Breaking down asset pricing models: The role of endogenous growth and wage inertia

by

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Abstract

This paper examines the implications of wage inertia in a benchmark production economy with endogenous growth. The benchmark model incorporates wage inertia such as wage stickiness with endogenous labor supply and search and matching models with Nash and with alternating offer bargaining (AOB). Following a productivity shock, we find that a) wage inertia creates pro-cyclical dividend behavior b) AOB framework brings unemployment, dividend and asset pricing moments closer to the data c) agents command higher risk premia as uncertainty in the endogenous growth model (long run risk channel) is exacerbated by uncertainty over wage flow from unemployment (cash flow channel).

1 Introduction

The paradigm shift from consumption based asset pricing models to the more recent production based asset pricing models pioneered by Cochrane (1991) and Jermann (1998) has mostly ignored the dynamics of the labor market. Recent papers by Tallarini (2000), Kaltenbrunner and Lochstoer (2010) and Croce (2014) have used non trivial production sectors to explain asset pricing moments, but have assumed a frictionless labor market so wage equals marginal productivity of labor. This could have far fetching implications on the asset pricing as dynamics of wage form an integral part of the value of the firm. For example, in standard frictionless labor models, dividends equal profits minus investment, and profits equal output minus wages. Since wages equal the marginal product of labor, it is procyclical as output. This makes profits smoother and dividends acyclical or countercyclical contradicting empirical evidence.[3]

The few studies which have integrated the more realistic wage dynamics in the asset pricing models have mostly assumed wage-setting subject to nominal rigidities. Li and Palomino (2014) belong to this category in the labor-asset pricing literature. They show that in the Kaltenbrunner and Lochstoer (2010) model of permanent and transitory technology shocks, the absence or presence of nominal rigidities – nominal rigidities are modeled following the Calvo (1983) staggered price and wage setting – can determine whether the risk premium is negative or positive, respectively. Though the model captures key macroeconomic moments and the Sharpe ratio of stock returns, equity premium falls short of its empirical counterpart. Favilukis and Lin (2016) consider a different variant of wage modeling in terms of infrequent wage resetting where average wage paid by firms is taken to be equal to the weighted average of historical spot wages. On account of this wage modeling, the average wage becomes smoother than the marginal product of labor. They find that the profit and dividend behavior look very much like the data. However, the volatility of equity and the value premium fall short of the data.

While Li and Palomino (2014) and Favilukis and Lin (2016) consider labor supply as exogenous, Donadelli and Grüning (2016) departs from this framework by considering endogenous labor supply in addition to wage rigidities. Donadelli and Grüning (2016) find that including endogenous labor supply leads to higher aggregate risk as labor becomes highly procyclical which leads the risk premia to rise by about 250 basis points. However, these models have been criticized for simply assuming wage inertia especially since wage inertia itself is what drives the results.

Instead of simply assuming wage inertia, search and matching labor market models derive wage inertia as an equilibrium outcome. As part of an emerging literature on asset pricing, Petrosky-Nadeau et al. (2018) integrate the standard Diamond-Mortensen-Pissarides (DMP) labor search and matching model to the asset pricing framework to avoid the common pitfall of countercyclical dividends in standard asset pricing models.[4] They use the labor search and matching framework to delink wages from the marginal product of labor to explain why wages

[3] Please refer to Favilukis and Lin (2016) among others.

[4] The standard search and matching model in the labor market was developed by Diamond (1982), Mortensen (1982) and Pissarides (1985).

fall during bad times, but not as much as the fall in output. This causes profits to drop disproportionately and makes the dividends more procyclical leading to higher equity premium. However, the risk free rate is higher than in the data and volatility of interest rate falls short of the data. Kuehn et al. (2017) develop a partial equilibrium labor search model and show that labor search frictions are vital in determining cross-section equity returns. For tractability, they use a partial equilibrium asset pricing model and assume an exogenous pricing kernel. In addition, DMP search models are subject to the Shimer (2005) critique that higher labor productivity will have small effects on unemployment, vacancy and job finding rates since the increase in productivity is absorbed by higher wages arising from the increase in workers' threat point in wage bargaining as unemployment duration decreases with lower unemployment and higher vacancy rates.

We examine the implications on asset prices and macroeconomic aggregates of incorporating labor market frictions in a production-based, asset-pricing, general equilibrium framework of Kung and Schmid (2015). Our paper differs from the aforementioned papers from the specification of the search and matching framework of the labor market. We pursue a variant of Christiano et al. (2016) approach to labor market in contrast to den Haan et al. (2000). Our motivation for using Christiano et al. (2016) labor market specification lies with the objective of using different bargaining regimes like alternating offer sharing rule in addition to Nash sharing rule to model rent sharing between firm and its workforce to see the impact on asset prices. alternating offer bargaining (AOB) framework is not subject to the Shimer (2005) critique of search and matching models (unlike Nash bargaining) and makes the unemployment volatility of the model more consistent with its empirical counterparts. For comparison, we also consider labor market friction which assumes nominal wage rigidities as in Uhlig (2007) and endogenous labor supply following Donadelli and Grüning (2016), and the frictionless labor market in Kung and Schmid (2015).[5]

We find that following a positive productivity shock, the models with wage inertia show slight improvements to the benchmark KS model compared with US data. For the search and matching labor market models, the AOB shows labor market moments closer to the data than the Nash bargaining consistent with the findings of Christiano et al. (2016). The AOB labor market framework also shows asset pricing moments including the standard deviations of the growth of dividends and the correlation between dividend and output, which are much closer to the data compared with the benchmark KS model and the other types of models of wage inertia. The impulse responses show that under AOB, wages rise the least, as labor, vacancies and unemployment are more responsive following a positive productivity shock. Hence, the response of dividends is larger – and closer to the data – under AOB than the benchmark KS model or the models with other types of wage inertia.

The higher asset pricing moments in our model arise from endogenous long run risk associated with consumption in the Kung and Schmid (2015) model which is aggravated by the higher unemployment volatility in the AOB framework of Christiano et al. (2016). In the Kung and

[5] Christiano et al. (2016) do not consider the impact of alternating offer bargaining on asset prices.

Schmid (2015) model, the long run risk is endogenously created by a persistent component of economic growth. With recursive preferences, people fear long-term low growth and economic downturn will lower asset prices, and require a higher risk premium to hold assets even with frictionless labor markets. Incorporating search and matching labor market frictions of the AOB model into the Kung and Schmid (2015) model means economic downturns and low growth are accompanied by high unemployment. The high unemployment rate creates cash flow risk with respect to wages during economic downturn for the household. In order to smooth consumption during periods of high unemployment, household agents would require an even higher equity premium to hold assets compared to the benchmark KS model.

The paper is organized as follows: Section 2 describes the benchmark KS model without labor market friction and modifications of the KS model with various types of labor market frictions; Section 3 describes the calibration of the models; Sections 4 and 5 discuss the aggregate quantity and labor market dynamics, and asset pricing implications, respectively: and Section 6 gives the conclusions.

2 Model

This section embeds the Kung and Schmid (2015) (henceforth KS) model with wage rigidities (Donadelli and Grüning (2016)), Nash bargaining and alternating offer bargaining (Christiano et al. (2016)) frameworks of the search and matching frictions in the labor market. We adopt the notations from the three papers whenever possible for easy reference across frameworks.

In the KS model, the labor market is perfectly competitive (i.e. wages equal marginal productivity of labor) resulting in 1) counter-factual highly pro-cyclical swings in wages, and 2) the inability of the model to capture the dynamics of dividends. Hence, we introduce labor market frictions in the model through wage rigidities (Donadelli and Grüning (2016)) and search and matching framework of labor market (Christiano et al. (2016)). The search and matching labor market model includes alternating offer bargaining (henceforth AOB) by Christiano et al. (2016) and the Nash bargaining framework. We compare the KS models with labor market frictions to see which of the models could better account for key properties of asset pricing and macroeconomic aggregates, including labor market variables.

2.1 Benchmark KS model without labor market frictions

Our benchmark model is the KS model where final goods are produced using intermediate goods, labor and capital. Sustained growth in intermediate goods arises on account of patents due to investment in research and development (R&D). Long run risk endogenously arises due to this sustained growth, which affects the expected consumption growth from Epstein-Zin utility preferences.[6]

[6]Subsection 2.1 presents Kung and Schmid (2015) model following the order of the presentation and notations of the earlier versions of their paper particularly their section on "benchmark endogenous growth model (ENDO)."

2.1.1 Final goods sector

The representative firm produces final goods based on the production function

$$Y_t = (K_t^\alpha(\Omega_t L_t)^{1-\alpha})^{1-\xi} G_t^\xi \tag{1}$$

where K_t is capital, L_t is labor, G_t is a composite of intermediate goods defined as $G_t \equiv [\int_0^{N_t} X_{i,t}^{\frac{1}{\nu}} \, di]^\nu$, $X_{i,t}$ is intermediate good $i \in [0, N_t]$, and Ω_t is the productivity shock. α, ξ and ν are the share of capital goods, the share of intermediate goods and the elasticity of substitution between the intermediate goods, respectively.

The firm maximizes shareholder's wealth

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

where M_t is the stochastic discount factor and D_t is the firm's dividends given as $D_t = Y_t - I_t - W_t L_t - \int_0^{N_t} P_{i,t} X_{i,t} \, di$. I_t is capital investment, W_t is the wage rate, and $P_{i,t}$ is the price per unit of intermediate good i.

As common in the literature, the evolution of capital stock is given by $K_{t+1} = (1-\delta)K_t + \Lambda\left(\frac{I_t}{K_t}\right) K_t$, where δ is the capital depreciation rate and $\Lambda(\cdot)$ is the capital adjustment costs defined as $\Lambda\left(\frac{I_t}{K_t}\right) \equiv \frac{\alpha_1}{1-\frac{1}{\zeta}} \left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\zeta}} + \alpha_2$. The parameter ζ is the elasticity of the investment rate with limiting cases $\zeta \to 0$ and $\zeta \to \infty$ indicating infinitely costly adjustment and frictionless adjustment, respectively. α_1 and α_2 are set so that adjustment costs are zero in the deterministic steady state.

The resulting first order conditions from maximizing shareholder's wealth are

$$q_t = \frac{1}{\Lambda_t'} \tag{2}$$

$$W_t = (1-\alpha)(1-\xi)\frac{Y_t}{L_t} \tag{3}$$

$$1 = E_t \left[M_{t+1} \left\{ \frac{1}{q_t} \left(\alpha(1-\xi)\frac{Y_{t+1}}{K_{t+1}} + q_{t+1}(1-\delta) - \frac{I_{t+1}}{K_{t+1}} + q_{t+1}\Lambda_{t+1} \right) \right\} \right] \tag{4}$$

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

where $\Lambda_t \equiv \Lambda\left(\frac{I_t}{K_t}\right)$ and $\Lambda_t' \equiv \Lambda'\left(\frac{I_t}{K_t}\right)$.

2.1.2 Intermediate goods sector

The intermediate goods sector produces patents. Each intermediate good $i \in [0, N_t]$ is produced by a monopolistic competitive firm. The equilibrium condition with respect to $X_{i,t}$ (Equation 5) provides the demand equation for intermediate good i as a function of the price $P_{i,t}$. The monopolistically competitive firm producing $X_{i,t}$ takes the demand equation $X_{i,t}(P_{i,t})$ as given and produces at unit cost. Thus, the firm produces each intermediate good by maximizing its profits

$$\max_{P_{i,t}} \Pi_{i,t} \equiv P_{i,t} \cdot X_{i,t}(P_{i,t}) - X_{i,t}(P_{i,t})$$

The intermediate goods sector is characterized as in Dixit and Stiglitz (1977) so that the symmetric equilibrium conditions obtained are $X_{i,t} = X_t$ and $P_{i,t} = P_t = \nu$, where $\nu > 1$ is the markup. These two equilibrium conditions are substituted into the definition for G_t and the first order condition with respect to $X_{i,t}$ and give

$$G_t = N_t^{\nu} X_t \tag{6}$$

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

Therefore, the profit maximizing equation $\pi_{i,t}$ and dividend equation D_t become

$$\pi_t = (\nu - 1) X_t \tag{8}$$

$$D_t = Y_t - I_t - W_t L_t - \nu N_t X_t \tag{9}$$

The value of owning exclusive rights to produce intermediate good i is given by $V_{i,t} = \Pi_{i,t} + \phi E_t[M_{t+1} V_{i,t+1}]$ where ϕ indicates the survival rate of an intermediate good. The symmetric equilibrium conditions are imposed so the i subscript could be dropped and the above is rewritten as

$$V_t = \Pi_t + \phi E_t[M_{t+1} V_{t+1}] \tag{10}$$

2.1.3 R&D sector

New intermediate goods are developed by the R&D sector and sold to firms in the intermediate goods sector. The law of motion for number of intermediate goods is $N_{t+1} = \vartheta_t S_t + \phi N_t$, where S_t refers to R&D expenditures and ϑ_t, the productivity of the R&D sector, is specified as $\vartheta_t = \frac{\chi \cdot N_t}{S_t^{1-\eta} N_t^{\eta}}$, where $\chi > 0$ is a scale parameter and $\eta \in [0, 1]$ is the elasticity of new intermediate goods with respect to R&D. The growth rate of intermediate goods provides the equilibrium foundation of long run risk in this model.

$$\Delta N_{t+1} = \vartheta_t \frac{S_t}{N_t} + \phi \tag{11}$$

Free entry into the R&D sector implies expected sales revenue equals costs: $E_t[M_{t+1} V_{t+1}](N_{t+1} - \phi N_t) = S_t$. This could also be stated in terms of marginal costs equal expected marginal revenue:

$$\frac{1}{\vartheta_t} = E_t[M_{t+1} V_{t+1}]. \tag{12}$$

2.1.4 Balanced growth and stochastic productivity shock

Kung and Schmid (2015) note that the condition for the balanced growth could be derived by substituting equations (6) and (7) into equation (1) which gives the expression of the aggregate production function:

$$Y_t = \left(\frac{\xi}{\nu}\right)^{\frac{\xi}{1-\xi}} K_t^{\alpha}(\Omega_t L_t)^{1-\alpha} N_t^{\frac{\nu\xi-\xi}{1-\xi}} \tag{13}$$

Equation 13 is homogeneous of degree one in K_t and N_t to ensure balanced growth so that the restriction, $\alpha + \frac{\nu\xi-\xi}{1-\xi} = 1$, must hold. When this restriction is imposed, it implies the standard neoclassical production function with labor augmenting technology which is $Y_t = K_t^{\alpha}(Z_t L_t)^{1-\alpha}$, where Z_t is the total factor productivity defined as $Z_t \equiv \overline{A}\Omega_t N_t$ and $\overline{A} \equiv \left(\frac{\xi}{\nu}\right)^{\frac{\xi}{(1-\xi)(1-\alpha)}} > 0$ is a constant.

The stochastic process Ω_t provides the ground for exogenous stochastic productivity shocks to the model are given by $\Omega_t = e^{a_t}$ where $a_t = \rho a_{t-1} + \epsilon_t$ and $\epsilon_t \sim N(0, \sigma^2)$.

2.1.5 Household

The representative household is assumed to have Epstein-Zin preferences

$$Util_t = \left\{(1-\beta)C_t^{1-\frac{1}{\psi}} + \beta\left(E_t[Util_{t+1}^{1-\gamma}]\right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}}\right\}^{\frac{1}{1-\frac{1}{\psi}}} \tag{14}$$

where C_t is consumption, γ is the relative risk aversion coefficient, ψ is the intertemporal elasticity of substitution and β is the discount rate. As in the long run risk literature, KS assume $\psi > \frac{1}{\gamma}$ so the agent prefers the early resolution of uncertainty. The preferences imply the stochastic discount factor

$$M_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{\frac{-1}{\psi}}\left(\frac{Util_{t+1}}{E_t(Util_{t+1}^{1-\gamma})^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma} \tag{15}$$

The budget constraint of the household is

$$C_t + V_{m,t}\mathcal{Z}_{t+1} + B_{t+1} = W_t L_t + (V_{m,t} + \mathcal{D}_t)\mathcal{Z}_t + (1 + r_{f,t})B_t \tag{16}$$

where $V_{m,t}$ is the stock price, $\mathcal{Z}_t$ is the household's stock holding which pays aggregate dividend $\mathcal{D}_t$, B_t indicates bonds, $r_{f,t}$ is the risk free rate, W_t is the wage rate and L_t is the hours worked.

Following Kung and Schmid (2015), stocks are assumed to be claims to all the production sectors, such as the final goods sector, the intermediate goods sector, and the R&D sector. Aggregate dividend is defined as the net payout from the production sector,

$$\mathcal{D}_t = D_t + \int_0^{N_t} \pi_{i,t} di - S_t \tag{17}$$

On account of symmetric equilibrium conditions, equation (17) could be rewritten as:

$$\mathcal{D}_t = D_t + N_t\pi_t - S_t \tag{18}$$

2.1.6 Market clearing

Market clearing conditions imply:

$$Y_t = C_t + I_t + N_tX_t + S_t \tag{19}$$

In the KS model without labor market friction and disutility for labor, households supply their whole labor so the labor force is normalized to one:

$$L_t = 1 \tag{20}$$

2.1.7 Asset prices

The risk-free bond rate, $r_{f,t}$, and risk-free return, $R_{f,t}$, are given by:

$$r_{f,t} = ln(R_{f,t}), \quad R_{f,t} = \frac{1}{M_{t+1}}$$

The stock price, the stock return and the risk premium of final goods sector firm are given by:

$$\begin{aligned} V_{d,t} &= D_t + M_{t+1}V_{d,t+1}, \\ R_{d,t} &= \frac{V_{d,t}}{V_{d,t-1} - D_{t-1}}, \text{and} \\ r_{d,t} - r_{f,t} &= (1 + l)(ln(R_{d,t}) - rf,t), \end{aligned}$$

respectively. The final goods sector excess return is leveraged by imposing $l = \frac{2}{3}$ as in Boldrin et al. (2001). Similarly, for aggregate market we have:

$$\begin{aligned} V_{m,t} &= \mathcal{D}_t + M_{t+1}V_{m,t+1}, \\ R_{m,t} &= \frac{V_{m,t}}{V_{m,t-1} - \mathcal{D}_{t-1}}, \\ r_{m,t} - r_{f,t} &= (1 + l)(ln(R_{m,t}) - rf,t) \end{aligned}$$

2.2 KS model with endogenous labor and assumed wage rigidity

Donadelli and Grüning (2016) incorporate wage rigidity into the KS model. They modify the Epstein-Zin preferences to include leisure, $leis_t$:

$$Util_t = \left\{ (1-\beta) util_t^{1-\frac{1}{\psi}} + \beta \left(E_t[Util_{t+1}^{1-\gamma}] \right)^{\frac{1-\frac{1}{\psi}}{1-\gamma}} \right\}^{\frac{1}{1-\frac{1}{\psi}}} ; \; util_t = C_t(leis_t)^{\tau} \tag{21}$$

where τ refers to the Frisch elasticity of labor supply and leisure is one minus the hours of work, ($leis_t = 1 - L_t$). The optimal (hours of) labor supply is endogenously determined from the behavior of household and is given as

$$W_t = \frac{\partial util_t / \partial L_t}{\partial util_t / \partial C_t} = \frac{\tau C_t}{leis_t} \tag{22}$$

where W_t is the market wage. Donadelli and Grüning (2016) follow Uhlig (2007) in assuming that wages are sticky and evolve as

$$W_t = (W_{t-1})^{\mu} (W_t^u)^{1-\mu} \tag{23}$$

where W_t^u refers to frictionless wages (equal to marginal productivity of labor as in Equation 3) and $\mu \in [0, 1]$ is the fraction of sticky wages.

2.3 KS model with search and matching labor frictions

Instead of assuming wage stickiness as in the previous section (Equation 23), we extend the KS model with the search and matching labor market model specifications as described by Christiano et al. (2016) in this section. L_t refers to aggregate employment with the law of motion given by

$$L_t = (\rho_1 + x_{1,t}) L_{t-1} \tag{24}$$

where ρ_1 is the probability that the match between the firm and the worker continues from period $t-1$ to t. Hence, $\rho_1 L_{t-1}$ refers to the number of workers that stays with the firm at the start of period t. $x_{1,t} L_{t-1}$ denotes the quantity of newly hired workers employed in period t.

In contrast to Equation 20, population now includes both the employed and the unemployed in the work force so that

$$L_t + U_t = 1 \tag{25}$$

Hence, the number of workers searching for work at the start of period t comprises of unemployed workers in period $t-1$, U_{t-1} or $1 - L_{t-1}$, and workers whose match with firms discontinued at the end of $t-1$, $(1-\rho_1)L_{t-1}$. The probability, f_t, that a period t job searching worker meets a final goods firm is given by

$$f_t = \frac{x_{1,t} L_{t-1}}{1 - \rho_1 L_{t-1}} \tag{26}$$

If a final goods firm decides in period t that it wants to meet a worker, then it must post a vacancy in period t at a cost, s_t. The firm then meets a worker in period t with probability Q_t. The firm must also pay a cost κ_t upon meeting a worker. Work begins in t as soon as a match is formed. Let J_t denote the value of a worker to the firm.

$$J_t = \Omega_t^p - W_t^p \tag{27}$$

where Ω_t^p is the present value of the marginal revenue product of the worker over the duration of firm worker match and W_t^p refers to the present value of wage earned while the match between worker and firm continues.

In recursive form,

$$\Omega_t^p = \Omega_t + \rho_1 E_t\{M_{t+1}\Omega_{t+1}^p\} \tag{28}$$

where Ω_t denotes the marginal revenue product of the worker in period t and derived as $\Omega_t = (1-\alpha)(1-\xi)\frac{Y_t}{L_t}$.

Similarly,

$$W_t^p = W_t + \rho_1 E_t\{M_{t+1}W_{t+1}^p\} \tag{29}$$

where W_t is determined through bargaining between worker and firm.

In equilibrium, the firm's cost of posting a vacancy, s_t, equals the firm's expected benefit of a vacancy (net of the firm's meeting cost κ_t):

$$s_t = Q_t\left(J_t - \kappa_t\right) \tag{30}$$

V_t^{work}, the value to a worker of a match with the firm at period t, is the sum of expected present value of wages earned over the duration of firm worker match, W_t^p, and the continuation value when the match terminates, A_t.

$$V_t^{work} = W_t^p + A_t \tag{31}$$

The recursive form of A_t is

$$A_t = (1-\rho_1)E_t\left\{M_{t+1}\left[f_{t+1}V_{t+1}^{work} + (1-f_{t+1})V_{t+1}^{unem}\right]\right\} + \rho_1 E_t\{M_{t+1}A_{t+1}\} \tag{32}$$

V_t^{unem} is the value to a worker of being unemployed and expressed as

$$V_t^{unem} = b_t + E_t\left\{M_{t+1}\left[f_{t+1}V_{t+1}^{work} + (1-f_{t+1})V_{t+1}^{unem}\right]\right\} \tag{33}$$

where b_t refers to the unemployment benefits.

The quantity of new hires in period t, $x_{1,t}L_{t-1}$, is a function of the number of job searching workers in period t, $1 - \rho_1 L_{t-1}$, and the number of vacancies posted by the firm in period t, $vac_t L_{t-1}$, based on the following matching function:

$$x_{1,t}L_{t-1} = \sigma_m (vac_t L_{t-1})^{1-\sigma_1}(1 - \rho_1 L_{t-1})^{\sigma_1},, \ \sigma_m > 0, \ 0 < \sigma_1 < 0 \tag{34}$$

where vac_t denotes vacancy rate. σ_1 and σ_m refer to the share of job searchers and level parameter, respectively.

The job finding rate for workers, f_t, and the vacancy filling rate, Q_t, are related to labor market tightness, Γ_t, where $\Gamma_t = \frac{vac_t L_{t-1}}{1-\rho_1 L_{t-1}}$, and expressed as:

$$f_t = \frac{x_{1,t}L_t}{1 - L_t} = \sigma_m \Gamma_t^{1-\sigma_1} \text{ and } \ Q_t = \frac{x_{1,t}L_t}{vac_t L_t} = \sigma_m \Gamma_t^{-\sigma_1} \tag{35}$$

Since a firm faces vacancy costs and hiring costs, the dividend specification changes from benchmark KS model Equation 9 to the following

$$D_t = Y_t - I_t - W_t L_t - \nu N_t X_t - (\frac{s_t}{Q_t} + \kappa_t) x_{1,t} L_{t-1} \tag{36}$$

The household budget constraint from Equation 16 now includes the unemployment benefit. Following Christiano et al. (2016), we assume that unemployment benefit b_t is provided by the government to an unemployed worker.

$$C_t + V_{m,t}\mathcal{Z}_{t+1} + B_{t+1} = W_t L_t + b_t(1 - L_t) + (V_{m,t} + \mathcal{D}_t)\mathcal{Z}_t + (1 + r_{f,t})B_t \tag{37}$$

Also, the market clearing condition Equation 19 changes to incorporate hiring costs and vacancy costs.

$$Y_t = C_t + I_t + N_t X_t + S_t + G_t + (\frac{s_t}{Q_t} + \kappa_t) x_{1,t} L_{t-1} \tag{38}$$

Based on the above search and matching labor market framework, we have two variants of wage bargaining: Nash wage bargaining framework and alternating offer wage bargaining (AOB) framework. The subsequent sections provide details of wage determination under both bargaining frameworks.

2.3.1 Wage determination: Nash Bargaining

Under Nash bargaining, the wage rate corresponds to the value of W_t which is determined by the following Nash sharing rule:

$$J_t = \frac{1 - \eta_{bargain}}{\eta_{bargain}} (V_t^{work} - V_t^{unem}) \tag{39}$$

where $\eta_{bargain}$ is the share of total surplus received by the worker.

2.3.2 Wage determination: Alternating Offer Bargaining

This section provides the details of alternating offer bargaining arrangements between firms and workers following Christiano et al. (2016). There are L_t matches determined at the start of period t. Bilateral bargaining on wage rate W_t occurs between every worker in L_t and the final goods firm. Bargaining in period t applies to only current wage rate W_t.

Periods $t = 1, 2....$ correspond to quarters. Workers and firm bargain over H subperiods within the period. H is assumed to be even. With regard to the timing of the bargaining over H subperiods, the firm makes a wage offer at the beginning of the first subperiod. In the next odd subperiod, the firm makes a wage offer in the event that previous wage offers are rejected. The worker also makes a wage offer at the beginning of an even subperiod if the previous wage offers are rejected. The recipient of the wage offer has the option to accept or reject the wage offer in subperiods $j = 1, ...H - 1$. The last (take-it-or-leave-it) offer in period H is made by the worker.

More specifically, suppose the firm makes a wage offer, $W_{j,t}$, in period $j < H$ (j is odd). The worker can accept the offer or reject it. If he accepts it, he can start working right away. If he rejects the offer, he can terminate bargaining or he can commit to come back next subperiod to make a counteroffer. If he terminates bargaining, the worker only has the outside option. If he commits to comeback to make a counter offer, δ_1 is the probability that negotiations break down and the worker and the firm revert to their outside options. The outside option is unemployment for the worker which he values at V_t^{unem}. However, the outside option has no value for the firm. With probability $1 - \delta_1$, the worker returns the next subperiod and makes a counter offer to the firm. The utility the worker receives by choosing to make a counter offer is called the disagreement payoff.

In subperiod j, the firm proposes the lowest possible wage offer, $W_{j,t}$, in which the worker will be indifferent between accepting and rejecting an offer. The wage offered by the firm satisfies

$$V_{j,t}^{wor} = max\left\{V_{j,t}^{unem}, \delta_1 V_{j,t}^{unem} + (1-\delta_1)\left[\frac{b_t}{H} + V_{j+1,t}^{wor}\right]\right\} \tag{40}$$

where $V_{j,t}^{wor}$ is the value to a worker of accepting wage offer $W_{j,t}$. The worker accepts the offer when he is indifferent between accepting and rejecting an offer. Using Equation 29 and Equation 31, we get the below function form of $V_{j,t}^{wor}$

$$V_{j,t}^{wor} = W_{j,t} + \tilde{W}_t^p + A_t \tag{41}$$

where $\tilde{W}_t^p \equiv \rho_1 E_t M_{t+1} W_{t+1}^p$, which denotes the present discounted value of the future wages expected by the firms-workers to continue during their match. Both $\tilde{W}_t^p$ and A_t are taken as given by the worker firm bargaining pair in period t.

Equation 40 shows a maximum among two options: the worker's outside option, $V_{j,t}^{unem}$ and worker's disagreement payoff. In practice, it is assumed that the latter is greater than the former. In the disagreement payoff, the value of the outside option for the worker is $V_{j,t}^{unem}$ if negotiation break down. Using Equation 33, we can derive the function form of $V^{unem}_{j,t}$.

$$V^{unem}_{j,t} = \frac{H-j+1}{H} b_t + E_t \left\{ M_{t+1} \left[f_{t+1} V^{work}_{t+1} + (1 - f_{t+1}) V^{unem}_{t+1} \right] \right\} \tag{42}$$

Unemployment benefits, b_t, are received by the worker by a proportion to the subperiods that he is unemployed, $\frac{H-j+1}{H}$. The second term in the disagreement payoff corresponds to unemployment benefits $\frac{b}{H}$ in subperiod j if negotiation do not break down with probability $1 - \delta_1$. The worker makes a counter offer $W_{j+1,t}$ in period $j+1$ which he expects the firm to accept.

Next, we look at the wage offer made by the worker. Worker makes a wage offer in subperiod j where $j < H$ and j is even. The worker offers a wage as high as possible without triggering a rejection by the firm. The resulting wage $W_{j,t}$ satisfies the below indifference condition.

$$J_{j,t} = max \left\{ 0, \delta_1 \times 0 + (1 - \delta_1)[-\gamma^{cost}_t + J_{j+1,t}] \right\} \tag{43}$$

$J_{j,t}$ refers to the value to a firm of accepting wage offer $W_{j,t}$. Using Equation 27, Equation 28 and Equation 29, we get the below functional form of $J_{j,t}$.

$$J_{j,t} = \frac{H-j+1}{H} \Omega_t + \tilde{\Omega}^p_t - (W_{j,t} + \tilde{W}^p_t) \tag{44}$$

where $\frac{H-j+1}{H}$ refer to the assumption that a worker produces $\frac{1}{H}$ marginal revenue product every subperiod and $\tilde{\Omega}^p_t \equiv \rho_1 \{E_t M_{t+1} \Omega^p_{t+1}\}$

The right hand side of Equation 43 corresponds to the maximum of firm's outside option and its disagreement payoff. If the firm decides to make a counter offer (prefers disagreement payoff) in the next subperiod , δ_1 is the probability that negotiations breakdown and the firm is thrown to its outside option (which is simply zero). With probability $1 - \delta_1$, the firm gets to make a counteroffer $W_{j+1,t}$ at the start of the next subperiod and the firm expects this wage offer to be accepted by the worker. The cost of making a counter offer is $-\gamma^{cost}_t$. The final term in the disagreement payoff refers to the value from making a successful counteroffer, $J_{j+1,t}$. It is assumed that firm's disagreement payoff exceeds its outside option.

In the final subperiod H, worker makes the final wage offer. Worker offers the highest possible wage without causing the firm to reject the offer. From Equation 43, this leads to indifference condition

$$J_{H,t} = 0 \tag{45}$$

$J_{H,t}$ is equivalent to $J_{j,t}$ in Equation 44 for $j = H$.

To solve the alternating offer bargaining game, let us define $W^p_{j,t}$ as

$$W^p_{j,t} \equiv W_{j,t} + \tilde{W}^p_t \text{ for } j = 1, ...H \tag{46}$$

where $W_{j,t}$ is the wage offered by the worker in subperiod j to the firm without causing the firm to reject the offer and $\tilde{W}_t^p$ is the present discounted value of the future wages while the match endures (as described earlier in Equation 40).

Substituting $W_{j,t}^p$ for $j = H$ (from Equation 46) and Equation 45 into Equation 44, we get the below solution for $W_{H,t}^p$

$$W_{H,t}^p = \frac{\Omega_t}{H} + \tilde{\Omega}_t^p \tag{47}$$

As described previously, the final subperiod H wage offer came from the worker. To determine $W_{H-1,t}^p$, it is important to note that firm makes the wage offer in subperiod $H-1$. Hence, $W_{H-1,t}^p$ can be solved using the worker's indifference condition in Equation 43. In line with the sequential order of bargaining, worker makes the wage offer in subperiod $H-2$. Hence, $W_{H-2,t}^p$ can be solved using the firm's decision on wage offer in Equation 40. Thus, we can solve for all sub periods to get unique values of

$$W_{1,t}^p, W_{2,t}^p, W_{3,t}^p, \cdots, W_{H,t}^p \tag{48}$$

With the assumptions of no mistakes in bargaining and of perfect information, the solution to the bargaining problem W_t^p is the offer in subperiod 1, $W_{1,t}^p$. Using the appendix of Christiano et al. (2016), we derive the below solution for W_t^p

$$W_t^p = \frac{1}{\beta_1 + \beta_2}\left[\beta_1 \Omega_t^p + \beta_2 (V_t^{unem} - A_t) + \beta_3 \gamma_t^{cost} - \beta_4(\Omega_t - b_t)\right] \tag{49}$$

where
$\beta_1 = 1 - \delta_1 + (1-\delta_1)^H$,
$\beta_2 = 1 - (1-\delta_1)^H$,
$\beta_3 = \beta_2 \frac{1-\delta_1}{\delta_1} - \beta_1$,
$\beta_4 = \frac{1-\delta_1}{2-\delta_1}\frac{\beta_2}{H} + 1 - \beta_2$.

By re-arranging the terms in Equation 49 and using Equation 27, Equation 31, we get the below alternating offer bargaining sharing rule that determines wage W_t:

$$J_t = \frac{\beta_2}{\beta_1}(V_t^{work} - V_t^{unem}) - \frac{\beta_3}{\beta_2}\gamma_t^{cost} + \frac{\beta_4}{\beta_3}(\Omega_t - b_t) \tag{50}$$

3 Calibration

Parameter values used to estimate the above models are presented in Panel A, Panel B and Panel C of Table 1. Panel A shows the benchmark KS model parameters calibrated following Kung and Schmid (2015). These parameters are common across all labor market specifications except for the R&D productivity parameter, χ, which is slightly adjusted to obtain identical consumption growth rates across models. Panel B shows the parameters pertaining to the wage rigidity framework following Uhlig (2007). The labor elasticity parameter, τ, is derived from the condition that household works 0.945 of its time endowment in the deterministic steady state. The wage rigidity parameter, μ, is equal to be 0.5.

Panel C of Table 1 reports the parameter values of both Nash bargaining and AOB framework used in Christiano et al. (2016). The probability that negotiations break down after an offer is rejected, δ_1, is set to 0.05%. The match survival rate, ρ_1, is set to be 0.9 and the share of job searchers in the labor matching function, σ_1, is set as 0.5. These values correspond to the calibration in Christiano et al. (2016). The derivations of remaining model parameters such as hiring costs κ, vacancy cost s, cost of making a counter offer γ_1, bargaining weight of worker $\eta_{bargain}$, level parameter in matching function σ_m and unemployment benefit b are implied by the steady state properties given by Christiano et al. (2016). The first property is a value of 1 percent for the steady state ratio of hiring costs to gross output. The second property assumes the steady state ratio of vacancy costs to gross output to be around 1 percent. Based on Christiano et al. (2016), we also give empirically plausible values of 0.055 and 0.7 to unemployment rate (U_t) and vacancy filling rate (Q_t), respectively at steady state. Finally, we also assume that unemployment benefit wage ratio at the steady state equal 0.1. The number of business days, H, in a quarter is assumed to be 60.

Using the parameters and implied steady state values, we solve the model using Dynare 4.6.1. Moments are obtained from 3000 simulations of 58 years at quarterly frequency, time-aggregated to annual frequency.

4 Results

4.1 Labor Market Dynamics

Figure 1 shows that impulse responses of labor and of wages to a productivity shock vary across models. In the benchmark KS model, labor is normalized to one since it is always fully utilized by households. Hence, labor does not respond to a shock. In the model with endogenous labor and assumed wage rigidity, labor has a initial upward response to a productivity shock. This is due to households' willingness to supply more labor with the increase in optimal wages and the eventual increase in their actual wages. Hence, households could fully exploit the increase in productivity. In the search and matching models of Nash bargaining and AOB labor market models, the responses of labor to the productivity shock are large in the Nash model and even more so in the AOB model. As expected, wage responds the most to a productivity shock in the frictionless benchmark KS model. After 20 quarters, the drop in the wage is larger in the wage rigidity model and the Nash bargaining model than in the KS model. The wage responds to a productivity shock the least in the AOB model. The different responses of labor and wage in the Nash bargaining and AOB models are explained below using Figure 2.

Figure 2 shows responses of unemployment, job vacancies, job finding rate, probability of meeting a new worker and new hires to a productivity shock for Nash bargaining and AOB models–whereby the Nash bargaining model shows more muted responses compared with the AOB model. There are no impulse responses associated with vacancy, unemployment and job finding rates in the benchmark KS model since labor is normalized as one. The same applies to the wage rigidity model as the sum of labor–defined as hours of work–and leisure is equal to one.

The weak effects of a productivity shock on unemployment, vacancies and job finding rate in the Nash bargaining model are closely related to the Shimer (2005) critique of the conventional search and matching models as in Diamond (1982), Mortensen (1982) and Pissarides (1985) (DMP). Nash bargained wage is a weighted average of the worker's productivity on the job and the value of unemployment. That latter value, in turn, depends in large part on the wages offered in other jobs. If a positive productivity shock increases every employer's reservation wage by one unit, then on average, both terms increase by almost equal amounts. If both changed by almost the same amount, then the employer's recruiting effort would be unchanged and unemployment would not fluctuate by much. However, the offer bargained wage no longer depends on the procyclical outside options but instead on the a-cyclical disagreement payoffs. This affects the recruiting effort of employer and unemployment fluctuates drastically in the AOB framework. Hence, Figure 2 shows that the AOB model gives rise to a sharp decrease in the unemployment rate together with a large increase in job vacancies and the job finding rate. Therefore, the Shimer (2005) critique does not apply to the AOB model.

Table 2 reports the aggregate labor market moments from the data and from stochastic simulation of the Nash bargaining and AOB models. We can see from Table 2 that AOB in the search and matching framework produces volatility statistics closer to the data than Nash bargaining. The AOB model also accounts for the unconditional correlations between these variables. The results of Table 2 make it evident that AOB does better in accounting for the cyclical properties of key labor market variables than the other models.[7]

4.2 Aggregate Quantity Dynamics

Figure 3 shows the impulse responses of consumption, investment, intermediate goods and output to a positive productivity shock in the benchmark KS, the wage rigidity, Nash bargaining and the AOB models. The figure shows that consumption volatility is highest in the AOB model followed by the wage-rigidity model, then the Nash bargaining model and the least in the benchmark KS model. Households' consumption rises the most in the AOB as it uses the larger response of labor (as shown in Figure 1) in response to a positive productivity shock. More labor translate to higher earnings so households increase consumption. The response of consumption is second highest in the wage-rigidity-with- endogenous-labor-supply model in response to a productivity shock. This could be attributed to the positive response of dividend immediately following the productivity shock in the wage-rigidity model (see Figure 4). Earnings from dividend enables households to consume more. Dividend responses in the benchmark KS, the wage rigidity, Nash bargaining and the AOB models would be discussed further in subsection 4.3.

The impulse responses of investment, intermediate goods and output to a positive productivity shock are also shown in Figure 3. The figure shows the response of investment is large

[7] Christiano et al. (2013) report higher volatilities for the Nash bargaining and AOB framework but unlike the benchmark KS model, their model has Calvo-type price rigidities.

and more sustained in the benchmark KS model (although initially trailed by AOB model). This is expected as investment drives the value of the firm in the benchmark KS model, with no emphasis on labor dynamics. When compared to labor models under consideration, the performance of AOB model in capturing both the volatility of labor and investment is evident from Figure 1 and Figure 3. The responses of intermediate goods and output continue to be largest in AOB model followed by nash bargaining model, then the wage rigidity model and finally the benchmark KS model.

The findings of the impulse responses are confirmed in moments generated by the models vis-á-vis the moments of data as shown in Table 3. The table shows the moments of the changes in consumption and output are closest to the moments of the data in the AOB framework compared with the benchmark KS, the wage rigidity and the Nash bargaining models. In contrast, the moment in the change in investment is slightly larger and closer to the moment in the data in the benchmark KS model than in the wage-rigidity, Nash bargaining and AOB models. The correlations among the moments of the variables in the four models have the same signs as the correlations, albeit larger, than suggested in the moments of the data.

4.3 Asset Pricing Implications

A main shortcoming of the standard production based asset pricing models is the inability to capture the cyclical behavior of dividend (Kung and Schmid (2015), Favilukis and Lin (2016)). In standard models, dividend equals output minus investment minus labor cost. Since wages are perfectly correlated to output and investment is procyclical, dividend is countercyclical in standard models. Figure 4 shows this criticism to hold in the benchmark KS model as dividend turns out to be counter cyclical. The same definition of dividend is used when wage rigidity is assumed in the KS model. However, dividend becomes procyclical on account of wages being rigid and smoother than the marginal product of labor and output. In fact, the immediate response of dividend following a positive productivity shock is largest in the wage rigidity model followed by AOB model and then by Nash bargaining model. The reason can be pinned down to the definition of dividend which is different in the search and matching models (see Equation 36). The cost of new hires in search and matching models reduces the initial impact of wage inertia on dividends. The decline in the probability of meeting a new worker, Q_t and more new hires, $x_{1,t}L_{t-1}$ (see Figure 2) increases the cost of hiring - leading to an initial smaller positive response of dividend following a productivity shock. Among the search and matching models, the dividend of the AOB model is more responsive than Nash bargaining model on account of larger wage inertia in AOB model.

Figure 4 also shows a steep drop in dividend of the wage rigidity model in quarter 2. This steep drop in dividend is caused by the steep drop in labor in the wage rigidity model (see Figure 1). In contrast, the dividends of the search and matching models are humped shaped in which the dividends continue to rise in quarter 2 (more so in AOB model than Nash bargaining model) before gradually declining. The procyclical behavior of dividends in the search and matching models is confirmed in Table 4 since it shows the correlations of dividend and output are positive and broadly consistent with the moments of the data. In contrast, the correlation of the dividend and output is negative in the benchmark KS model. Also among to four models, the AOB model shows the closest values in the moments of the change in dividend, and the moment of dividend over moment of output compared with the corresponding values in the data.

Table 5 shows marginal improvement in the the asset pricing moments after labor market model is incorporated in the benchmark KS model. The equity premium moment under AOB model is very close to its data counterpart. This can be explained using the long run risk component of the benchmark model. Kung and Schmid (2015) describe how agent's fear about periods of economic downturn and the associated low valuation of assets cause the agent to demand a higher equity premium.

There are two points to the search and matching model associated with long run risk that makes the equity premium closer to the data. The first point is with respect to the presence of unemployment in the model. Periods of economic downturn are associated with relatively higher levels of unemployment. Hence, the agent may fear being unemployed and receiving unemployment benefits instead of wages. Since wages are not perfectly correlated with output, wages are relatively higher than unemployment benefits during periods of economic downturn. The fear of cashflow risk may force the agent to command a higher equity premium under the search and matching market model. The second point considers the cyclical behavior of dividends and the performance of AOB model. In the benchmark KS model, the agent's cashflow associated with dividend is counter cyclical. In the AOB model, the highly procyclical dividend causes agent's dividend to decline during periods of economic downturn. With long run risk and the agent's preference for consumption smoothing in the model, higher equity premium under AOB can be associated with the agent's perceived fear of being limited to unemployment benefits and smaller dividend during economic downturn.

Table 5 shows an improvement in the volatility of risk premium in models with wage inertia but falls short of their empirical counterparts. As mentioned by Kung and Schmid (2015), this shortcoming could be due to the non-incorporation of short run risks, which may not be entirely productivity driven. However, Table 5 shows the mean of the risk free rate is worse in the AOB model than the benchmark KS model. This may be explained by the agents preference for saving to prepare for persistent low growth episodes in the AOB model. Agents tend to save more to smooth consumption during periods of low growth since dividends are procyclical in the AOB model compared to the benchmark KS model. The volatility of the risk free asset is also shown to improve in the presence of wage inertia with AOB model closest to the data.

5 Conclusion

We extend the Kung and Schmid (2015) with a search and matching labor market with Nash bargaining framework and alternating offer bargaining framework following Christiano et al. (2016). We also replicate Donadelli and Grüning (2016)'s extension of the Kung and Schmid (2015) to include wage rigidities as in Uhlig (2007). Among the aforementioned labor market models, rent sharing rule based on alternating bargaining framework in a search and matching model framework captures the key asset pricing moments and aggregate macroeconomic quantities found empirically. We show the importance of incorporating labor market elements in production based asset pricing model.

Using the extended model, we highlight the labor market implications of long run risk which endogenously arise in the Kung and Schmid (2015) model. The long run risk channel which makes the agents fear about persistent economic downturn in the future is aggravated further with the unemployment that accompanies such downturns. As alternating offer bargaining framework is better able to replicate the responses of unemployment to productivity shock, this channel makes the cash flow risk (uncertainty over wage flow) of agents higher resulting in them commanding higher risk premia over assets held.

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Table 1: Parameters and steady state values

Parameter	Description	Value		Source
Panel A: Common parameters				
β	Subjective discount factor	0.9945		
ψ	Elasticity of intertemporal substitution	1.8		
γ	Risk aversion	10		
ξ	Patent share	0.5		
ν	Inverse markup	1.65		
α	Capital share	0.35		KS (2015)
ρ	Productivity shock persistence	0.99		
χ	R&D productivity parameter	0.345		
ϕ	Patent obsolescence rate	0.0375		
η	Elasticity of new patents with respect to R&D	0.83		
δ	Depreciation rate of capital stock	0.02		
ζ	Investment adjustment cost parameter	0.83		
Panel B: Wage rigidity				
χ	R&D productivity parameter	0.360		KS (2015) and authors' calculations
τ	Labor elasticity	0.0515		Authors' calculations
μ	Sticky wage parameter	0.5		Author's choice
Panel C: Search and matching				
Parameters		Nash	AOB	
χ	R&D productivity parameter	0.360	0.360	KS (2015) and authors' calculations
$100\delta_1$	Prob. of bargaining session break-up	-	0.05	Authors' choice
ρ_1	Job survival probability	0.9	0.9	CET (2016)
σ_1	Share of job searchers	0.5	0.5	CET (2016)
$\eta_{bargain}$	Total surplus share received by workers	0.1	-	Hagedorn and Manovskii (2008)
κ	Hiring cost to meet a worker	0.0043	0.0453	CET (2016) and authors' calculations
γ^{cost}	Counteroffer costs	-	0.0013	CET (2016) and authors' calculations
b	Unemployment benefits	0.0106	0.0137	CET (2016) and authors' calculations
s	Vacancy cost	0.0453	0.0151	CET (2016) and authors' calculations
σ_m	Level parameter in matching function	0.6652	0.6652	CET (2016) and authors' calculations
H	No of days in a quarter	-	60	CET (2016)

Notes: The table reports the quarterly calibrations of the four models considered in this study. Panel A: KS benchmark model. Panel B: Wage rigidities following Uhlig (2007). Panel C: Search and matching model following Christiano et al. (2016). CET (2016) refers to Christiano et al. (2016). Authors' calculation refers to the calibration of the parameters based on the steady state assumptions of Christiano et al. (2016). The steady state assumptions are detailed in section 3.

Table 2: Labor Market Moments

Moments	Data	Benchmark KS	Wage rigidity	Nash Bargaining	AOB
$\sigma(u)$	13.00%	-	-	4.77%	5.20%
$\sigma(vac)$	14.00%	-	-	3.79%	6.42%
$\sigma(\frac{vac}{u})$	26.00%	-	-	8.12%	10.80%
$corr(u, vac)$	-0.860	-	-	-0.8072	-0.8068
$corr(u, vac/u)$	-0.960	-	-	-0.9659	-0.9657
$corr(vac, vac/u)$	0.98	-	-	0.9326	0.9326

Note: This table reports the aggregate labor market moments obtained from a stochastic simulations of the relevant models. Volatility moments are derived using third-order perturbations around the stochastic steady state in Dynare 4.6.1. Correlation moments are obtained using first-order perturbation around the stochastic steady state. The moments in the data column are from Christiano et al. (2013) for the period 1951–2008. The benchmark KS model and the wage rigidity model show no moments associated with vacancy and unemployment since the labor force is fixed at unity in KS benchmark model and the sum of labor (defined as hours of work) and leisure is equal to one in the wage rigidity model. Model (1): KS benchmark model. Model (2): Wage rigidities following Uhlig (2007). Model (3): Nash bargaining framework in search and matching labor model following Christiano et al. (2016) Model(4):Alternating offer bargaining framework in search and matching labor model following Christiano et al. (2016). All data are in log levels.

Table 3: Aggregate Moments

Moments	Data	Benchmark KS	Wage rigidity	Nash Bargaining	Alternating Offer Bargaining
$\sigma[\Delta c]$	1.95%	1.274%	1.494%	1.437%	1.509%
$\sigma[\Delta i]$	6.22%	2.595%	2.507%	2.375%	2.466%
$\sigma[\Delta y]$	3.24%	2.209%	2.328%	2.305%	2.365%
$\sigma[\Delta c]/\sigma[\Delta y]$	0.60	0.577	0.642	0.623	0.638
$\sigma[\Delta i]/\sigma[\Delta y]$	1.92	1.175	1.077	1.031	1.043
$corr(\Delta c, \Delta i)$	0.39	0.998	0.997	0.998	0.998
$corr(\Delta c, \Delta y)$	0.84	0.9986	0.999	0.999	0.998
$corr(\Delta i, \Delta y)$	0.670	0.9999	0.9996	1.000	1.000

Note: This table reports the aggregate quantity moments obtained from a stochastic simulation of the four models considered in this study. Volatility moments are derived using third-order perturbations around the stochastic steady state in Dynare 4.6.1. Correlation moments are obtained using first-order perturbation around the stochastic steady state. The moments in the data column are from Papanikolaou (2011) for the period 1951–2008. Model (1): KS benchmark model. Model (2): Wage rigidities following Uhlig (2007). Model (3): Nash bargaining framework in search and matching labor model following Christiano et al. (2016) Model(4):Alternating offer bargaining framework in search and matching labor model following Christiano et al. (2016). Variables considered are log consumption (c), log investment (i) and log output (y)

Table 4: Dividend and P/D ratio

Moments	Data	Benchmark KS	Wage rigidity	Nash Bargaining	Alternating Offer Bargaining
$\sigma[\Delta d]$	2.60%	1.108%	1.774%	1.745%	2.499%
$\sigma[p-d]$	41.54%	2.773%	6.441%	8.536%	7.964%
$\sigma[d]/\sigma[y]$	1.40	0.507	0.612	0.839	1.078
$corr(d, y)$	0.968	-0.999	0.766	0.821	0.858
$\sigma[\Delta d]/\sigma[\Delta y]$	2.62	0.501	0.885	0.757	1.057
$corr(\Delta d, \Delta y)$	0.42	-0.970	0.859	0.531	0.635

Note: This table reports the dividend and output ratio moments obtained from a stochastic simulation of the four models considered in this study. Volatility moments are derived using third-order perturbations around the stochastic steady state in Dynare 4.6.1. Correlation moments are obtained using first-order perturbation around the stochastic steady state. The moments in the data column except for P/D ratio are calculated from the data obtained from Federal Reserve Bank of St. Louis for the period 1953–2008. The volatility moment of P/D ratio in the data column is taken from Kung and Schmid (2015). Model (1): KS benchmark model. Model (2): Wage rigidities following Uhlig (2007). Model (3): Nash bargaining framework in search and matching labor model following Christiano et al. (2016) Model(4):Alternating offer bargaining framework in search and matching labor model following Christiano et al. (2016). Variables considered are log dividend (d) and log output (y)

Table 5: Asset Pricing Moments

Moments	Data	Benchmark KS	Wage rigidity	Nash Bargaining	Alternating Offer Bargaining
$E(r_d - r_f)$	4.89%	2.137%	3.228%	3.060%	4.92%
$\sigma(r_d - r_f)$	17.92%	3.489%	5.202%	4.368%	4.555%
$E(r_f)$	2.90%	1.405%	1.689%	1.563%	1.244%
$\sigma(r_f)$	3.00%	0.067%	0.063%	0.092%	0.106%

Note: This table reports the asset pricing 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 4.6.1. The moments in the data column are from Papanikolaou (2011) for the period 1951–2008. Model (1): benchmark KS model. Model (2): Wage rigidities following Uhlig (2007). Model (3): Nash bargaining framework in search and matching labor model following Christiano et al. (2016) Model(4):Alternating offer bargaining framework in search and matching labor model following Christiano et al. (2016).

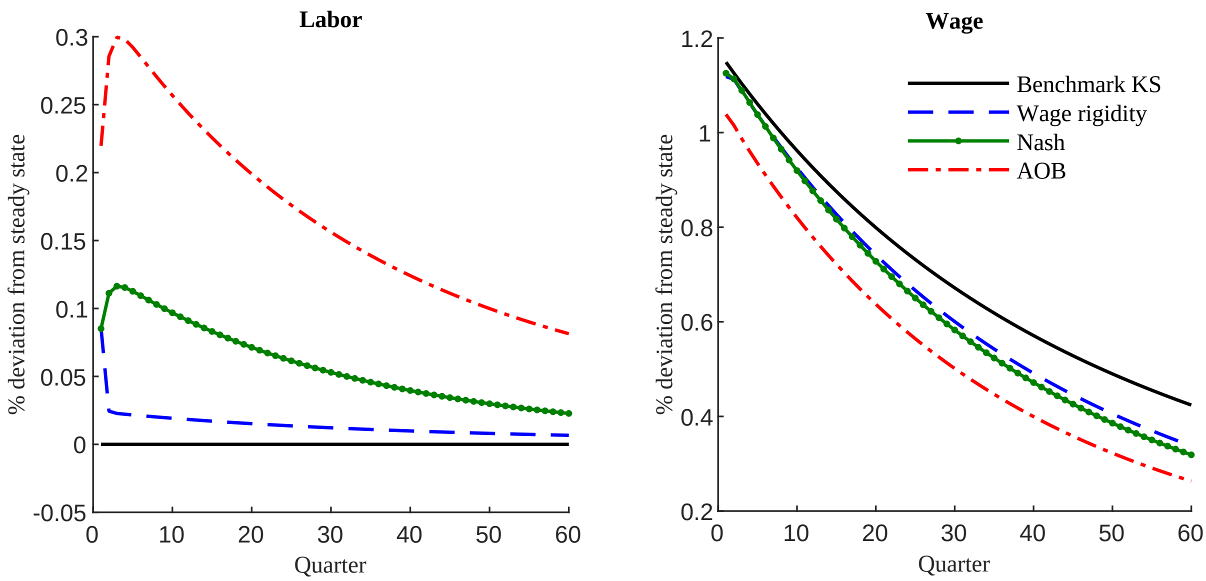

Figure 1: Response of labor (L_t) and wages (W_t) to a positive 1.75% productivity shock.

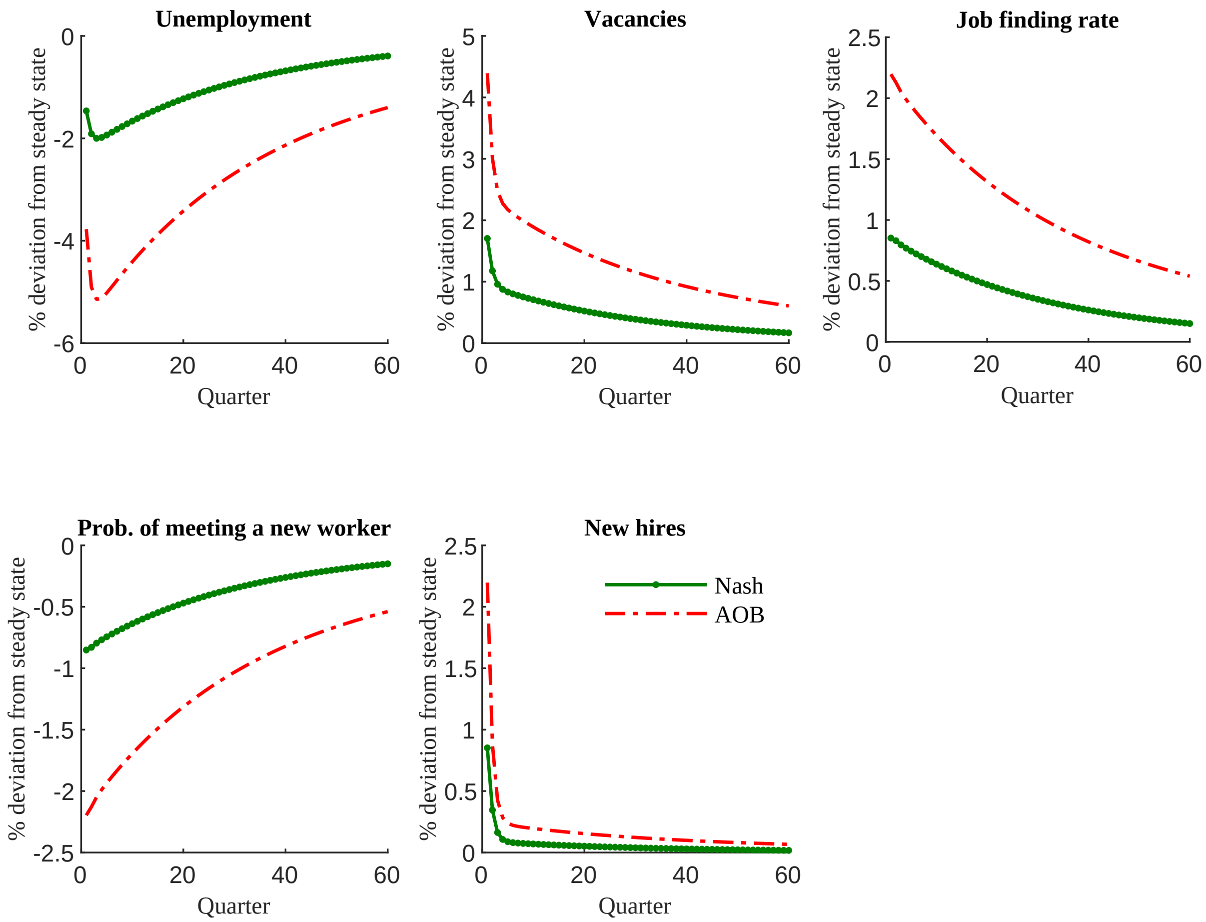

Figure 2: Response of unemployment (U_t), vacancies (Vac_tL_t) job finding rate (f_t), probability of meeting a new worker (Q_t) and new hires ($x_{1,t}L_{t-1}$) to a positive 1.75% productivity shock.

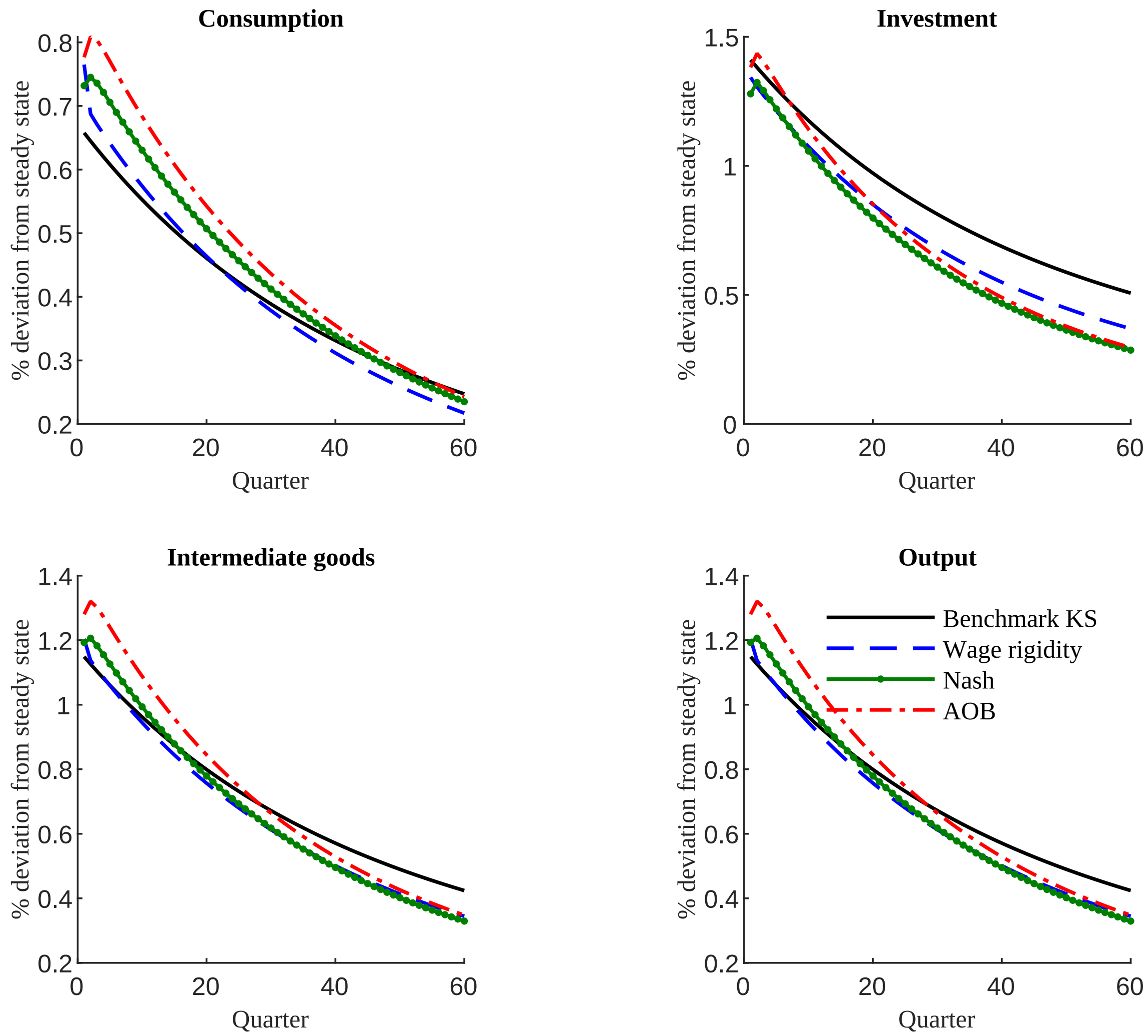

Figure 3: Response of consumption (C_t), investment (I_t), intermediate goods (X_t) and output (Y_t) to a positive 1.75% productivity shock.

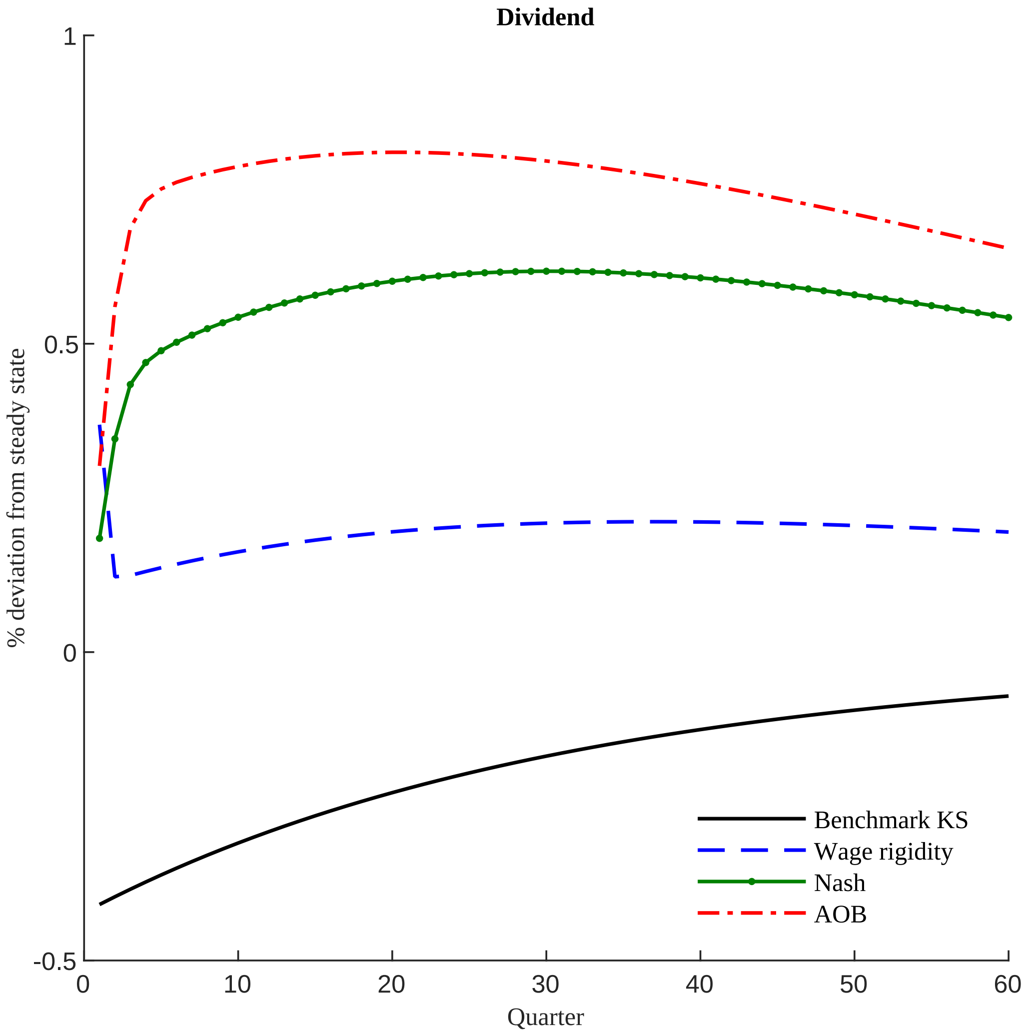

Figure 4: Response of dividend (D_t) to a positive 1.75% productivity shock.