PALMA FILEP-MOSBERGER LORANT KASZAB ZHOU REN

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Endogenous Growth, Countercyclical Dividends, and Asset Prices*

(Endogén növekedés, kontraciklikus osztalék és eszközárazás)

Written by Palma Filep-Mosberger** Lorant Kaszab*** Zhou Ren****

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**Central Bank of Hungary. 1113 Budapest Krisztina körút 55. Email: mosbergerp@mnb.hu

***Corresponding author. Central Bank of Hungary. 1113 Budapest Krisztina körút 55. Email: mosbergerp@mnb.hu. Email: kaszabl@mnb.hu

****Vienna Graduate School of Finance, Vienna University of Economics and Business. 1020 Wien, 1 Welthandelsplatz. Email: zhou.ren@wu.ac.at

Contents

Abstract

We study the nexus between endogenous growth and asset prices. We show that endogenous growth models with either horizontal and vertical innovation match financial data well due to countercyclical dividends which are either procyclical or acyclical in US data. Countercyclical dividends redistribute income from consumption towards investment in innovation improving growth prospects which are reflected in asset prices. In the horizontal innovation model of Kung and Schmid (2015) countercyclical dividends are the result of high monopoly markups. When markup is lowered from their benchmark 65 percent to 60 or 55 percent dividends become procyclical, the price-dividend ratio countercyclical, and the mean of the equity risk premia reduces from 290 to 82 or 46 basis points, respectively. When we introduce leisure preferences the wealth effect of technology shocks makes the aggregate dividends countercyclical as long as labour supply is not too elastic even with low values of the monopolist markup.

JEL: E13, E31, E43, E44, E62.

Keywords: endogenous growth, innovation, markup, asset pricing, dividends, equity premium.

Összefoglaló

Tanulmányunkban az endogén növekedés és az eszközárazás közötti kapcsolatot vizsgáljuk. Megmutatjuk, hogy a horizontális vagy vertikális innovációt tartalmazó endogén növekedéses modelleknek a kontraciklikus osztalék miatt kedvezőek az eszközárazási implikációi. Az osztalék azonban USA adatokon inkább prociklikus vagy aciklikus. A modell által implikált osztalék a magas monopolista haszonkulcsok miatt negatív. A referenciaként használt 65 százalékos haszonkulcs 60 illetve 50 százalékosra csökkentésekor a modell által implikált részvénykockázati prémium a referencia kulcs melletti 290 bázis pontos értékről, rendre 82 illetve 46 bázispontra esik vissza. Amikor a modellt kiegészítjük endogén munkakínálattal, akkor a technológia sokkok vagyonhatása miatt az aggregált osztalék kontraciklikussá válik még alacsony haszonkulcs mellett is, amennyiben a munkakínálat nem túl elasztikus.

1 Introduction

The endogenous growth model of Kung and Schmid (2015 KS for short) delivers outstanding asset pricing performance including a high excess return on equity with good fit to macroeconomic moments as well. These models feature process innovation whereby R&D and the accumulation of patented intermediate goods lead to endogenous technology movements that engineer significant and persistent long-run fluctuations in macroeconomic aggregates, asset payoffs as well as asset returns.

As a first contribution we show and explain that the transmission of shocks in endogenous growth models relies on countercyclical aggregate dividends, which is the key to generate significant and persistent growth prospects as well as vital to achieve a high risk-premium on (aggregate) dividend claims. In post-war US data dividends are, however, procyclical (see e.g. Favilukis and Lin (2016)) or acyclical (Davydiuk et al. (2023)). In the innovation model current and expected consumption are endogenously jointly determined by wage and dividend income. Following a positive productivity shock dividends fall with sufficiently high markups in the KS model limiting the increase in current consumption and leads to higher investment in physical capital and R&D.

Countercyclical dividends redistribute income from consumption towards investment in the tangible and intangible capital sectors for a given increase in output securing higher growth in the future.[1] Higher growth prospects engineer a significant rise in price-dividend ratio that dominates countercyclical dividends, and leads to an increase in the asset return. Indeed, Bansal and Yaron (2004) consider the significant reaction of price-dividend ratio to news about growth prospects as the main channel of long-run risks.[2]

We show that countercyclical dividends are triggered by the choice of a relatively high markup (65 percent in the benchmark calibration of KS) in the intangible goods sector[3]. With a lower markup (e.g. 60 percent) dividends become procyclical, and the majority of long-run risks disappear. Note that the stress is not on the absolute value of the markup as markups are hard to measure and, especially so for the intangible goods sector. Rather, we emphasize that a small decrease in the markup leads to procyclical dividends which eliminates the majority of long-run variation in consumption and dividends as well as making the price-dividend ratio countercyclical.

We demonstrate that standard statistics calculated from the models to detect long-run risks are sensitive to the choice of the markup. For instance, the standard deviation of expected consumption growth is diminished with markups lower than the benchmark calibration. Further, the excess return on the aggregate dividend claim drops from the benchmark 290 basis points based on the 65 percent markup to 82 basis points with a 60 percent markup, and to 46 basis points with a 55 percent markup.

Second, we extend the KS model with leisure preferences, and find improved asset pricing performance echoing the results of Donadelli and Grüning (2016). They argue that households can exploit more the endogenous increase in productivity due to R&D by raising labour supply which unlike capital is not burdened by adjustment costs. Our argument is, instead, focusing on the role of the dividends on growth prospects and labour supply. Similar to Donadelli and Grüning (2016) we use King et al. (1988, KPR for short) preferences which are consistent with balanced growth path and imply strong wealth effects on labour supply.

We contribute by explaining how KPR preferences affect dividends and risk-premia. With elastic labour the wage bill is larger and dividends become countercyclical if the curvature of labour—related to the wage bill linearly—is sufficiently high. The

[1] Broer et al. (2019) stresses the importance of income effects and, in particular, the dividend channel in models featuring monopolistic competition in the context of monetary policy shocks. They find that the income effects arising from the dividend channel in the wake of monetary policy shocks lead to counterfactual responses in hours worked.

[2] In their paper the dividend stream is exogenous and is assumed to be procyclical while they are endogenously countercyclical in the model of KS. In these models the elasticity of intertemporal substitution (EIS>1) is calibrated to be higher than one implying that the household prefers to consume more in the future. Utility in these models features Epstein-Zin curvature with a calibration that implies preference for early resolution of uncertainty the household requires higher risk-premia as a compensation for the increased variation in expected consumption growth.

[3] This is higher than the markups used in the literature. In particular, Corhay et al. (2020) use an average markup of 35 percent.

negative wealth effect of dividends implies that household reduces leisure upon the realisation of a positive technology shock. With a fixed time frame, less leisure implies higher labour supply. With procyclical labour the price-dividend ratio also more procyclical leading to higher mean and standard deviation of stock returns on average. [4]

Finally, we contribute by showing that countercyclical dividends are also the main driver of risk premia in the vertical innovation model of Kung (2015) which can admit lower values of the markup. In the horizontal innovation model of KS capital share and the markup are inversely linked to maintain balanced growth path. In the vertical innovation model it is possible to study markups lower than 55 percent without a counterfactually high share of physical capital in production as intermediate goods are not directly used as input in production. Instead, intermediate goods are produced with capital, labour, and R&D and, then, are aggregated to a final good with a CES aggregator.

We study the Kung (2015) model with his benchmark calibration of a 20 percent markup. Besides leisure preferences Kung (2015) has some extra features such as stochastic volatility relative to KS. Despite the extra features we find that his results are driven by the labour supply and markup channels described before. Dividends are very sensitive to the curvature of labour which is positively related to the wage bill. Indeed, his model delivers an equity premium of around ten basis points when labour curvature or the markup is chosen to be somewhat lower than his benchmark values. Intuitively, lower labour curvature implies higher Frisch elasticity and countercyclical labour due to dividends turning procyclical. Countercyclical labour insures against negative shocks and leads to lower risk-premia.

[4] There is another way to argue that aggregate dividends affect labour supply. Following Broer et al. (2019) we assume that the majority of households has no dividend income (assumed only in this footnote and not in the paper). If aggregate dividends are zero the combination of the intratemporal condition and the household budget constraint implies fixed labour supply (KPR preferences are necessary for this result to hold).

2 The model

2.1 THE HORIZONTAL INNOVATION MODEL WITHOUT LEISURE

We consider the horizontal innovation model of KS. There is a perfectly competitive firm using tangible capital, labour and patented intermediate goods as inputs. The intangible goods sector produces patents through a monopolistically competitive firm which sets the price to maximise its profits given the demand of final goods firms. In the innovation sector firms develop patents through R&D using the final good as input at unit cost. In KS prices and wages are flexible.

Representative household. The household maximises the present and continuation value of its utility which has Epstein-Zin curvature:

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

where $\beta, \psi,$ and γ are time discount factor, the elasticity of intertemporal substitution and risk-aversion. In KS household derive utility from consumption only: $u_t = C_t$. The household takes position on the stock market, Z_t, supplies labour, L_t, and holds risk-free government bonds, B_t. In the absence of leisure time, the household works the whole time endowment normalised to $L_t = 1$. In the symmetric equilibrium bonds are zero in net supply, $B_t = B_{t+1} = 0$, the shares are $Z_t = Z_{t+1} = 1$, and, thus, consumption is determined by wages and aggregate dividends:

$$C_t = W_t L_t + AD_t,$$

where W_t is the real wage, and AD_t is aggregate dividends defined

$$AD_t = D_t + N_t \Pi_t - S_t,$$

where the dividend of the representative final-good firm, D_t, is defined below in equation (3). Π_t is the profit of an intangible good sector firm and is given by equation (6). $N_t \Pi_t$ is the total profit of the intangible good sector. S_t is the cost of developing new patents in the R&D sector.

Final good sector. The final good is produced with the following technology:

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

where $\alpha, 1-\alpha,$ and ξ are the share of tangible capital, labour, and intermediate goods, respectively. J_t is the aggregator of patented intermediate goods whose number are growing due to R&D. Labour augmenting technology follows an exogenous AR(1) process:

$$A_t = e^{a_t},\ a_t = \rho_a a_t + \varepsilon_{a,t} \tag{2}$$

where ρ_a denotes the persistence of the shock and $\varepsilon_{a,t} \sim N(0, \sigma_a)$.

The final good firm maximises the present discounted value of dividends by optimally choosing capital investment, I_t, labour, L_t, next period's capital, K_{t+1}, and demand for intermediate goods $X_{i,t}$:

$$\max_{\{I_t, L_t, K_{t+1}, X_{i,t}\}_{t\geq 0}} E_0\left[\sum_{t=0}^{\infty} M_{0,t} D_t\right]$$

subject to the definition of dividends and the evolution of physical capital:

$$D_t = Y_t - I_t - W_t L_t - \int_0^{N_t} P_{i,t} X_{i,t} di, \tag{3}$$

$$K_{t+1} = (1-\delta)K_t + \Lambda\left(\frac{I_t}{K_t}\right)K_t \tag{4}$$

where $P_{i,t}$ is the price of the intermediate good i, δ is the depreciation rate of capital. In the definition of dividends $Y_t - W_tL_t$ stands for firm profits. Λ denotes Jermann (1998) type capital adjustment cost function $\Lambda\left(\frac{I_t}{K_t}\right) = \frac{\alpha_1}{1-1/\zeta}\left(\frac{I_t}{K_t}\right)^{1-1/\zeta} + \alpha_2$ which has an elasticity parameter ζ. α_1 and α_2 ensure that adjustment costs are zero in the deterministic steady-state. The first-order conditions from the final goods producers problem are given by:

$$1 = E_t\left[M_{t,t+1}\Lambda'\left(\frac{I_t}{K_t}\right)\left\{\frac{(1-\xi)\alpha Y_{t+1} - I_{t+1}}{K_{t+1}} + \frac{\Lambda\left(\frac{I_t}{K_t}\right) + 1 - \delta}{\Lambda'\left(\frac{I_t}{K_t}\right)}\right\}\right],$$

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

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

Intermediate goods sector. Intermediate good i produced by monopolistically competitive firm i which maximises its profits taking account of the demand by the final good producer:

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

The first-order conditions associated with this problem are given by (index i is dropped due to symmetric choices of firms):

$$P_t = \frac{1}{\nu}, \tag{5}$$

$$\Pi_t = \left(\frac{1}{\nu} - 1\right)X_t, \tag{6}$$

$$X_t = \left(\xi\nu\left(K_t^{\alpha}(A_tL_t)^{1-\alpha}\right)^{1-\xi}N_t^{\xi/\nu-1}\right)^{\frac{1}{1-\xi}}. \tag{7}$$

The combination of equations (7) and (1) gives way to the aggregate production function

$$Y_t = (\xi\nu)^{\frac{\xi}{1-\xi}}K_t^{\alpha}(A_tN_tL_t)^{1-\alpha}$$

where $1-\alpha = \frac{\xi/\nu-\xi}{1-\xi}$ must be imposed to maintain balanced growth path.

Innovation sector. The number of patented intermediate goods N_t evolves as:

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

where S_t denotes R&D expenditure and ϕ is patent obsolesence rate. ϑ_t represents the innovation sector's productivity and is given by $\vartheta_t = \chi\,(S_t/N_t)^{\eta-1}$. Free entry into the innovation sector implies that the expected sales revenues (left-hand side of the following equation) equal to the innovation costs (right-hand side):

$$E_t\left\{M_{t,t+1}\left(N_{t+1} - (1-\phi)N_t\right)\right\} = S_t.$$

Aggregation. Final output good is used to purchase consumption, intermediate goods and is used to finance capital investment and R&D expenditure:

$$Y_t = C_t + N_tX_t + I_t + S_t.$$

Note that the individual firm's dividend is very sensitive to the choice of the markup which can be seen by rewriting equation (3) using (5) to obtain:

$$D_t = Y_t - I_t - W_t L_t - \frac{1}{\nu} X_t. \tag{8}$$

Asset pricing. To obtain the risk premium on various assets we define the difference between the return on (aggregate) dividend claims, and the risk-free rate. The final good sector's cum-dividend stock price, return and excess return for either individual firm ($x = D$) or aggregate dividends ($x = AD$) are given, respectively, by:

$$V_{x,t} = x_t + E_t M_{t,t+1} V_{x,t+1},$$

$$R_{x,t} = \frac{V_{x,t}}{V_{x,t-1} - x_{t-1}},$$

$$r_{x,t} - r_{f,t-1} = (1+\varphi)\left(log\left(R_{x,t}\right) - r_{f,t-1}\right). \tag{9}$$

where $r_{f,t} = log\left(R_{f,t}\right)$ is the log of the risk-free rate that is defined as $R_{f,t} = E_t M_{t,t+1}^{-1}$ where M is the stochastic discount factor.[5]

$$M_{t,t+1} = \beta \left(\frac{u_{t+1}}{u_t}\right)^{-1/\psi} \left(\frac{U_{t+1}}{\left(E_t\left[U_{t+1}^{1-\gamma}\right]\right)^{\frac{1}{1-\gamma}}}\right)^{1/\psi-\gamma}.$$

In equation (9) the excess return is levered as in KS.

Table 1
Calibration

β	discount factor	0.9945
γ	risk-aversion	10
ψ	elasticity of intertemporal subst.	1.8
ξ	patented intermediate goods share	0.5
ν	gross markup	1.65
α	capital share	0.35
ρ	persistence of a_t	0.9925
σ	size of the shock $\varepsilon_{a,t}$	0.0175
ϕ	patent obsolesence rate	0.0375
ζ	capital adjustment cost param.	0.8
δ	depreciation rate of capital	0.02
η	elasticity of new patent w.r.t. R&D	0.83
χ	scale parameter	0.343
φ	leverage factor	0.67

Notes: calibration follows the values in the published code of Kung and Schmid (2015).

[5] In their code KS use the return representation of the pricing kernel, $M_{t,t+1} = \beta^{\vartheta}\left(\frac{u_{t+1}}{u_t}\right)^{-\vartheta/\psi} R_{c,t+1}^{\vartheta-1}$ where $\vartheta \equiv \frac{1-\gamma}{1-1/\psi}$, and $R_{c,t+1}$ is the return on the consumption claim. Whereas we use the expression reported here and in their paper. The two representations are equivalent in the absence of leisure preferences.

3 Calibration and solution method

Table (1) follows the calibration in the published code of KS which is reasonably close to calibration reported in their paper. Based on the restriction $1-\alpha=\frac{\xi/v-\xi}{1-\xi}$ needed for balanced growth, the benchmark markup value, $1/v$ of 65 percent from KS, and the two alternative choices of 60 and 55 percent used for the robustness checks imply that the share of physical capital, α in the production function is 0.35, 0.4, and 0.45, respectively. The model is first detrended with the number of patents, N_t and, then solved with second-order perturbation using the Dynare package.

4 Results

4.1 RESULTS FROM THE BENCHMARK KS MODEL WITHOUT LEISURE

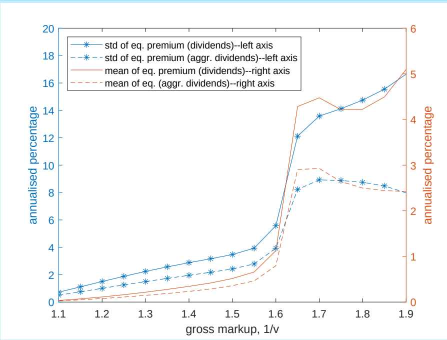
As a first step we display the mean and standard deviation of equity premium from the KS model for a range of possible markups on Figure (1). The picture reveals two 'regimes': a low and a high excess return regime. The mean of the excess return based on aggregate dividends is below one percent for markups lower than 60 percent. Above the 60 percent markup there is jump in the mean and standard deviation of the excess return. The benchmark calibration of KS with a 65 percent markup lies in the high excess return regime. Below we document that the switch from the low to the high excess return regime is accompanied by a change in the cyclicality of aggregate dividends which turn from pro- to countercyclical.

Figure (2) displays impulse responses to a one-standard deviation positive productivity shock for three calibrations of the gross markup using the KS model without leisure. The solid blue line shows the benchmark calibration of KS. With sufficiently high markup ($1/v = 1.65$) aggregate dividends reduce in response to a positive technology shock limiting the rise in current consumption, c, but crowding in more investment into physical capital, i and R&D, s. Further, the figure shows that there is significant variation in expected consumption, $E_t[\Delta c_{t+1}]$ and aggregate dividends, $E_t[\Delta ad_{t+1}]$ in the case of countercyclical aggregate dividends. The increase in price-to-aggregate-dividend ratio, pad_t, dominates the decrease in aggregate dividends in the benchmark case and, eventually, leads to a rise in the return on the aggregate dividend claim, $r_{ad,t}$. We can tell the same story for the dividend claim which has procyclical price and return (not reported on figure 2). Note one difference, however, between dividends and aggregate dividends. The former are acyclical while aggregate dividends are countercyclical in response to technology shocks (on figure 2).

Hence, the transmission of shocks in the endogenous growth model happens through the counterfactual negative aggregate dividends channel. In particular, technology shocks lead to variation in growth prospects if countercyclical aggregate dividends are limiting the response of current consumption and, thus, resources are directed towards capital and R&D investment. Note that these endogenous dividend dynamics in the benchmark calibration of the KS model is different from the exogenous process proposed by Bansal and Yaron (2004). They posit an exogenous process for dividends similar to the one for consumption to match the positive autocorrelation in dividend growth. With a markup of 60 percent or lower aggregate dividend growth is procyclical, and the reaction of expected consumption and aggregate dividends are significantly reduced. With procyclical dividends the growth prospects are not sufficiently strong to induce a rise in stock prices and, hence, the price-dividend ratio declines.

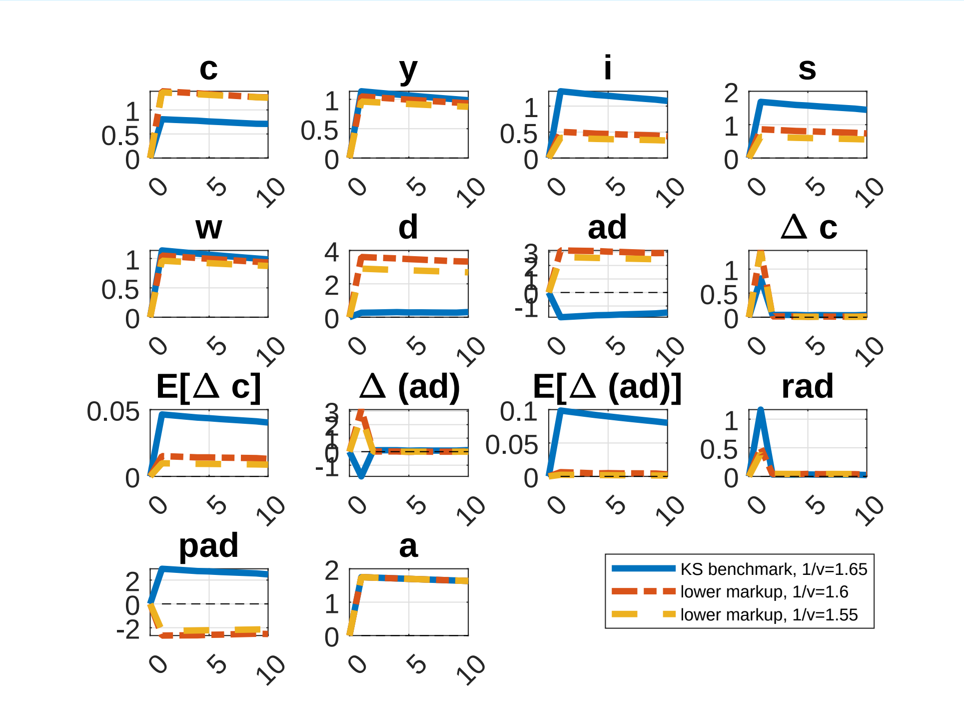
Data and simulated model moments can be found in Table 1. The data column follows Bansal and Yaron (2004) who report unfiltered moments on US data for 1929-1998. Column 2-4 contains results from three calibrations of the KS model. Column 5-7 includes results from three calibrations of the Kung (2015) model discussed in section 3.3 below.

Figure 1
The connection between the excess return and the markup in the KS model without leisure



Notes: in this figure α adjusts to maintain balanced growth path for values of $1/v$.

Figure 2
Impulse responses to a one standard deviation positive technology shock from the KS model without leisure preferences for three different calibrations of the gross markup.



Notes: Time is in quarters on the horizontal axis. Variables displayed are consumption, c, output, y, investment in tangible capital, i, R&D spending, s, real wages, w, dividends, d, aggregate dividends, ad, realised consumption growth, $\Delta c = c_t - c_{t-1}$*, expected consumption growth,* $E[\Delta c] = E_t c_{t+1} - c_t$*, realised aggregate dividend growth,* $\Delta(ad) = ad_t - ad_{t-1}$*, expected aggregate dividend growth,* $E[\Delta(ad)] = E_t ad_{t+1} - ad_t$*, return on aggregate dividends, rad, price-to-aggregate-dividend ratio, pad, and technology shock, a. All variables are detrended and expressed as percentage deviation from the steady-state, e.g.,* $s_t = 100\,[log(S_t/N_t) - log(S/N)]$.

Table 2
Moments from the Kung and Schmid (2015 KS) and Kung (2015) models

	Data	KS $1/v = 1.65$	KS $1/v = 1.6$	KS $1/v = 1.55$	Kung $\tau = 1.57$	Kung $\tau = 1$	Kung $\nu = 11$
Panel A							
E[rd-rf]	6.33	4.28	1.15	0.66	1.70	0.14	0.10
E[rad-rf]	6.33	2.90	0.82	0.46	1.70	0.14	0.10
$\sigma(rd - rf)$	19.42	12.12	5.67	3.94	6.34	2.06	1.53
$\sigma(rad - rf)$	19.42	8.23	4.05	2.78	6.34	2.06	1.53
E[rf]	0.86	1.22	3.84	6.13	1.05	2.56	2.79
$\sigma(rf)$	0.97	0.97	1.31	1.54	1.30	1.24	1.11
Panel B							
$\sigma(\Delta c)$	2.93	3.43	5.33	5.46	2.44	3.13	3.30
$AC1(\Delta c)$	0.49	0.26	0.04	0.03	0.25	0.03	0.02
$\sigma(E[\Delta c])$	–	1.52	0.64	0.37	1.07	0.51	0.32
ρ_c	0.98	1.00	1.00	1.00	0.99	0.98	0.99
$\widehat{\sigma}_c$	0.12	0.20	0.09	0.04	0.27	0.40	0.19
$\sigma(E[\Delta c])/\sigma(\Delta c)$	0.34	0.44	0.12	0.07	0.44	0.16	0.10
$corr(E[\Delta c], \Delta c)$	0.34	0.56	0.24	0.20	0.57	0.18	0.20
Panel C							
$\sigma(\Delta ad)$	11.49	10.40	11.53	10.68	27.67	27.46	43.73
$AC1(\Delta ad)$	0.21	0.04	0.01	0.02	-0.30	-0.32	-0.35
$\sigma(E[\Delta ad])$	–	2.64	0.67	0.04	15.91	15.53	25.81
$corr(\Delta c, \Delta ad)$	0.55	-0.51	0.97	1.00	-0.11	-0.02	0.20
E[p-ad]	3.28	6.20	5.71	4.75	6.48	5.99	5.48
$\sigma(p - ad)$	0.29	0.26	0.23	0.22	0.18	0.07	0.10
$AC1(\Delta(p - ad))$	0.80	0.99	0.99	0.99	0.91	0.40	0.37
ρ_{ad}	0.98	0.99	1.00	1.00	0.40	0.36	0.29
$\widehat{\sigma}_{ad}$	0.36	0.42	0.15	0.01	14.72	14.54	24.69
$\sigma(E[\Delta ad])/\sigma(\Delta ad)$	0.24	0.25	0.06	0.00	0.58	0.57	0.59
$corr(E[\Delta ad], \Delta ad)$	0.24	0.09	0.10	0.29	-0.53	-0.57	-0.60

Notes: In the rows E(.), σ(.), and corr(.,.) refers to unconditional mean, standard deviation and correlations, respectively. AC1 means the first-order auto-correlation. Panel A contains financial moments. Panel B contains statistics related to consumption growth. Panel C reports moments of aggregate dividends and price-dividend ratio. In the last four rows of Panel B and C we fit simulated expected consumption and aggregate dividend growth, $E[\Delta(x)]$ where $x \in (c, ad)$ to an AR(1) process $x_t = \rho_x x_{t-1} + \sigma_x \epsilon_{x,t}$, where $\epsilon_{x,t} \sim N(0,1)$, and compare them to the exogenous consumption and dividend growth process in Bansal and Yaron (2004) displayed in the data column. We report the persistence parameter and the annualised volatility parameter, $\widehat{\sigma}_x$, from the fitted AR(1) process. Note that individual firm and aggregate dividends coincide in the Kung (2015) model.

Although KS report model moments after filtering out high frequency variations from simulated data, we instead focus on moments from unfiltered simulated data as Bansal and Yaron (2004) and Donadelli and Grüning (2016). We do so to ensure that the differences in simulated moments between the high and low markup versions of the model are not the artifacts of filtering methods. Filtering has no effect on the simulated mean of macroeconomic and financial data. In general, we find the standard deviation of macroeconomic and financial data exhibit higher standard deviation in the absence of filtering but still have a reasonably good match to the data moments of Bansal and Yaron (2004).

On Panel A we report financial moments such as the mean and standard deviation of the excess return based on dividends and aggregate dividends. We also compute the mean and variability of the risk-free rate. The best fit is achieved with the benchmark calibration of a high markup when dividends are countercyclical. The means of excess returns are close to the ones reported by KS. The standard deviations of excess returns are, of course, higher than those in KS due to the omission of filtering.

On Panel B we fit the standard deviation of realised and expected consumption growth as well as first-order autocorrelation of the former. The high markup version produces the highest autocorrelation in consumption growth and predicts the highest variability in expected consumption which are crucial for the model to predict long-run risks. Realised consumption growth is higher than in KS due to the omission of filtering.

On Panel C we study moments of dividends growth, the price-dividend ratio and the correlation between consumption and dividends. Only the high markup version produces countercyclical dividends, $corr(\Delta c, \Delta ad) = -0.51$. Similar to consumption growth, dividend growth and price-dividend ratio exhibit the highest variability with the benchmark version of KS. With a markup of 60 percent or lower the model generates less variability in expected aggregate dividend growth.

In the last four rows of panel B and C we follow KS and report the estimated AR(1) process for expected consumption and dividends to compare them to the exogenous processes in Bansal and Yaron (2004). In these four rows that data column contains the estimates of Bansal and Yaron (2004) for the persistence, ρ_c and ρ_{ad} and annualised volatility parameters, $\widehat{\sigma_c}$ and $\widehat{\sigma_{ad}}$, of the AR(1) processes fitted to expected consumption and dividend growth, respectively. The high markup calibration produces the highest variability in the volatility parameter of the expected consumption and aggregate dividends processes. The estimated persistence for expected consumption and dividends is similar across model versions with different markups.

4.2 THE KS MODEL WITH LEISURE PREFERENCES

The intuition from the previous section carries through with leisure preferences. In particular, we introduce leisure in the form of King et al. (1988 KPR) preferences which are consistent with the balanced growth path and implies that technology shocks have wealth effects on labour supply. With leisure the period utility changes to $u_t^* = C_t(\bar{L} - L_t)^\tau$, where $\bar{L}$ denotes the steady-state time endowment. The benchmark curvature parameter τ is chosen such that 1/3 of the time frame is spent on labour, and the rest is on leisure in the deterministic steady-state.

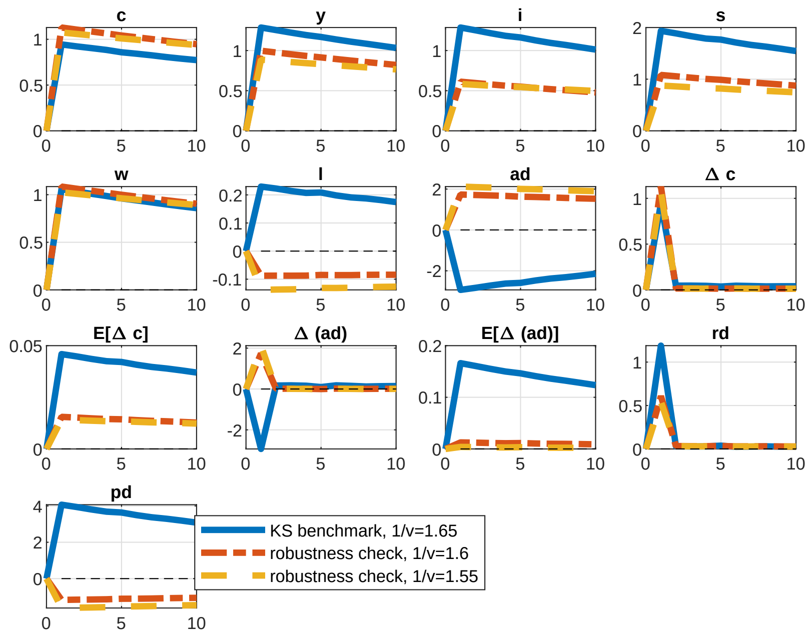
Figure (3) shows impulse responses to a positive technology shock from the KS model extended with leisure preferences for the benchmark and two further calibrations of the gross markup. Following a positive shock to technology leisure falls and labour rises due to the negative income effect of dividends. With a fixed time frame this is equivalent to a rise in labour which makes the economy more procyclical, supporting higher future growth, and leads to a rise in risk premia on dividend claims in line with the findings of Donadelli and Grüning (2016). [6]

Elastic labour makes the wage cost term larger in the profits[7] and, thus, leads to larger downward adjustment in dividends in the wake of positive technology shocks. On the other hand, procyclical labour increases the marginal productivity of R&D further improving growth prospects, and implying an even larger increase in the price-dividend ratio. Indeed, the risk-premium is higher with procyclical labour confirming the results in Donadelli and Grüning (2016) who report unconditional moments.

[6] There is another route to argue that changes in aggregate dividends are shifting labour supply. Suppose aggregate dividends are zero due to some mechanism (e.g. firm entry-exit) not modelled in this paper. In the absence of dividends the combination of household budget constraint ($C_t = W_t L_t$), and the intratemporal condition ($W_t = \tau C_t(\bar{L} - L_t)^{-1}$) leads to constant labour.

[7] Substituting the intratemporal condition ($W_t = \tau C_t(\bar{L} - L_t)^{-1}$) for wage in the expression of dividends reveals that the latter depends linearly on τ.

Figure 3
Impulse responses to a one-standard deviation positive technology shock from the KS model extended with leisure preferences for three different calibrations of the gross markup.



Notes: notations are identical to figure 2. $l_t = 100log(L_t/L)$ *denotes the percentage deviation of labour from the steady-state.*

4.3 VERTICAL INNOVATION MODEL

In the horizontal innovation model we could not investigate cases where the markup is lower than 55 percent as that would imply an implausibly high share of physical capital due to the restriction that guarantees the balanced growth path. In this section, we propose a market structure where markups in the intermediate goods sector are not linked to the share of physical capital. We follow the model structure of Kung (2015) with vertical innovation.

Different from the horizontal innovation model of KS the vertical innovation model of Kung (2015) assumes that intermediate goods are not directly used as an input in the product of the final good (joint with capital and labour). Instead, each intermediate good is produced with capital and labour and added up through a Dixit-Stiglitz aggregator which is essentially a vertical scheme. In the interest of space we skip the formal description of the vertical innovation model and redirect the interested reader to Kung (2015).

The last three columns of table (2) contain simulated moments from the Kung (2015) model which assumes a markup of twenty percent as the benchmark calibration. To show the importance of the curvature parameter of labour we consider his benchmark, $\tau = 1.57$, and an alternative calibration of $\tau = 1$. The higher is τ the more sensitive dividends are to the wage bill which is larger when labour is elastic. For the benchmark calibration of τ, aggregate dividends decline, and labour increases in response to a positive technology shock predicting an equity premium of 170 basis points on average (see the column 'Kung $\tau = 1.57$').

For the alternative calibration of $\tau = 1$ dividends are slightly procyclical and more leisure is consumed due to the positive income effects of dividends[8]. Due to the fixed time frame higher leisure implies less labour.

In the case of $\tau = 1$ there is reduced variation in expected consumption growth and in the price-dividend ratio. Thus, growth prospects and significance of the innovation channel is limited with procyclical dividends and countercyclical labour. Indeed, the excess return reduces to 14 basis points (see the column 'Kung $\tau = 1$'). According to Kung (2015 pp. 52): "the growth

[8] For the full picture we need to add that $\tau = 1$ implies that the share of labour time in steady-state rises from 1/3 to 43 percent of total time endowment.

channel dampens incentives to consume leisure when expected growth is high." Hence, Kung (2015) considers the endogenous growth channel to be the driver of procyclical labour.

Our experiment with the case of $\tau = 1$ reveals, however, that the labour response is mainly driven by the wealth effects of dividends which is the channel emphasized by Broer et al. (2019). τ is inversely related to the Frisch elasticity of labour supply. With higher elasticity of labour supply (moving from $\tau = 1.57$ to $\tau = 1$), dividends, and leisure become procyclical. Labour equals to one minus leisure. Hence, labour becomes countercyclical, insures against the shocks and, thus, leads to lower risk-premia. The latter is similar to the findings in real business cycle models which are equipped with preferences containing a wealth effect on labour supply.

Finally, we show that the vertical innovation model is also sensitive to the choice of the markup due to its influence on labour demand and dividends (equations are reported in the appendix of Kung (2015)). With a net markup of ten percent (invoked by setting $\nu = 11$ in the net markup, $1/(\nu - 1)$ using the notation of Kung (2015)) the excess return drops from 170 to 10 basis points (see the last column of table (2)).

5 Conclusion

This paper shows that the high risk premia in recent innovation models is driven by the countercyclical dividends channel which is implausible as post-war US data exhibit procyclical or acyclical dividends at best. A high markup in the patent producer sector leads to countercyclical dividends. When the model is extended with leisure preference dividends become more sensitive to the wage bill and turns more countercyclical, which, again improves the asset pricing performance of the innovation models. In the vertical innovation model elastic labour supply is the channel that makes dividends countercyclical, labour procyclical and brings a high risk premia through significant growth prospects. More research is needed to explain which features are needed for the innovation-driven endogenous growth model to explain risk-premia joint with procyclical dividends.

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Appendix

5.1 FORECASTING REGRESSIONS

Following Kung and Schmid (2015) we study whether R&D intensity (S/N) and R&D stock growth (ΔN) is forecasting consumption growth from the simulated models. Table 3-5 contain regressions forecasting annualised consumption growth for three calibrations of the KS model (with net markups of 65, 60 and 55 percent) for horizons (k) of one to five years. In Panel A the log of simulated annual consumption growth is projected on simulated R&D intensity, $\Delta c_{t,t+1} + ... + \Delta c_{t+k-1,t+k} = \alpha + \beta \Delta (s-n)_t + v_{t,t+k}$. In Panel B the log of simulated annual consumption growth is projected on simulated R&D growth, $\Delta c_{t,t+1} + ... + \Delta c_{t+k-1,t+k} = \alpha + \beta \Delta n_t + v_{t,t+k}$. The regressions are estimated via OLS with Newey-West standard errors with $k-1$ lags and overlapping annual observations. The estimates from the regressions are averaged across $N = 100$ simulations. KS also provides empirical estimates. In the first row we report the estimated β. The second row contains the standard error of the estimate. The third row contains R^2 which is the measure of fit.

For the benchmark markup (65 percent) of KS we obtain estimates similar to those reported in Table VIII of KS. For lower markups there is a radical decrease in the forecasting performance captured by the lower R^2. For a markup of 55 percent the connection between R&D measures and consumption growth turns to negative.

Table 3
KS model with 65 percent markup (benchmark)

	Horizon (years)				
	1	2	3	4	5
	Panel A: Forecasts with R&D Intensity				
β	0.026	0.052	0.077	0.102	0.126
SE	0.003	0.006	0.009	0.012	0.015
R^2	0.153	0.238	0.292	0.330	0.355
	Panel B: Forecasts with R&D Growth				
β	0.770	1.525	2.263	2.986	3.691
SE	0.090	0.170	0.254	0.342	0.435
R^2	0.153	0.238	0.293	0.330	0.356
N	100	100	100	100	100

Notes: R&D intensity (S/N) and R&D stock growth (ΔN) are used to forecast annualised consumption growth for horizons (k) of one to five years based on the simulations from the KS model (calibrated with a net markup of 65 percent). In Panel A the log of simulated annual consumption growth is projected on simulated R&D intensity, $\Delta c_{t,t+1} + ... + \Delta c_{t+k-1,t+k} = \alpha + \beta \Delta (s-n)_t + v_{t,t+k}$. In Panel B the log of simulated annual consumption growth is projected on simulated R&D growth, $\Delta c_{t,t+1} + ... + \Delta c_{t+k-1,t+k} = \alpha + \beta \Delta n_t + v_{t,t+k}$.

5.2 MODEL EQUATIONS

Here we list the equilibrium conditions of the Kung and Schmid (2015) model extended with leisure preferences. The symmetric equilibrium is defined as a sequence of endogenous variables

$$\{C_t, U_t, M_t, Y_t, W_t, q_t, I_t, \Lambda_t, X_t, \Pi_t, V_t, S_t, K_t, L_t\},$$

and exogenous shock process

$$\{A_t = e^{a_t}\}_{t=0}^{\infty},$$

and initial conditions

$$\{K_0, N_0\}_{t=0}^{\infty}.$$

Table 4
KS model with 60 percent markup

	Horizon (years)				
	1	2	3	4	5
	Panel A: Forecasts with R&D Intensity				
β	0.020	0.040	0.058	0.077	0.094
SE	0.010	0.017	0.025	0.033	0.041
R^2	0.050	0.083	0.107	0.126	0.141
	Panel B: Forecasts with R&D Growth				
β	0.5136	1.0194	1.5057	1.9814	2.4311
SE	0.2491	0.4564	0.6636	0.8707	1.0796
R^2	0.0492	0.0817	0.1054	0.1244	0.1391
N	100	100	100	100	100

Notes: notations are identical to table 3.

Table 5
KS model with 55 percent markup

	Horizon (years)				
	1	2	3	4	5
	Panel A: Forecasts with R&D Intensity				
β	-0.002	-0.004	-0.005	-0.006	-0.008
SE	0.019	0.035	0.051	0.066	0.082
R^2	0.003	0.006	0.009	0.012	0.014
	Panel B: Forecasts with R&D Growth				
β	-0.0515	-0.0897	-0.1286	-0.1518	-0.1949
SE	0.4999	0.9062	1.3047	1.6985	2.0922
R^2	0.0033	0.0063	0.0091	0.0117	0.0144
N	100	100	100	100	100

Notes: notations are identical to table 3.

The equilibrium conditions are listed as follows:

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

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

$$W_t = \tau\frac{C_t}{\bar{L}-L_t},$$

$$M_{t,t+1} = \beta\left(\frac{u_{t+1}}{u_t}\right)^{1-1/\psi}\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(\frac{U_{t+1}}{\left(E_t\left[U_{t+1}^{1-\gamma}\right]\right)^{\frac{1}{1-\gamma}}}\right)^{1/\psi-\gamma},$$

$$Y_t = (\xi v)^{\frac{\xi}{1-\xi}}K_t^{\alpha}(e^{a_t}N_tL_t)^{1-\alpha},$$

$$a_t = \rho a_{t-1} + \sigma\varepsilon_t,$$

$$1 = E_t\left[M_{t,t+1}\Lambda'\left(\frac{I_t}{K_t}\right)\left\{\frac{(1-\xi)\alpha Y_{t+1} - I_{t+1}}{K_{t+1}} + \frac{\Lambda\left(\frac{I_t}{K_t}\right)+1-\delta}{\Lambda'\left(\frac{I_t}{K_t}\right)}\right\}\right],$$

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

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

$$\Lambda\left(\frac{I_t}{K_t}\right) = \frac{\alpha_1}{1-\frac{1}{\zeta}}\left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\zeta}} + \alpha_2,$$

$$\Lambda_t' = \alpha_1\left(\frac{I_t}{K_t}\right)^{-\frac{1}{\zeta}},$$

$$q_t = \frac{1}{\Lambda_t'},$$

$$V_t = \Pi_t + (1-\phi)E_t\left[M_{t,t+1}V_{t+1}\right],$$

$$\Pi_t = \left(\frac{1}{v}-1\right)X_t,$$

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

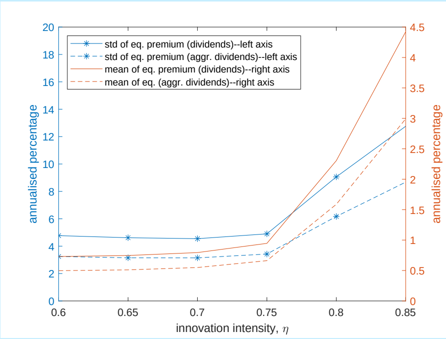
$$\vartheta_t = \chi\left(\frac{S_t}{N_t}\right)^{\eta-1},$$

$$E_tM_{t,t+1}\left(N_{t+1}-(1-\phi)N_t\right) = S_t,$$

$$Y_t = C_t + N_tX_t + I_t + S_t.$$

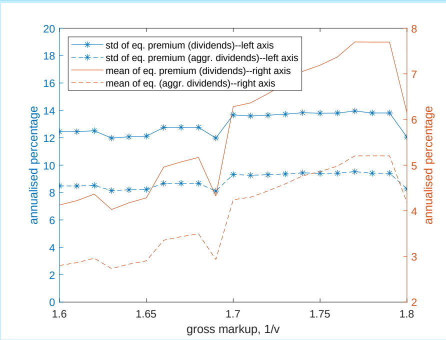
The equilibrium conditions needs to be stationarised by the number of patents, N_t and the stationary model can be solved by second- or third-order perturbation in Dynare. Second order perturbation is sufficient to capture the equity risk premium.

Figure 4
Looping over innovation intensity, η



Notes: in this figure α adjusts to maintain balanced growth path for values of η.

Figure 5
Replicating figure 3 in the paper by adjusting ξ to maintain balanced growth path.



Notes: in this figure ξ adjusts to maintain balanced growth path for values of $1/v$ and fixing $\alpha = 0.35$.

The continuation value of utility can be normalised by the period utility as

$$U_t \equiv \frac{V_t}{u_t} = \left[(1-\beta) + \beta\left(E_t\left[\frac{V_{t+1}^{1-\gamma}}{u_{t+1}^{1-\gamma}}\frac{u_{t+1}^{1-\gamma}}{u_t^{1-\gamma}}\right]\right)^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}}.$$

The previous can be rewritten to the expression used in the code:

$$U_t = \left[(1-\beta) + \beta\left(E_t\left[U_{t+1}^{1-\gamma}\Delta u_{t+1}^{1-\gamma}\right]\right)^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}}$$

where in the code U_{t+1} is called u(1) and $\Delta u_{t+1}$is called cg(1).

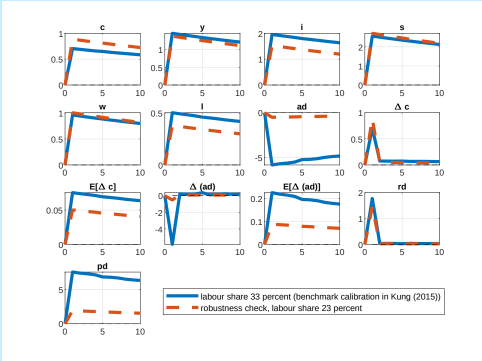
5.3 FURTHER ROBUSTNESS CHECKS

On figure (4) we assess how sensitivity the mean and standard deviation of equity premia to innovation intensity, η.

On figure (5) we display how the equity premia change when balanced growth path condition is satisfied through adjusting ξ instead of α as in figure (1) of this paper. The balanced growth condition can be rewritten as $\xi = 1/[1 + (1/v - 1)/(1 - \alpha)]$. According to the graph the positive relationship between the gross markup and excess return holds.

On figure (7) we study the impact of the share of hours worked using the KS model extended with leisure preferences. In the baseline case of 0.33 percent hours share the excess return on the aggregate dividends is 7.93 (5.39) percent which decreases to (2.98) 2.17 percent with a 23 percent hours share. With the 23 percent hours share the τ is equal to 2.4048. With the 33

Figure 6
Assessing the impact of the labour share on model dynamics–impulse responses to a positive productivity shock



Notes: on the figure τ is adjusted for the different shares of hours worked in the total time endowment.

percent labour share the τ is equal to 1.7688. For both values of the τ the aggregate dividend is countercyclical, and labour is procyclical. The aggregate dividends are more countercyclical in the higher labour share case. Hence, the labour share has major impact on the results.

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