_t - r_t k_t. \tag{10}$$

From a firm's output - which is net of employment adjustment costs - we subtract wage payments and capital rental costs to obtain profits.

2.3 Hours, effort and productivity

Suppose that the worker can choose the combination of hours and effort that minimizes labor disutility, given a certain number of effective hours demanded. Each period, the worker solves the following intratemporal problem:

$$\min_{e_t,h_t} \frac{A}{1+\eta}n_t^{1+\eta} + \frac{B}{1+\gamma}n_t h_t^{1+\gamma} + \frac{C}{1+\tau}n_t h_t e_t^{1+\tau}, \tag{11}$$

subject to the production technology (6).

This setup can be viewed as an implicit contract between worker and firm. The firm leaves the allocation of labor between effort and hours to the worker in return for the guarantee that the worker will supply a certain number of effective hours. The worker is free to choose how many hours to work and how hard to work within the constraint of providing the required effective hours. Both parties are happy, the deal is incentive-compatible and the outcome is efficient. Differently from the shirking model of Shapiro and Stiglitz (1984), there is no need for the firm to monitor effort in this framework, and hence the fact that effort is unobserved is inconsequential. In Section 5.3, we briefly discuss how the model predictions change if we assume a gift exchange motive for effort as in Akerlof (1982).

The first order conditions for hours and effort are, respectively,

$$Bn_t h_t^{\gamma} + \frac{C}{1+\tau}n_t e_t^{1+\tau} - \varphi_t(1-\alpha)\frac{y_t+g_t}{h_t} = 0, \tag{12}$$

$$Cn_t h_t e_t^{\tau} - \varphi_t(1-\alpha)\frac{y_t+g_t}{e_t} = 0, \tag{13}$$

where φ_t is the Lagrange multiplier on the constraint (6). The left hand side of (12) is the marginal rate of substitution between hours and consumption. The right hand side is the marginal product of hours worked. Equation (13) sets equal the marginal rate of substitution and the marginal product in the case of effort. Combining the two first order conditions (12) and (13) yields an equilibrium effort function which is increasing and convex in hours worked,

$$e_t = e_0 h_t^{\frac{\gamma}{1+\tau}}. \tag{14}$$

The elasticity of effort with respect to hours is given by $\gamma/(1+\tau) > 0$ and we define $e_0 = (\frac{1+\tau}{\tau}\frac{B}{C})^{1/(1+\tau)}$. Now, we can substitute effort (14) back into the production function (6) to obtain

$$y_t = z_t k_t^{\alpha}(e_0 h_t^{\phi} n_t)^{1-\alpha} - g_t. \tag{15}$$

where we define $\phi = 1 + \gamma/(1+\tau)$. The composite parameter ϕ determines the degree of short-run increasing returns to hours in production and is critical for the cyclicality of labor productivity predicted by the model.

Labor productivity is defined as (net) output divided by total hours worked,

$$\mathcal{P}_t \equiv \frac{y_t}{n_t h_t}. \tag{16}$$

Measured labor productivity in (16) is distinct from 'true' productivity, which is output per *effective* hour worked, y_t/H_t.

Hours are determined jointly by the firm and the worker to maximize the sum of both parties' surpluses arising from the employment relationship. The firm's surplus is given by profits D_t, see (10). The household's surplus is wage income less the disutility from working (11) which we divide by the marginal utility of consumption $1/c_t$ to convert utils into consumption goods. The resulting equilibrium condition,

$$(1-\alpha)\phi\frac{y_t + g_t}{h_t} = \frac{1+\gamma+\tau}{\tau} B n_t h_t^{\gamma} c_t, \tag{17}$$

equates the marginal product of an extra hour worked to the corresponding marginal disutility.

2.4 Closing the model

Imposing that the household budget constraint (2) hold with equality, and combining it with firm profits (10), we obtain the aggregate accounting relation,

$$c_t + k_{t+1} - (1-\delta)k_t + \frac{\phi_k}{2}(k_{t+1} - k_t)^2 + a_t = y_t, \tag{18}$$

where a_t is an exogenous component of aggregate demand such as net exports or government spending. Demand shocks and technology shocks follow first-order autoregressive processes (in logarithms) with *i.i.d.* normal innovations,

$$\ln a_t = (1-\rho_a)\ln a + \rho_a \ln a_{t-1} + \varepsilon_t^a, \tag{19}$$

$$\ln z_t = (1-\rho_z)\ln z + \rho_z \ln z_{t-1} + \varepsilon_t^z, \tag{20}$$

where $\varepsilon_t^i \sim N(0, \sigma_i)$, $i = z, a$. A formal definition of equilibrium, as summarized in Table 1, is as follows.

Definition 1. *A competitive equilibrium is a set of sequences* $\{k_t,\, n_t,\, y_t,\, r_t,\, w_t,\, h_t,\, e_t,\, c_t\}_{t=0}^{\infty}$ *that satisfy the household's first order conditions for capital (3) and employment (4), the firm's production function (6), the firm's demand for capital (8) and employment (9), the worker's optimality conditions for hours (12) and effort (13), and aggregate accounting (18), given exogenous processes for technology* $\{z_t\}_{t=0}^{\infty}$ *and demand shocks* $\{a_t\}_{t=0}^{\infty}$.

We now turn to the non-stochastic steady state before giving details on our calibration strategy. Let a variable without a time subscript denote its steady state value. We consider the non-stochastic steady state, where both technology and demand shocks are switched off, $\varepsilon_t^z = \varepsilon_t^a = 0$ for all t. Technology at the steady state is normalized to unity, $z = 1$. The share of exogenous demand in GDP is set to the average US government spending share of 20%, that is, we set $a = 0.2$.

Table 1. Equilibrium conditions

$1+\phi_k(k_t-k_{t-1})=\mathrm{E}_t\left\{\beta_{t,t+1}\left[1-\delta+\phi_k(k_{t+1}-k_t)+r_{t+1}\right]\right\}$	FOC capital
$[An_t^{\eta}+Bh_t^{1+\gamma}/(1+\gamma)+Ce_t^{1+\tau}h_t/(1+\tau)]c_t=w_th_t$	FOC employment
$y_t=z_tk_{t-1}^{\alpha}H_t^{1-\alpha}-g_t$	Production function
$\alpha(y_t+g_t)/k_{t-1}=r_t$	Demand for capital
$(1-\alpha)(y_t+g_t)/n_t=w_th_t+\phi_n(n_t-n_{t-1})-\mathrm{E}_t\{\beta_{t,t+1}\phi_n(n_{t+1}-n_t)\}$	Demand for employment
$e_t=[(1+\tau)B/(\tau C)]^{1/(1+\tau)}\,h_t^{\gamma/(1+\tau)}$	Effort per hour
$(1-\alpha)\phi(y_t+g_t)/h_t=[(1+\gamma+\tau)/\tau]Bn_th_t^{\gamma}c_t$	Hours per worker
$c_t+k_t-(1-\delta)k_{t-1}+0.5\cdot\phi_k(k_t-k_{t-1})^2+a_t=y_t$	Aggregate accounting
$H_t=e_th_tn_t$	Total effective hours
$i_t=k_t-(1-\delta)k_{t-1}$	Investment
$g_t=0.5\cdot\phi_n(n_t-n_{t-1})^2$	Employment adj. cost
$\beta_{t-1,t}=\beta c_{t-1}/c_t$	Stoch. discount factor

Notes. Endogenous variables: k_t, n_t, y_t, r_t, w_t, h_t, H_t, e_t, c_t, i_t, g_t, $\beta_{t-1,t}$.

2.5 Steady state

From the household's first order condition for capital (3), the rental rate on capital satisfies $r=1/\beta-(1-\delta)$. We normalize gross output (or GDP) at the steady state to unity and set $y+g=1$. Since employment adjustment costs are zero in steady state, this implies that net output is $y=1$. The firm's capital demand (8) is used to derive the capital stock, $k=\alpha(y+g)/r$. Given net output, exogenous demand a and the value of the capital stock, we derive consumption from the aggregate accounting identity (18), $c=y-a-\delta k$. From the production function (6), we find the steady state total effective hours, $H=[(y+g)/(zk^{\alpha})]^{1/(1-\alpha)}$. Then, steady state employment is given by $n=H/(he)$ from the definition of total effective hours. The wage can be derived from the firm's employment demand (9). In steady state, the wage rate w is proportional to gross output per hour, $(y+g)/(nh)$, where the factor of proportionality is the labor share in production, $1-\alpha$. The optimality condition for hours (17) pins down the utility parameter B. Given B, the optimality condition for effort (14) pins down the utility parameter C. Finally, we can use the household's first order condition for employment (4), to pin down the remaining utility parameter A. Table 2 summarizes the recursive formulation of the steady state.

Table 2. Recursive steady state

$y + g = h = e = 1$	GDP, hours and effort (normalization)
$g = 0$	employment adjustment cost
$r = 1/\beta - (1 - \delta)$	rental rate on capital
$k = \alpha(y + g)/r$	capital stock
$c = y - a - \delta k$	consumption
$H = [(y + g)/(zk^{\alpha})]^{1/(1-\alpha)}$	total effective hours
$n = H/(eh)$	employment
$w = (1 - \alpha)(y + g)/(nh)$	wage per hour
$B = (1 - \alpha)\phi[(y + g)/h] \{[(1 + \gamma + \tau)/\tau]nh^{\gamma}c\}^{-1}$	weight on hours in utility
$C = [(1 + \tau)B/\tau]h^{\gamma}e^{-(1+\tau)}$	weight on effort in utility
$A = [wh/c - Bh^{1+\gamma}/(1 + \gamma) - Ce^{1+\tau}h/(1 + \tau)]n^{-\eta}$	weight on employment in utility

2.6 Calibration

Table 3 presents our parameter choices. We calibrate the model to the US economy, where one period is a quarter.

There are two types of deep parameters in the model, those that affect the steady state, and those that do not. We fix the parameters in the first category as follows. As the model is calibrated to a quarterly frequency, a household discount factor of $\beta = 0.99$ produces a steady state net interest rate of 4% per annum. Over the post-1894 period in the US, the average labor share was roughly 60% (Giandrea and Sprague, 2017), such that $\alpha = 0.4$.[11] The capital depreciation rate is set to $\delta = 0.011$, as implied by an average depreciation of fixed assets over the net stock of fixed assets equal to 14% in US post-war data. The elasticity of labor disutility to employment η is fixed to 0.5 as in Cho and Cooley (1994). The elasticity of labor disutility to hours γ is set to 0.6 following Llosa

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[11] We do not seek to capture here the secular decline in the labor share that has been observed in the US (Elsby et al., 2013) and in other advanced economies (Karabarbounis and Neiman, 2014).

Table 3. US Parameterization

Value	Name	Target/Source
$\beta = 0.99$	household discount factor	4% real return p.a.
$\alpha = 0.4$	capital share in production	Giandrea and Sprague (2017)
$\delta = 0.011$	capital depreciation rate	US data (BEA)
$a = 0.2$	government share in output	US data (BEA)
$\eta = 0.5$	elasticity of disutility to employment	Cho and Cooley (1994)
$\gamma = 0.6$	elasticity of disutility to hours	Llosa et al. (2014)
$\tau = 350.05$	elasticity of disutility to effort	$corr(\mathcal{P}, y) = -0.216$
$\phi_k = 0.5929$	capital adjustment cost	$\sigma_I/\sigma_y = 4.6$
$\phi_n = 3.3633$	employment adjustment cost	$\sigma_n/\sigma_y = 1.012$
$\sigma_z = 0.0059$	size technology shock	*Shock processes chosen to match*
$\rho_z = 0.2151$	persistence technology shock	*standard deviation and persistence*
$\sigma_a = 0.0830$	size demand shock	*of real output and labor productivity*
$\rho_a = 0.7743$	persistence demand shock	*observed in US post-1984 data(*)*

Notes: BLS: U.S. Bureau of Labor Statistics, BEA: U.S. Bureau of Economic Analysis. σ_x denotes the standard deviation of variable x_t; $corr(x, y)$ denotes the correlation between the variables x_t and y_t. (*)See main text for more details.

et al. (2014). The elasticity of labor disutility to effort, τ, is calibrated to target the cyclicality of labor productivity observed in the US. We find a value for τ equal to 350. A large number for τ corresponds to the standard constant-effort model as in e.g. Llosa et al. (2014). In the steady state, we normalize hours and effort to unity; from this we obtain the implied utility function parameters C, B, and A, as explained above.

Second, there are parameters that are purely dynamic and do not affect the steady state. More specifically, these are the capital adjustment cost parameter, ϕ_k, and the employment adjustment cost ϕ_n. We calibrate ϕ_k to target the volatility of investment relative to output, which in US data is equal to 4.6. The parameter ϕ_n is set to match the volatility of employment relative to output, which equals 1.012 in the US after 1984, see Figure 1.

Finally, we need to calibrate the size and persistence of the two shock processes. Following the procedure in Batini et al. (2019), we set the shock parameters to match the empirical volatility and persistence of output and labor productivity. We search numerically for those parameters that minimize the quadratic loss function $\sum_{j=1}^{4}(x_j^m - x_j^d)^2$, where x_j^m is the j-th moment in the model and x_j^d is its analogue in the data. Data on real GDP were downloaded from the St. Louis Fed database, series GDPC1, sample period 1984q1 to 2020q2. Labor productivity was computed as real output divided by total hours; hours per worker are obtained from Ohanian and Raffo (2012) for the period 1984q1-2016q4 and extended to 2020q2 as explained in the online appendix. The time series are detrended using the Hodrick-Prescott filter with smoothing parameter 1600. Volatility is measured as the standard deviation and persistence is measured as the first order autocorrelation coefficient of the cyclical component. We obtain the following data moments: $\sigma_y = 0.0130$, $\rho_y = 0.5526$, $\sigma_{\mathcal{P}} = 0.0095$, $\rho_{\mathcal{P}} = 0.7450$.

3 Labor market adjustment and model dynamics

We first examine the effect of labor effort on the conditional dynamics and on the unconditional moments of model. Second, we consider the implications of a structural reform of the labor market for the nature of short-run macroeconomic fluctuations. Finally, we show that the two features, labor effort and employment adjustment costs, jointly produce model predictions that are consistent with the empirical evidence presented in Figure 1.

3.1 Variable labor effort

Let us first examine how variable labor effort alters the dynamic effects of business cycle shocks. To this end, we switch on the effort margin by setting the parameter τ to a small value and compare the resulting impulse responses to a standard deviation shock with those produced by a standard calibration where τ is large. In practice, we approximate the constant-effort model by setting τ to 350 as in the US calibration. Recall the definition of the returns to hours in production, $\phi = 1 + \gamma/(1+\tau)$. Setting $\gamma = 0.6$ and allowing for an upper bound of $\phi = 1.5$, this implies $\tau = 0.2$.[12] Figures 2 and 3 illustrate the outcome of this exercise. It shows the impulse response functions (IRFs) of output, the three labor margins, wages and measured labor productivity to a 1% shock with persistence 0.75. The impulse responses of consumption, investment and the rental rate are not shown on the figures, because they barely change when we vary τ.

[insert Figure 2 here]

Consider Figure 2. In the standard model without effort, depicted by the blue dashed lines, employment and hours rise in response to a positive *technology shock*, while measured labor productivity increases. In the presence of variable labor effort (red solid lines), also effort expands. Hours increase by more, and employment by less, than in the constant-effort model. This allows firms to economize on employment adjustment costs. Labor productivity responds in a procyclical fashion, rising by more in the model with effort.

[insert Figure 3 here]

An expansionary *demand shock* is depicted in Figure 3. Also here, the presence of variable effort shifts part of the adjustment away from the extensive margin and towards the intensive labor margin. Employment moves by less, while hours and effort adjust by more in response to the shock. Labor productivity is countercyclical conditional on the demand shock. With variable effort, measured productivity drops by less than in the constant-effort model. As a result, the drop in the wage is visibly reduced.

[insert Figures 4 and 5 here]

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[12] Lewis et al. (2019) estimate ϕ for the Euro Area and obtain a value that is even higher than 1.5.

Figures 4 and 5 show impulse responses to the two shocks in a model with a rigid labor market; ϕ_n is set to 200, all other parameter values are unchanged. Qualitatively, the response patterns are similar to the baseline calibration with a fluid labor market. However, the response of employment to both shocks is visibly dampened, as are the responses of wages and productivity to demand shocks.

In sum, variable labor effort has two main effects in the model. The first is to lower the use of the extensive labor margin (employment) relative to the intensive margin (hours and effort). The second is that the response of labor productivity and wages to demand shocks is dampened – even more so when labor markets are rigid – and its response to technology shocks is (slightly) increased in the variable-effort-model. These findings suggest that the two statistics displayed in Figure 1, the unconditional volatility of employment versus output and the cyclicality of labor productivity, are likely to depend on the size of the effort margin and on the size of labor market frictions.

In the following experiment, we keep all model parameters fixed as in Table 2, except for τ and ϕ_n. We vary the size of the effort margin between 0.2 to 5, and simulate the model with both shocks.[13] We do this for two values of the employment adjustment cost, namely $\phi_n = 0.01$ and $\phi_n = 200$. The aim is to simulate an economy with a very fluid labor market and one with a very rigid labor market, and illustrate the effect of the effort margin on business cycle moments. In this exercise, the persistence and size of the two types of business cycle shocks are kept constant at the values shown in Table 3.

[insert Figure 6 here]

The upper part of Figure 6 displays the results of our investigation, where the red solid line depicts the rigid economy and the blue dashed line shows the fluid economy with costless adjustment. We see in the left panel that in a rigid labor market with

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[13] Setting τ to a larger number does not change the second moments by much. Therefore, we choose 5 as our upper bound.

large employment adjustment costs, labor productivity is procyclical. Moreover, a more important effort margin (lower τ) goes hand-in-hand with higher cyclicality of labor productivity. A perfectly flexible economy is characterized by negative labor productivity cyclicality of around -0.2, whatever the value of τ. We also plot true productivity y_t/H_t in the rigid economy (red line with circles) and in the fluid economy (black dotted line). The mismeasurement of productivity is greater if labor market are more rigid and if the effort margin is more important for labor adjustment.

The top-right panel of Figure 6 shows two results. First, in the flexible economy, employment is roughly as volatile as output. In contrast, the use of the intensive labor margin in the rigid economy strongly reduces the relative volatility of employment. Second, a lower τ reduces the volatility of employment if employment adjustment costs are high. Whereas in an economy with no labor market frictions, the value of τ has little effect on employment volatility.

3.2 Structural reforms in the labor market

In the literature on labor market reforms, a variety of modelling approaches exist. In Blanchard and Giavazzi (2003), for instance, labor market deregulation is modelled as a fall in workers' bargaining power. Eggertsson et al. (2014) model increased competition in product and labor markets in the form of lower wage and goods price markups. Cacciatore et al. (2017) consider a reduction in firing costs.

We analyse labor market deregulation modelled as a fall in employment adjustment costs. For this purpose, we repeat the above simulation exercise, where we vary ϕ_n on a grid between 0.01 and 200 to capture a continuum going from an essentially frictionless labor market to a highly rigid labor market. The value of τ is set to either 0.2, mimicking a variable-effort economy (red solid lines), or to 5 so as to fit a constant-effort economy (blue dashed lines).

The bottom-left subplot of Figure 6 shows that a reduction of employment adjustment costs has a sizeable negative effect on the cyclicality of labor productivity in our model. This is true in both the variable-effort and the constant-effort model variants. This result is in line with the point made in Galí and van Rens (2020), which links the 'vanishing procyclicality of labor productivity' in the US to labor market deregulation. We would like to stress again that, among the various explanations put forward in the literature to explain the sign switch in the cyclicality of US labor productivity, the one by Galí and van Rens (2020) appears particularly convincing to us, given that it can also reproduce the cross-country evidence that we have presented in this paper.

From the bottom-right subplot in Figure 6, we note the – unsurprising – prediction that lower employment adjustment costs raise the volatility of employment relative to output. Clearly, firms make greater use of the extensive margin of labor adjustment when ϕ_n falls.

3.3 Matching the cross-country evidence

As the analysis up to here has shown, the interaction of labor market frictions and variable effort has powerful effects on the implied model dynamics. We now investigate to what extent our model can replicate the cross-country evidence shown in the scatter plot in Figure 1. To this end, we overlay the empirical data with the moments generated by baseline the model, where we only vary the size of employment adjustment costs ϕ_n. We do this for two extreme values of the effort margin, $\tau = 0.01$ and $\tau = 350$. The result is shown in Figure 7.

[insert Figure 7 here]

Consider first the dashed blue line, which represents the moments implied by the constant-effort model. The curve goes through the data point for the US with coordinates (1.012,-0.216). Recall that the shock mix is calibrated to produce the US data point. As we see in Table 3, this requires a technology process with rather low persistence. Now, when we increase the size of employment adjustment costs, we move to the left along the dashed blue line; the relative volatility of employment falls. The cyclicality of labor productivity increases; however, it remains negative for the all values of ϕ_n considered. Thus, the model has no chance of replicating the data points for all the other countries, except Spain, that have procyclical labor productivity. Moreover, the lowest relative employment volatility generated by the model is around 0.6, while several countries lower values for employment volatility.

Next, consider the solid red line, which displays the model moments generated by our baseline model with variable effort. When labor markets are flexible and ϕ_n is low, this model also generates countercyclical labor productivity under the US shock mix. However, as labor market frictions increase, the cyclicality of labor productivity moves into positive territory. Therefore, with variable labor effort, labor market frictions reduce and – if they are large enough – even overturn the model-generated countercyclicality of labor productivity.

While the slope of the red curve appears to match well the slope of the data scatter, we see that for all values of ϕ_n, the model-implied labor productivity cyclicality is too low. Recall that, to generate the countercyclical labor productivity observed in the US, demand shocks must dominate the cyclical properties of labor productivity in the model. As mentioned above, this is achieved by calibrating the technology shock to have low persistence. Our conjecture is that the remaining gap between the model and the data is likely to reflect larger and more persistent technology shocks outside the US. Moreover, we would like to emphasize that ours is a small-scale model with one possible source of labor productivity procyclicality; it abstracts from other potentially important factors that we discussed in the introduction.

To conclude, labor market frictions combined with variable effort go a long way in replicating the cross-country evidence. Differences in the persistence and relative importance of technology shocks across countries likely play a role, too.

4 Sticky-price model

Galí (1999) shows that under sticky prices, labor input falls in response to a positive technology shock. Firms are monopolistically competitive; they first set a profit-maximizing price and then produce the amount of output that is demanded at that price. In this setup, sticky prices imply that output is demand-determined in the short run. With demand unchanged, firms thus reduce their labor input following a technological improvement. Given that firms' labor input strongly depends on the degree of price stickiness, we might conjecture that labor productivity dynamics are also affected by price rigidities.

4.1 Model setup

We now extend the model to allow for monopolistic competition and price setting power on the part of intermediate goods firms, as well as price adjustment costs. Households have access to a one-period nominal bond. The nominal interest rate is set by the central bank.

Households. The household chooses paths for consumption, bonds b_t, capital and employment to maximize lifetime utility (1), subject to the budget constraint

$$c_t + k_{t+1} - (1-\delta)k_t + \frac{\phi_k}{2}(k_{t+1}-k_t)^2 + b_t \leq w_t h_t n_t + r_t k_t + D_t + b_{t-1}R_{t-1}/\pi_t, \tag{21}$$

where b_t are holdings of one-period risk-free nominal bonds that yield a gross interest rate R_t and π_t is the gross inflation rate between $t-1$ and t. The household's equilibrium conditions satisfy (3) and (4) as well as the standard Euler equation for bonds,

$$1 = R_t \mathrm{E}_t\{\beta_{t,t+1}/\pi_{t+1}\}. \tag{22}$$

Firms. The goods market structure follows Dixit and Stiglitz (1977) with a constant number of producers. Final goods producers operate under perfect competition. For each intermediate good i on the unit interval that costs P_{it} currency units, they choose an amount y_{it} to minimize their production cost, $\int_0^1 P_{it}y_{it}di$, subject to the production function $y_t = (\int_0^1 y_{it}^{(\varepsilon-1)/\varepsilon}di)^{\varepsilon/(\varepsilon-1)}$, where $\varepsilon > 1$ is the elasticity of substitution between inputs. This yields the demand functions $y_{it} = (P_i/P_t)^{-\varepsilon}y_t$, where $P_t = (\int_0^1 P_{it}^{1-\varepsilon}di)^{1/(1-\varepsilon)}$ is the price of the final good. The latter can be interpreted as the price index.

Intermediate goods firms have market power, represented by (the inverse of) ε, which allows them to set prices. They also choose optimally their inputs employment and capital. The representative firm i thus chooses paths for k_t, n_t and P_{it} to maximize the expected discounted stream of profits,

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta_{t,t+1} \left\{ (P_{it}/P_t)^{1-\varepsilon}y_t - w_t h_t n_t - r_t k_t - 0.5 \cdot \phi_p (P_{it}/P_{i,t-1} - 1)^2 y_t \right\}, \qquad (23)$$

where $\phi_p \geq 0$ scales the (quadratic) price adjustment costs (Rotemberg, 1982), subject to the constraint

$$(P_i/P_t)^{-\varepsilon}y_t = z_t k_{it}^{\alpha} H_{it}^{1-\alpha} - 0.5 \cdot \phi_n (n_{it} - n_{it-1})^2. \qquad (24)$$

In a symmetric equilibrium, the firm's first order conditions with respect to capital and employment are, respectively,

$$\alpha \frac{y_t + g_t}{k_t} = \frac{r_t}{\Psi_t}, \qquad (25)$$

$$(1-\alpha)\frac{y_t + g_t}{n_t} - \phi_n(n_{it} - n_{it-1}) + \mathrm{E}_t \left\{ \beta_{t,t+1} \phi_n (n_{it+1} - n_{it}) \right\} = \frac{w_t h_t}{\Psi_t}, \qquad (26)$$

where the variable Ψ_t is the Lagrange multiplier on the constraint (24) and represents the firm's real marginal cost, or the cost of increasing output by one unit. The left hand side of (25) is the firm's marginal product of capital, $\alpha z_t k_t^{\alpha-1} H_t^{1-\alpha}$. At the optimum, this equals the marginal cost of capital, i.e. the rental rate r_t, divided by the real marginal cost Ψ_t. In (26), the marginal product of employment on the left hand side equals the marginal cost of employment, i.e. the wage per worker, $w_t h_t$, divided by the real marginal cost Ψ_t. If all firms' real marginal costs are the same, individual goods prices are identical and we obtain the New Keynesian Phillips Curve,

$$(1-\varepsilon)+\varepsilon\Psi_t=\phi_p(\pi_t-1)\pi_t-\phi_p \mathrm{E}_t\left\{\beta_{t,t+1}(\pi_{t+1}-1)\pi_{t+1}y_{t+1}/y_t\right\}. \tag{27}$$

In the sticky-price model, firm profits are given by:

$$D_t=y_t-w_t h_t n_t-r_t k_t-0.5\cdot\phi_p(\pi_t-1)^2 y_t. \tag{28}$$

From a firm's net output y_t we subtract wage payments, capital rental costs and price adjustment costs to obtain profits.

Effort and hours. For each employer i on the unit interval, the household chooses the combination of hours and effort that minimizes labor disutility, i.e. he solves the problem (11), subject to the firm's demand constraint (24). In a symmetric equilibrium, we obtain the same optimality conditions for hours and effort as in the baseline model.

Closing the model. Market clearing in the bond market implies that $b_t=0$ for all t as bonds are in zero net supply in equilibrium. Imposing this condition in the household budget constraint (21) holding with equality, and combining with symmetric firm profits (28), we obtain the aggregate accounting relation,

$$c_t+k_{t+1}-(1-\delta)k_t+0.5\cdot\phi_k(k_{t+1}-k_t)^2+a_t=y_t-0.5\cdot\phi_p\left(\pi_t-1\right)^2 y_t. \tag{29}$$

The model is closed with a feedback rule that determines the interest rate R_t in response to deviations of inflation from steady state,

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{\Omega_\pi}, \tag{30}$$

where $\Omega_\pi > 0$. A formal definition of equilibrium in the sticky-price model, as summarized in Table 4, is as follows.

Definition 2. *A competitive equilibrium in the sticky-price model is a set of sequences* $\{\pi_t, k_t, n_t, y_t, r_t, w_t, \Psi_t, e_t, h_t, c_t, R_t\}_{t=0}^{\infty}$ *that satisfy the household's first order conditions for bonds (22), capital (3) and employment (4), the firm's production function (15), the firm's demand for capital (25) and employment (26), the price setting decision (27), the optimality conditions for effort (13) and hours (12), aggregate accounting (29), and the interest rate rule (30), given exogenous processes for technology* $\{z_t\}_{t=0}^{\infty}$ *and demand shocks* $\{a_t\}_{t=0}^{\infty}$.

Steady state and calibration. The recursive steady state is computed in the same way as in the baseline model. There are three additional parameters in the sticky-price model as compared with the baseline model. The elasticity of substitution between intermediate goods varieties ε is calibrated to 7.5, which corresponds to the median elasticity of substitution across brand modules estimated in Broda and Weinstein (2010). This value implies a steady state net price markup of 15%, such that $\Psi = 1.15$. The parameter scaling the price adjustment cost ϕ_p is set to 13, which corresponds to a Phillips curve coefficient of $(\varepsilon - 1)/\phi_p$ equal to 0.5 as in Lubik and Schorfheide (2004). Finally, the inflation coefficient in the interest rate rule Ω_π is set to 1.5 in line with the work of Taylor (1993).

4.2 Price rigidities and model dynamics

Figures 8 and 9 show the impulse response functions to technology and demand shocks, respectively, in the sticky-price model.

[insert Figure 8 here]

Consistent with Galí (1999), employment declines after a positive *technology shock*. Hours and effort, however, increase as they do in the baseline model with flexible prices. This is because the substitution effect from the higher wage, which induces workers to increase their labor supply, dominates the income effect, which would lead people to work less. Despite this shift from the extensive to the intensive labor margin, the effect of labor effort on the response of measured productivity is not much affected by price stickiness. Here, as in the baseline model, labor effort increases the rise in labor productivity, which makes productivity more procyclical overall.

[insert Figure 9 here]

In response to a positive *demand shock*, labor input is instead shifted from the two intensive margins to the extensive margin when the effort margin is active: employment rises, while hours and effort eventually fall below their steady state levels. To understand the difference in the hours response between the baseline model and the constant effort model, recall that in the former model, the marginal product of labor is increasing in hours per worker, while it is decreasing in the latter model. Consumption and wages fall in the wake of an exogenous demand expansion. Since wages are set efficiently, they move in tandem with the marginal product of labor. For the marginal product of labor to drop, hours must rise in the constant-effort model and must fall in the variable-effort model. We notice that labor productivity falls more after a positive demand shock in the presence of labor effort. This runs counter to our main argument that effort makes labor productivity more procyclical.

The dynamics displayed in Figures 8 and 9 are derived under our baseline calibration for the US, where the employment adjustment cost parameter ϕ_n is rather low. What if we consider instead an economy with a less liquid labor market? Figures 10 and 11 depict the results of an exercise where we keep all parameters as in the baseline calibration, but raise the employment adjustment cost to $\phi_n = 200$.

[insert Figures 10 and 11 here]

We see from Figure 10 that the responses to a technology shock are qualitatively unchanged when we increase the size of employment adjustment costs. In contrast, the responses to a demand shock are strongly affected by the size of labor market frictions, see Figure 11. In particular, hours and effort now rise over the full response horizon following a positive demand shock. To produce the higher output that is demanded with unchanged technology, firms will increase their labor input. With high employment adjustment costs, firms increase employment only a little and use also the two intensive margins of adjustment, hours and effort. As a result of the greater positive response of hours and effort to a demand expansion, the drop in productivity and wages is dampened considerably.

To summarize, our main result - labor effort reduces the countercyclical response of labor productivity to demand shocks, making labor productivity more procyclical overall – is re-established under sticky prices when labor market frictions are large.

[insert Figure 12 here]

Figure 12 corroborates this finding. It shows the same exercise in the sticky-price model that Figure 6 presents for the baseline model. The figure shows that in a rigid economy, labor productivity is less countercyclical and employment is less volatile than in a fluid one. In addition, variable labor effort raises the cyclicality of productivity even further.

5 Robustness

In the following, we make three types of modifications to the baseline model and investigate how our main result — that endogenous effort can generate procyclical labor productivity in a frictional labor market — is affected. First, we introduce alternative forms of labor market frictions into the model to replace employment adjustment costs. Second, we replace simultaneous bargaining of hours and wages with a 'right-to-manage' setup where firms choose hours unilaterally once wages have been set in a bargaining process. Third, we assume a gift exchange motive for effort as originally proposed by Akerlof (1982).

5.1 Alternative types of labor market frictions

To show that the exact type of labor market friction does not matter for our main result, we derive three additional model variants in the online appendix. Overall, the impulse responses to technology shocks and to demand shocks look very similar to the impulse response functions of our baseline model shown in Figures 2 and 3. Here, we briefly discuss how the model-predicted dynamics change relative to the baseline model.

Firing costs. When we replace employment adjustment costs with firing costs à la Hopenhayn and Rogerson (1993), impulse response functions are almost identical to the baseline. This is because, to a first order approximation, firing costs and quadratic employment adjustment costs are not very different.

Search-and-matching. Another modeling choice would be the 'standard' search-and-matching model à la Diamond, Mortensen and Pissarides, see Mortensen and Pissarides (1994) or the first chapter of Pissarides (2000). Unemployed workers and firms engage in labor market search. New job matches are the output of a Cobb-Douglas matching function, where unemployment and vacancies are the inputs. Wages and hours are set in a Nash bargaining game between a firm and a worker. Qualitatively, the impulse responses and the effect of introducing variable effort are similar to the baseline. The main difference is the response of employment to demand shocks, which is larger in the variable effort model than in the constant-effort model. This can be explained by the greater value of a marginal worker who works more hours and exerts more effort, which raises firms' hiring incentives.

Hiring costs. In this model variant, firms pay a cost of hiring workers rather than posting vacancies, see Gertler and Trigari (2009), Hertweck (2013), or Hertweck et al. (2021). The costs of hiring an additional worker are a function of the aggregate hiring rate. The impulse responses resemble those in the search model; the key difference is that the response of vacancies to shocks is hump-shaped, a pattern which carries over to employment. Other than that, we note that hours and effort first increase and then drop below their long run values during the adjustment period. Our main insight is unaltered by this alternative modeling assumption.

5.2 An alternative model of bargaining

We consider a search-and-matching model with right-to-manage bargaining (RTM) as in Trigari (2006). This model differs from the search model with 'efficient bargaining' (EB) in the way that wages and hours are determined. Instead of being set simultaneously, the assumption here is that wages are set first and hours are then set unilaterally by the firm, taking the wage bargaining outcome as given. Trigari (2006) shows that under RTM, real marginal costs reflect real wages, whereas they reflect the marginal disutility of supplying hours of work in the standard EB setup. In a world with sticky prices, this has important implications for inflation dynamics, since any slugglishness in real wages carries over to inflation under RTM but not under EB.

As in the standard search model, effort increases the rise in hours in response to an expansionary business cycle shock. This is because every additional hour comes with greater work effort and is therefore more productive. Our main finding still holds; labor effort reduces the negative effect of expansionary demand shocks on measured productivity.

5.3 An alternative effort mechanism

We now discuss the implications of replacing the effort mechanism of Bils and Cho (1994) of our baseline model with the gift exchange model of effort determination (Akerlof, 1982). In that model, firms can raise worker effort by setting a wage sufficiently above a reference wage, which in turn depends on aggregate wages and on labor market tightness. We use the effort function proposed by de la Croix et al. (2009), which allows for effort to co-move with wages. This is a generalization of the logarithmic function used in Danthine and Kurmann (2004), which predicts that effort is constant in equilibrium. The main effect of the gift exchange mechanism is to dampen the response of the wage. As pointed out by de la Croix et al. (2009) among others, this model feature is akin to a real wage rigidity, which reduces the need for nominal price or wage stickiness to generate inflation persistence.

The responses of the main macroeconomic variables to a *technology shock* in the gift exchange model are qualitatively similar to those in the Walrasian labor market. Wages increase, which incentivizes workers to exert more effort. As a result of the rise in effort, output and consumption expand by more than in the competitive labor market model.

In response to an *exogenous rise in demand*, firms need to produce more with unchanged technology. They expand labor input along both margins, employment and effort. Firms can raise worker effort only indirectly by increasing the wage. Thus, wages respond procyclically to a demand shock. This is the most obvious difference with the Walrasian labor market model, since the latter implies a fall in wages along with consumption crowding-out. Labor productivity falls by less when the effort mechanism is active.

6 Conclusion

This paper documents a new stylized fact: countries with lower employment variability are characterized by more procyclical labor productivity, i.e., output per hour worked. We propose a model combining employment adjustment costs and intensive margin labor adjustment – variable hours per worker and effort per hour – to capture this pattern in the data. Economic research focusing on the US, where hiring and firing is relatively inexpensive, often neglects the intensive margin of labor adjustment. However, the inclusion of such as an adjustment margin can alter quite considerably the effects of business cycle shocks and structural reform. Our model makes two predictions. First, varying only the size of employment adjustment costs and holding the relative size of supply and demand shocks constant, we are able to reproduce the observed pattern by which countries with little employment volatility are characterized by procyclical labor productivity. Secondly, labor market deregulation in the form of lower employment adjustment costs has a greater effect on the two business cycle moments shown in Figure 1 when effort can vary. In particular, variable labor effort implies that the cyclicality of labor productivity falls by more than the constant-effort model would predict. An important lesson from this exercise is that the cyclicality of labor productivity does not reliably reveal the relative importance of technology versus demand shocks as the dominant source of fluctuations.

References

Akerlof, G. A. (1982). Labor contracts as partial gift exchange. *The Quarterly Journal of Economics*, 97(4):543–569.

Balleer, A., Gehrke, B., Lechthaler, W., and Merkl, C. (2016). Does short-time work save jobs? a business cycle analysis. *European Economic Review*, 84:99–122. European Labor Market Issues.

Barnichon, R. (2010). Productivity and unemployment over the business cycle. *Journal of Monetary Economics*, 57(8):1013–1025.

Basu, S. (1996). Procyclical productivity: increasing returns or cyclical utilization? *The Quarterly Journal of Economics*, 111(3):719–751.

Basu, S. and Fernald, J. (2001). Why is productivity procyclical? Why do we care? In *New Developments in Productivity Analysis*, NBER Chapters, pages 225–302. National Bureau of Economic Research, Inc.

Basu, S. and Kimball, M. S. (1997). Cyclical Productivity with Unobserved Input Variation. NBER Working Papers 5915, National Bureau of Economic Research, Inc.

Batini, N., Melina, G., and Villa, S. (2019). Fiscal buffers, private debt, and recession: The good, the bad and the ugly. *Journal of Macroeconomics*, 62:103044.

Bernanke, B. S. and Parkinson, M. L. (1991). Procyclical labor productivity and competing theories of the business cycle: some evidence from interwar U.S. manufacturing industries. *Journal of Political Economy*, 99(3):439–459.

Biddle, J. E. (2014). Retrospectives: The cyclical behavior of labor productivity and the emergence of the labor hoarding concept. *Journal of Economic Perspectives*, 28(2):197–212.

Bils, M. and Cho, J.-O. (1994). Cyclical factor utilization. *Journal of Monetary Economics*, 33(2):319–354.

Blanchard, O. and Giavazzi, F. (2003). Macroeconomic effects of regulation and deregulation in goods and labor markets. *The Quarterly Journal of Economics*, 118(3):879–907.

Boone, J. and van Ours, J. C. (2002). Cyclical fluctuations in workplace accidents. CEPR Discussion Papers 3655, C.E.P.R. Discussion Papers.

Brey, B. and Hertweck, M. S. (2020). The extension of short-time work schemes during the Great Recession: a story of success? *Macroeconomic Dynamics*, 24(2).

Broda, C. and Weinstein, D. E. (2010). Product creation and destruction: evidence and price implications. *American Economic Review*, 100(3):691–723.

Burda, M. C., Genadek, K. R., and Hamermesh, D. S. (2020). Unemployment and effort at work. *Economica*, 87(347):662–681.

Burda, M. C. and Hunt, J. (2011). What explains the German labor market miracle in the Great Recession. *Brookings Papers on Economic Activity*, 42(1):273–335.

Burnside, C., Eichenbaum, M., and Rebelo, S. (1993). Labor hoarding and the business cycle. *Journal of Political Economy*, 101(2):245–273.

Cacciatore, M., Duval, R., Fiori, G., and Ghironi, F. (2017). Market reforms at the zero lower bound. NBER Working Papers 23960, National Bureau of Economic Research, Inc.

Cho, J.-O. and Cooley, T. F. (1994). Employment and hours over the business cycle. *Journal of Economic Dynamics and Control*, 18(2):411–432.

Christiano, L., Eichenbaum, M., and Evans, C. (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45.

Christiano, L. J., Eichenbaum, M. S., and Trabandt, M. (2015). Understanding the Great Recession. *American Economic Journal: Macroeconomics*, 7(1):110–67.

Christiano, L. J. and Fitzgerald, T. J. (2003). The band pass filter. *International Economic Review*, 44(2):435–465.

Danthine, J.-P. and Kurmann, A. (2004). Fair wages in a New Keynesian model of the business cycle. *Review of Economic Dynamics*, 7(1):107–142.

de la Croix, D., de Walque, G., and Wouters, R. (2009). A note on inflation persistence in a fair wage model of the business cycle. *Macroeconomic Dynamics*, 13(05):673–684.

Deutsche Bundesbank (2019). Structural reforms in the euro area. Monthly Report, October 2019, 83-105, Deutsche Bundesbank.

Dixit, A. K. and Stiglitz, J. E. (1977). Monopolistic competition and optimum product diversity. *American Economic Review*, 67(3):297–308.

Dossche, M., Lewis, V., and Poilly, C. (2019). Employment, hours and the welfare effects of intra-firm bargaining. *Journal of Monetary Economics*, 104:67–84.

Eggertsson, G., Ferrero, A., and Raffo, A. (2014). Can structural reforms help Europe? *Journal of Monetary Economics*, 61(C):2–22.

Elsby, M. W. L., Hobijn, B., and Sahin, A. (2013). The decline of the U.S. labor share. *Brookings Papers on Economic Activity*, pages 1–52.

Fairris, D. (1998). Institutional Change in Shopfloor Governance and the Trajectory of Postwar Injury Rates in U.S. Manufacturing, 1946-1970. *Industrial and Labor Relations Review*, 51(2):187–203.

Fay, J. A. and Medoff, J. L. (1985). Labor and output over the business cycle: Some direct evidence. *The American Economic Review*, 75(4):638–655.

Fernald, J. G. and Wang, J. C. (2016). Why has the cyclicality of productivity changed? What does it mean? *Annual Review of Economics*, 8(1):465–496.

Galí, J. (1999). Technology, employment, and the business cycle; do technology shocks explain aggregate fluctuations? *The American Economic Review*, 89(1):249–271.

Galí, J. and Gambetti, L. (2009). On the sources of the Great Moderation. *American Economic Journal: Macroeconomics*, 1(1):26–57.

Galí, J. and van Rens, T. (2020). The Vanishing Procyclicality of Labour Productivity. *The Economic Journal*, 131(633):302–326.

Garin, J., Pries, M. J., and Sims, E. R. (2018). The relative importance of aggregate and sectoral shocks and the changing nature of economic fluctuations. *American Economic Journal: Macroeconomics*, 10(1):119–48.

Gertler, M. and Trigari, A. (2009). Unemployment fluctuations with staggered Nash wage bargaining. *Journal of Political Economy*, 117(1):38–86.

Giandrea, M. D. and Sprague, S. (2017). Estimating the U.S. labor share. Monthly labor review, U.S. Bureau of Labor Statistics.

Gnocchi, S., Lagerborg, A., and Pappa, E. (2015). Do labor market institutions matter for business cycles? *Journal of Economic Dynamics and Control*, 51:299–317.

Gordon, R. (2011). The Evolution of Okun's Law and of Cyclical Productivity Fluctuations in the United States and in the EU-15. In *EES/IAB Workshop, Labor Market Institutions and the Macroeconomy Nuremberg, June 17-18, 2011.*

Hall, R. E. (1987). Productivity and the business cycle. *Carnegie-Rochester Conference Series on Public Policy*, 27(1):421–444.

Hamilton, J. D. (2018). Why you should never use the hodrick-prescott filter. *The Review of Economics and Statistics*, 100(5):831–843.

Hertweck, M. S. (2013). Strategic wage bargaining, labor market volatility, and persistence. *The B.E. Journal of Macroeconomics*, 13(1):1–27.

Hertweck, M. S., Lewis, V., and Villa, S. (2021). Going the extra mile: Effort by workers and job-seekers. *Journal of Money, Credit and Banking*, forthcoming.

Herzog-Stein, A., Lindner, F., and Sturn, S. (2018). The German employment miracle in the Great Recession: the significance and institutional foundations of temporary working-time reductions. *Oxford Economic Papers*, 70(1):206–224.

Hodrick, R. J. and Prescott, E. C. (1997). Postwar U.S. business cycles: an empirical investigation. *Journal of Money, Credit and Banking*, 29(1):1–16.

Hopenhayn, H. and Rogerson, R. (1993). Job turnover and policy evaluation: a general equilibrium analysis. *Journal of Political Economy*, 101(5):915–938.

Karabarbounis, L. and Neiman, B. (2014). The global decline of the labor share. *The Quarterly Journal of Economics*, 129(1):61–103.

Lazear, E. P. (1990). Job security provisions and employment. *The Quarterly Journal of Economics*, 105(3):699–726.

Lazear, E. P., Shaw, K. L., and Stanton, C. (2016). Making do with less: Working harder during recessions. *Journal of Labor Economics*, 34(S1):333–360.

Leigh, J. (1985). The effects of unemployment and the business cycle on absenteeism. *Journal of Economics and Business*, 37(2):159–170.

Lewis, V. and van Dijcke, D. (2020). Work effort and the cycle: Evidence from survey data. Manuscript, Deutsche Bundesbank.

Lewis, V., Villa, S., and Wolters, M. H. (2019). Labor productivity, effort and the euro area business cycle. Discussion Papers 44/2019, Deutsche Bundesbank.

Llosa, G., Ohanian, L., Raffo, A., and Rogerson, R. (2014). Firing costs and labor market fluctuations: a cross-country analysis. 2014 Meeting Papers 533, Society for Economic Dynamics.

Lubik, T. A. and Schorfheide, F. (2004). Testing for Indeterminacy: An Application to U.S. Monetary Policy. *American Economic Review*, 94(1):190–217.

Lydon, R., Mathä, T. Y., and Millard, S. (2019). Short-time work in the Great Recession: firm-level evidence from 20 EU countries. *IZA Journal of Labor Policy*, 8(1):2.

McGrattan, E. R. and Prescott, E. C. (2012). The labor productivity puzzle. In Ohanian, L. E., Taylor, J. B., and Wright, I. J., editors, *Government Policies and the Delayed Economic Recovery*, Book Chapters, chapter 6. Hoover Institution, Stanford University.

Mitra, A. (2020). The productivity puzzle and the decline of unions. Technical report, University of British Columbia.

Mortensen, D. T. and Pissarides, C. A. (1994). Job creation and job destruction in the theory of unemployment. *Review of Economic Studies*, 61(3):397–415.

Nickell, S. (1979). Unemployment and the structure of labor costs. *Carnegie-Rochester Conference Series on Public Policy*, 11:187–222.

Nunziata, L. (2003). Labour market institutions and the cyclical dynamics of employment. *Labour Economics*, 10(1):31–53.

Ohanian, L. E. (2010). The economic crisis from a neoclassical perspective. *Journal of Economic Perspectives*, 24(4):45–66.

Ohanian, L. E. and Raffo, A. (2012). Aggregate hours worked in OECD countries: New measurement and implications for business cycles. *Journal of Monetary Economics*, 59(1):40–56.

Oi, W. Y. (1962). Labor as a quasi-fixed factor. *Journal of Political Economy*, 70:538–538.

Okun, A. M. (1963). *Potential GNP: Its Measurement and Significance*. Cowles foundation paper. Cowles Foundation for Research in Economics at Yale University.

Perri, F. and Quadrini, V. (2018). International recessions. *American Economic Review*, 108(4-5):935–84.

Pissarides, C. A. (2000). *Equilibrium Unemployment Theory, 2nd Edition*. Number 0262161877 in MIT Press Books. The MIT Press.

Rotemberg, J. J. (1982). Monopolistic price adjustment and aggregate output. *Review of Economic Studies*, 49(4):517–531.

Rotemberg, J. J. and Summers, L. H. (1990). Inflexible prices and procyclical productivity. *The Quarterly Journal of Economics*, 105(4):851–874.

Ruhm, C. J. (2000). Are recessions good for your health? *The Quarterly Journal of Economics*, 115(2):617–650.

Sbordone, A. M. (1996). Cyclical productivity in a model of labor hoarding. *Journal of Monetary Economics*, 38(2):331–361.

Schaal, E. (2017). Uncertainty and unemployment. *Econometrica*, 85(6):1675–1721.

Schön, M. (2015). Unemployment, sick leave and health. Annual Conference 2015 (Muenster): Economic Development - Theory and Policy 113013, Verein für Socialpolitik / German Economic Association.

Senney, G. T. and Dunn, L. F. (2019). The role of work schedules and the macroeconomy on labor effort. *Labour Economics*, 57:23–34.

Shapiro, C. and Stiglitz, J. E. (1984). Equilibrium unemployment as a worker discipline device. *The American Economic Review*, 74(3):433–444.

Shea, J. (1999). What do technology shocks do? In *NBER Macroeconomics Annual 1998, volume 13*, NBER Chapters, pages 275–322. National Bureau of Economic Research, Inc.

Stock, J. H. and Watson, M. W. (1999). Business cycle fluctuations in US macroeconomic time series. In Taylor, J. B. and Woodford, M., editors, *Handbook of Macroeconomics*, volume 1 of *Handbook of Macroeconomics*, chapter 1, pages 3–64. Elsevier.

Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy*, 39(1):195–214.

Trigari, A. (2006). The role of search frictions and bargaining for inflation dynamics. Working Papers 304, Innocenzo Gasparini Institute for Economic Research, Bocconi University.

van Zandweghe, W. (2010). Why have the dynamics of labor productivity changed? *Kansas City Fed Economic Review*, 95(Q III):5–30.

vom Lehn, C. and Winberry, T. (2019). The Investment Network, Sectoral Comovement, and the Changing U.S. Business Cycle. NBER Working Papers 26507, National Bureau of Economic Research, Inc.

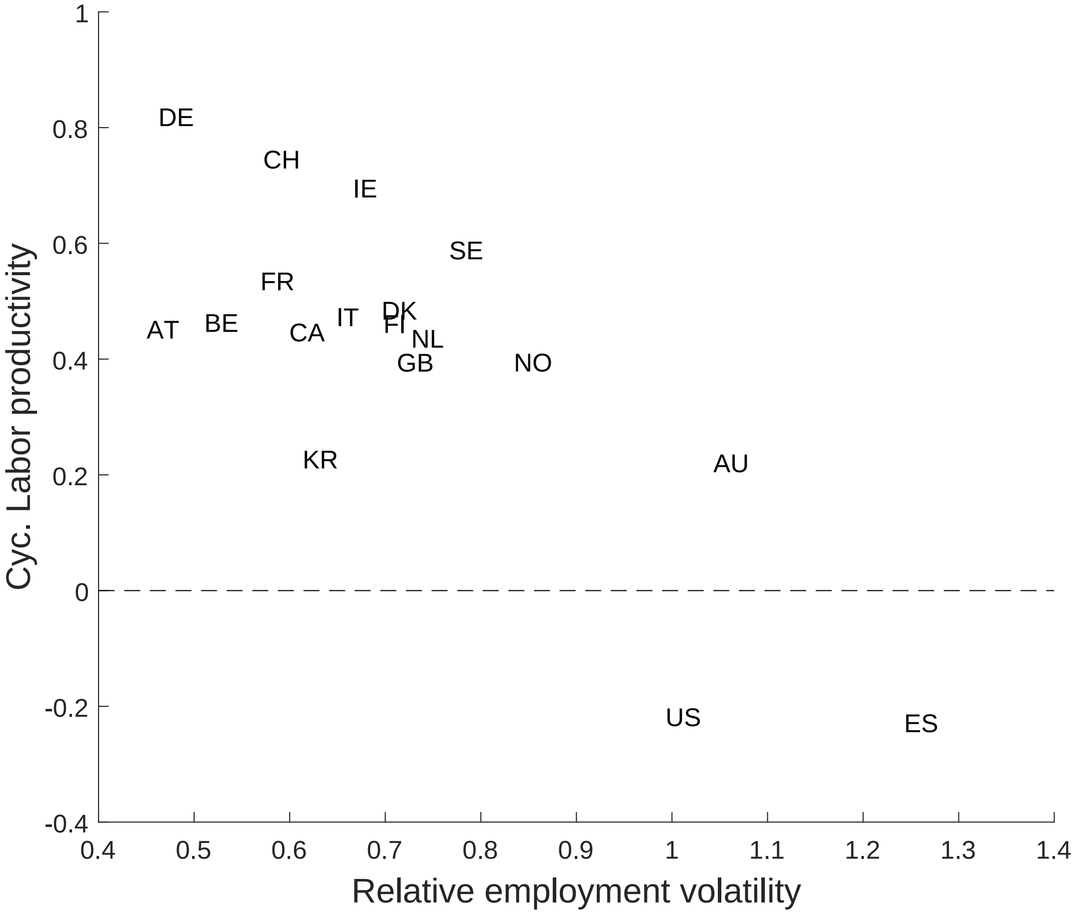

Figure 1: Relative employment volatility and cyclicality of labor productivity

Notes. Sample period 1984q1-2019q4. Labor productivity measured as quarterly real output per hour. Employment volatility measured relative to output. Cyclical component of log productivity, log employment and log output extracted with HP filter (Hodrick and Prescott, 1997). Volatility measured as standard deviation, cyclicality measured as correlation between cyclical components of output and labor productivity. Data sources: OECD, Eurostat, Ohanian and Raffo (2012), ILO, National Offices of Statistics. See online appendix for details.

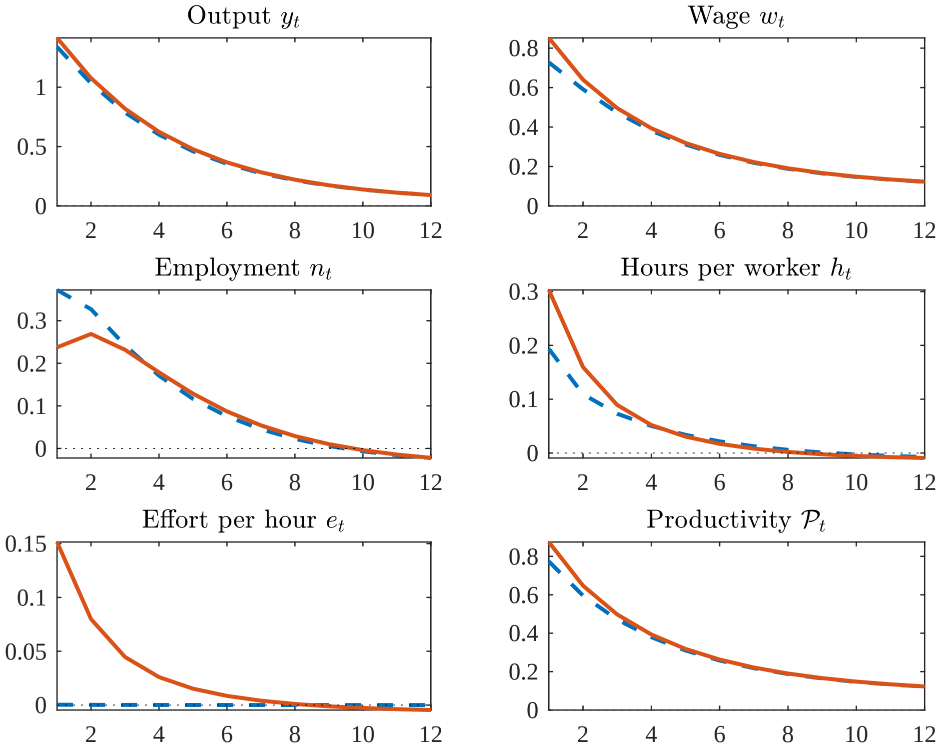

Figure 2: Baseline model responses to one-percent technology shock

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

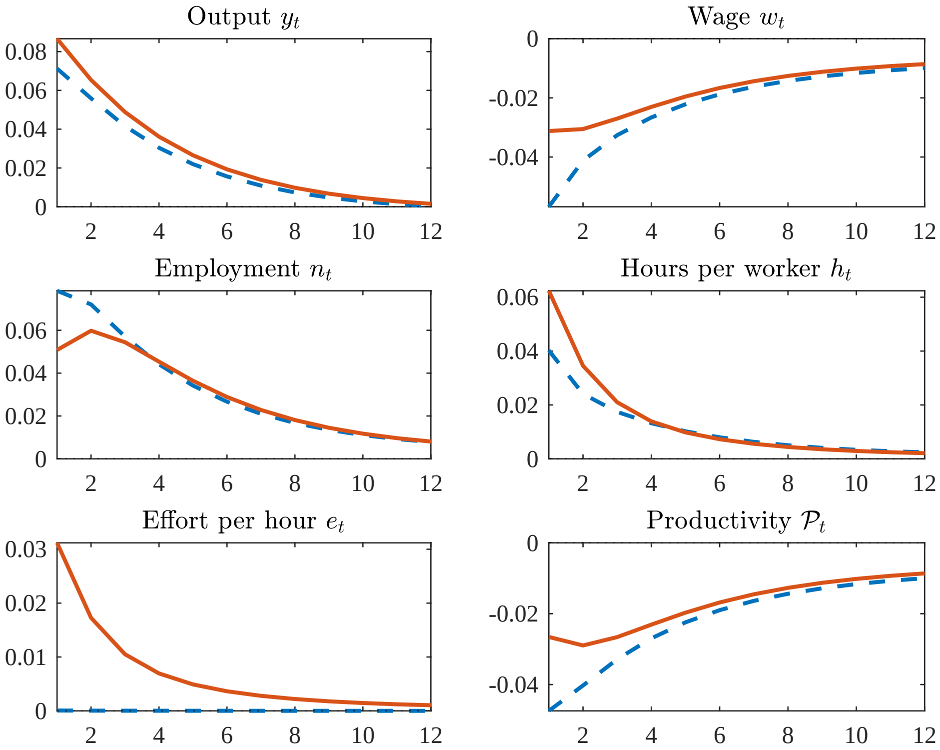

Figure 3: Baseline model responses to one-percent demand shock

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

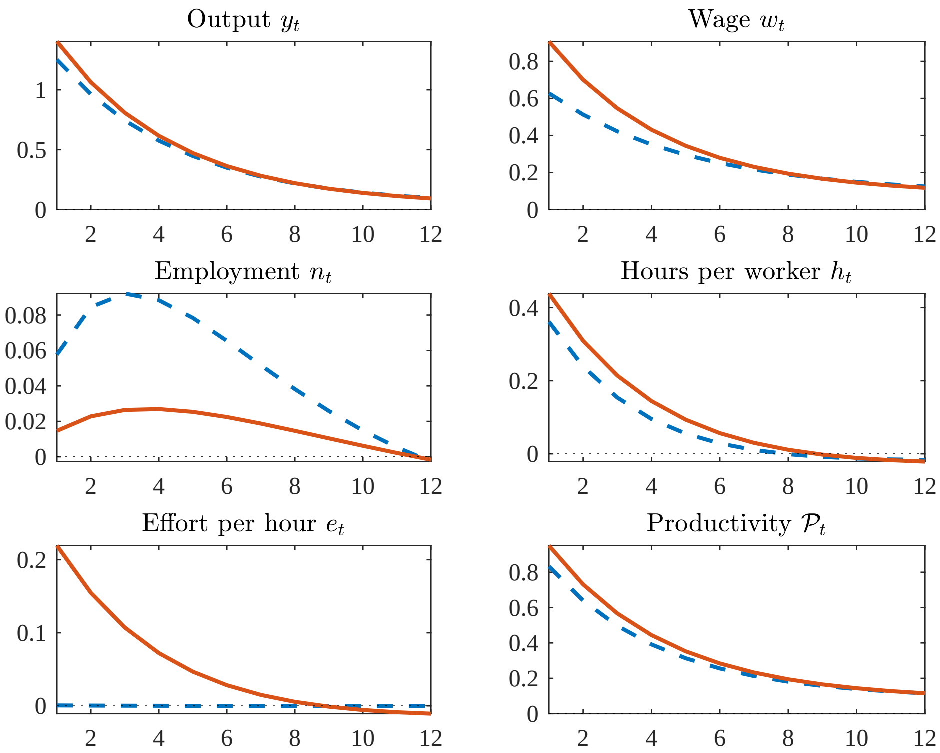

Figure 4: Baseline model responses to one-percent technology shock, rigid labor market

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

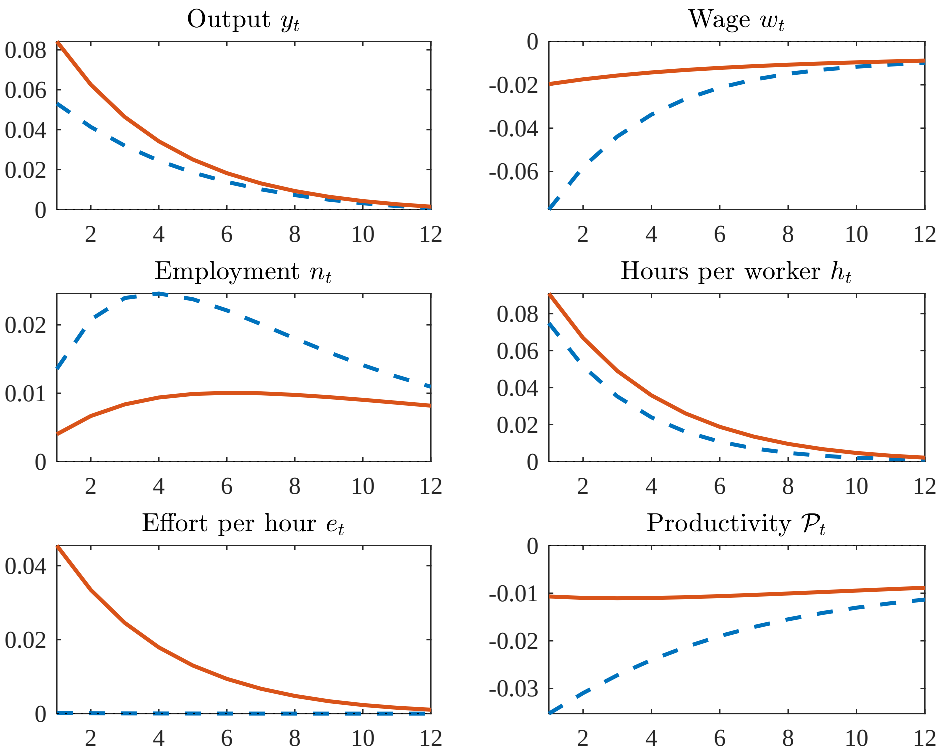

Figure 5: Baseline model responses to one-percent demand shock, rigid labor market

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

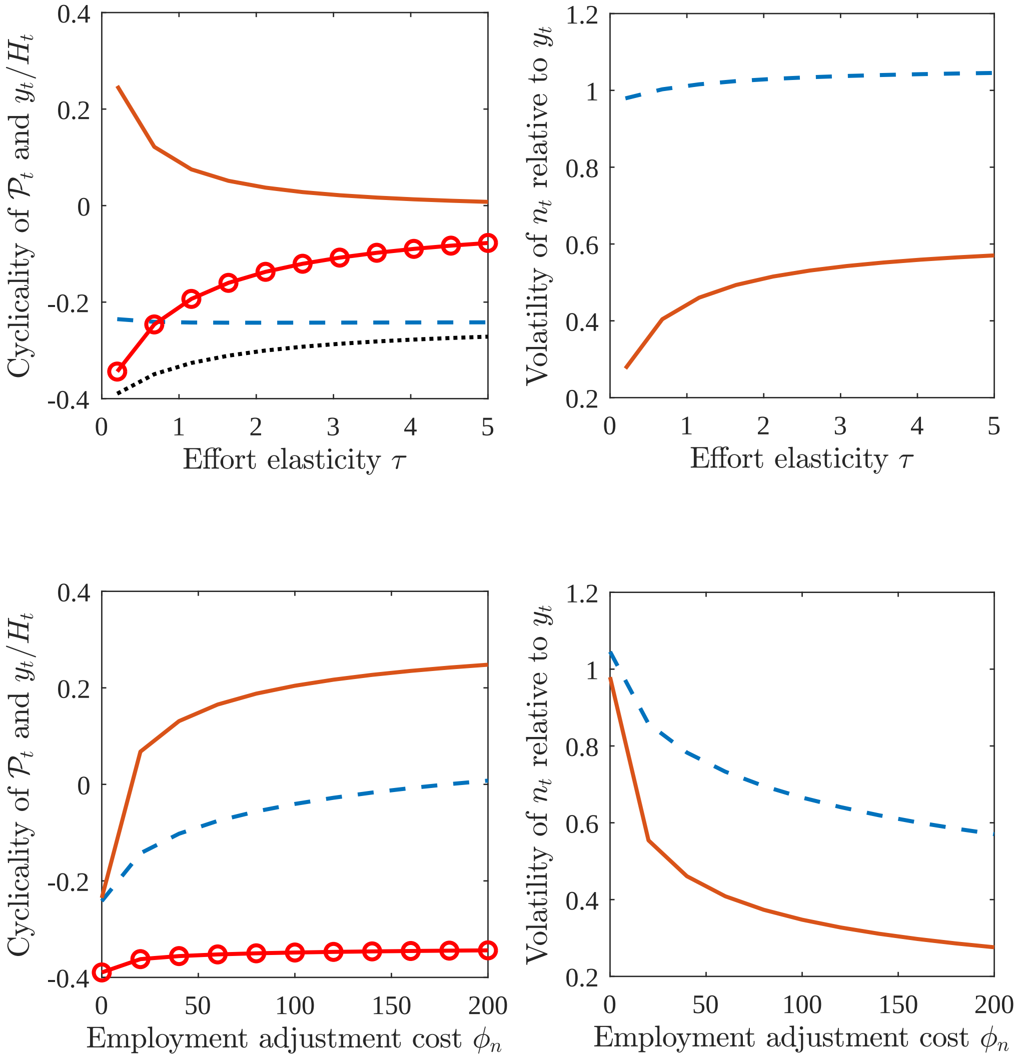

Figure 6: Labor adjustment and second moments, **baseline model**

Notes. In the upper panel, blue dashed lines show model with fluid labor market (low ϕ_n), red solid lines show model with rigid labor market (high ϕ_n). Black dotted line shows true productivity, y/H, in model with fluid labor market, red line with circles depicts true productivity in model with rigid labor market. In the lower panel, blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Red line with circles depicts true productivity in model with variable labor effort.

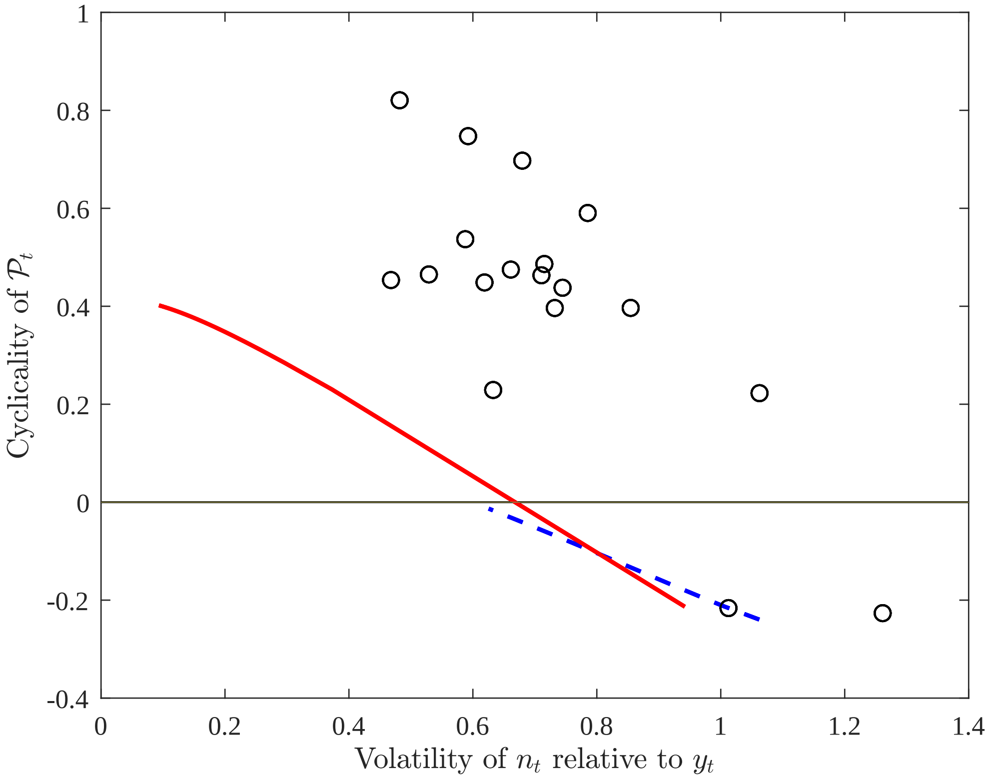

Figure 7: Matching the cross-country evidence

Notes. Scatter of points represents empirical data from Figure 1. Blue dashed line shows moments implied by constant-effort model (high τ). Red solid line shows moments implied by model with variable labor effort (low τ). The line represents combinations of $corr(y_t, \mathcal{P}_t)$ and $\sigma(n_t)/\sigma(y_t)$ for values of ϕ_n between 0.01 and 200.

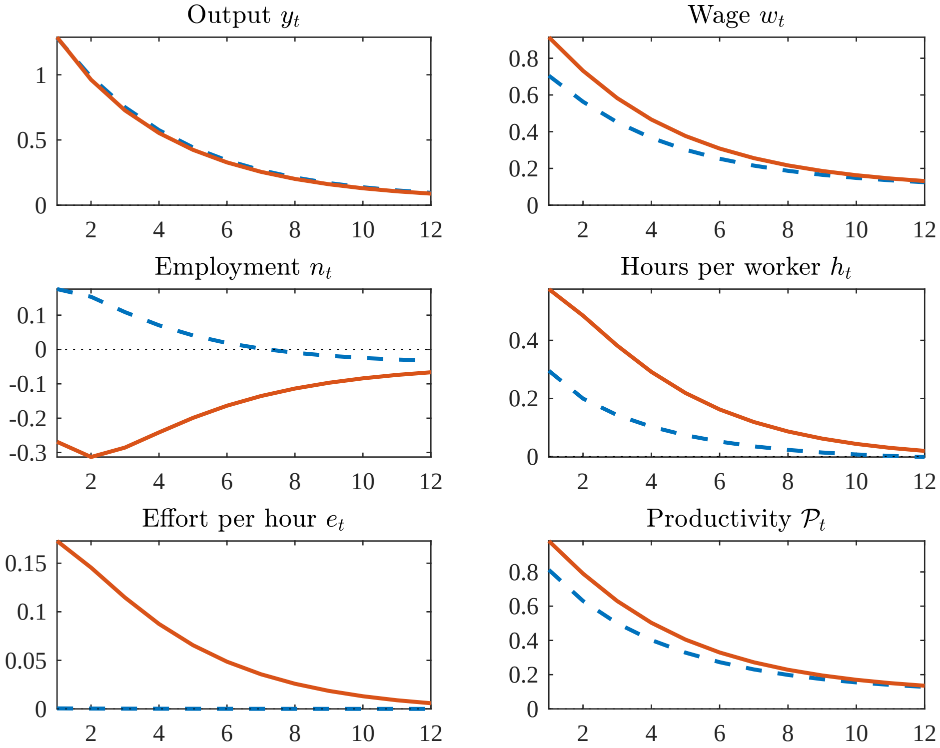

Figure 8: Sticky-price model responses to one-percent technology shock

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

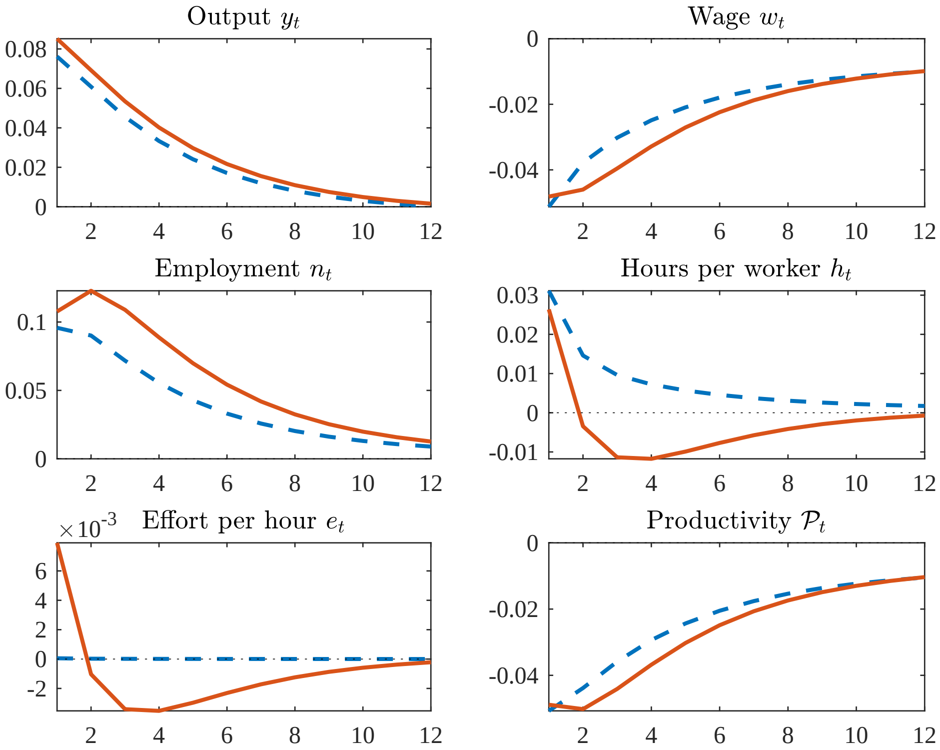

Figure 9: Sticky-price model responses to one-percent demand shock

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

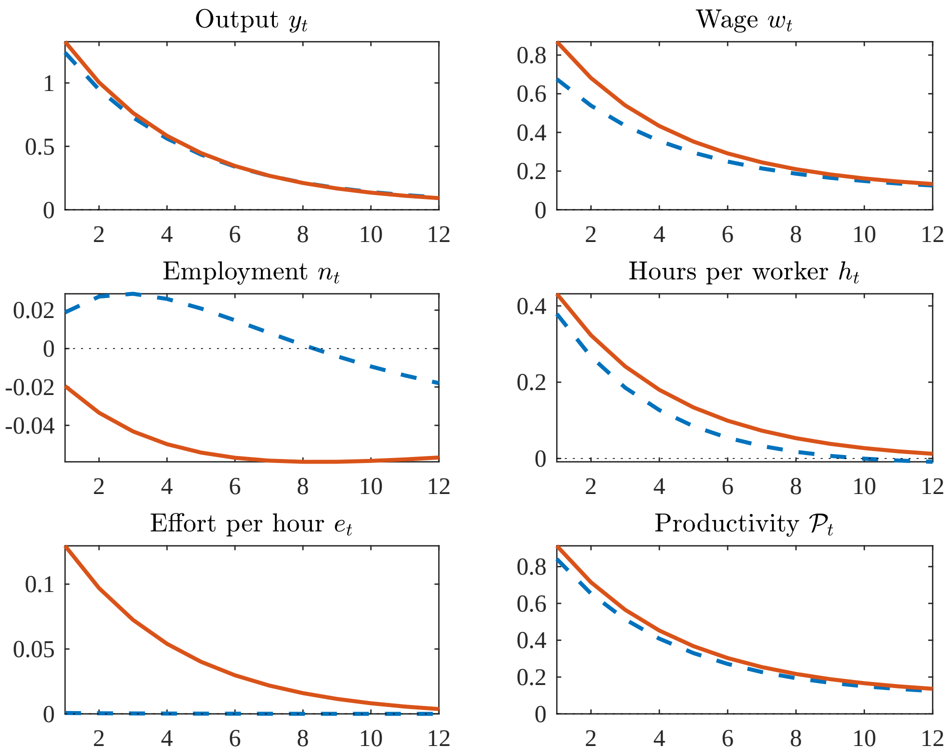

Figure 10: Sticky-price model responses to one-percent technology shock, rigid labor market

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

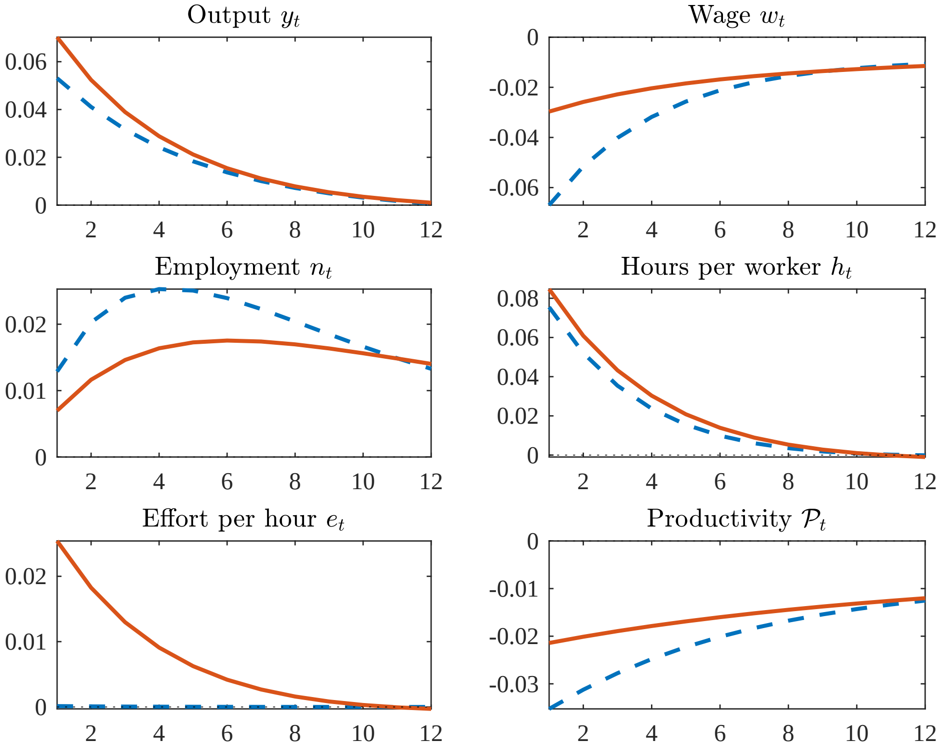

Figure 11: Sticky-price model responses to one-percent demand shock, rigid labor market

Notes. Blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Impulse responses measured as percentage deviation from steady state. Horizontal axis shows time horizon in quarters.

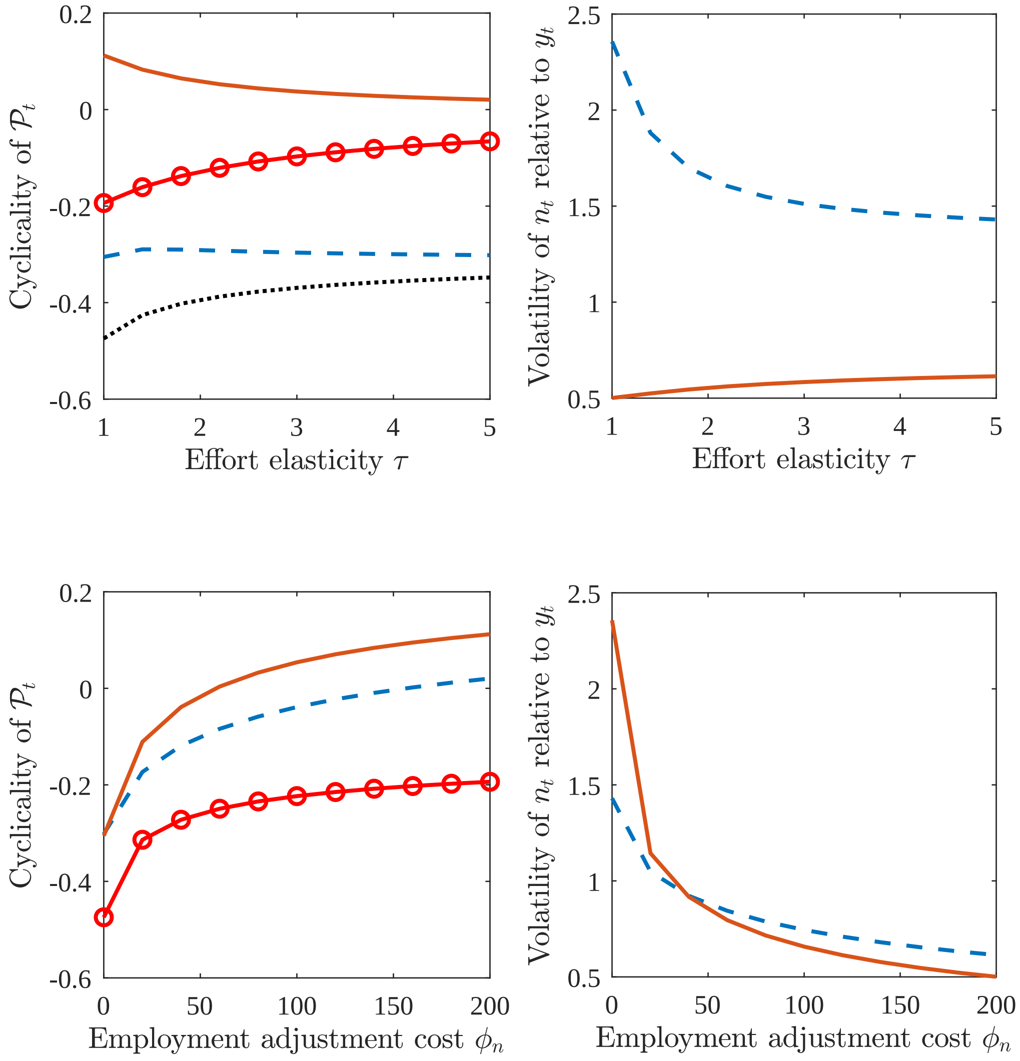

Figure 12: Labor adjustment and second moments, **sticky-price model**

Notes. In the upper panel, blue dashed lines show model with fluid labor market (low ϕ_n), red solid lines show model with rigid labor market (high ϕ_n). Black dotted line shows true productivity, y/H, in model with fluid labor market, red line with circles depicts true productivity in model with rigid labor market. In the lower panel, blue dashed lines show constant-effort model (high τ), red solid lines show model with variable labor effort (low τ). Red line with circles depicts true productivity in model with variable labor effort.