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Labor market dynamics, endogenous growth, and asset prices

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HIGHLIGHTS

- We introduce endogenous labor decisions into the Kung and Schmid (2015) economy.
- Moreover, two variants of wage rigidities are added.
- Pro-cyclical labor generates a rise in the equity risk premium of 250 basis points.
- Wage rigidities produce sufficiently volatile labor hours and smooth wages.

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ABSTRACT

We extend the endogenous growth model of Kung and Schmid (2015) by adding endogenous labor dynamics and two variants of wage rigidities. This leads to an increase of 250–350 basis points in the risk premia, depending on the model specification. Additionally, it brings labor market quantities much closer to their empirical counterparts. In particular, wage rigidities generate an increase of around 60–250 basis points in labor growth volatility, which depends on how wage rigidities are modeled.

1. Introduction

In this study we present an extension of a key macro-finance model which links endogenous growth theory to asset pricing. The leading literature in this field either accounts for endogenous capital accumulation or endogenous labor supply, but not for both. In the economy of Kung and Schmid (2015), which we use as a benchmark, labor supply is inelastic (i.e. fixed). On the other hand, Croce et al. (2013) do not utilize physical capital as a production factor.[2,3]

We bridge this gap by adding endogenous labor supply and wage rigidities to the Kung and Schmid (2015) model (hereinafter 'KS'). Labor market dynamics have been shown to be an important driver of business cycles. Particularly, both empirical and theoretical studies emphasize the importance

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2 Recent contributions that only consider either endogenous capital or endogenous labor supply include Akcigit and Kerr (2012); Gârleanu et al. (2012); Bena et al. (forthcoming); Jinnai (2015).

3 An exception is the New Keynesian model of Kung (2015) where both capital and labor decisions are endogenized. However, his setting – aimed at capturing the link between monetary policy and endogenous growth – cannot be directly compared to ours.

of wage rigidities in explaining labor growth volatility, wage dynamics, and asset prices (Campbell and Kamlani, 1997; Agell and Lundborg, 2003; Hall, 2005; Blanchard and Galí, 2007; Merz and Yashiv, 2007; Smets and Wouters, 2007; Uhlig, 2007; Belo et al., 2014; Favilukis and Lin, 2016). In this respect, our work is closely related to Favilukis and Lin (2016) who introduce sticky wages into a production economy in order to explain several features of financial data. In their setting, the introduction of wage rigidities makes wages less pro-cyclical, profits more volatile and dividends highly pro-cyclical. If coupled with several other frictions and shocks, the model produces relatively smooth wages, a high equity premium, and it can account for 75% of the equity return volatility. However, similarly to KS, labor supply decisions are not endogenized.

We find that the inclusion of endogenous labor decisions in KS leads to higher aggregate risk. The reason being that households decide to work more in response to productivity shocks to fully exploit the boost in innovation intensities. As a result, labor becomes highly pro-cyclical leading to a rise of about 250 basis points (bps) in the risk premia.[4]

By introducing wage rigidities in the spirit of Uhlig (2007), our model produces a further increase in the risk premia (around 25 bps) and brings labor market quantities – including labor and wage volatility – closer to their empirical counterparts. This is due to labor (wages) becoming more (less) pro-cyclical when wage rigidities are accounted for.[5] In order to shed robustness on the effect of wage rigidities, we additionally model wage rigidities differently. Specifically, following Schmitt-Grohe and Uribe (2006), we introduce Calvo-type wage stickiness. In this setting, the aforementioned effects are moderately amplified.

2. Model

This section extends KS by accounting for endogenous labor supply and wage rigidities. In Section 2.1 we review KS. Section 2.2 introduces the aforementioned extensions.

2.1. Benchmark model

Kung and Schmid (2015) develop a stochastic version of the endogenous growth model by Romer (1990), where the household has recursive preferences and capital investment is subject to convex adjustment costs.

Representative household. The representative household has Epstein and Zin (1989) preferences over the utility flow u_t:

$$U_t = \left[(1-\beta) u_t^{1-\frac{1}{\psi}} + \beta \left(\mathbb{E}_t [U_{t+1}^{1-\gamma}] \right)^{\frac{1-1/\psi}{1-\gamma}} \right]^{\frac{1}{1-1/\psi}}, \tag{1}$$

where γ is relative risk aversion, ψ determines the elasticity of intertemporal substitution, and β is the time discount factor. The utility flow is identical to consumption:

$$u_t = C_t. \tag{2}$$

The budget constraint of the household reads:

$$C_t = W_t L_t + D_{a,t}, \tag{3}$$

where W_t denotes wages, L_t is the amount of labor supplied by the household, and $D_{a,t}$ is aggregate dividends. Since there is no disutility from labor, the household supplies its total time endowment each period. Hence, $L_t \equiv 1$ in equilibrium. The household's stochastic discount factor (SDF) is:

$$\mathbb{M}_{t,t+1} = \beta \left(\frac{u_{t+1}}{u_t} \right)^{-\frac{1}{\psi}} \left(\frac{U_{t+1}}{\mathbb{E}_t [U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}} \right)^{\frac{1}{\psi}-\gamma}. \tag{4}$$

Final good sector. Production output of the representative final good sector firm is given by:

$$Y_t = (K_t^{\alpha} (A_t L_t)^{1-\alpha})^{1-\xi} G_t^{\xi}, \qquad G_t = \left[\int_0^{N_t} X_{i,t}^{\nu} \, di \right]^{\frac{1}{\nu}}. \tag{5}$$

The capital share, the share of intermediate goods and the elasticity of substitution between any two intermediate goods in the intermediate goods bundle G_t are denoted by α, ξ and ν, respectively. The total number of intermediate goods or patents in the economy is N_t. The stochastic process A_t introduces exogenous stochastic productivity shocks to the model with dynamics:

$$A_t = e^{a_t}, \quad a_t = \rho_a \cdot a_{t-1} + \varepsilon_{a,t}, \tag{6}$$

where ρ_a determines the persistence of these shocks and $\varepsilon_{a,t} \sim \mathcal{N}(0, \sigma_a)$. The final good firm maximizes its shareholder value by optimally choosing capital investment I_t, labor L_t, next period's capital K_{t+1} and the demand for intermediate good i, $X_{i,t}$:

$$\max_{\{I_t, L_t, K_{t+1}, X_{i,t}\}_{t\geq 0, i\in[0,N_t]}} \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \mathbb{M}_{0,t} D_t \right], \tag{7}$$

subject to the final good firm's dividends' definition and the capital accumulation equation:

$$D_t = Y_t - I_t - W_t L_t - \int_0^{N_t} P_{i,t} X_{i,t} \, di, \tag{8}$$

$$K_{t+1} = (1-\delta) K_t + \Lambda \left(\frac{I_t}{K_t} \right) K_t, \tag{9}$$

where $P_{i,t}$ is the price of intermediate good i, δ is the capital depreciation rate and $\Lambda\left(\frac{I_t}{K_t}\right) = \frac{\alpha_1}{1-\frac{1}{\zeta}} \left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\zeta}} + \alpha_2$ is the adjustment cost function transforming investment in new capital as in Jermann (1998), where the constants α_1 and α_2 are chosen so that there are no adjustment costs in the deterministic steady state. The resulting equilibrium conditions are as follows:

$$1 = \mathbb{E}_t \left[\mathbb{M}_{t,t+1} \Lambda' \left(\frac{I_t}{K_t} \right) \left\{ \frac{(1-\xi)\alpha Y_{t+1} - I_{t+1}}{K_{t+1}} + \frac{\Lambda\left(\frac{I_{t+1}}{K_{t+1}}\right) + 1 - \delta}{\Lambda'\left(\frac{I_{t+1}}{K_{t+1}}\right)} \right\} \right], \tag{10}$$

$$W_t = \frac{(1-\xi)(1-\alpha) Y_t}{L_t}, \tag{11}$$

$$X_{i,t}(P_{i,t}) = \left(\frac{\xi Y_t}{P_{i,t}} \right)^{\frac{1}{1-\nu}} G_t^{\frac{\nu}{\nu-1}}. \tag{12}$$

Intermediate goods sector. Each intermediate good $i \in [0, N_t]$ is produced by a monopolistically competitive firm maximizing its profits:

$$\max_{\{P_{i,t}\}} \Pi_{i,t} = \max_{\{P_{i,t}\}} \left\{ P_{i,t} X_{i,t}(P_{i,t}) - X_{i,t}(P_{i,t}) \right\}. \tag{13}$$

[4] Note that this effect would be reversed in a model with exogenous growth.

[5] As in Favilukis and Lin (2016), the inclusion of wage rigidities allows the model to generate smoother wages. Still, as in related production economy models (Jermann, 1998; Boldrin et al., 2001; Kung and Schmid, 2015), equity volatility is relatively low. This finding is at odds with Favilukis and Lin (2016) who explain up to 75% of the empirically observed equity return volatility. However, there are several differences between their setting and ours, in particular regarding the structure of wage rigidities and of financial leverage.

A symmetric equilibrium is obtained by solving the maximization problem (13):

$$P_{i,t} \equiv P_t = \frac{1}{\nu}, \tag{14}$$

$$\Pi_{i,t} \equiv \Pi_t = \left(\frac{1}{\nu} - 1\right) X_t, \tag{15}$$

$$X_{i,t} \equiv X_t = \left(\xi \nu (K_t^{\alpha}(A_t L_t)^{1-\alpha})^{1-\xi} N_t^{\frac{\xi}{\nu}-1}\right)^{\frac{1}{\xi-1}}. \tag{16}$$

Substituting Eq. (16) into the production function (5) and imposing the following restriction to ensure balanced growth,

$$1 - \alpha = \frac{\frac{\xi}{\nu} - \xi}{1 - \xi}, \tag{17}$$

implies:

$$Y_t = K_t^{\alpha}(A_t N_t L_t)^{1-\alpha}(\xi \nu)^{\frac{\xi}{\xi-1}}. \tag{18}$$

Finally, the value $V_{i,t} \equiv V_t$ of owning exclusive rights to produce intermediate good i using the respective patent i is equal to the present value of the current and future monopoly profits:

$$V_{i,t} \equiv V_t = \Pi_t + (1-\phi)\mathbb{E}_t[\mathbb{M}_{t,t+1} V_{t+1}], \tag{19}$$

where ϕ is the probability that a patent becomes obsolete.

Innovation sector. The number of intermediate goods N_t evolves according to:

$$N_{t+1} = \vartheta_t S_t + (1-\phi) N_t, \tag{20}$$

where S_t denotes the economy's expenditure in research and development (R&D), and ϑ_t represents the innovation sector's productivity that is taken as given by innovating firms. Its functional form is:

$$\vartheta_t = \chi \left(\frac{S_t}{N_t}\right)^{\eta-1}. \tag{21}$$

The payoff to innovation is the expected value of discounted future profits on a patent (i.e., $\mathbb{E}_t[\mathbb{M}_{t,t+1} V_{t+1}]$). Thus, free entry into the innovation sector implies:

$$\mathbb{E}_t[\mathbb{M}_{t,t+1} V_{t+1}](N_{t+1} - (1-\phi)N_t) = S_t, \tag{22}$$

which states that the expected sales revenues equal the innovation costs. Equivalently: $\frac{1}{\vartheta_t} = \mathbb{E}_t[\mathbb{M}_{t,t+1} V_{t+1}]$.

Aggregate resource constraint. Final good output is used for consumption, purchasing intermediate goods, capital investment, and R&D expenditure. Hence, the aggregate resource constraint takes the following form:

$$Y_t = C_t + N_t X_t + I_t + S_t. \tag{23}$$

Aggregate dividends are given by:

$$\begin{aligned} D_{a,t} &= C_t - W_t L_t = Y_t - N_t X_t - S_t - I_t - W_t L_t \\ &= D_t + N_t \Pi_t - S_t. \end{aligned} \tag{24}$$

Asset prices. We study the dynamics of three asset prices in this economy: a risk-free bond, the final good sector firm's stock price and the aggregate market's stock price. First, the risk-free rate solves:

$$r_{f,t} = \ln(R_{f,t}), \quad R_{f,t} = \frac{1}{\mathbb{E}_t[\mathbb{M}_{t,t+1}]}. \tag{25}$$

Second, the final good sector's stock price, its return and risk premium are given by:

$$V_{d,t} = D_t + \mathbb{E}_t[\mathbb{M}_{t,t+1} V_{d,t+1}], \tag{26}$$

$$R_{d,t} = \frac{V_{d,t}}{V_{d,t-1} - D_{t-1}}, \tag{27}$$

$$r_{d,t} - r_{f,t} = (1+\varphi)(\ln(R_{d,t}) - r_{f,t}), \tag{28}$$

where the final good sector excess return is levered by imposing $\varphi = \frac{2}{3}$ as in Boldrin et al. (2001). Similarly, for the aggregate market one obtains:

$$V_{a,t} = D_{a,t} + \mathbb{E}_t[\mathbb{M}_{t,t+1} V_{a,t+1}], \tag{29}$$

$$R_{a,t} = \frac{V_{a,t}}{V_{a,t-1} - D_{a,t-1}}, \tag{30}$$

$$r_{a,t} - r_{f,t} = (1+\varphi)(\ln(R_{a,t}) - r_{f,t}). \tag{31}$$

2.2. Extensions

To account for endogenous labor supply, preferences for leisure are added to the utility flow definition (2). Formally,

$$u_t = C_t(\bar{L} - L_t)^{\tau}, \tag{32}$$

where τ determines the elasticity of the labor supply. The optimal labor supply is determined by the following condition:

$$W_t^u = \frac{\tau C_t}{\bar{L} - L_t}, \tag{33}$$

where W_t^u denotes frictionless wages. As in Uhlig (2007), we assume that only a fraction of the optimal labor supply reaches the market. Thus, wages are sticky and evolve as follows:

$$W_t = (W_{t-1})^{\mu}(W_t^u)^{1-\mu}, \tag{34}$$

where $\mu \in [0, 1]$ is the fraction of sticky wages. For robustness purposes, we model wage rigidities in a less-reduced way. Practically, we follow Schmitt-Grohe and Uribe (2006) by incorporating Calvo-type wage stickiness. This implies that the following equilibrium conditions, alongside Eq. (32), need to be added to the benchmark model of Section 2.1:

$$\lambda_t = (1-\beta) U_t^{\frac{1}{\psi}} u_t^{-\frac{1}{\psi}} (\bar{L} - L_t)^{\tau} \tag{35}$$

$$f_t^1 = f_t^2 \tag{36}$$

$$f_t^1 = \frac{\tilde{\eta} - 1}{\tilde{\eta}} \tilde{W}_t \lambda_t \left(\frac{W_t}{\tilde{W}_t}\right)^{\tilde{\eta}} L_t^d + \beta \mu \mathbb{E}_t \left[\left(\frac{\tilde{W}_{t+1}}{\tilde{W}_t}\right)^{\tilde{\eta}-1} f_{t+1}^1\right] \tag{37}$$

$$f_t^2 = \frac{\tau C_t}{\bar{L} - L_t} \lambda_t \left(\frac{W_t}{\tilde{W}_t}\right)^{\tilde{\eta}} L_t^d + \beta \mu \mathbb{E}_t \left[\left(\frac{\tilde{W}_{t+1}}{\tilde{W}_t}\right)^{\tilde{\eta}} f_{t+1}^2\right] \tag{38}$$

$$L_t = \tilde{s}_t L_t^d \tag{39}$$

$$W_t^{1-\tilde{\eta}} = (1-\mu)(\tilde{W}_t)^{1-\tilde{\eta}} + \mu (W_{t-1})^{1-\tilde{\eta}} \tag{40}$$

$$\tilde{s}_t = (1-\mu)\left(\frac{\tilde{W}_t}{W_t}\right)^{-\tilde{\eta}} + \mu \left(\frac{W_{t-1}}{W_t}\right)^{-\tilde{\eta}} \tilde{s}_{t-1}, \tag{41}$$

where L_t^d denotes the final good firm's labor demand, L_t gives the labor supply of the household, λ_t is the Lagrange multiplier attached to the budget constraint in the household's problem, $\tilde{s}_t$ measures the degree of wage dispersion across different labor types, $1 - \mu$ denotes the fraction of labor markets in which wages

Table 1
Model parameters.

(a) Panel A: Common parameters

Parameter	Description	Value
β	Time discount factor	0.996
ψ	Elasticity of intertemporal substitution	1.85
γ	Relative risk aversion	10
η	R&D technology elasticity	0.83
ν	Inverse monopoly markup	1/1.65
ϕ	Patent obsolescence	0.0375
α	Capital share	0.35
ξ	Intermediate goods share	0.50
δ	Capital depreciation rate	0.02
ζ	Capital adjustment costs elasticity	0.7
ρ_a	Productivity shock persistence	0.988
σ_a	Productivity shock volatility	0.0175

(b) Panel B: Additional parameters

Parameter	Description	(1)	(2)	(3)	(4)	(5)
χ	R&D productivity parameter	0.332	0.3296	0.329375	0.3299	0.3299
τ	Labor elasticity	–	1.8670	1.8660	1.7792	1.7792
μ	Sticky wage parameter	–	0	0.35	0.35	0.64
$\tilde{\eta}$	Labor services substitution elasticity	–	–	–	21	21

Notes: The table reports the quarterly calibrations of the five models considered in this study. Model (1): Kung and Schmid (2015) benchmark model. Model (2): Endogenous labor. Model (3): Wage rigidities following Uhlig (2007). Models (4)–(5): Wage rigidities following Schmitt-Grohe and Uribe (2006).

are set optimally each period, the optimal wage is denoted by $\tilde{W}_t$, and $\tilde{\eta}$ is the intratemporal elasticity of substitution across different labor services types. Furthermore, in Eqs. (3), (5), (8), (11), (16), (18), and (24) one needs to replace L_t by L_t^d to fully account for this type of wage rigidity.

With these extensions, the SDF in units of the final consumption good takes the following form:

$$\mathbb{M}_{t,t+1} = \beta \left(\frac{u_{t+1}}{u_t}\right)^{1-\frac{1}{\psi}} \left(\frac{C_{t+1}}{C_t}\right)^{-1} \left(\frac{U_{t+1}}{\mathbb{E}_t[U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma}. \quad (42)$$

3. Calibration

Parameter values for the benchmark economy and for the other four economies are reported in Table 1. Panel A reports the common parameters across models, taken from Kung and Schmid (2015). Panel B adds the parameters and their related values for different economies. The R&D productivity parameter χ in Model (1) also corresponds to the value used in KS. To obtain identical consumption growth rates across models this parameter is slightly adjusted. In Models (2)–(5), the labor elasticity τ is pinned down by the condition that the household works one third of its time endowment in the deterministic steady state. The wage rigidity parameter $\mu = 0.35$ in Model (3) is taken from Uhlig (2007). In Models (4) and (5), wage rigidities are modeled following Schmitt-Grohe and Uribe (2006). The intratemporal elasticity of substitution across different labor services $\tilde{\eta} = 21$ is calibrated as in their study. In Model (4), μ is set as in Model (3) to being able to solely analyze the impact of modeling wage rigidities differently. Finally, in Model (5) we use the benchmark calibration of Schmitt-Grohe and Uribe (2006) and impose $\mu = 0.64$.

4. Results

In this section, we compare the moments for asset prices and macroeconomic quantities produced by KS with those from the alternative specifications. This allows us to investigate whether the effects of including labor dynamics in KS are quantitatively relevant. Results are reported in Table 2.

Table 2
Simulation results.

	Data	(1)	(2)	(3)	(4)	(5)
Asset prices						
$\mathbb{E}[r_a - r_f]$	4.89	2.88	5.30	5.53	5.66	6.49
$\sigma(r_a - r_f)$	17.92	3.90	5.15	5.55	5.66	6.67
$\mathbb{E}[r_d - r_f]$	–	3.99	5.42	5.97	6.07	6.98
$\sigma(r_d - r_f)$	–	6.04	7.22	7.98	8.05	9.35
$\mathbb{E}[r_f]$	2.90	1.21	0.59	0.28	0.23	−0.24
$\sigma(r_f)$	3.00	0.43	0.44	0.50	0.56	0.84
Macro quantities						
$E[\Delta c]$	2.51	1.92	1.92	1.92	1.92	1.92
$\sigma(\Delta c)$	1.95	1.65	1.93	1.96	2.00	2.14
$\sigma(\Delta l)$	2.52	0.00	0.78	1.35	1.54	2.94
$\sigma(\Delta c)/\sigma(\Delta y)$	0.60	0.69	0.66	0.62	0.62	0.53
$\sigma(\Delta l)/\sigma(\Delta y)$	0.78	0.00	0.27	0.43	0.48	0.73
$\sigma(\Delta w)/\sigma(\Delta y)$	0.49	1.00	0.76	0.70	0.69	0.56
$\text{corr}(\Delta c, \Delta y)$	0.84	0.97	0.96	0.93	0.93	0.85
$\text{corr}(\Delta c, \Delta l)$	0.41	0.00	0.76	0.55	0.51	0.43
$\text{corr}(\Delta i, \Delta l)$	0.83	0.00	0.92	0.77	0.74	0.75
$\text{corr}(\Delta y, \Delta l)$	0.64	0.00	0.90	0.81	0.79	0.83

Notes: This table reports the moments obtained from a stochastic simulation of the five models considered in this study. The model is solved using third-order perturbations around the stochastic steady state in Dynare++ 4.4.3. The moments are computed using a simulation of 3,000 economies at quarterly frequency for 304 quarters, from which the first 80 quarters are not considered for the calculation of the moments ("burn in-period"). The moments in the data column are from Papanikolaou (2011) for the period 1951–2008 except for the ratio of wage to output growth volatility, taken from Favilukis and Lin (2016) for the period 1948–2013. Model (1): Kung and Schmid (2015) benchmark model. Model (2): Endogenous labor. Model (3): Wage rigidities following Uhlig (2007). Models (4)–(5): Wage rigidities following Schmitt-Grohe and Uribe (2006).

It is worth noting that by adding endogenous labor decisions to KS, the aggregate risk premium jumps from 2.88 to 5.30 percentage points. This result is accompanied by (i) an increase in consumption growth volatility from 1.65 to 1.93 percentage points; (ii) an increase in the aggregate excess stock return volatility from 3.90 percentage to 5.15 percentage points; and (iii) a decrease in the risk-free rate from 1.21 percentage to 0.59 percentage points.

This seems to be counter-intuitive at first sight since the additional possibility to smooth the productivity shock by allowing agents to adjust labor hours would be rather expected to lead to lower risk premia. We stress that this result is due to the presence of the endogenous growth channel. The opportunity to invest in R&D makes labor hours pro-cyclical implying an increase in the market price of risk. This pro-cyclicality occurs as a positive productivity shock leads to an increase in innovation productivity which the household can fully exploit by supplying more labor. Differently, in an equivalent model with exogenous growth, labor hours are counter-cyclical as the household chooses to increase leisure upon the realization of a productivity shock. When growth is exogenous, the only possibility is to invest in capital, which is far less attractive than investing in R&D due to the inclusion of capital adjustment costs.[6] Hence, increasing leisure is maximizing the household's utility in this case. In order to show that the implications solely differ due to the presence of endogenous growth, Appendix A presents the results of an otherwise equivalent exogenous growth model.

The resulting co-movement between labor and productivity and, consequently, the number of intermediate goods also

6 Free entry into the innovation sector implies that R&D investment is not subject to any stringent rigidities.

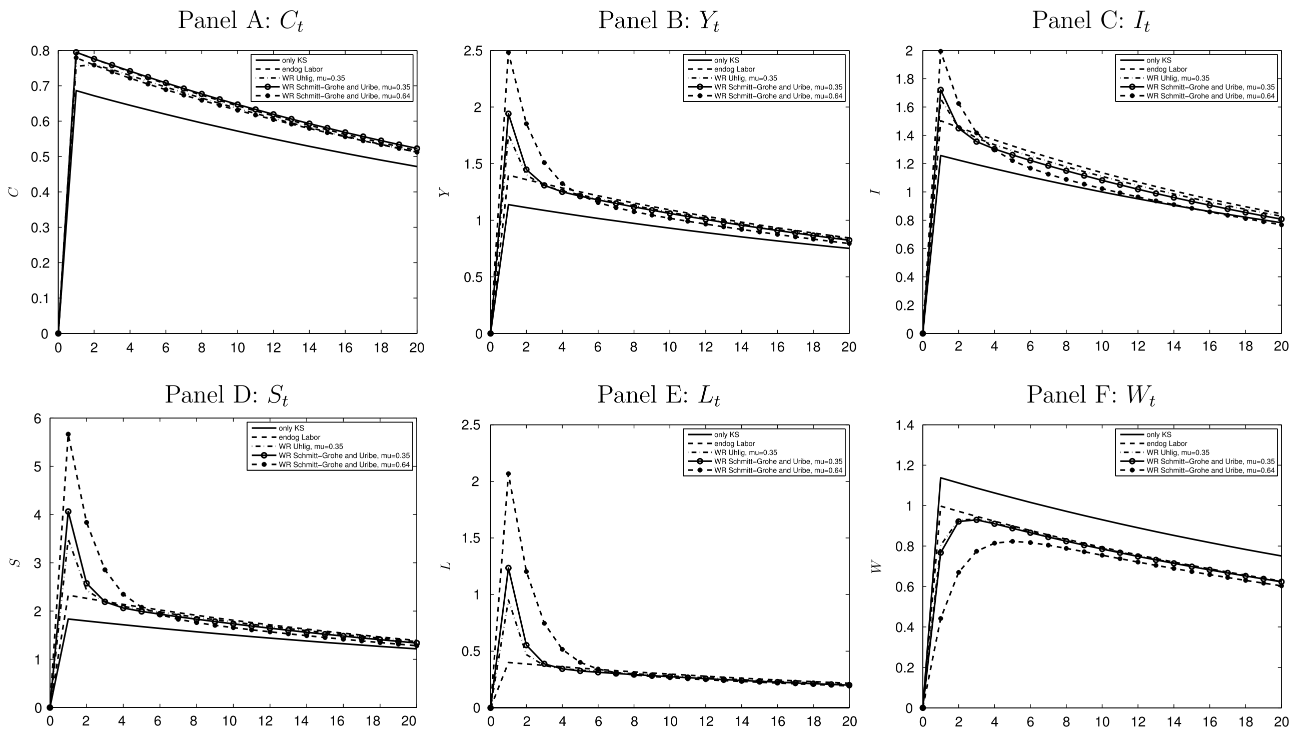

Fig. 1. Macroeconomic quantities—positive productivity shock. *Notes*: This figure depicts consumption C_t, output Y_t, capital investment I_t, R&D expenditure S_t, labor L_t, and wages W_t in response to a positive one-standard-deviation shock in the productivity process a_t. The values reported are log deviations from the steady state in percentage points.

produces a relatively good fit of the empirically observed correlation between consumption, investment, and output growth with labor supply growth (see Model (2) in Table 2).

Motivated by both empirical and theoretical studies arguing that labor market frictions may play an important role in driving business cycles, we re-compute asset prices and macro quantities in the presence of wage rigidities. Model (3) in Table 2 reports the results for modeling wage rigidities in the spirit of Uhlig (2007). Differently, in Models (4) and (5) wage rigidities are modeled as in Schmitt-Grohe and Uribe (2006). The household's impossibility to react freely to productivity shocks amplifies the overall level of risk. As a result, we observe further increases in the risk premia (around 25, 30, and 100 bps, respectively, depending on the imposed wage rigidities' structure).[7] Labor market frictions enable the model to better match the co-movement between macroeconomic variables. In particular, this leads to an improvement in the correlation between (i) consumption and labor, and (ii) investment and labor. By comparing Models (3) and (4), we observe that the Calvo-type wage stickiness proposed by Schmitt-Grohe and Uribe (2006) does a better job in matching the data than the reduced-form approach of Uhlig (2007) as the equilibrium effects of the former are slightly stronger. Remarkably perfect is the fit of the correlation between (i) consumption and output and (ii) consumption and labor in Model (5). Additionally albeit not surprisingly, Model (5) produces the highest risk premia and return volatilities, and it creates a very large precautionary savings motive yielding a negative risk-free rate. This comes at the cost of a relatively high labor growth volatility, which jumps to 2.94 percentage points. It is worth noting that already a moderate amount of wage rigidities produces a relatively high (low) labor (wage) growth volatility (consistent with labor market data).

To shed further light on the mechanisms behind these results, we depict impulse response functions of major macroeconomic quantities in response to a positive one-standard-deviation shock in the productivity process a_t for the five models (see Fig. 1). Due to the presence of a new smoothing channel, which provides households the possibility to adjust hours worked in response to productivity shocks, consumption, output, investment, R&D expenditures, and labor react more strongly in response to an exogenous increase in productivity (see Fig. 1, Panels A–E). In other words, households, upon the realization of a positive shock, are willing to supply more labor, allowing them to fully exploit the increase in productivity. Without endogenous labor, the household can only react by investing more in capital and R&D. However, capital investment is subject to adjustment costs and the higher innovation probability only pays off over the next period. Thus, increments in output and consumption are weaker than in the case where the household can choose to work more immediately in response to increased productivity. Moreover, wages react less in response to productivity shocks as the optimal response is now partly achieved by adjusting labor hours (see Fig. 1, Panel F).

The presence of wage rigidities amplifies these effects due to wages being sticky and thus responding less to productivity shocks. Accordingly, there is a stronger response of labor hours translating into higher output and, subsequently, higher consumption, capital investment, and R&D expenditure. When we model wage rigidities as in Schmitt-Grohe and Uribe (2006), these amplification effects are even stronger.

5. Conclusion

We show that the inclusion of endogenous labor decisions and sticky wages in a stochastic endogenous growth model is key in producing more realistic labor market and asset pricing

[7] As an additional exercise – within the framework of modeling wage rigidities following Uhlig (2007) – we included stochastic wage rigidities by making the parameter μ stochastic. The effects on both asset prices and macroeconomic quantities are slightly amplified. For the sake of brevity, results are not reported but available upon request from the authors.

dynamics. Specifically, endogenous labor leads to an increase in the aggregate risk premium of about 250 basis points. Wage rigidities bring macroeconomic quantity dynamics closer to the data and further amplify risk. We would like to emphasize that such improvements originate from endogenous equilibrium effects and not from additional exogenous sources of macroeconomic risk.

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Appendix A. Equivalent model with exogenous growth

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