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Abstract

We extend the endogenous growth model of Kung and Schmid (2015) by adding endogenous labor dynamics and wage rigidities. This leads to an increase of about 250 basis points in risk premia. Additionally, it brings labor market quantities much closer to their empirical counterparts. In particular, wage rigidities generate an increase of around 60 basis points in labor growth volatility.

Keywords: Endogenous growth, asset pricing, wage rigidities, innovation

JEL: E22, G12, O30, O41

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, Nguyen, and Schmid (2013) do not utilize physical capital as a production factor.[1]

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 cycle dynamics. Particularly, the literature emphasizes the importance of wage rigidities in explaining labor growth volatility, business cycles and asset prices.[2]

We find that the inclusion of endogenous labor decisions to the benchmark economy leads to higher aggregate risk. This commands a rise of about 250 basis points (bps) in the risk premia. By introducing wage rigidities, our model (*i*) produces a further small increase in the risk premia (around 25 bps) and (*ii*) brings labor market quantities closer to their empirical counterparts. Finally, stochastic wage rigidities amplify these effects.

2 Model

This section extends KS by accounting for endogenous labor supply, wage rigidities (in the spirit of Uhlig (2007)) and stochastic fluctuations in the amount of 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. The benchmark economy and the corresponding equilibrium conditions are detailed below.

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:

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

[1]Recent contributions that only consider either endogenous capital or endogenous labor supply include Akcigit and Kerr (2012), Gârleanu, Kogan, and Panageas (2012), Bena, Garlappi, and Grüning (2015), Jinnai (2015).

[2]See, among others, Campbell and Kamlani (1997), Agell and Lundborg (2003), Hall (2005), Blanchard and Galí (2007), Uhlig (2007).

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 stochastic discount factor of the household 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. The production function of the representative final good sector firm is given by:

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

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 definition of the final good firm's dividends 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:

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

A symmetric equilibirum 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 Equation (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 thus given by:

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

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 following Boldrin, Christiano, and Fisher (2001), i.e. $\varphi = \frac{2}{3}$, consistently with the data. 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,

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

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

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

where W_t^u denotes frictionless wages, since as in Uhlig (2007), we assume that not all of the optimal labor supply reaches the market. Thus, wages are sticky and evolve as follows:

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

where $\mu_t \in [0,1]$ is the fraction of wages that is sticky. This wage rigidity parameter can be stochastic and to restrict it to the interval $[0,1]$, it is assumed to obey the following dynamics:

$$\mu_t = \frac{e^{\theta_{\mu,t}}}{1 + e^{\theta_{\mu,t}}}, \tag{35}$$

$$\theta_{\mu,t} = \log\left(\frac{\overline{\mu}}{1-\overline{\mu}}\right) \cdot (1-\rho_\mu) + \rho_\mu \cdot \theta_{\mu,t-1} + \varepsilon_{\mu,t}, \tag{36}$$

where $\overline{\mu}$ is the long-run mean of μ_t, ρ_μ determines the persistence of wage rigidity shocks and $\varepsilon_{\mu,t} \sim \mathcal{N}(0, \sigma_\mu)$. With these extensions, the stochastic discount factor in units of the final consumption good replacing Equation (4) is:

$$\mathbb{M}_{t,t+1} = \beta \left(\frac{u_{t+1}}{u_t}\right)^{1-\frac{1}{\psi}} \left(\frac{C_{t+1}}{C_t}\right)^{-1} \left(\frac{U_{t+1}}{\mathbb{E}_t[U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma}. \qquad (37)$$

3 Calibration

Parameter values for the benchmark economy and for the other three economies are reported in Table 1. As reported in Panel A, in the benchmark model all parameters are calibrated as in Kung and Schmid (2015). In Models 2–4, for which the additional parameters are reported in Panel B, 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 long-run mean of the wage rigidity parameters in Models 3 and 4 is taken from Uhlig (2007). The persistence of the wage rigidity parameter process in Model 4 is assumed to be quite high to feature persistent deviations from the long-run mean since changes in the labor market are usually either permanent or at least highly persistent. This is consistent with the idea that implementing political decisions regarding labor market reforms represent a long process.

Table 1: Model parameters

(a) Panel A: Common parameters across models

Parameter	Description	Value
β	Time discount factor	0.996
ψ	Elasticity of intertemporal substitution	1.85
γ	Relative risk aversion	10
χ	R&D productivity parameter	0.332
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	Elasticity of capital adjustment costs	0.7
ρ_a	Persistence of productivity shocks	0.988
σ_a	Volatility of productivity shocks	0.0175

(b) Panel B: Parameters differing across models

Parameter	Description	(1)	(2)	(3)	(4)
τ	Labor elasticity	—	1.8670	1.866	1.866
$\overline{\mu}$	Long-run mean of wage rigidity parameter	—	0	0.35	0.35
ρ_μ	Persistence of wage rigidity shocks	—	0	0	0.9975
σ_μ	Volatility of wage rigidity shocks	—	0	0	0.05
$\text{corr}(a, \mu)$	Correlation between productivity and wage rigidity shocks	—	0	0	0

Notes: The table reports the quarterly calibrations of the four models considered in this study. Model 1: Kung and Schmid (2015) benchmark model. Model 2: Endogenous labor. Model 3: Constant wage rigidities. Model 4: Stochastic wage rigidities.

4 Results

To investigate the effects of including labor dynamics in KS, we simulate the four models and compare a number of key asset pricing and macroeconomic moments across the models. Results are reported in Table 2.

It is worth noting that by adding the endogenous labor decision 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 to 5.15 percentage points and (*iii*) a decrease in the risk-free rate from 1.21 to 0.59 percentage points.

Table 2: Simulation results

	Data	(1)	(2)	(3)	(4)
ASSET PRICES					
$\mathbb{E}[r_a - r_f]$	4.89	2.88	5.30	5.53	5.58
$\sigma(r_a - r_f)$	17.92	3.90	5.15	5.55	5.59
$\mathbb{E}[r_d - r_f]$	—	3.99	5.42	5.97	6.03
$\sigma(r_d - r_f)$	—	6.04	7.22	7.98	8.07
$\mathbb{E}[r_f]$	2.90	1.21	0.59	0.28	0.25
$\sigma(r_f)$	3.00	0.43	0.44	0.50	0.56
MACRO QUANTITIES					
$E[\Delta c]$	2.51	1.92	1.92	1.92	1.92
$\sigma(\Delta c)$	1.95	1.65	1.93	1.96	1.97
$\sigma(\Delta l)$	2.52	0.00	0.78	1.35	1.47
$\sigma(\Delta c)/\sigma(\Delta y)$	0.60	0.69	0.66	0.62	0.61
$\sigma(\Delta l)/\sigma(\Delta y)$	0.78	0.00	0.27	0.43	0.46
$\text{corr}(\Delta c, \Delta y)$	0.84	0.97	0.96	0.93	0.93
$\text{corr}(\Delta c, \Delta l)$	0.41	0.00	0.76	0.55	0.52
$\text{corr}(\Delta i, \Delta l)$	0.83	0.00	0.92	0.77	0.75
$\text{corr}(\Delta y, \Delta l)$	0.64	0.00	0.90	0.81	0.79

Notes: This table reports the moments obtained from a stochastic simulation of the four 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 have been taken from Papanikolaou (2011) for the period 1951–2008. Model 1: Kung and Schmid (2015) benchmark model. Model 2: Endogenous labor. Model 3: Constant wage rigidities. Model 4: Stochastic wage rigidities.

We stress that our result is driven by the labor share in the production function being equal to 65 per cent. Loosely speaking, endogenous fluctuations in the labor supply, implying a non-negligible labor growth volatility, amplify movements in output and consumption growth.

A higher output and consumption growth volatility, coupled with endogenous growth, amplify long-run risks in the spirit of Bansal and Yaron (2004). In the presence of preferences for early resolution of uncertainty (i.e. $\gamma > 1/\psi$), this translates into higher risk premia and higher stock return volatilities. Furthermore, this leads to a higher precautionary savings motive of the household and thus to a lower risk-free rate. The resulting co-movement between labor and exogenous productivity and, consequently, the number of intermediate goods also produces a relatively good fit of the empirically observed correlation between consumption, investment, and output growth with labor supply growth.

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 both constant and stochastic wage rigidities (see specifications (3) and (4) in Table 2, respectively). The household's impossibility to react freely to productivity shock amplifies the overall level of risk. As a result, we observe a further small increase in the risk premia (around 25 bps). Labor market frictions, coupled with capital adjustment costs, 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. Additionally, a moderate amount of wage rigidities produces a relatively high labor growth volatility (consistent with labor market data).

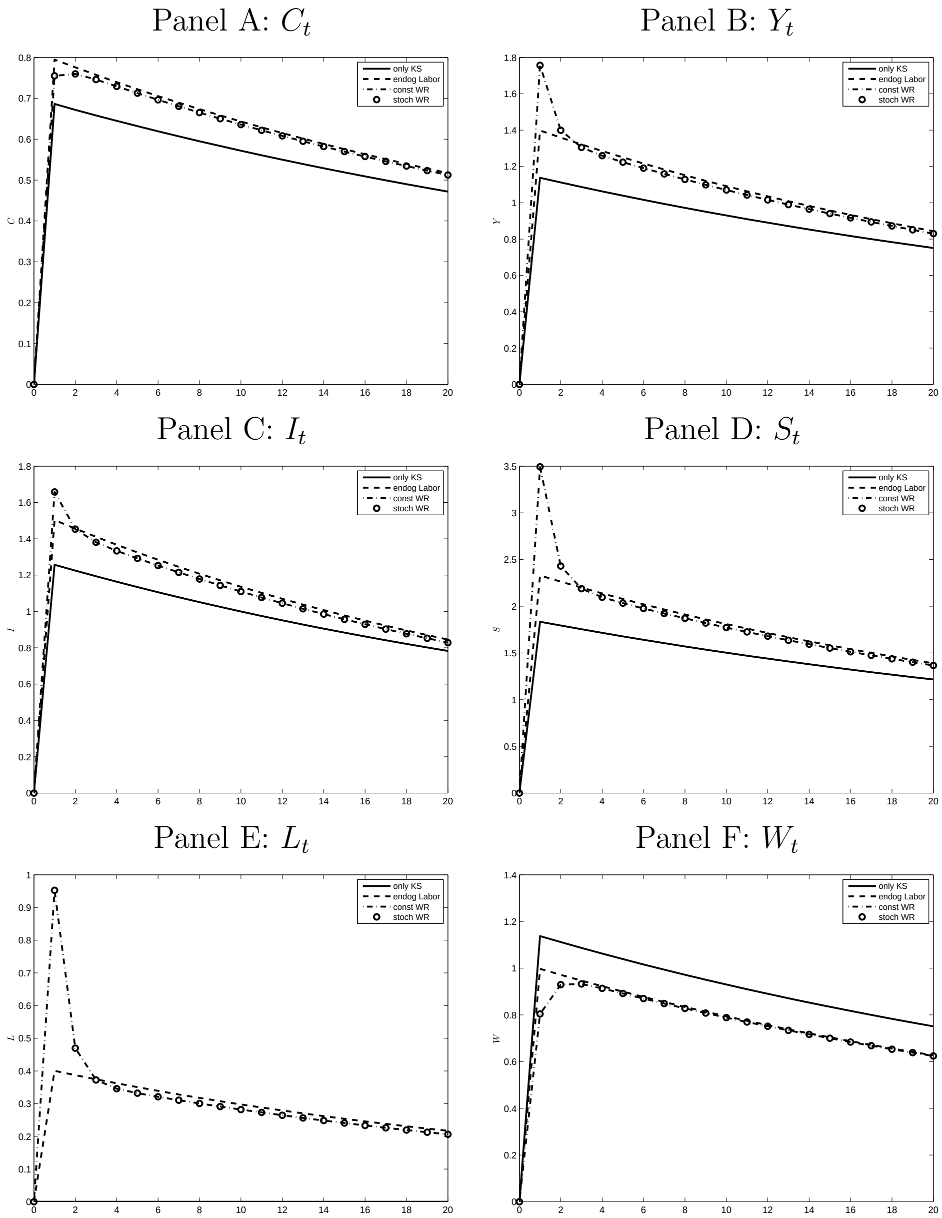

Figure 1: **Macro Quantities – Positive Productivity Shock.** *Notes*: This figure depicts consumption C_t, output Y_t, capital investment I_t, R&D expenditure S_t, labor L_t and wages W_t in response to a positive one-standard-deviation shock in the productivity process a_t. The values we report are log deviations from the steady state in percentage points.

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 four model specifications in Figure 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 hours react more strongly in response to an exogenous increase in productivity. 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.

We stress that the presence of wage rigidities amplifies these effects. This is obtained because wages are sticky and thus respond less to productivity shocks. Accordingly, there is a stronger response to labor hours, which translates into higher output and, subsequently, higher consumption, capital investment and R&D expenditure.

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 dynamics. Specifically, endogenous labor leads to an increase in the aggregate risk premium of about 250 basis points. Wage rigidities (*i*) allow the model to produce macroeconomic quantities closer to the data and (*ii*) 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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