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Labor productivity, effort and the euro area business cycle

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Non-technical summary

Research Question

A cross-country comparison of business cycle characteristics shows that the euro area has a unique combination of highly procyclical labor productivity, low unemployment variability and stable inflation. The procyclicality of labor productivity indicates that total hours respond less to shocks than output. Standard business cycle models cannot replicate this pattern if non-technology shocks are an important source of fluctuations. What is needed are short-run increasing returns to hours in production.

Contribution

We develop a New Keynesian business cycle model with labor search frictions, variable labor effort, and price and wage rigidities. Variable labor effort provides an additional margin through which more output can be produced without the need for adjusting employment (or hours). In response to a demand expansion, labor productivity rises through an increase in effort. Using Bayesian methods, we estimate the model on euro area quarterly data from 1999 to 2016.

Results

According to our estimates, the effort margin is quantitatively important. Two other common explanations for procyclical productivity, variable capital utilization and a dominance of technology shocks in driving business cycles, are far less successful in achieving a good model fit. Finally, we demonstrate that variable labor effort dampens the variability of inflation.

Nichttechnische Zusammenfassung

Fragestellung

Ein Vergleich der konjunkturellen Dynamik wichtiger makroökonomischer Variablen zwischen verschiedenen Volkswirtschaften zeigt, dass der Euroraum eine einzigartige Kombination aus einer hochgradig prozyklischen Arbeitsproduktivität, geringen Schwankungen der Arbeitslosigkeit und einer stabilen Inflationsrate aufweist. Die Prozyklizität der Arbeitsproduktivität deutet darauf hin, dass die Gesamtzahl der geleisteten Arbeitsstunden weniger stark auf Schocks reagiert als die gesamtwirtschaftliche Produktion. Mit herkömmlichen Modellen lässt sich dies nicht replizieren, wenn Konjunkturschwankungen zu einem wesentlichen Teil von Nachfrageschocks herrühren. Benötigt werden vielmehr steigende Skalenerträge der geleisteten Arbeitsstunden.

Beitrag

Wir entwickeln ein Neu-Keynesianisches Modell, das Suchfriktionen auf dem Arbeitsmarkt, eine variable Arbeitsintensität sowie Preis- und Lohnrigiditäten enthält. Durch die variable Arbeitsintensität wird die Möglichkeit geschaffen, die Produktion ohne Anpassung der Beschäftigung (oder der geleisteten Arbeitsstunden) zu steigern. So kann die Arbeitsproduktivität durch eine Erhöhung der Arbeitsintensität auf einen Nachfrageanstieg reagieren. Geschätzt wird das Modell für den Euroraum mithilfe Bayesianischer Methoden auf Basis vierteljährlicher Daten für den Zeitraum von 1999 bis 2016.

Ergebnisse

Die Schätzungen zeigen, dass die variable Arbeitsintensität ein quantitativ bedeutsamer Modellbaustein ist. Zwei weitere gängige Erklärungen für die prozyklische Arbeitsproduktivität, nämlich ein variabler Kapitaleinsatz und die Dominanz von Technologieschocks als Ursache für Konjunkturschwankungen, erweisen sich als sehr viel schlechter geeignet, um die konjunkturelle Dynamik der Euroraumdaten abzubilden. Außerdem zeigen wir, dass durch den variablen Arbeitseinsatz die Inflationsrate stabiler wird.

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Labor Productivity, Effort and the Euro Area Business Cycle*

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Abstract

The Euro Area is characterized by little variation in unemployment and strongly procyclical labor productivity. We capture both characteristics in a New Keynesian business cycle model with labor search frictions, where labor can vary along three margins: employment, hours, and effort. We estimate the model with Bayesian methods and find evidence for a significant use of the effort margin in generating procyclical productivity. We show that a model with labor effort is more successful at matching the business cycle facts than is one with variable capital utilization or dominant technology shocks. Finally, we demonstrate that effort dampens the response of inflation to exogenous shocks.

Keywords: effort, labor utilization, labor productivity, inflation.

JEL classification: E30, E50, E60.

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1 Introduction

The Euro Area business cycle is characterized by strongly procyclical labor productivity, low unemployment volatility and stable inflation. In this paper, we propose variable labor effort (or utilization) as a model feature that allows us to jointly replicate these empirical findings.[1] In an estimated general equilibrium model with frictional labor markets, we disentangle the role of alternative sources of procyclical labor productivity. Our analysis shows that effort outperforms variable capital utilization or dominant technology shocks in terms of model fit.

By way of motivation, Table 1 shows the correlations with output and the relative volatilities of labor market measures, labor productivity, inflation and the policy interest rate in a number of developed countries.

Table 1: Business cycle statistics: Euro Area and beyond.

Variable	Output correlations					Relative standard deviations				
	EA	Canada	Japan	UK	US	EA	Canada	Japan	UK	US
Total hours	0.87	0.78	0.77	0.76	0.85	0.70	0.83	0.77	0.69	1.26
Unemployment	-0.51	-0.79	-0.42	-0.47	-0.65	0.11	0.07	0.10	0.16	0.23
Productivity	0.75	0.47	0.58	0.71	-0.09	0.50	0.60	0.68	0.69	0.63
Inflation	0.38	0.09	0.12	0.11	0.39	0.12	0.69	0.27	0.43	0.17
Policy rate	0.80	0.78	0.50	0.82	0.77	0.16	0.17	0.19	0.23	0.24

Notes: Data sources and transformations are provided in the online appendix. Sample: 1999Q1-2016Q4. Data have been HP-filtered, except for the unemployment rate, which is demeaned. Standard deviations are computed relative to output. Inflation is measured as quarter-on-quarter percentage changes in the GDP deflator.

The most striking observation from Table 1 is that productivity is procyclical in all countries considered, except the US, where the correlation of labor productivity and output is negative and close to zero. The Euro Area has the highest cyclicality, followed by the UK. Turning to the labor market variables, we see that unemployment is rather stable in the Euro Area, Canada and Japan. In the UK, and particularly in the US, unemployment volatility is much higher. The US also has very volatile labor measured as total hours worked. Finally, inflation and the policy interest rate are more stable in the Euro Area than elsewhere. Canada, Japan and the UK have more variable inflation rates. The main take-away from the table is, therefore, that the Euro Area has a unique combination of procyclical productivity, low employment variability and stable inflation, which we seek to capture in a suitably specified business cycle model.

Institutional frictions in Euro Area labor market adjustment may explain why employment flows are relatively small there (Gnocchi, Lagerborg, and Pappa, 2015, among others). In a downturn, firms that are reluctant to lay off workers may adjust labor input along the intensive margin – hours per worker and effort per hour – instead. In a study of 20 OECD countries over the period 1975-1997, Nunziata (2003) concludes that stricter employment protection and looser working time regulations are associated with a lower

[1] The related concept of labor hoarding goes back to Oi (1962), Okun (1963), Rotemberg and Summers (1990) and Burnside, Eichenbaum, and Rebelo (1993).

variability of employment over the cycle. Dossche, Lewis, and Poilly (2019) report that in Germany, France and Italy, around half of the cyclical adjustment of hours worked is in terms of hours per person, while in the US most of this adjustment takes place along the employment margin (see also Abraham and Houseman, 1995).

The procyclicality of labor productivity documented in Table 1 indicates that total hours respond less to shocks than output. Standard business cycle models cannot replicate this pattern if non-technology shocks are an important source of fluctuations. What is needed are increasing returns to hours in production. This can be accomplished by introducing variable labor effort into the model, providing an additional margin through which an extra unit of output can be produced without the need for adjusting employment (or hours). In response to a demand expansion, labor productivity rises through an increase in labor effort. This puts downward pressure on real marginal costs, which in turn dampens inflation.

We thus derive a New Keynesian model with labor search frictions, variable labor effort, and price and wage rigidities. Using Bayesian methods, we estimate the model on Euro Area quarterly data from 1999Q1 to 2016Q4. The estimates show that the effort margin is quantitatively important. Using a likelihood test, we show that the model featuring labor effort is overwhelmingly preferred by the data compared to a standard model with constant effort. Two other common explanations for procyclical productivity, variable capital utilization and a dominance of technology shocks in driving business cycles, are shown to be far less successful at generating a good model fit. Counterfactual simulations of our model show that effort reduces inflation variability and makes output more volatile.

Note that the effort margin only generates procyclical labor productivity if effort is procyclical. From a theoretical perspective, it is not clear a priori whether this is the case. The shirking model by Shapiro and Stiglitz (1984) instead implies countercyclical effort: people work harder in a downturn, when the job finding probability is low and so the costs of getting fired are higher. Empirically, however, various studies find that labor effort is procyclical. Based on data from the American Time Use Survey 2003-2012, Burda, Genadek, and Hamermesh (2017) find that time at work spent on non-work activities conditional on any positive amount rises with unemployment, while the fraction of workers reporting positive values declines. Since the former effect dominates, there is a positive relationship between non-work and the unemployment rate, i.e. effort is procyclical. Lewis and van Dijcke (2019) consider cross-country survey data and find that self-reported effort is procyclical. Evidence from health economics shows that sick leave, workplace accidents and mortality rates are all procyclical.[2] One possible explanation is job-related stress and hazardous working conditions, consistent with the idea that labor is used more intensively in boom periods, implying procyclical effort. There is less evidence in support of countercyclical effort. Based on a direct measure of productivity in a single US firm, Lazear, Shaw, and Stanton (2016) find that effort was countercyclical between 2006 and 2010.

There are a number of papers that focus on the role of variable labor utilization or

[2] Ruhm (2000) shows that people are healthier in recessions. For evidence on procyclical accident rates, see Kossoris (1938), Fairris (1998), and Boone and van Ours (2002). Procyclical sick leave is documented in Taylor (1979), Leigh (1985), Arai and Thoursie (2005), Askildsen, Bratberg, and Nilsen (2005) and Schön (2015).

effort, but differently from our work they study changes in the procyclicality of US labor productivity. If labor market frictions are reduced, firms rely less on the effort margin; as a result, labor productivity becomes less procyclical. Barnichon (2010) uses this mechanism to explain the switch from a negative to a positive correlation between US productivity and unemployment in the mid-1980s. Galí and van Rens (2017) argue that a decline in US labor market turnover has reduced hiring frictions so that variable effort has become a less important adjustment margin. The implied reduction in the procyclicality of labor productivity has, according to their model, reduced the volatility of output. Fernald and Wang (2016) show empirically that lower variation in factor utilization – the workweek of capital and labor effort – is indeed the main driver for the change in the cyclicality of US labor productivity.

Outline. The remainder of the paper is structured as follows. Section 2 outlines the model. In Section 3, we estimate the model using Bayesian techniques. Section 4 estimates the importance of the effort margin vs. variable capital utilization and dominant technology shocks for fitting the data. In Section 5, we discuss the dynamic adjustment of the economy to shocks and we conduct counterfactual exercises. Section 6 concludes. Technical details and robustness checks are provided in an online appendix.

2 Model

In the following, we present a labor search-and-matching model of the business cycle, which allows for labor adjustment along three margins: employment, hours and effort.[3] Furthermore, it features a host of nominal and real frictions (price and wage adjustment costs, investment adjustment costs, variable capital utilization, consumption habit formation). We outline the optimization problem of each agent in the model and derive the most important equilibrium conditions. The full model derivation can be found in the online appendix.

2.1 Households

There exists a unit mass of households. A fraction n_t of workers in a household are employed in the market economy and receive the nominal wage W_{it} from firm $i \in (0,1)$ for providing hours h_{it} and effort e_{it}. The remaining $1 - n_t$ workers are unemployed. The representative household has expected lifetime utility given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[U(C_t) - Z_t^{\ell} n_t \int_0^1 g\left(h_{it}, e_{it}\right) di \right], \tag{1}$$

where $\beta \in (0,1)$ is the subjective discount factor, C_t is consumption, Z_t^{ℓ} is a labor supply shock, and $g\left(h_{it}, e_{it}\right)$ denotes individual labor disutility of providing hours and effort to firm i to those n_t household members that are employed. Each employed household

[3] Leaving out hours per worker, as in Bils, Chang, and Kim (2014), could bias upwards the importance of the effort margin. Moreover, changes in hours per worker account for around half of the variation in total hours in the Euro Area, see Dossche et al. (2019).

member works for all firms on the unit interval; therefore, we sum labor disutility across all firms. Consumption utility is further specified as $U(C_t) = \ln(C_t - \lambda_c C_{t-1})$, where $0 \leq \lambda_c < 1$ is the degree of habit persistence. There exists an insurance technology guaranteeing complete consumption risk sharing between household members, such that C_t denotes individual as well as household consumption.

The household owns the capital stock K_t and finances investment I_t. It faces a sequence of budget constraints,

$$C_t + \frac{B_{t+1}}{Z_t^r R_t P_t} + I_t + a(u_t^k)K_t = n_t \int_0^1 \frac{W_{it}}{P_t} di + r_t^k u_t^k K_t + \frac{B_t}{P_t} + (1 - n_t)b + D_t + T_t. \quad (2)$$

Consumption expenditure, bond purchases B_{t+1}, investment and capital utilization costs $a(u_t^k)K_t$ are financed through wage income by employed members, rental income on capital holdings, income on bond holdings, the leisure value b enjoyed by the unemployed members, real profits D_t, and lump sum government transfers T_t.[4] One-period bonds pay a nominal return R_t, which is subject to a risk premium shock Z_t^r; u_t^k is the rate of utilization of the capital stock, and r_t^k represents the rental rate on capital. Capital utilization costs are $a(u_t^k) = (1-\kappa_u)(u_t^k - 1) + \frac{\kappa_u}{2}(u_t^k - 1)^2$, with $\kappa_u \in [0, 1]$.[5] Normalizing the steady state utilization rate to unity, $u^k = 1$, it follows that the elasticity of the utilization rate to changes in the marginal utilization cost, defined as $\sigma_u \equiv \frac{a'(u^k)}{a''(u^k)u^k}$, equals $\frac{1-\kappa_u}{\kappa_u}$. Letting Z_t^I denote a shock to investment-specific technology, the aggregate capital stock evolves according to the law of motion $K_{t+1} = (1 - \delta)K_t + F(I_t, I_{t-1}) Z_t^I$, with $F(I_t, I_{t-1}) = [1 - \frac{\kappa_I}{2}(I_t/I_{t-1} - 1)^2]I_t$ representing flow adjustment costs to investment. The parameter $\kappa_I > 0$ measures the size of these adjustment costs.

The optimization problem consists in maximizing utility (1), subject to the household budget constraint (2) and capital accumulation. Letting Λ_t denote the Lagrange multiplier on (2), the optimality conditions for bonds, investment, capital holdings and capital utilization are, respectively,

$$1 = Z_t^r R_t E_t\{\beta_{t,t+1}/\Pi_{t+1}\}, \quad (3)$$

$$1 = p_t^k Z_t^I F_{1t} + E_t\{\beta_{t,t+1} p_{t+1}^k Z_{t+1}^I F_{2t+1}\}, \quad (4)$$

$$p_t^k = E_t\{\beta_{t,t+1}[r_{t+1}^k u_{t+1}^k - a(u_{t+1}^k) + (1 - \delta)p_{t+1}^k]\}, \quad (5)$$

$$r_t^k = a'(u_t^k), \quad (6)$$

where F_{it} is the derivative of the function $F(.)$ with respect to its i^{th} argument, $\beta_{t-1,t} \equiv \beta\frac{\Lambda_t}{\Lambda_{t-1}}$ is the stochastic discount factor or the growth of the marginal utility of consumption between $t - 1$ and t, $\Pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate between $t - 1$ and t, and p_t^k denotes the household's shadow price of physical capital. So far, we have described the representative household. Given that all households are identical in equilibrium and

[4] The leisure value b can represent unemployment benefits or home production.

[5] See Zubairy (2014) and Melina and Villa (2018), among others. Following Smets and Wouters (2007), we estimate κ_u.

the mass of households is normalized to unity, C_t is household consumption as well as economy-wide consumption.

2.2 Final Goods

Final output Y_t is an aggregate of intermediate goods Y_{it} bundled according to the function $Y_t = (\int_0^1 Y_{it}^{\frac{\varepsilon_t - 1}{\varepsilon_t}} di)^{\frac{\varepsilon_t}{\varepsilon_t - 1}}$, where ε_t, the elasticity of substitution between the individual varieties, varies exogenously. Given a price P_{it} for each variety i, perfectly competitive final goods firms choose optimally the inputs Y_{it} to minimize total expenditure $\int_0^1 P_{it} Y_{it} di$ subject to the aggregator function given above. This yields the demand functions $Y_{it}^d = (P_{it}/P_t)^{-\varepsilon_t} Y_t$, where the price of the final good P_t can be interpreted as the consumer price index.

2.3 Labor Market Search and Matching Frictions

Firms post vacancies and unemployed workers search for jobs. Let M_t denote the number of successful matches in the labor market. The matching technology is a Cobb-Douglas function of the unemployment rate $u_t = 1 - n_t$ and the aggregate number of vacancies $v_t = \int_0^1 v_{it} di$, $M_t = M_0 u_t^{\eta} v_t^{1-\eta}$, where $\eta \in (0, 1)$ is the elasticity of matches to the unemployment rate and M_0 scales the matching technology. The probability of a vacancy being filled next period q_t equals the number of matches divided by the number of vacancies posted, $q_t = M_t/v_t = M_0 \theta_t^{-\eta}$, where the ratio of vacancies to unemployed workers, $\theta_t \equiv v_t/u_t$, is a measure of labor market tightness. The job finding rate equals the number of matches divided by the number of unemployed, $p_t = M_t/u_t = q_t \theta_t$. An alternative expression for the job finding rate is the probability of filling a vacancy multiplied by the degree of labor market tightness. Defining the aggregate labor force as $n_t = \int_0^1 n_{it} di$, we can write the law of motion for employment as $n_{t+1} = (1 - \lambda) n_t + q_t v_t$. A fraction $\lambda \in (0, 1)$ of matches are destroyed each period.

2.4 Intermediate Goods

Intermediate firms produce differentiated goods under monopolistic competition. Firm i produces output according to the following technology $Y_{it} = Z_t^A (l_{it}^s)^{1-\alpha} (k_{it}^s)^{\alpha}$, where Z_t^A is an exogenous technology index common to all firms, l_{it}^s are labor services, k_{it}^s are capital services, and α is the weight on capital services in production. Labor services are the product of employment, hours per worker and effort per hour; capital services are given by the capital stock multiplied by the capital utilization rate,

$$l_{it}^s = e_{it} h_{it} n_{it}, \tag{7}$$

$$k_{it}^s = u_t^k K_{it}. \tag{8}$$

Since both capital and employment are predetermined, a firm cannot raise output on impact by increasing k_{it} or n_{it}. Instead, the firm adjusts capital and labor *services*, by varying utilization, hours or effort, to satisfy demand in the short run.

Labor Effort. Following Bils and Cho (1994), labor disutility is given by

$$g\left(h_{it},e_{it}\right)=\frac{\lambda_h h_{it}^{1+\sigma_h}}{1+\sigma_h}+h_{it}\frac{\lambda_e e_{it}^{1+\sigma_e}}{1+\sigma_e}, \tag{9}$$

where $\lambda_h\left(\lambda_e\right)>0$ is the weight on hours (effort) in labor disutility and $\sigma_h\left(\sigma_e\right)\geq 0$ determines the degree of increasing marginal disutility of hours (effort). The first term in (9) captures disutility from spending h_{it} hours at work, rather than some best alternative, even when exerting no productive effort. The second term reflects disutility from exerting effort.

Every period, firms and workers choose jointly the combination of hours and effort to minimize labor disutility (9) subject to the production function, yielding the following optimality condition:

$$e_{it}=e_0 h_{it}^{\frac{\sigma_h}{1+\sigma_e}}, \tag{10}$$

where $e_0=(\frac{1+\sigma_e}{\sigma_e}\frac{\lambda_h}{\lambda_e})^{\frac{1}{1+\sigma_e}}$. Equilibrium effort is therefore an increasing and convex function of hours worked.

Returns to Hours in Production. Using the optimal effort choice (10), we can replace labor services in the production function,

$$Y_{it}=y_0 Z_t^A(n_{it}h_{it}^{\phi})^{1-\alpha}(k_{it}^s)^{\alpha}, \tag{11}$$

with $y_0=e_0^{1-\alpha}$ and $\phi=1+\frac{\sigma_h}{1+\sigma_e}$. The elasticity of output to hours worked is thus $\phi(1-\alpha)$. The production function displays short-run increasing returns to hours if $\phi\left(1-\alpha\right)>1$. In response to an expansionary demand shock, firms increase both hours and effort, such that measured productivity (output per hour) increases. To obtain a procyclical response of labor productivity to demand shocks, we need that either the marginal product of hours and effort $(1-\alpha)$, or the effort elasticity to hours, $\sigma_h/(1+\sigma_e)$, is sufficiently high.[6]

Firm Value, Capital Services and Price Setting. The value of firm i in period t is

$$V_{it}^f=\frac{P_{it}}{P_t}Y_{it}^d-w_{it}n_{it}-r_t^k k_{it}^s-cv_{it}-\Phi n_{it}-\Psi_{it}^w-\Psi_{it}^p+E_t\{\beta_{t,t+1}V_{it+1}^f\}, \tag{12}$$

where $w_{it}\equiv W_{it}/P_t$ is the firm-level real wage; $c>0$ is the cost of posting a vacancy, common to all firms and expressed in terms of the final good, v_{it} is the number of vacancies posted by the i^{th} firm, and Φ denotes job-related overhead costs independent of the number of hours per worker.[7] As originally proposed by Rotemberg (1982) and applied to wages by, inter alia, Arseneau and Chugh (2008) and Furlanetto and Groshenny (2016), Ψ_{it}^w and Ψ_{it}^p are quadratic wage and price adjustment costs given by

$$\Psi_{it}^w=\frac{\kappa_w}{2}(\Omega_{it}^w-1)^2 n_{it}, \tag{13}$$

[6]While, in general, a model with increasing returns may feature equilibrium indeterminacy, Hertweck, Lewis, and Villa (2019) show that it does so only under a large deviation from the Hosios condition.

[7]Overhead costs in production facilitate the calibration of the model as shown in Christoffel, Kuester, and Linzert (2009).

$$\Psi^p_{it} = \frac{\kappa_p}{2}(\Omega^p_{it} - 1)^2 Y_{it}, \tag{14}$$

where $\Omega^w_{it} = \frac{w_{it}}{w_{it-1}} \frac{\Pi_t}{\Pi} \left(\frac{\Pi_{t-1}}{\Pi}\right)^{-\lambda_w}$, $\Omega^p_{it} = \frac{\Pi_{it}}{\Pi} \left(\frac{\Pi_{t-1}}{\Pi}\right)^{-\lambda_p}$ and $\Pi_{it} \equiv P_{it}/P_{it-1}$ is firm-level price inflation. The parameters $\kappa_w \geq 0$ and $\kappa_p \geq 0$ capture, respectively, the size of wage and price adjustment costs. Firm i chooses capital services, k^s_{it}, and a price P_{it}, so as to maximize its value V^f_{it}, subject to the law of motion for its workforce and the demand constraint,

$$n_{it+1} = (1 - \lambda) n_{it} + q_t v_{it}, \tag{15}$$

$$(P_{it}/P_t)^{-\varepsilon_t} Y_t = y_0 Z^A_t (n_{it} h^{\phi}_{it})^{1-\alpha} (k^s_{it})^{\alpha}. \tag{16}$$

Denoting by s_{it} the Lagrange multiplier on (16), the demand for capital services satisfies $r^k_t = s_{it} \alpha \frac{Y_{it}}{k^s_{it}}$, such that the real marginal cost equals the rental rate of capital divided by the marginal product of capital. In a symmetric equilibrium, the optimal pricing decision leads to the New Keynesian Phillips Curve,

$$\kappa_p \Omega^p_t (\Omega^p_t - 1) = \varepsilon_t s_t - (\varepsilon_t - 1) + \kappa_p E_t \{\beta_{t,t+1} \Omega^p_{t+1} (\Omega^p_{t+1} - 1) Y_{t+1}/Y_t\}, \tag{17}$$

where $\Omega^p_t = \frac{\Pi_t}{\Pi} (\frac{\Pi_{t-1}}{\Pi})^{-\lambda_p}$. We now derive the firm's and worker's match surplus.

Firm's Match Surplus and Vacancy Posting. The surplus from employing a marginal worker, defined as $S^f_{it} \equiv \frac{\partial V^f_{it}}{\partial n_{it}}$, is given by

$$S^f_{it} = s_{it}(mpn_{it}) - w_{it} - \Phi - \Psi^{w'}_{it} + (1 - \lambda) E_t\{\beta_{t,t+1} S^f_{it+1}\}, \tag{18}$$

where mpn_{it} is the marginal product of employment and $\Psi^{w'}_{it}$ is the derivative of the wage adjustment cost to the number of employees. A vacancy is filled with probability q_t and remains open otherwise. The value of posting a vacancy, in terms of the final good, is

$$V^v_{it} = -c + E_t\{\beta_{t,t+1}[q_t S^f_{it+1} + (1 - q_t) V^v_{it+1}]\}. \tag{19}$$

The firm posts vacancies as long as the value of a vacancy is greater than zero. In equilibrium, $V^v_{it} = 0$ and so the vacancy posting condition is $c/q_t = E_t\{\beta_{t,t+1} S^f_{it+1}\}$, or using the firm's match surplus (18):

$$c/q_t = E_t\{\beta_{t,t+1}[s_{it+1}(mpn_{it+1}) - w_{it+1} - \Phi - \Psi^{w'}_{it+1} + (1 - \lambda) c/q_{t+1}]\}. \tag{20}$$

A firm posts vacancies until the cost of hiring a worker equals the expected discounted future benefits from an extra worker. The costs of hiring a worker are given by the vacancy posting costs divided by the probability of filling a vacancy, which is equivalent to vacancy posting costs multiplied by the average duration of a vacancy, $1/q_t$.

Worker's Surplus. Denote the value of being employed at the i^{th} firm $\mathcal{W}_{it}$ and the value of being unemployed $\mathcal{U}_t$. In period t, an employed worker receives the real wage w_{it} and suffers the disutility $g(h_{it})$ given by (9). In the next period, he is either still employed at firm i with probability $1 - \lambda$, or the employment relation is dissolved with probability

λ. The worker's asset value of being matched to firm i is therefore

$$\mathcal{W}_{it} = w_{it} - mrs_{it} + E_t\{\beta_{t,t+1}[(1-\lambda)\mathcal{W}_{it+1} + \lambda\mathcal{U}_{t+1}]\}, \tag{21}$$

where $mrs_{it} \equiv Z_t^{\ell}\frac{g(h_{it})}{\Lambda_t}$ denotes the marginal rate of substitution between hours and consumption. We divide labor disutility $g(h_{it})$ by the marginal utility of consumption Λ_t to convert utils into consumption units. The value of being unemployed is in turn given by

$$\mathcal{U}_t = b + E_t\left\{\beta_{t,t+1}\left[\int_0^1 \frac{v_{jt}}{u_t}q_t W_{jt+1}dj + (1-p_t)\mathcal{U}_{t+1}\right]\right\}. \tag{22}$$

An unemployed worker receives or produces b units of market consumption goods in period t. In the next period, he faces a probability $\frac{v_{jt}}{u_t}q_t$ of finding a new job with firm j and a probability $1-p_t$ of remaining unemployed. Defining the worker's surplus as $S_{it}^w \equiv \mathcal{W}_{it} - \mathcal{U}_t$, we can write

$$S_{it}^w = w_{it} - mrs_{it} - b + E_t\left\{\beta_{t,t+1}\left[(1-\lambda)\,S_{it+1}^w - p_t\int_0^1 \frac{v_{jt}}{v_t}S_{jt+1}^w dj\right]\right\}. \tag{23}$$

Hours worked. Following Trigari (2006), Thomas (2008) and Cantore, Levine, and Melina (2014) among many others, hours are determined jointly by the firm and the worker to maximize the sum of the firm's surplus, S_{it}^f, and the worker's surplus, S_{it}^w. The first order condition for hours worked implies that the firm's real marginal cost is

$$s_{it} = \frac{1}{\phi(1-\alpha)^2}\frac{mrs_{it}}{\mathcal{P}_{it}}, \tag{24}$$

where $\mathcal{P}_{it} \equiv \frac{Y_{it}}{n_{it}h_{it}}$ is firm-level labor productivity, or firm output divided by total hours. Equation (24) shows that movements in real marginal costs are driven by variations in the marginal rate of substitution between hours and consumption, adjusted for labor productivity.

Wage bargaining. Workers and firms bargain bilaterally over the nominal wage W_{it} and split the surplus according to their respective bargaining weights given by Z_t^B and $(1-Z_t^B)$. Similarly to Cacciatore, Fiori, and Traum (2019), the workers' bargaining power is exogenous and follows an AR(1) process.[8] Under Nash bargaining, the wage is chosen to maximize the joint match surplus, $(S_{it}^w)^{Z_t^B}(S_{it}^f)^{1-Z_t^B}$. The first order condition implies the following sharing rule $S_{it}^w = \Upsilon_t S_{it}^f$, where Υ_t is the workers' effective bargaining power defined as

$$\Upsilon_t \equiv \frac{Z_t^B}{1-Z_t^B}\frac{\delta_{it}^w}{-\delta_{it}^f}. \tag{25}$$

In (25), $\delta_{it}^w \equiv \frac{\partial S_{it}^w}{\partial W_{it}}$ and $\delta_{it}^f \equiv \frac{\partial S_{it}^f}{\partial W_{it}}$ are the changes to the worker's and firm's surplus, respectively, that result from a marginal increase in the nominal wage. Without wage adjustment costs, i.e. if $\kappa_w = 0$, the effective bargaining power reduces to $\Upsilon_t = \frac{Z_t^B}{1-Z_t^B}$.

[8] This shock can be interpreted as the counterpart of the wage markup shock in standard New Keynesian models featuring competitive labor markets.

Taking wage adjustment costs into account, the effective bargaining power can be written as

$$\frac{Z_t^B}{1-Z_t^B}\frac{1}{\Upsilon_t}w_{it}h_{it} = w_{it}h_{it} + \kappa_w(\Omega_{it}-1)\Omega_{it} + (1-\lambda)E_t\{\beta_{t,t+1}\kappa_w(\Omega_{it+1}-1)\Omega_{it+1}\}. \quad (26)$$

Substituting the definitions of the worker's and the firm's surplus, using the sharing rule and the vacancy-posting rule, yields the following equation for the equilibrium real wage:

$$\begin{aligned} w_{it}h_{it} &= \frac{\Upsilon_t}{1+\Upsilon_t}[s_{it}(mpn_{it}) - \Psi_{it}^{w'} + (1-\lambda)c/q_t] \\ &+\frac{1}{1+\Upsilon_t}[mrs_{it} + b - E_t\{\Upsilon_{t+1}(1-\lambda-p_t)c/q_t\}]. \end{aligned} \quad (27)$$

The real wage is a convex combination of two terms. The first term on the right hand side of (27) reflects the surplus to the firm of hiring a new worker: the marginal product of this worker, less wage adjustment costs per worker, plus the continuation value of the match. The second term on the right hand side of (27) reflects the required compensation to the worker of forming a match: the marginal rate of substitution – at the household level – between having one more worker in employment and consumption, plus the leisure value, b, less the worker's continuation value of forming a match.

2.5 Closing the Model

The government budget constraint equates current income (bond issues) with current expenditure (government spending, unemployment benefits, lump-sum transfers, and maturing government bonds),

$$B_{t-1}/P_t = Z_t^G + (1-n_t)b + T_t + R_tB_t/P_t. \quad (28)$$

Combining the household budget constraint (2), summed over households, with the government budget constraint (28), we obtain the aggregate accounting identity,

$$Y_t = C_t + Z_t^G + I_t + a\left(u_t^k\right)K_t + cv_t - \Phi n_t + \Psi_t^w + \Psi_t^p. \quad (29)$$

The central bank follows an interest rate rule given by

$$\ln(R_t/R) = \tau_R \ln(R_{t-1}/R) + (1-\tau_R)[\tau_\Pi \ln(\Pi_t/\Pi) + \tau_y \ln(Y_t/Y_t^n)] + Z_t^R, \quad (30)$$

where Y_t^n is the level of output under flexible prices and wages in the absence of price mark-up and bargaining power shocks; and Z_t^R is a shock to monetary policy.

The model is closed by a set of AR(1) shock processes,

$$\ln\left(Z_t^x/Z^x\right) = \varrho_x \ln\left(Z_{t-1}^x/Z^x\right) + \epsilon_t^x \quad \text{with} \quad \epsilon_t^x \sim N\left(0,\varsigma_x\right), \quad (31)$$

where $x = \{r, \ell, A, B, I, G, R, \epsilon\}$, $Z_t^\varepsilon = \varepsilon_t$, ϱ_x and ς_x denote the persistence and standard deviation of innovation ϵ_{xt}, respectively.

3 Model Estimation

The model is estimated on quarterly data for the period 1999Q1-2016Q4. The eight observable variables are real GDP, real investment, real private consumption, wages per hour, total hours worked, inflation, unemployment and the nominal interest rate. The online appendix reports data sources and definitions. All variables are expressed in logarithms as in Leduc and Liu (2019), except the nominal interest rate. The inflation rate is measured as the first difference of the log GDP deflator. All variables are detrended using the Hodrick-Prescott filter except the unemployment rate, which is demeaned as in Leduc and Liu (2019).[9]

3.1 Calibration and Prior Distributions

Table 2 reports the calibration of the parameters which are related to great ratios or long-run averages, and for which not enough information is contained in the dataset. The time period in the model corresponds to one quarter. Steady state gross inflation Π is set to one. The discount factor, β, is set equal to 0.99, implying a yearly real interest rate of 4%. The depreciation rate of capital, δ_K, is equal to 0.025, such that 10% of the capital stock is written off each year. The capital share of income, α, is set to the conventional value of 0.3. In line with the literature, we set the elasticity of substitution between the individual varieties of goods, ε, to 11 in order to target a steady-state gross price mark-up equal to 1.10.

We normalize the weights on hours and effort in labor disutility, λ_h and λ_e, to unity. The parameter that is key to our mechanism linking variable labor utilization and productivity is the degree of short-run returns to hours, ϕ. It is a function of the curvatures of labor disutility with respect to hours worked, σ_h, and with respect to effort, σ_e. We set σ_h to unity and estimate the composite parameter ϕ. Our calibration for σ_h lies between the values favored by the macro literature, which are typically greater than 1, and estimates elasticities, which tend to be smaller than 1. See Keane and Rogerson (2012) for a survey. Given our estimate of ϕ, we can back out the value the deep parameter σ_e consistent with this value.

The workers' bargaining weight is calibrated at 0.5 as in Cantore et al. (2014). The elasticity of matches to the unemployment rate, η, is set to 0.65, which is in the middle of the range of values estimated in a number of studies on Euro Area countries (Burda and Wyplosz, 1994; Christoffel et al., 2009; Lubik, 2009; Justiniano and Michelacci, 2011; Barnichon and Figura, 2015), similarly to the calibration strategy adopted by Furlanetto and Groshenny (2016). The cost of posting a vacancy, c, is set to target total hiring costs equal to 1% of output, a value that is consistent with Gertler and Trigari (2009), Blanchard and Galí (2010) and Nucci and Riggi (2018). Steady state output is normalized to unity. Following Shimer (2005) and Christoffel and Kuester (2009), the replacement rate, b/wh, equals 0.40. We derive the steady state employment rate n, the separation rate λ, and the number of matches M, as a function of the job finding rate, p, set equal to 0.30 (as in Christoffel et al., 2009), and the unemployment rate u, calibrated to the

[9] For business cycle models with search and matching frictions estimated with HP-detrended data, see Christoffel et al. (2009) among others. We investigate the sensitivity of our results to an alternative filtering technique proposed by Hamilton (2018) in the online appendix.

Table 2: Calibrated parameters

Parameter		Value	Target/Reference
Discount factor	β	0.99	4% risk-free rate p.a.
Capital depreciation rate	δ	0.025	10% depreciation rate p.a.
Production function parameter	α	0.3	SW (2003)
Elasticity of substitution in goods	ε	11	10% price markup
Weight on hours in labor disutility	λ_h	1	Normalization
Weight on effort in labor disutility	λ_e	1	Normalization
Returns to hours in labor disutility	σ_h	1	Keane and Rogerson (2012)
Workers' bargaining weight	Z^B	0.5	Cantore et al. (2014)
Match elasticity	η	0.65	various studies
Cost of posting a vacancy	c	$cv/Y = 1\%$	GT (2009), BG (2010)
Replacement rate	$b/(wh)$	0.40	Shimer (2005), CK (2009)
Steady state unemployment rate	u	9.6%	Data
Steady state job finding rate	p	0.30	Christoffel et al. (2009)
Steady state vacancy filling rate	q	0.70	Christoffel et al. (2009)
Government spending share	Z^G/Y	0.20	Data

Notes: SW (2003): Smets and Wouters (2003), CK (2009): Christoffel et al. (2009), GT (2009): Gertler and Trigari (2009), BG (2010): Blanchard and Galí (2010).

average value in the dataset, 9.6%. The implied separation rate is 3% in the Euro Area, in line with the data (Christoffel et al., 2009). Using a calibrated value of 0.70 for the vacancy filling rate, q, as in Christoffel et al. (2009) and Cantore et al. (2014), we then calculate the number of vacancies v and the degree of labor market tightness θ. The government share in output, Z^G/Y, is equal to 20%. The online appendix provides more details on the calibration strategy.

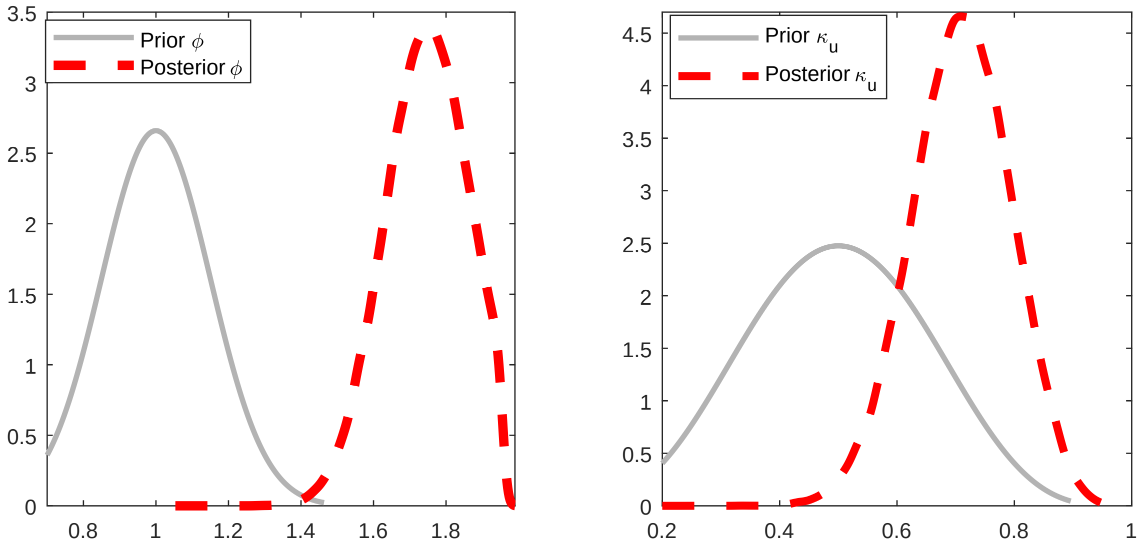
All the remaining parameters are estimated, as shown in Table 3. The locations of the prior means correspond to a great extent to those in Smets and Wouters (2007). The prior mean of the Rotemberg price adjustment cost parameter corresponds to a Calvo contract average duration of around three quarters, with a loose standard deviation, as in Di Pace and Villa (2016). The prior mean of the parameter measuring short-run returns to hours, ϕ, is set to 1 with a loose standard deviation so that the prior distribution encompasses a broad range of values around 1. In this way, we allow for both decreasing and increasing returns to hours in production. In setting the prior mean for the wage adjustment cost parameter, κ_w, we choose the value 10 proposed by Arseneau and Chugh (2008), which corresponds to nominal wages being sticky for four quarters on average.

In the following, we discuss the parameter estimates that are the most relevant for our research question, examine the role of shocks in driving business-cycle fluctuations, and compare the model-implied series of effort with an available proxy.

3.2 Estimation Results

Parameter Estimates. Effort plays an important role in the Euro Area business cycle; the median estimate of the returns to hours ϕ is equal to 1.74. Given this estimate and the calibrated value of σ_h, the curvature of the effort disutility function, σ_e, is equal to

Figure 1: Prior and posterior densities of returns to hours ϕ and capital utilization κ_u.



0.35. In the standard model, varying effort is extremely costly, $\sigma_e \to \infty$, and hence effort is constant. A lower σ_e implies a greater use of the effort margin. There is evidence of both price and wage stickiness; prices are sticky for about three quarters.[10] The mean of the parameter measuring the elasticity of the capital utilization function is higher than its prior mean, indicating a limited role for this margin of adjustment (see Section 4 on this). The posterior distributions of the remaining parameters are in line with the literature.

Figure 1 shows the prior and posterior densities of the two parameters measuring the degree of factor utilization: short-run returns to hours in production, ϕ, and the elasticity of the capital utilization adjustment cost function, κ_u. Both parameters are well identified by the data, exhibiting a probability density tightly gathered around the posterior mean, despite the loose prior. The posterior distribution of ϕ is located to the right of the parameter range, providing evidence for increasing returns to hours. The posterior distribution of κ_u is located to the right of the parameter range, revealing high capital utilization costs and, hence, a limited role for this margin of input adjustment.

Variance decomposition. Table 4 shows the unconditional (long-run) variance decomposition in the baseline model, in the constant-effort model and in the model without variable capital utilization (no-VCU model). In the baseline model, price mark-up and labor supply shocks are the most important supply-side innovations explaining fluctuations in output, while risk premium shocks are the most important demand-side exogenous innovations. The important role played by labor supply shocks is confirmed by other studies (Blanchard and Diamond, 1989; Shapiro and Watson, 1988; Chang and Schorfheide, 2003; Foroni, Furlanetto, and Lepetit, 2018). Inflation is mainly driven by monetary policy, risk premium and price mark-up shocks. Labor productivity and wages are mainly driven by

[10] For the algebraic relationship between the Rotemberg and the Calvo parameter see Cantore et al. (2014). Note that in the presence of Nash bargaining under search and matching frictions there is no 'wage Phillips curve', hence it is not possible to make a precise mapping from the duration of wage-stickiness to the cost-adjustment parameter κ_w.

Table 3: Parameter estimates: baseline model.

Parameter			Prior		Posterior
		Distrib.	Mean	Std/df	Mean
Structural					
Returns to hours	ϕ	Normal	1.00	0.15	1.74 [1.58;1.93]
Habits in consumption	λ_c	Beta	0.50	0.15	0.33 [0.20;0.46]
Capital utilization	κ_u	Beta	0.50	0.15	0.71 [0.57;0.85]
Investment adjust. costs	κ_I	Gamma	4.00	1.50	1.78 [0.76;2.85]
Price stickiness	κ_p	Gamma	60.0	20.00	61.92 [45.60;77.54]
Price indexation	λ_p	Beta	0.50	0.15	0.26 [0.10;0.41]
Wage stickiness	ψ^w	Gamma	10.0	3.00	6.48 [4.54;8.44]
Wage indexation	λ_w	Beta	0.50	0.15	0.43 [0.21;0.65]
Inflation -Taylor rule	τ_Π	Normal	1.70	0.20	1.70 [1.40;2.01]
Output gap -Taylor rule	τ_y	Normal	0.12	0.05	0.11 [0.04;0.18]
Interest rate smoothing	τ_R	Beta	0.75	0.10	0.77 [0.72;0.82]
Exogenous processes					
Technology	ρ_a	Beta	0.50	0.15	0.43 [0.30;0.56]
	σ_a	IG	0.10	2.0	0.58 [0.49;0.66]
Price mark-up	ρ_P	Beta	0.50	0.15	0.47 [0.34;0.61]
	σ_P	IG	0.10	2.0	8.91 [6.14;11.63]
Bargaining power	ρ_{γ^B}	Beta	0.50	0.15	0.71 [0.58;0.84]
	σ_{γ^B}	IG	0.10	2.0	1.34 [0.92;1.76]
Labor supply	ρ_ℓ	Beta	0.50	0.15	0.73 [0.64;0.83]
	σ_ℓ	IG	0.10	2.0	0.81 [0.67;0.95]
Government spending	ρ_g	Beta	0.50	0.15	0.67 [0.57;0.77]
	σ_g	IG	0.10	2.0	1.66 [1.42;1.88]
Interest rate	ρ_R	Beta	0.50	0.15	0.27 [0.18;0.38]
	σ_R	IG	0.10	2.0	0.10 [0.09;0.12]
Investment-specific	ρ_I	Beta	0.50	0.15	0.13 [0.05;0.21]
	σ_I	IG	0.10	2.0	2.57 [1.14;4.12]
Risk premium	ρ_{zr}	Beta	0.50	0.15	0.25 [0.09;0.40]
	σ_{zr}	IG	0.10	2.0	0.73 [0.45;1.01]
Marginal log likelihood					–182.392

Notes: Table shows prior and posterior distributions of estimated parameters; 90% HPD intervals in square brackets. Posterior mean computed with two chains of the Metropolis-Hastings algorithm on sample of 400,000 draws.

supply-side shocks. In particular, technology shocks are the main driver of productivity, while wages are mainly explained by price mark-up shocks. The role of bargaining power shocks is limited, in line with the results by Furlanetto and Robstad (2019) for the US economy. Labor market variables, employment and hours, are mainly explained by labor supply shocks.

Model-implied labor effort. The correlation of the implied effort series with output is 0.87. This procyclicality as also visible in Figure 2 is by construction, since equilibrium

Table 4: Variance decomposition.

Variable	Structural shocks							
	Techno-logy	Price mark-up	Barg. power	Labour supply	Risk premium	Investment specific	Monetary policy	Fiscal policy
				Baseline model				
Output	7.08	13.39	0.01	34.84	17.43	11.40	5.94	9.91
Inflation	14.95	16.70	0.00	14.52	24.62	1.52	26.96	0.74
Wage	15.30	50.08	5.13	6.62	7.21	6.15	9.19	0.31
Productivity	63.25	5.25	0.04	10.58	8.14	7.81	2.43	2.51
Employment	10.12	24.42	17.38	33.52	4.11	1.74	8.44	0.27
Hours	16.39	10.40	0.04	33.78	13.79	10.53	4.73	10.35
				Constant-effort model				
Output	15.88	13.52	0.03	15.68	29.69	9.15	7.48	8.56
Inflation	15.51	4.13	0.01	7.90	35.79	4.06	30.18	2.41
Wage	29.39	39.58	15.91	6.85	0.92	3.50	2.53	1.33
Productivity	87.20	0.85	0.00	5.92	2.78	2.40	0.42	0.41
Employment	21.47	34.80	11.14	17.83	3.52	0.59	10.28	0.38
Hours	15.11	10.57	0.04	24.32	22.48	10.95	6.11	10.42
				No-VCU model				
Output	11.83	8.79	0.01	49.06	6.46	11.31	3.19	9.34
Inflation	15.99	16.18	0.00	16.68	25.20	2.37	22.22	1.35
Wage	23.44	39.09	2.44	10.80	2.79	0.24	11.71	9.48
Productivity	78.20	1.03	0.03	10.06	0.42	9.45	0.25	0.55
Employment	12.43	20.15	13.04	39.13	6.37	2.46	6.28	0.15
Hours	13.74	8.74	0.04	45.99	7.37	9.65	3.48	10.99

effort is a positive function of hours worked which are procyclical. The figure also reports the cyclical component of fatal and non-fatal accidents at work (number) for the Euro Area, which can be broadly interpreted as a proxy for effort (see also Galí and van Rens, 2017).[11] These series are available at annual frequency, from 2008 to 2016, by Eurostat. The proxy for effort is clearly pro-cyclical and its correlation with the model-implied effort is 0.61.

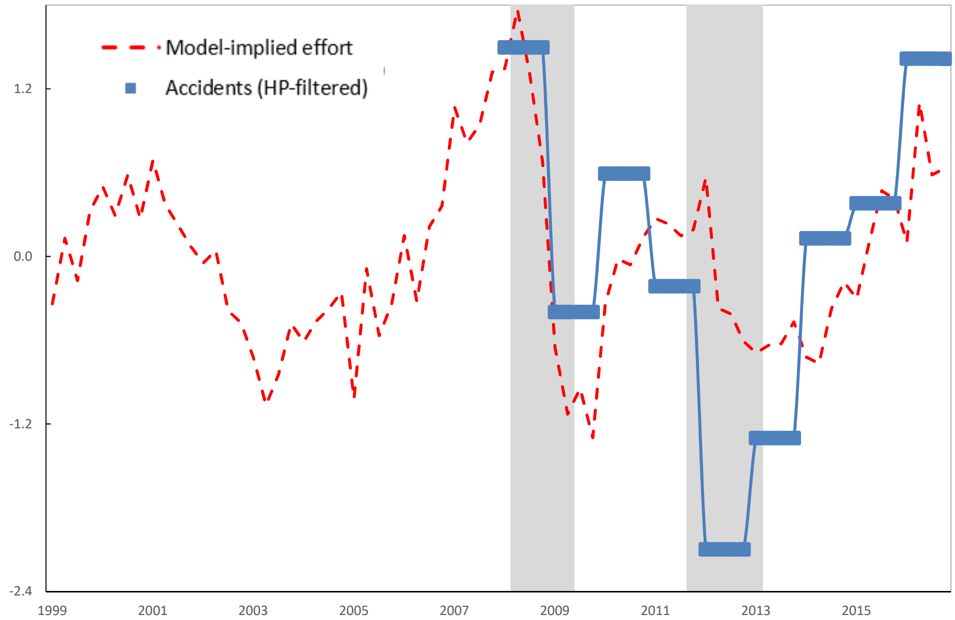
4 Alternative Explanations for Procyclical Productivity

What is the importance of effort relative to competing mechanisms in accounting for the observed procyclicality of labor productivity? We consider two prominent candidate explanations: variable capital utilization and dominant technology shocks.

First, Christiano, Eichenbaum, and Evans (2005) point to wage staggering and variable capital utilization (VCU) as key features that can account for the observed macroeconomic inertia. Their proposed model indeed matches very well the response of output and

[11] Data on accidents have been HP-filtered for comparison with the model-implied variable.

Figure 2: Model-implied labor effort and accidents at work (HP-filtered).



Notes: Shaded areas show recessions as identified by the Centre for Economic Policy Research (CEPR).

inflation to a monetary policy shock. However, the response of productivity is more procyclical in the data than it is in their model.[12] If the model is missing important frictions that would capture better the observed productivity response, these frictions will very likely also influence the implied output and inflation dynamics, and hence might affect any inference one draws regarding the relative importance of various real rigidities in generating realistic impulse response functions. Since in their model, variable capital utilization appears to be unable to generate sufficiently procyclical labor productivity, we investigate whether this is the case also in our model.

Second, procyclical productivity could simply be explained by technology shocks being the dominant source of Euro Area business cycle fluctuations. In that case, any model extension involving the introduction of variable labor effort would be wasted effort.

4.1 Variable Capital Utilization

We first analyse to what extent the goodness of fit can be attributed to either labor or capital utilization. To this end, we estimate two alternative model specifications: (1) a 'standard' model with constant labor effort; and (2) a model with no variable capital utilization. In the first model, we set ϕ close to 1, thus implicitly we let $\sigma_e \to \infty$. In other words, we impose that increasing effort leads to a prohibitively large rise in disutility, hence effort does not vary in equilibrium. In the second model, we impose that κ_u is close to 1, such that variation in capital utilization is costly and, thus, capital utilization is

[12] In fact, the model response is outside the probability bands of the corresponding empirical impulse response, indicating a poor fit in that dimension.

Table 5: Marginal log-likelihood comparison baseline vs. alternative models.

	baseline	vs.	constant effort
Marginal log-likelihood	-182.392		-201.986
Bayes factor		3.23×10^8	
Kass-Raftery statistic		39.19	
	baseline	vs.	no VCU
Marginal log-likelihood	-182.392		-187.163
Bayes factor		1.18×10^2	
Kass-Raftery statistic		9.54	
	no VCU	vs.	constant effort
Marginal log-likelihood	-187.163		-201.986
Bayes factor		2.74×10^6	
Kass-Raftery statistic		29.65	

Notes: The marginal log-likelihood is computed as in Geweke (1999). Let m_i be a given model, with $m_i \in M$, and $L(Y|m_i)$ be the marginal data density of model i for the common dataset Y, then the Bayes factor (BF) between model i and model j is computed as:

$$BF_{i/j} = \frac{L(Y|m_i)}{L(Y|m_j)} = \frac{exp(LL(Y|m_i))}{exp(LL(Y|m_j))}$$

where LL stands for log-likelihood. According to Jeffreys (1998), a BF of 3 to 10 provides 'slight' evidence in favor of model i relative to model j; a BF in the range 10 to 100 provides 'strong to very strong' evidence; and a BF greater than 100 provides 'decisive evidence'. Values of the KR statistic above 10 can be considered 'very strong' evidence in favor of model i relative to model j; between 6 and 10 represent 'strong' evidence; between 2 and 6 'positive' evidence; while values below 2 are 'not worth more than a bare mention'.

virtually constant.[13]

Table 5 reports the Bayes factor (BF) and the statistics by Kass and Raftery (1995) (KR), computed as twice the log of the BF, between the baseline model and the constant-effort model. With a BF well above 100, we find 'decisive evidence' in favor of our baseline model featuring effort. The KR statistics points to 'very strong' evidence in favor of the unconstrained baseline model versus the restricted model without effort. What is most interesting for our research question is the comparison between the constant-effort versus the no-VCU model. Table 5 reveals that the latter is strongly preferred by the data. Hence the baseline model with both features (effort and VCU) is most preferred by the data, while the constant-effort model comes out last in our likelihood race.

The online appendix reports the estimated parameters of the two restricted models. A comparison between the estimates of the baseline model with the two alternative models shows a significant difference between some of the parameter estimates. We consider two parameters different if the mean estimate of a parameter in one model economy does not fall in the 90% highest probability density (HPD) intervals for the same parameter of the other model economy, as in Smets and Wouters (2005).

In the constant-effort model, two mechanisms appear to replace the role played by

[13] In contrast, if κ_u is close to 0, the variable capital utilization is a very important margin for amplifying business cycle fluctuations as shown in a calibrated model by Villa (2012).

labor effort, an endogenous mechanism and an exogenous one. First, κ_u is estimated to be significantly lower than the baseline model, revealing a greater role of capital utilization. Second, the restricted model features a significantly higher estimate of ρ_a, i.e. a more persistent technology shock. Thus, in the absence of the endogenous labor effort, the model relies more on exogenous sources of persistence.

Parameter estimates are similar under the two model specifications, baseline and no-VCU. A notable difference is the estimate of the degree of wage stickiness, whose mean value is 10.36 [7.27; 13.48] in the no-VCU model versus 6.48 [4.54; 8.44] in the baseline model.

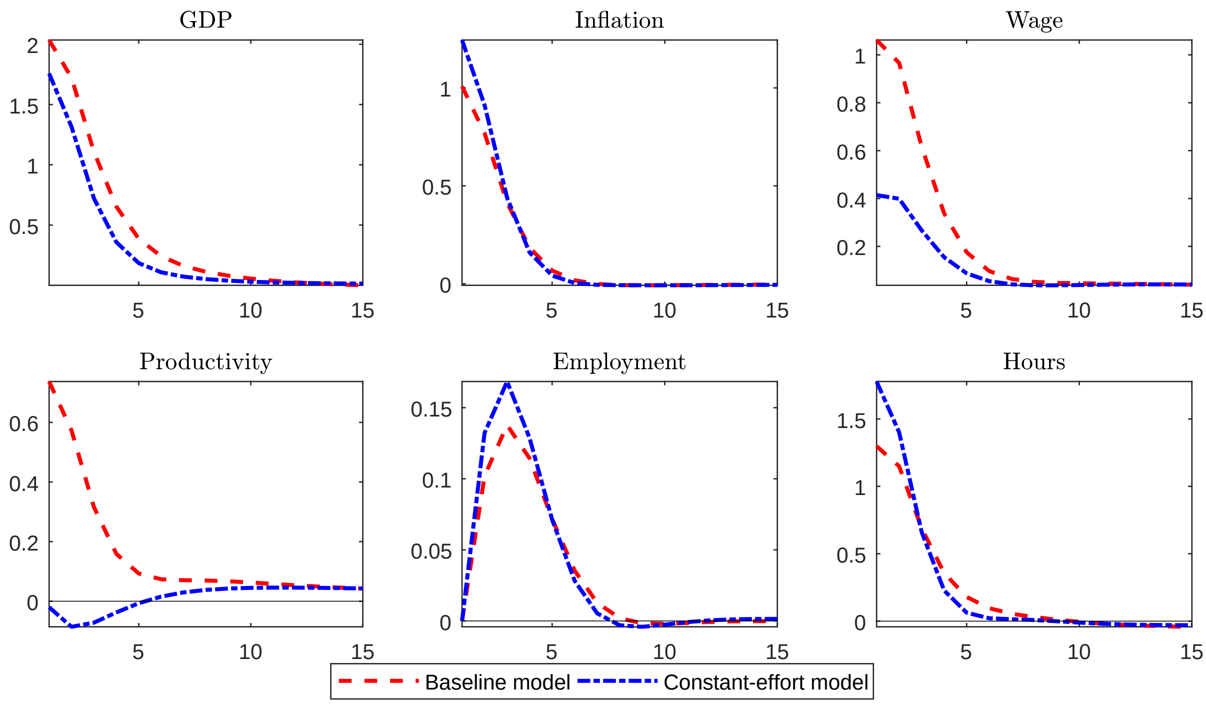
4.2 The Role of Technology Shocks

The variance decomposition in Table 4 shows that productivity shocks are more important in accounting for business cycle fluctuations in the constant-effort model compared to the baseline model with effort. This result is in line with Hornstein (1993), who shows that the introduction of increasing returns in production (and imperfectly competitive markets) reduces the contribution of exogenous productivity changes to aggregate fluctuations. Hornstein's setup differs with respect to the modeling of increasing returns in production though. He directly imposes a scale parameter that leads to declining marginal cost and also fixed cost parameter, while in our setup increasing returns to hours are generated endogenously by the variable effort margin. He finds based on Solow-residuals that a model with constant returns in production overestimates the magnitude of productivity shocks, which leads to a too high share of output explained by productivity shocks. In our setup, the differences in the shock size are small and insignificant. In the baseline model we estimate $\sigma_a = 0.58$ and $\rho_a = 0.43$, while in the model with constant effort the parameter estimates are: $\sigma_a = 0.47$ and $\rho_a = 0.55$. Hence, in our case the change in the propagation mechanism is key for the reduction of the importance of productivity shocks for explaining output.

The role of labor supply shocks is more important in the model with variable effort compared to the constant-effort specification, though the variance of labor supply shocks is even somewhat smaller in the former specification. Hence, again the change in the propagation mechanism is key for the change in the variance decomposition. Finally, the risk-premium shock accounts for a smaller fraction of business cycle fluctuations in the model with an effort margin. The magnitude of risk-premium shocks is smaller in the baseline model, but the difference is relatively small and insignificant. Hence, again changes in the propagation are key for the lower importance of risk-premium shocks in the baseline model. This underlines our finding from Table 5 that the transmission mechanisms of the model with variable effort are a better description of the data than those of the constant-effort specification.

The variance decomposition of the no-VCU model is more in line with that of the baseline model. There main differences are the larger role of productivity shocks in affecting movements in productivity and the larger role of labor supply shocks in accounting for output and hours fluctuations compared to the baseline model.

Figure 3: Impulse responses to a monetary policy shock.



Notes: Figure shows estimated mean and counterfactual responses. Y-axes show percent deviations from steady state. Time horizon on X-axes measured in quarters. Shock size normalized to one in both scenarios.

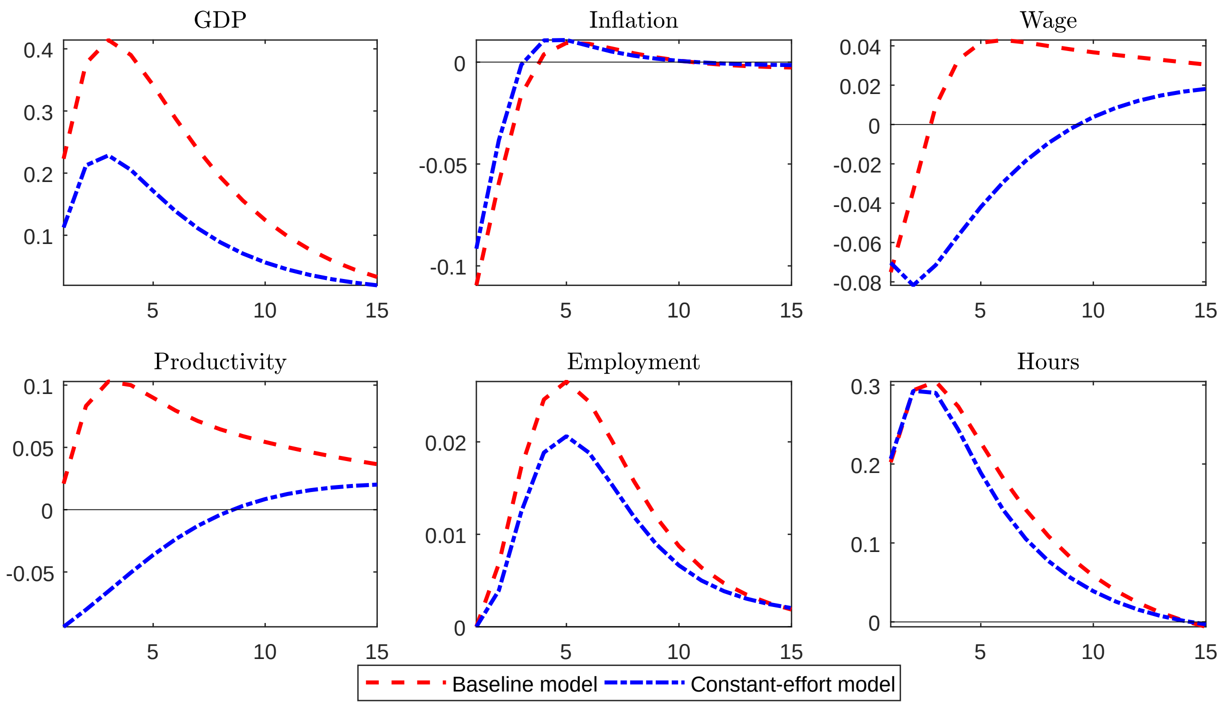
5 Labor Effort and Macroeconomic Dynamics

This section examines the role of variable labor effort in affecting the transmission of shocks to macroeconomic aggregates. Figures 3 to 5 show impulse response functions to monetary policy, labor supply and technology shocks.[14] Those three shocks are the most important source of fluctuations in output, inflation and productivity, our main variables of interest. Risk premium shocks also matter; however, since they are qualitatively very similar to monetary policy shocks, we do not discuss them separately here. Two different scenarios are depicted: (1) the estimated responses in the baseline model; and (2) a counterfactual constant-effort model, where again all parameters are set to their estimated values, except the parameter measuring the returns to hours, ϕ, which is set close to one.

Monetary policy shock. An expansionary monetary policy shock, modelled as an exogenous fall in the nominal interest rate, is depicted in Figure 3. It raises output by boosting investment and bringing consumption forward. Demand pressures feed through to inflation through the New Keynesian Phillips Curve (17) by opening up an output gap. Producing more output requires more factors of production. Both the intensive and extensive margins of labor rise. Since employment can adjust only slowly, its response is

[14] In the interest of clarity, we report only the mean impulse response function, without probability bands.

Figure 4: Impulse responses to a labor supply shock.



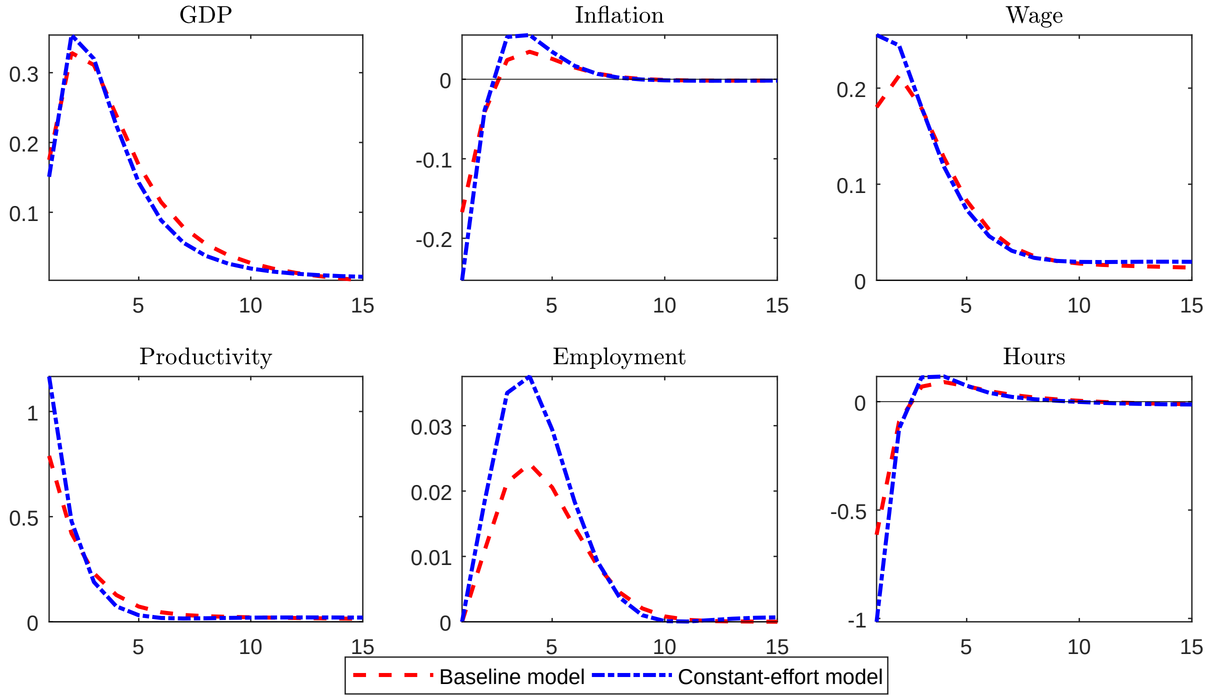
Notes: Figure shows estimated mean and counterfactual responses. Y-axes show percent deviations from steady state. Time horizon on X-axes measured in quarters. Shock size normalized to one in both scenarios.

hump-shaped; hours per worker increase on impact. In the *baseline model*, the response of productivity is procyclical, reflecting increasing returns to hours in production.

The *counterfactual model* shows that the two labor margins, hours and employment, are exploited more when effort is kept constant. It is also evident that in the presence of constant returns to hours, labor productivity becomes countercyclical in response to a demand shock. Thus, parameter ϕ governs the sign of the response of productivity. The real wage rises by less under constant returns to hours; this reflects the fact that workers are not working any harder, and therefore are less productive than in the baseline model. Recall that wage setting is efficient in our setup. Finally, the procyclicality of labor productivity dampens the rise in inflation.

Labor supply shock. Figure 4 shows impulse response functions to an expansionary labor supply shock. As the disutility of providing hours of work falls and the labor supply schedule (24) shifts out, hours rise and the bargaining wage drops, see (27). The qualitative effects of this shock on output, inflation, and the interest rate are similar to those of a productivity shock, as explained by Smets and Wouters (2003). The decrease in the real wage leads to a reduction in marginal costs and hence to a fall in inflation. In the absence of an effort margin, the increase in GDP is less than proportional to the increase in hours, hence labor productivity falls. Similarly to the case of the monetary policy shock, the real wage falls by more because workers are now less productive. The reduction in

Figure 5: Impulse responses to a technology shock.



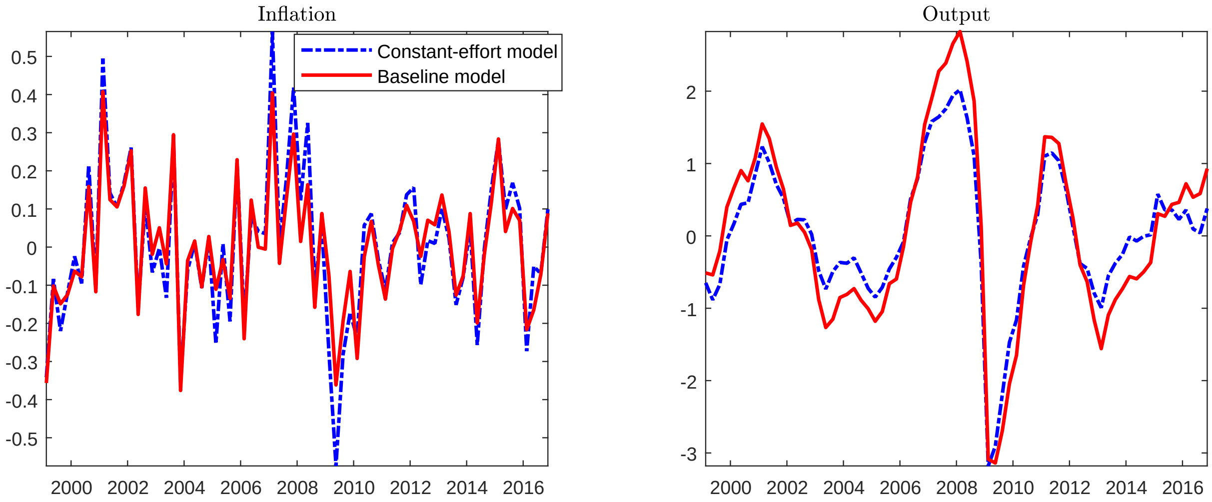
Notes: Figure shows estimated mean and counterfactual responses. Y-axes show percent deviations from steady state. Time horizon on X-axes measured in quarters. Shock size normalized to one in both scenarios.

labor disutility affects the short-run response of hours similarly in the two models, baseline and counterfactual. However, the limited output expansion in the counterfactual scenario means less labor input is required for production compared to the baseline model. Hence, the increase in employment is less pronounced in the counterfactual scenario.

Technology shock. Unsurprisingly, technology shocks explain a large proportion of the variability in labor productivity. Their contribution to fluctuations in inflation is a lot smaller, 15%, while they matter even less for output in our baseline model, 7%. Figure 5 shows that productivity responds less in our baseline model than it does when effort is constant. Accordingly, the real wage rises by more in the counterfactual model, reflecting the (larger) rise in productivity. Higher productivity allows firms to reduce their other adjustable labor input margin downwards: hours per worker fall on impact. The endogenous fall in effort explains why labor productivity rises less under increasing returns to hours in production. Employment increases; hiring becomes more attractive as the marginal worker becomes more productive and therefore more valuable. Moreover, the firm's wage bill is reduced by the drop in hours per worker.

Counterfactual simulations. How does labor effort affect movements in output and inflation? We have seen that increasing returns to hours make labor productivity procyclical in response to demand shocks. According to the variance decomposition in Table 4,

Figure 6: Counterfactual simulations of inflation and output.



Notes: The figures report the smoothed series of inflation and output, i.e. the best guess for the variable given all observations derived from the Kalman smoother at the posterior mean.

demand shocks explain a substantial part of both output and inflation variability. Therefore, we conjecture that the effort margin: (a) makes output more volatile and (b) reduces inflation volatility by dampening fluctuations in real marginal costs. This intuition in confirmed in Figure 6, which shows – for inflation and output – the smoothed series and the counterfactual simulation when the returns to hours parameter, ϕ, is set to 1.

6 Conclusion

We investigate the role of labor effort in explaining the procyclical movements in labor productivity in the Euro Area. Such movements are puzzling when they are observed concurrently with demand shocks. Indeed, a decline in labor productivity has been observed during the Great Recession, widely thought of as the result of a negative demand shock. The current vintage of business cycle models do not provide an explanation for the procyclicality of labor productivity, low employment volatility and inflation dynamics observed in the Euro Area. Our proposed model features increasing returns to hours through variable labor effort. The estimation of the model with Bayesian techniques reveals that the parameter measuring returns to hours in production is substantially greater than one, evidence in support of our specification. In addition, we show that the effort margin affects the dynamics of inflation as the procyclicality of labor productivity dampens real marginal costs. We allow for variable capital utilization as well, and show that the data prefer the labor utilization margin over the capital utilization margin. Our model with endogenous effort is useful as a way to generating increasing returns to hours in production. But the fact that effort is not observed makes the underlying preference assumptions hard to test empirically. Future research might therefore focus on finding ways to capture increasing returns to hours which are consistent with microeconomic models of the labor market.

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