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JOB TURNOVER, TREND GROWTH, AND THE LONG-RUN PHILLIPS CURVE

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The paper reexamines the long-run Phillips curve in a New Keynesian model with job turnover and trend productivity growth. We show that an increase in money growth has substantial positive effects on steady state output, consumption, and employment in the presence of (i) observed job turnover rates and, if consumption smoothing is sufficiently strong, (ii) observed productive growth rates. Furthermore, we show that the optimal inflation rate is slightly under 2% for reasonable calibrations of job turnover and trend growth.

Keywords: Trend Growth, Job Turnover, Nominal Inertia, Phillips Curve, Optimal Inflation

1. INTRODUCTION

The evidence concerning the long-run Phillips curve, which relates steady-state output to trend inflation, is mixed and heavily colored by theoretical preconceptions. Mankiw (2001) wrote that "if one does not approach the data with a prior favoring long-run neutrality, one would not leave the data with that posterior. The data's best guess is that monetary shocks leave permanent scars on the economy." It is well known that, in the context of the standard New Keynesian model featuring nominal price rigidity or wage rigidity [e.g., King and Wolman (1996), Ascari (1998, 2004), Graham and Snower (2004), Graham and Snower (2008), and Ascari and Rossi (2012)], monetary policy (modeled as changes in trend money growth or trend inflation) has nonlinear steady state effects on output, employment, and consumption.[1]

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This paper reexamines the long-run Phillips curve in the presence of job turnover and trend productivity growth. Both job turnover and trend productivity growth are important aspects of macroeconomic activity in practice that are commonly ignored in the literature on the long-run effects of monetary policy.[2] The literature on innovation-based growth suggests that the process of growth involves job turnover, in the sense that old jobs are replaced by new, more productive ones.[3] Our analysis shows that both job turnover and trend productivity growth exert a substantial expansionary influence on the effect of long-run money growth on real macroeconomic activity. In particular, we show that (i) the job turnover rate flattens the long-run Phillips curve (in the sense that a given increase in trend inflation is associated with a larger percentage increase in steady state output, consumption, and employment), (ii) trend productivity growth flattens the long-run Phillips curve if the consumption-smoothing motive is sufficiently strong, and (iii) job turnover reinforces the effect of trend productivity growth on consumption more than it does that on employment, and because of this, optimal steady state inflation is higher than it would be in the absence of job turnover.

The intuition underlying our analysis may be summarized as follows. In the presence of sticky wages and prices (which take the form of Rotemberg-type quadratic adjustment costs in this paper), permanent changes in money growth—or, equivalently, changes in the inflation target of the monetary authority—lead to permanent changes in real economic activity. Our analysis describes four rationales for this phenomenon, two minor and two potentially major: (i) discounting, (ii) Rotemberg adjustment costs, linking the size of the costs to the magnitude of the change, (iii) job turnover, and (iv) trend productivity growth.

The two minor rationales (in the sense of being either well-known or trivial) are discounting and Rotemberg nominal adjustment costs: (a) When agents have positive rates of time discounting, current wage and price adjustment costs receive more weight than future ones in determining current prices and wages. As is well known, the more myopic agents are, the more a permanent increase in inflation leads to a permanent increase in real macroeconomic activity (in terms of, say, production). However, because discount rates are low in practice (say, between two and seven percent), the resulting asymmetry is negligible for standard calibrations. (b) With Rotemberg nominal adjustment costs, the size of these costs depends on the magnitude of nominal adjustment. Thus, the higher the rate of inflation, the greater the nominal adjustment costs, which implies lower markups. The lower markups, in turn, imply greater adjustment of real macroeconomic activity. Thus a permanent increase in inflation leads to a permanent increase in real macroeconomic activity.

The first major rationale (which is neither well-known nor trivial) rests on an intertemporal weighting asymmetry arising from job turnover. The higher the rate of job turnover, the less likely it becomes that the future wage adjustment costs incurred by a particular labor type will be paid (because it is more likely that the worker has left her job before the adjustment costs materialize). Thus, when the current wage is set, a worker attaches greater weight to current wage adjustment

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costs than to future wage adjustment costs. The effect is a lower wage markup. The average monthly job separation rate in the United States has exceeded 3% for much of the past decade.[4] Because a 3% monthly rate corresponds to a 30.6% yearly rate, this is a much more powerful source of intertemporal weighting asymmetry than discounting.

The second major rationale rests on an intertemporal weighting asymmetry arising from trend productivity growth, which, along a balanced growth path, implies trend growth in nominal and real wages, aggregate consumption, and output. This has the following effects: (1) The real interest rate effect: Along a balanced growth path, higher productivity growth increases the real interest rate, the effect of which is larger the stronger the degree of consumption smoothing.[5] A higher real interest rate leads to a stronger discounting of future payoffs. (2) The wage adjustment cost effect: Along a balanced growth path, wage adjustment costs rise with aggregate output (i.e., the scale of economic activity). Higher output growth implies that future wage adjustment costs rise relative to present ones, inducing households to raise their wage markup. (3) The nominal wage growth effect: Along a balanced growth path, higher trend productivity growth implies higher current and future nominal wage growth. The former effect raises current wage adjustment costs and thus implies a lower wage markup, whereas the latter effect raises future wage adjustment costs and thus implies a higher wage markup.[6] The former effect dominates because of time discounting. To summarize, effects (1) and (3) generate a positive long-run tradeoff between inflation and macroeconomic activity, whereas effect (2) generates a negative long-run tradeoff. Effects (1) and (3) dominate effect (2), provided the elasticity of intertemporal substitution in consumption is sufficiently small (i.e., the degree of consumption smoothing is sufficiently high). In this case the rise in the real interest rate [for the reason set out under effect (1)], in the face of consumption growth, is sufficiently large so that the discounting of future payoffs is sufficiently strong. As a result, trend productivity growth leads to a positive long-run tradeoff. Analogous effects are at play on the part of firms, as trend productivity growth affects the price markup and price adjustment costs.

The discounting effects of job turnover and trend productivity growth mitigate the negative effect of trend inflation on macroeconomic activity by reducing the inefficiencies associated with wage adjustment costs. We show that, even for significantly positive inflation rates, increases in money growth lead to increases in real macroeconomic activity.

The paper is organized as follows. In Section 2 we extend the standard New Keynesian model with nominal wage and price rigidities to allow for trend growth and job turnover. Then in Section 3 we discuss the model's balanced growth path and the long-run Phillips curve and give the intuition behind our numerical analysis presented in Section 4, which also covers some sensitivity analysis. In Section 5 we present results on the model's implications for the optimal steady state inflation rate. Section 6 concludes.

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2. THE MODEL

Our analysis builds on standard conceptual building blocks of the New Keynesian model: (i) general equilibrium with microfoundations based on intertemporal optimization, (ii) rational expectations, (iii) imperfect competition, and (iv) nominal rigidities. We extend this model by including exogenous trend productivity growth (henceforth, trend growth) and exogenous job turnover.

The model allows for nonseparable utility, in a way that is consistent with recent empirical evidence on the consumption Euler equation [see, e.g., Basu and Kimball (2002) and Guerron-Quintana (2008)], in which parameter restrictions are imposed consistent with balanced growth facts. Such evidence has motivated recent theoretical work on the government spending multiplier [see, e.g., Monacelli and Perotti (2009), Bilbiie (2011), and Tesfaselassie (2013)]. For simplicity, we assume labor to be the only input in the production function, and monetary policy is characterized by a choice of the inflation target, which in turn pins down the level of steady state inflation.[7] The model has the property that, along the balanced growth path, employment is constant, whereas the other macroeconomic variables (aggregate output, consumption, and real wages) grow at the same rate as productivity.

2.1. Households

There is a representative household with a continuum of members over the unit interval. As in Schmitt-Grohe and Uribe (2006), consumption and hours worked are identical across members.

The household cares about aggregate consumption C_t and hours worked N_t. We use a functional form of the utility function, which is consistent with balanced growth [as first pointed out by King et al. (1988a,b)]:

$$U(C_t, N_t) = \frac{[C_t^{\alpha}(1 - N_t)^{1-\alpha}]^{1-\sigma}}{1 - \sigma}, \tag{1}$$

where the parameter $\alpha(1 - \sigma)$ controls the degree of consumption smoothing and $\sigma > 0$ the degree of nonseparability between consumption and leisure.[8] This utility function encompasses the log-separable utility as a special case [see, e.g., Guerron-Quintana (2008) and references therein]. The parameter α determines the weight of consumption relative to hours worked in the utility function and $0 < \alpha < 1$.

There is a continuum of labor markets of measure one, each indexed by j. In each labor market j, wages are set by a monopolistically competitive household, as in Schmitt-Grohe and Uribe (2006). Along the same lines as in the literature on search and matching with exogenous separation rates in the labor market [e.g., Pissarides (2000)], we assume that, in each period of analysis, an exogenous fraction of workers leave their jobs.[9] In contrast to this literature, however, we assume that employment is determined by firms' labor demands, which are derived from profit maximization (along the lines explained later). Consequently, all workers

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who separate from their jobs are replaced by new hires during each period of analysis.[10] We choose to model employment in this way, because our analysis is meant to include job turnover in an otherwise standard dynamic stochastic general equilibrium model.[11]

We assume that each labor market type faces an exogenous probability of exit δ. Furthermore, we assume deterministic growth in labor productivity A_t, where Γ is gross productivity growth and $\gamma = \Gamma - 1$ is the growth rate. Let $\Pi_w = 1 + \pi_w$ and $\Pi_p = 1 + \pi_p$ denote, respectively, gross trend wage inflation and gross trend price inflation. Along a balanced growth path, aggregate real wage grows at the same rate as productivity (i.e., $\Gamma > 1$), implying that $\Pi_w = \Gamma \Pi_p$.

We introduce nominal wage and price rigidity by assuming quadratic adjustment costs of wage–price changes.[12] The wage adjustment cost is given by

$$c_{w,j,t} = \frac{\kappa_w}{2} \left(\frac{W_t^j}{W_{t-1}^j \Pi_w^{\varphi_w}} - 1 \right)^2 Y_t, \tag{2}$$

where $c_{w,j}$ denotes wage adjustment costs of labor type j, $\kappa_w \geq 0$ controls the strength of wage adjustment costs, Y_t is aggregate output, W_t^j is the nominal wage of labor type j, and $0 \leq \varphi_w \leq 1$ controls the degree of wage indexation.

As is standard practice [see, e.g., Chugh (2006), Bilbiie et al. (2007), and Ireland (2011)] the adjustment costs are expressed in terms of the bundle of differentiated goods and may be interpreted as the amount of marketing materials that the household must purchase when implementing a wage change. The fact that wage adjustment costs increase with the magnitude of wage changes reflects reputational damage from wage changes. This is in the spirit of Rotemberg (1982). For convenience the basket is assumed to have the same composition as the household's consumption basket (defined in the following). The specification of the wage adjustment costs ensures that along the balanced growth path the wage adjustment cost grows at the same rate as output.[13]

The household faces labor demand in market j,

$$N_t^j = \left(\frac{W_t^j}{W_t} \right)^{-\theta_w} N_{d,t}, \tag{3}$$

where W_t is the corresponding wage index, given by

$$W_t = \left[\int_0^1 W_t^{j(1-\theta_w)} dj \right]^{\frac{1}{1-\theta_w}}, \tag{4}$$

and $N_{d,t}$ is the aggregate labor demand (the derivation of which is given in Section 2.2).

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The household consumes a continuum of differentiated goods on the unit interval, which are transformed into a Dixit–Stiglitz composite good C_t as follows:

$$C_t = \left(\int_0^1 C_{k,t}^{1/\mu_p} dk \right)^{\mu_p}, \tag{5}$$

where each good is indexed by k, $\mu_p \equiv \frac{\theta_p}{\theta_p - 1}$, and θ_p is the elasticity of substitution between any two differentiated goods. We first solve for the household's consumption allocation across all goods for a given level of C_t. Minimizing total expenditure $\int_0^1 P_{k,t} C_{k,t} dk$ subject to (5) gives the consumption demand for each good k,

$$C_{k,t} = \left(\frac{P_{k,t}}{P_t} \right)^{-\theta_p} C_t, \tag{6}$$

where P_t is the price index (or the price level), which is defined as

$$P_t = \left(\int_0^1 P_{k,t}^{1-\theta_p} dk \right)^{\frac{1}{1-\theta_p}}. \tag{7}$$

Next we derive the optimal decisions regarding the paths of C_t, N_t, and W_t^j. The household maximizes the expected discounted lifetime utility $E_t \sum_{i=0}^{\infty} \beta^i U(C_{t+i}, N_{t+i})$ subject to the budget constraint

$$\begin{aligned} C_t + \frac{B_t}{P_t} &= N_{d,t} \int_0^1 \frac{W_t^j}{P_t} \left(\frac{W_t^j}{W_t} \right)^{-\theta_w} dj + R_{t-1} \frac{B_{t-1}}{P_t} + \frac{D_t}{P_t} - \int_0^1 c_{w,j,t} dj \\ &= N_{d,t} \int_0^1 \frac{W_t^j}{P_t} \left(\frac{W_t^j}{W_t} \right)^{-\theta_w} dj + \frac{R_{t-1} B_{t-1}}{P_t} + \frac{D_t}{P_t} \\ &\quad - \int_0^1 \frac{\kappa_w}{2} \left(\frac{W_t^j}{W_{t-1}^j \Pi_w^{\varphi_w}} - 1 \right)^2 Y_t dj \end{aligned} \tag{8}$$

and the resource constraint

$$\begin{aligned} N_t &= \int_0^1 N_t^j dj \\ &= N_{d,t} \int_0^1 \left(\frac{W_t^j}{W_t} \right)^{-\theta_w} dj, \end{aligned} \tag{9}$$

where we have substituted out N_t^j using equation (3). The sum of each labor type's wage adjustment costs reduces the resources available for consumption and bond purchases. Here, β is the discount factor, R_t is the gross nominal interest rate on per capita bond holdings B_t, and D_t is the per capita nominal profit income from all firms.

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In each period, the household sets the wage in each labor market type. In setting the wage of a new market, we impose symmetry across markets and interpret the term W_{t-1}^{j} in the wage adjustment cost as the "notional wage" that would have been set in period $t-1$ if the new market had been in existence in period $t-1$ [see Bilbiie et al. (2007) for a similar interpretation in the case of firm entry and exit].

Let λ_t^c and λ_t^n be the Lagrange multipliers associated with the period-t budget constraint (8) and the resource constraint (9), respectively. The first-order conditions with respect to C_t, N_t, and B_t are, respectively, $U_{C,t} = -\lambda_t^c$, $U_{N,t} = -\lambda_t^n$, and

$$1 = \beta R_t E_t \left(\frac{\lambda_{t+1}^c P_t}{\lambda_t^c P_{t+1}} \right). \tag{10}$$

Using the first-order condition with respect to C_t in equation (10) gives the consumption Euler equation,

$$1 = R_t E_t \left(\frac{Q_{t,t+1}}{\Pi_{t+1}} \right), \tag{11}$$

where $Q_{t,t+1} \equiv \beta U_{C,t+1}/U_{C,t}$ is the stochastic discount factor and $U_{C,t} = \alpha C_t^{\alpha(1-\sigma)-1}(1-N_t)^{(1-\alpha)(1-\sigma)}$. Note here that the stochastic discount factor depends negatively on trend consumption growth if $\alpha(1-\sigma)-1<0$ (or $\sigma > 1-1/\alpha$). Along the balanced growth path with constant consumption growth and constant employment, equation (11) becomes

$$\frac{R}{\Pi_p} = \beta^{-1}\Gamma_C^{\alpha(\sigma-1)+1}, \tag{12}$$

where Γ_C is trend consumption growth. Thus, along the balanced growth path, the real interest rate increases with consumption growth (the relationship is stronger the stronger the consumption smoothing motive). Next, the first-order condition with respect to W_t^j gives

$$\begin{aligned}(\theta_w - 1)\frac{W_t}{P_t} &= \theta_w \frac{(1-\alpha)C_t}{\alpha(1-N_t)} - \kappa_w \left(\frac{\Pi_{w,t}}{\Pi_w^{\varphi_w}} - 1 \right) \frac{\Pi_{w,t}}{\Pi_w^{\varphi_w}} \frac{Y_t}{N_{d,t}} \\ &+ \kappa_w(1-\delta)E_t \left[Q_{t,t+1} \left(\frac{\Pi_{w,t+1}}{\Pi_w^{\varphi_w}} - 1 \right) \frac{\Pi_{w,t+1}}{\Pi_w^{\varphi_w}} \frac{Y_{t+1}}{N_{d,t}} \right],\end{aligned} \tag{13}$$

where in deriving equation (13) we imposed symmetry across labor types and used $U_{C,t}$ and $U_{N,t} = -(1-\alpha)C_t^{\alpha(1-\sigma)}(1-N_t)^{(1-\alpha)(1-\sigma)-1}$ to eliminate the Lagrangian multipliers. Note that job turnover, as modeled in this paper, implies the presence of the term $1-\delta$ in equation (13). Because $1-\delta$ is the probability that a labor market type does not separate in period $t+1$, job turnover ultimately implies a higher discount rate in wage setting.

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Detrending equation (13) (i.e., dividing it through by A_t) leads to[14]

$$(\theta_w - 1)\phi_t = \theta_w \frac{(1-\alpha)c_t}{\alpha(1-N_t)} - \kappa_w \left(\frac{\Pi_{w,t}}{\Pi_w^{\varphi_w}} - 1 \right) \frac{\Pi_{w,t}}{\Pi_w^{\varphi_w}} + \kappa_w (1-\delta) E_t \left[Q_{t,t+1} \left(\frac{\Pi_{w,t+1}}{\Pi_w^{\varphi_w}} - 1 \right) \frac{\Pi_{w,t+1}}{\Pi_w^{\varphi_w}} \frac{Y_{t+1}}{Y_t} \right], \tag{14}$$

where $c_t \equiv C_t/A_t$ and $\phi_t \equiv W_t/(A_t P_t)$. The steady state of equation (14) is

$$(\theta_w - 1)\phi = \theta_w \frac{(1-\alpha)c}{\alpha(1-N)} - \kappa_w \left[1 - \beta(1-\delta)\Gamma_C^{\alpha(1-\sigma)-1}\Gamma_Y \right] \left(\Pi_w^{1-\varphi_w} - 1 \right) \Pi_w^{1-\varphi_w}, \tag{15}$$

where Γ_Y is trend output growth.

Equation (15) shows that, because of wage adjustment costs, the average wage markup differs from the level, $\theta_w/(\theta_w - 1)$, that would have obtained in the absence of wage adjustment costs ($\kappa_w = 0$). Higher job turnover δ implies stronger discounting of future wage adjustment costs, and this leads to a lower wage markup. Moreover, trend growth matters through its effects on Γ_C, Γ_Y, and Π_w. First, an increase in Γ_C implies an increase in the real interest rate and a stronger discounting of future wage adjustment costs, and this leads to a lower wage markup. Second, Γ_Y increases future relative to present wage adjustment costs and this leads to a higher wage markup. Finally, an increase in Π_w increases both current-period wage adjustment costs (which in turn decrease the wage markup) and future-period wage adjustment costs (which in turn increase the wage markup). Because of the presence of time discounting, the first effect dominates.

2.2. Firms

There is a continuum of monopolistically competitive firms over the unit interval. Firm k's production function is given by $Y_{k,t} = A_t N_{k,t}$, where $N_{k,t}$ is a composite made of a continuum of differentiated labor services,

$$N_{k,t} = \left(\int_0^1 N_{k,t}^{j\frac{1}{\mu_w}} dj \right)^{\mu_w}, \tag{16}$$

where $\mu_w = \theta_w/(\theta_w - 1)$, with θ_w being the elasticity of substitution between any two different labor types. Minimizing firm k 's total wage bill $\int_0^1 W_t^j N_{k,t}^j dj$ subject to equation (16) leads to the labor demand for type j,

$$N_{k,t}^j = \left(\frac{W_t^j}{W_t} \right)^{-\theta_w} N_{k,t}. \tag{17}$$

Aggregating (17) across firms, we get the labor demand for labor type j, namely (3), where $N_{d,t} = \int_0^1 N_{k,t} dk$, and the aggregate wage index is given by (4).

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The pricing decision of firm k is subject to quadratic price adjustment costs, $c_{p,k,t}$,

$$c_{p,k,t} = \frac{\kappa_p}{2}\left(\frac{P_{k,t+i}}{P_{k,t+i-1}\Pi_p^{\varphi_p}} - 1\right)^2 Y_{t+i}, \tag{18}$$

where $\kappa_p \geq 0$ controls the strength of price adjustment costs and $0 < \varphi_p < 1$ controls the degree of price indexation. Note that equation (18) is analogous to equation (2), which defines wage adjustment costs.

Firm k maximizes the expected lifetime profit,

$$E_t \sum_{i=0}^{\infty} Q_{t,t+i}\left[\left(\frac{P_{k,t+i}}{P_{t+i}} - \phi_{t+i}\right) Y_{k,t+i} - c_{p,k,t+i}\right], \tag{19}$$

where ϕ_t is the real marginal cost. The demand for good k comes from consumption demand (6) as well as demand from households adjusting their wages and firms adjusting their prices,

$$Y_{k,t} = \left(\frac{P_{k,t}}{P_t}\right)^{-\theta_p} Y_t, \tag{20}$$

where $Y_t = C_t + \mathrm{AC}_t$ and

$$\mathrm{AC}_t = \left[\frac{\kappa_p}{2}\left(\frac{\Pi_{p,t}}{\Pi_p^{\varphi_p}} - 1\right)^2 + \frac{\kappa_w}{2}\left(\frac{\Pi_{w,t}}{\Pi_w^{\varphi_w}} - 1\right)^2\right] Y_t \tag{21}$$

is the aggregate resource cost due to price and wage changes.

Substituting the price adjustment cost (18) and the demand function (20) into the profit function (19), differentiating with respect to $P_{k,t}$, and imposing symmetry across firms leads to

$$\begin{aligned}\theta_p - 1 = {} & \theta_p \phi_t - \kappa_p\left(\frac{\Pi_{p,t}}{\Pi_p^{\varphi_p}} - 1\right)\frac{\Pi_{p,t}}{\Pi_p^{\varphi_p}} \\ & + \kappa_p \beta E_t\left[Q_{t,t+1}\frac{Y_{t+1}}{Y_t}\left(\frac{\Pi_{p,t+1}}{\Pi_p^{\varphi_p}} - 1\right)\frac{\Pi_{p,t+1}}{\Pi_p^{\varphi_p}}\right],\end{aligned} \tag{22}$$

which is written in detrended form. The aggregate resource constraint relating consumption and output [taking note of (21) and detrending] is given by

$$c_t = \left[1 - \frac{\kappa_p}{2}\left(\frac{\Pi_{p,t}}{\Pi_p^{\varphi_p}} - 1\right)^2 - \frac{\kappa_w}{2}\left(\frac{\Pi_{w,t}}{\Pi_w^{\varphi_w}} - 1\right)^2\right] y_t, \tag{23}$$

where $y_t \equiv Y_t / A_t$. The steady state of equation (23) is

$$c = \left[1 - \frac{\kappa_p}{2}\left(\Pi_p^{1-\varphi_p} - 1\right)^2 - \frac{\kappa_w}{2}\left(\Pi_w^{1-\varphi_w} - 1\right)^2\right] y. \tag{24}$$

An increase in Π_p or Π_w decreases steady state consumption for a given level of output. Finally, from the aggregate production function, $y_t = N_t$.

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3. STEADY-STATE GROWTH

Along the steady-state growth path, $\Gamma_C = \Gamma_Y = \Gamma$ and $\Pi_w = \Gamma\Pi_p$ so that equation (15) can be simplified to

$$\phi - \mu_w \frac{(1-\alpha)c}{\alpha(1-N)} = -(\theta_w - 1)^{-1}\kappa_w \left(1 - \beta(1-\delta)\Gamma^{\alpha(1-\sigma)}\right) \times \left[(\Gamma\Pi_p)^{1-\varphi_w} - 1\right](\Gamma\Pi_p)^{1-\varphi_w}. \quad (25)$$

Job turnover unambiguously decreases the steady state wage markup (the ratio ϕ/MRS, where MRS $\equiv (1-\alpha)c/[\alpha(1-N)]$), whereas a sufficient condition for trend growth to decrease the steady state wage markup and raise employment given consumption is $\sigma \geq 1$. In this case, the larger $\alpha(1-\sigma)$ in absolute value (the stronger the consumption smoothing motive), the larger is the negative effect of trend growth on the wage markup.

Similarly, along the balanced growth path, equation (24) simplifies to

$$c = \left[1 - \frac{\kappa_p}{2}\left(\Pi_p^{1-\varphi_p} - 1\right)^2 - \frac{\kappa_w}{2}\left((\Gamma\Pi_p)^{1-\varphi_w} - 1\right)^2\right]N, \quad (26)$$

where, using the aggregate production function, y is replaced with N. By increasing the resource cost of wage adjustments, higher trend growth reduces consumption, given employment. Equations (25) and (26) jointly determine c and N for a given level of Π_p:

$$\phi = \frac{\theta_p - 1}{\theta_p} + [1 - \beta\Gamma^{\alpha(1-\sigma)}]\kappa_p\theta_p^{-1}(\Pi_p^{1-\varphi_p} - 1)\Pi_p^{1-\varphi_p}. \quad (27)$$

Equation (27) shows that, because of price adjustment costs, the average price markup differs from the desired level, $\theta_p/(\theta_p - 1)$. Similarly to the wage setting problem, there are two countervailing effects of trend growth. On one hand, higher output growth increases future relative to present price adjustment costs, and this leads to a higher price markup. On the other hand, higher consumption growth implies stronger discounting of future price adjustment costs, and this leads to a lower price markup.

Finally, note that wage and price adjustment costs are less costly, the stronger is the degree of indexation in wages and prices, respectively. Consequently, indexation behavior lowers the response of real variables to inflation.

In order to gain intuition, take for instance the special case where $\kappa_p = 0$, implying that $\phi = \mu_p^{-1}$ (real wage equals the inverse of the price markup). In this case equations (25) and (26) can be combined to yield

$$(\theta_w - 1)\mu_p^{-1} + Q = \theta_w \frac{(1-\alpha)}{\alpha(1/c - K)}, \quad (28)$$

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where we define

$$Q \equiv \kappa_w \left[1 - \beta(1-\delta)\Gamma^{\alpha(1-\sigma)}\right]\left[(\Gamma\Pi_p)^{1-\varphi_w} - 1\right](\Gamma\Pi_p)^{1-\varphi_w}$$

and

$$K \equiv \left\{1 - \frac{\kappa_w}{2}\left[(\Gamma\Pi_p)^{1-\varphi_w} - 1\right]^2\right\}^{-1}.$$

It is easy to check that $K_\Gamma > 0$ (higher growth increases the resource cost of wage adjustment) whereas $Q_\Gamma > 0$ (higher trend growth reinforces the intertemporal asymmetry due to time discounting) under our baseline assumption that $\sigma > 1$. In this case, both the left-hand side and the right-hand side terms in equation (28) increase as Γ increases. How consumption responds is thus ambiguous a priori. For instance, if σ is large enough, α is large enough, or θ_w is small enough, then the wage markup effect of growth dominates the resource cost effect and consumption must increase to restore equilibrium.

In the more general case where $\kappa_p > 0$, ϕ is larger the larger the value of Γ if $\sigma > 1$. Then the rise in ϕ in response to an increase in Γ reinforces the rise in Q under the equilibrium condition

$$(\theta_w - 1)\phi + Q = \theta_w \frac{(1-\alpha)}{\alpha(1/c - K)},$$

so that consumption needs to rise more than implied under $\kappa_p = 0$ to restore equilibrium.

4. CALIBRATION AND NUMERICAL ANALYSIS

We now examine the properties of the macroeconomy just described by calibrating the model to the U.S. economy (see Table 1). Most of the calibrated parameters are within a range of values used in the literature [see, e.g., Erceg et al. (2000), Smets and Wouters (2007) and Graham and Snower (2008)]. The values of σ and α are taken from Guerron-Quintana (2008), whereas the values of κ_p and κ_w are calibrated so that they correspond to their Calvo price and wage stickiness parameters, respectively [see, e.g., Chugh (2006), Keen and Wang (2007), and

TABLE 1. Parameter configuration

Parameter		Calibrated value
β	Discount factor	0.99
α	Weight of consumption in utility	0.39
σ	Degree of nonseparability in utility	7.5
Γ	Productivity growth	1.005
δ	Quarterly job turnover rate	0.085
θ_p	Elasticity of substitution in goods	5
θ_w	Elasticity of substitution in labor	5

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Lombardo and Vestin (2008)], whose estimate is reported in Smets and Wouters (2007). The productivity growth rate is set to be 2% (annualized), whereas the implied annualized job turnover rate is 0.3, which is consistent with empirical estimates.

The calibrated value of Γ implies an annualized productivity growth rate of 2%. The value of σ is set so that the degree of consumption smoothing is at the lower end of reported estimates with nonseparable utility in the literature. For instance, Guerron-Quintana (2008) reports values of σ as high as 23 in a New Keynesian model with Calvo-type price and wage staggering. In line with Graham and Snower (2008), we set $\theta_w = 5$ as a baseline value and assume that $\theta_p = \theta_w$.[15] Finally, the baseline specification has no price and wage indexation (i.e., $\varphi_p = \varphi_w = 0$). We discuss the effects of nominal indexation further in the following.

The two key parameters of the model are the trend productivity growth Γ and the job turnover rate δ. In what follows we compare versions of the model with and without trend productivity growth and/or job turnover.

4.1. Baseline Results

In the figures that follow, we plot the percentage deviation of steady state consumption and employment from their levels at a zero steady state rate of price inflation, denoted by $\hat{c}$ and $\hat{n}$, respectively, against the trend rate of price inflation π_p (annualized). Figure 1 shows our main result. The left panel of the figure shows the relationship between consumption and inflation for alternative values of the trend growth rate γ and the job turnover rate δ. The right panel shows the corresponding relation between employment and inflation. The case of no growth–no job turnover ($\gamma = 0\%, \delta = 0$) is shown by the dotted line. The case with trend growth but no job turnover ($\gamma = 2\%, \delta = 0$) is shown by the dashed line. Finally, the joint effect of trend growth and job turnover ($\gamma = 2\%, \delta = 0.3$) is shown by the solid line.

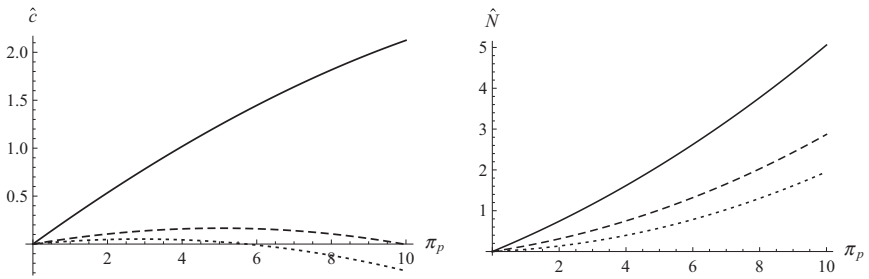


FIGURE 1. The steady-state relation between real variables and inflation (i) in the absence of trend growth and job turnover ($\gamma = 0\%, \delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%, \delta = 0$, dashed line), and (iii) in the presence of trend growth and job turnover ($\gamma = 2\%, \delta = 0.3$, solid line).

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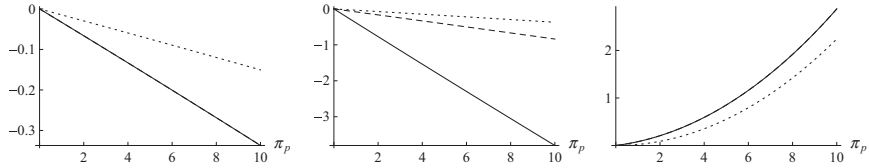


FIGURE 2. Steady state price markup (left panel), wage markup (middle panel), and consumption–employment wedge (right panel) (i) in the absence of trend growth and job turnover ($\gamma = 0\%, \delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%, \delta = 0$, dashed line), and (iii) in the presence of trend growth and job turnover ($\gamma = 2\%, \delta = 0.3$, solid line).

Note that the relationship between inflation and consumption is concave whereas that between inflation and employment is convex. The reason for this result is the convex nature of price and wage adjustment costs. A given rise in steady state inflation raises price and wage adjustment costs (and therefore output and employment, because these adjustments are implemented by purchases of final output) by a larger amount, the higher the level of inflation. At the same time, the resulting increase in the resource costs associated with higher price and wage adjustments widens the wedge between consumption and employment. From the aggregate resource constraint, at any given employment, consumption is lower the higher the steady state inflation.

In the absence of trend growth and job turnover, consumption and inflation are negatively related for inflation rates higher than 6%. The presence of trend growth alone implies a positive response of consumption to changes in inflation over the range of inflation rates considered. The positive relationship is, however, quantitatively small. In the presence of trend growth and job turnover, the expansionary long-run effect of inflation on consumption is even more pronounced. From the right panel we see that employment rises monotonically with inflation regardless of the parameter configuration. Moreover, the response of output to a given change in inflation is larger the higher is trend growth and/or the higher is the job turnover rate.

Given that the main mechanism in the model works through changes in the price markup $1/\phi$ [see equation (25)] and the wage markup ϕ/MRS [see equation (27)], as well as the consumption–employment wedge N/c [see equation (26)], it is instructive to plot the behavior of these variables. Figure 2 shows the percentage deviations of steady state price markup, wage markup, and the consumption–employment wedge from their respective levels at zero steady state price inflation. Looking first at the case with no job turnover and no trend growth (shown by dotted lines), we see that the price markup and the wage markup, shown, respectively, in the left and middle panels of the figure, decrease with trend inflation whereas the consumption–employment wedge, shown in the right panel of the figure, increases with trend inflation. These are standard properties of a model with Rotemberg adjustment costs [see, e.g., Ascari and Rossi (2012)]. The fall in the

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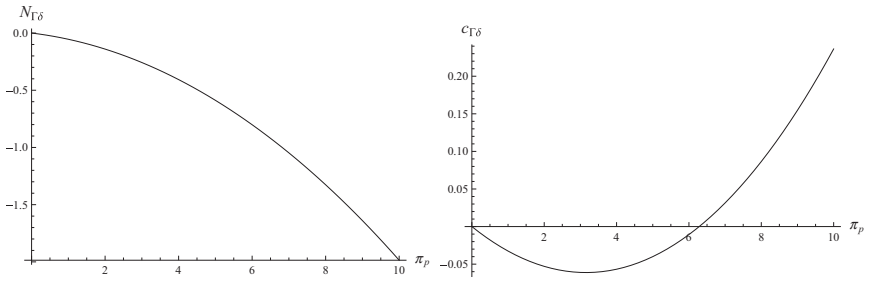


FIGURE 3. Complementarity between trend growth and job turnover in employment (left panel) and consumption (right panel).

markups raises employment given consumption, whereas the rise in the wedge implies a lower level of consumption given employment. In this case, the general equilibrium effects are shown in Figure 1. There is a threshold inflation rate of about 6% below which the markup effects dominate the wedge effect so that both employment and consumption rise with the rate of inflation. At higher rates of inflation employment rises but consumption falls with the rate of inflation.

In accordance with our preceding discussion, Figure 2 shows that, given the inflation rate, (i) the steady state price and wage markups are lower the higher is trend growth, (ii) the steady state wage markup is lower the higher is the job turnover rate, and (iii) the consumption–employment wedge is higher the higher is trend growth.[16] In the presence of trend growth but in the absence of job turnover, the magnitude of the declines in the price and wage markups is quantitatively similar. For example, a rise in inflation from zero to 10% lowers the price markup by 0.34% and the wage markup by 0.54%. In the presence of both trend growth and job turnover the corresponding drop in the wage markup, 2.5%, is much larger.

4.2. Complementarity between Trend Growth and Job Turnover

Let $c_{\Gamma\delta}$ denote the difference between the joint effect and the sum of the individual effects on consumption at any given inflation rate. Then trend growth and job turnover are complementary in affecting consumption if $c_{\Gamma\delta} > 0$ and substitutes if $c_{\Gamma\delta} < 0$. We define $N_{\Gamma\delta}$ analogously for employment effects of trend growth and job turnover. Figure 3 illustrates our results.

We can see that, with regard to employment, trend growth and job turnover are substitutes. With regard to consumption, there is a threshold inflation rate of about 6.25%, below which trend growth and job turnover are substitutes and above which they are complements.

4.3. The Influence of Consumption Smoothing

To show how the degree of consumption smoothing matters for our results, Figure 4 shows the relationship between employment and inflation as well as that between

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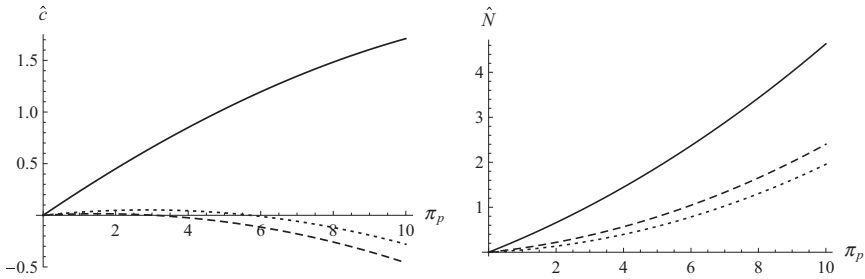


FIGURE 4. The steady-state relation between real variables and inflation under log separable utility (i) in the absence of trend growth and job turnover ($\gamma = 0\%, \delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%, \delta = 0$, dashed line), and (iii) in the presence of trend growth and job turnover ($\gamma = 2\%, \delta = 0.3$, solid line).

consumption and inflation for the case of $\sigma = 1$, implying that utility is of the log separable form and that the consumption smoothing motive is relatively weak. In contrast to the baseline case shown in Figure 1, higher trend growth lowers consumption at any given inflation. The intuition for this result is as follows. When $\sigma = 1$, the effects of consumption growth and output growth exactly offset each other, so that the price markup is independent of trend growth. However, as in the baseline case, owing to intertemporal asymmetry, higher trend growth decreases the wage markup (which increases employment and output) but increases the wedge between output and consumption (from the aggregate resource constraint, consumption falls at any given level of output). Consumption falls on net, implying that the resource cost effect of trend growth dominates the wage markup effect.

4.4. Price and Wage Indexation

Figure 5 shows the relationships between inflation and consumption and inflation and employment in the presence and absence of price and wage indexation. The indexation parameters φ_p and φ_w are analogous to price and wage indexation in Calvo-type models. They are calibrated based on estimated values in Smets and Wouters (2007).

As can be seen from the figure the presence of indexation does not alter the long-run relationships under discussion qualitatively. The intuition is straightforward. The presence of indexation mitigates the effects of trend wage (price) inflation on the wage (price) markup, but it does not affect the discounting effects of trend growth and job turnover. Note, however, that price and wage indexation flatten the consumption and employment curves, as they lower wage and price adjustment costs, respectively. This result that the presence of indexation weakens the response of real variables to inflation is a general feature of models with nominal rigidity.

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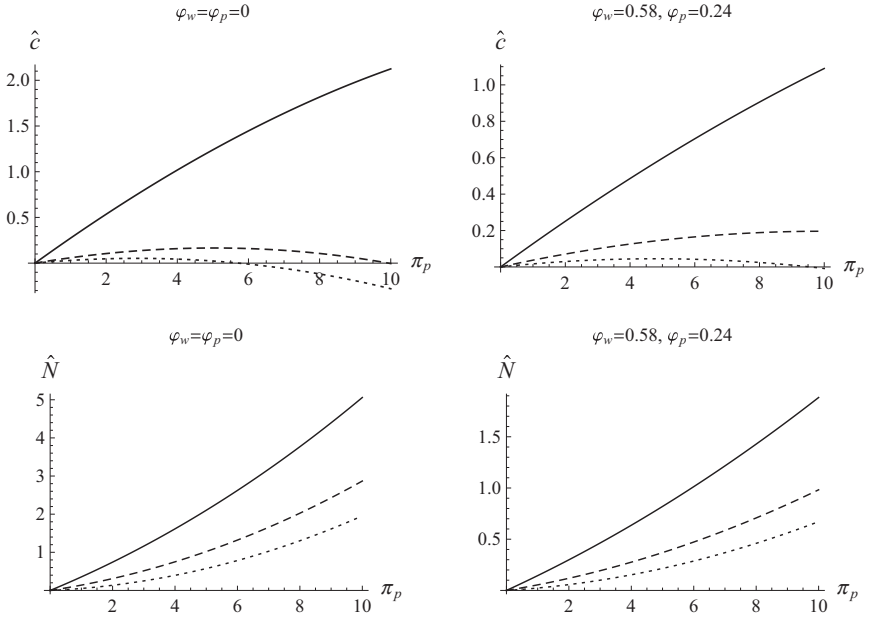


FIGURE 5. The steady-state relations between real variables and inflation with and without partial indexation.

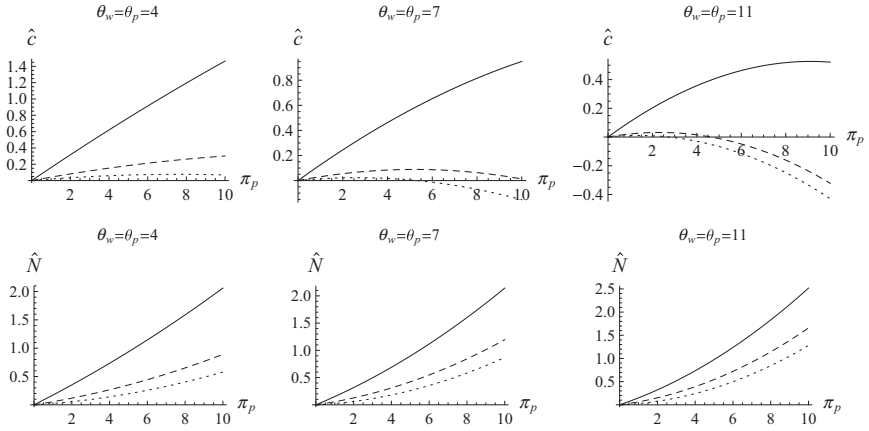


FIGURE 6. The steady-state relations between real variables and inflation under alternative values of the elasticity of substitution between goods θ_p and labor services θ_w.

4.5. The Elasticity of Substitution Between Goods and Between Labor Services

Figure 6 shows the relation between real variables and inflation under alternative values of the elasticity of substitution between goods θ_p and labor services θ_w.

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In the figure $\theta_p = \theta_w$ takes three alternative values: $\theta_p = \theta_w \in \{4, 7, 11\}$. As was pointed out earlier, these alternative values have been suggested in the literature. As can be seen from Figure 6, the higher the elasticity of substitution between goods and between labor services, the stronger is the response of employment, but the weaker is the response of consumption to changes in inflation.

4.6. Analysis under the Calvo Model of Nominal Staggering

In this subsection we briefly discuss the effects of trend growth and job turnover on the steady state Phillips curve under the Calvo-type model of price and wage staggering (see the Appendix for a more detailed derivation). We show that, as in the Rotemberg model and at any given price inflation, higher job turnover lowers the wage markup whereas higher trend growth lowers the wage and price markups if the degree of consumption smoothing is high enough.

The key feature of the Calvo-type model is that in any given period a fraction ω_w (ω_p) of wages (prices) are not reset optimally. The underlying steady state analysis in the Calvo-type model may be summarized as follows. The steady state optimal reset relative wage, aggregate wage level, and wage dispersion are, respectively,[17]

$$\frac{W_t^*}{W_t} = \mu_w \frac{\sum[\beta(1-\delta)\omega_w \Gamma_C^{\alpha(1-\sigma)-1}\Gamma_C \Pi_w^{\theta_w}]^i}{\sum[\beta(1-\delta)\omega_w \Gamma_C^{\alpha(1-\sigma)-1}\Pi_w^{\theta_w}\Pi_p^{-1}]^i}\frac{\text{MRS}}{\phi}$$
$$= \mu_w \frac{1-\beta(1-\delta)\omega_w \Gamma^{\alpha(1-\sigma)-1+\theta_w}\Pi_p^{\theta_w-1}}{1-\beta(1-\delta)\omega_w \Gamma^{\alpha(1-\sigma)+\theta_w}\Pi_p^{\theta_w}}\frac{\text{MRS}}{\phi}, \tag{29}$$

$$\frac{W_t^*}{W_t} = \left[\frac{1-\omega_w(\Gamma\Pi_p)^{\theta_w-1}}{1-\omega_w}\right]^{1/(1-\theta_w)}, \tag{30}$$

and

$$\Delta_w = \frac{(1-\omega_w)(W_t^*/W_t)^{-\theta_w}}{1-\omega_w(\Gamma\Pi_p)^{\theta_w}}. \tag{31}$$

Analogously, the steady state optimal reset relative price, aggregate price level, and price dispersion are, respectively,

$$\frac{P_t^*}{P_t} = \mu_p \frac{\sum[\beta\omega_p \Gamma_C^{\alpha(1-\sigma)-1}\Gamma_C \Pi_p^{\theta_p}]^i}{\sum[\beta\omega_p \Gamma_C^{\alpha(1-\sigma)-1}\Pi_p^{\theta_p-1}]^i}\phi$$
$$= \mu_p \frac{1-\beta\omega_p \Gamma^{\alpha(1-\sigma)}\Pi_p^{\theta_p-1}}{1-\beta\omega_p \Gamma^{\alpha(1-\sigma)}\Pi_p^{\theta_p}}\phi, \tag{32}$$

$$\frac{P_t^*}{P_t} = \left(\frac{1-\omega_p \Pi_p^{\theta_p-1}}{1-\omega_p}\right)^{1/(1-\theta_p)}, \tag{33}$$

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and

$$\Delta_p = \frac{(1-\omega_p)(P_t^*/P_t)^{-\theta_p}}{1-\omega_p \Pi_p^{\theta_p}}. \tag{34}$$

A standard property of the model is that positive steady state wage inflation implies a faster erosion of wage markup of labor types whose wages were set in the past [as captured by equation (30)]. In anticipation, wage setters choose a higher markup than is implied by zero wage inflation, as is shown in equation (29). The result is higher wage dispersion across differentiated labor types and more inefficiency associated with imperfect substitutability among these labor types, as shown in equation (31). Equations (32), (33), and (34) show analogous effects when steady state price inflation is positive.

Next, equation (29) shows that by reinforcing time discounting, higher job turnover δ lowers the optimal wage markup. It also shows that higher trend growth lowers the optimal wage markup if the degree of consumption smoothing is high enough. From equation (29), higher wage inflation increases the optimal wage markup whereas higher consumption growth has two opposing effects. On one hand, it implies higher growth of the marginal rate of substitution between consumption and labor, and thus higher optimal wage markup, as it reinforces the markup-eroding effect of positive wage inflation. This effect is stronger the larger the elasticity of substitution between differentiated labor types θ_w. On the other hand, it implies a higher real interest rate, and thus a lower optimal wage markup, as it reinforces time discounting. This effect is stronger the higher the degree of consumption smoothing (i.e., the value of α or σ is larger).

From equation (32), higher consumption growth also has two opposing effects on the optimal price markup. On one hand, it implies higher output demand growth and thus higher price markup, as it reinforces the markup-eroding effect of positive price inflation. On the other hand, it implies a higher real interest rate and thus a lower price markup, as it reinforces time discounting.

Not surprisingly, owing to differences in the rationale for nominal rigidities, the Calvo- and Rotemberg-type models differ in their quantitative properties. In the Rotemberg model, nominal adjustment costs are parameterized to be quadratic so that higher wage growth (due to higher productivity growth) raises the resource costs of nominal adjustment in a quadratic fashion. In the Calvo model, higher wage growth raises inefficiency because of higher wage dispersion. The wage dispersion effect depends crucially on the elasticity of substitution between differentiated labor types, which is set equal to 5 in the baseline calibration. In this case, for an increase in productivity growth to lead to lower wage markup (and, all else equal, higher consumption), one would need to assume a higher degree of consumption smoothing than is the case in the Rotemberg model. Figure 7, which is the Calvo counterpart of Figure 1, illustrates this general point. In both cases higher trend growth raises employment at any given inflation. However, similarly to Figure 4, higher trend growth lowers consumption.

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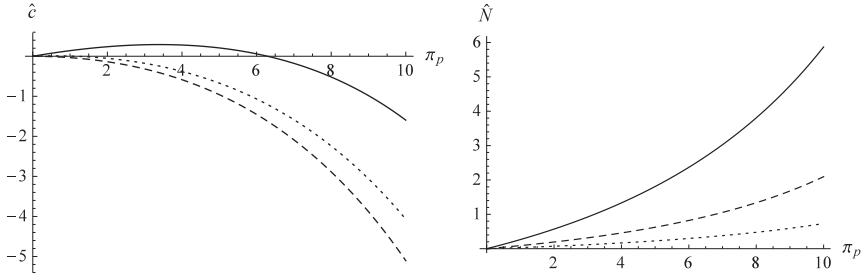


FIGURE 7. The steady-state relation between real variables and inflation in the Calvo model (i) in the absence of trend growth and job turnover ($\gamma = 0\%$, $\delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%$, $\delta = 0$, dashed line), and (iii) in the presence of trend growth and job turnover ($\gamma = 2\%$, $\delta = 0.3$, solid line).

As pointed out, for example, by Bakhshi et al. (2003) and Graham and Snower (2008), a drawback of Calvo nominal staggering is that the nominal wages and prices of some labor services and goods are never reset in the face of positive steady state inflation. This property of the model raises conceptual issues, as the respective real wages and relative prices eventually fall toward zero. Given the CES aggregate of differentiated labor services (goods), firms (households) substitute completely to these labor services (goods), meaning production (consumption) falls toward zero.

5. THE OPTIMAL STEADY STATE INFLATION RATE

In this section we discuss the optimal level of steady state inflation in the presence of job turnover and trend growth. The optimal level of inflation is the one that maximizes the steady-state welfare of the household [see, e.g., Wolman (2001)]. The steady-state welfare is given by the period utility of the household evaluated at steady state consumption and employment; that is, $U(c, N) = [c^{\alpha}(1-N)^{1-\alpha}]^{1-\sigma}/(1-\sigma)$. A given change in inflation raises household utility to the extent that it raises consumption and reduces household utility to the extent that it raises employment (lowers leisure). The first-order condition for optimal inflation is given by $\partial U[c(\Pi_p), N(\Pi_p)]/\partial \Pi_p = 0$, implying that

$$\frac{\partial c/\partial \Pi_p}{c} = \frac{(1-\alpha)\partial N/\partial \Pi_p}{\alpha(1-N)}.$$

Because c and N are nonlinear functions of Π_p, a closed-form solution for the optimal Π_p is not feasible. Table 2 shows the optimal inflation rate under alternative assumptions about job turnover and trend growth. In the presence of job turnover and trend growth effects (the baseline), the optimal inflation rate is 1.8%.[18]

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TABLE 2. Selectively removing channels

Case		Optimal inflation rate (%)
1	Baseline	1.8
2	No job turnover	−0.4
3	No trend growth	2.7
4	No job turnover and no trend growth	0.4

No job turnover. The optimal inflation rate in the absence of job turnover is −0.4% (see case 2 of Table 2), which is a deflation. In the absence of job turnover, the intertemporal asymmetry due to discounting is weaker, implying high wage markup [see equation (25)]. The result is that employment rises less strongly for a given rise in price inflation (see Figure 1) and so does consumption [see equation (26)]. The implication is that the disutility from employment and the utility from consumption both rise less strongly for a given rise in price inflation. The former (latter) effect implies a higher (lower) optimal inflation rate. The result that the optimal inflation rate is lower when the job turnover channel is removed implies that the latter effect dominates the former.

No trend growth. The optimal inflation rate in the absence of trend growth is 2.7% (see case 3 of Table 2), which is higher than that implied in the baseline case.[19] In the model, the absence of trend growth has two implications: (i) As in the case of no job turnover, the intertemporal asymmetry due to discounting becomes weaker, implying higher wage markup [equation (25)] and higher price markup [equation (27)]. In turn, employment and consumption rise less strongly for a given rise in price inflation.[20] (ii) Nominal wages, and thus the resource cost of wage adjustments, rise less strongly, implying that consumption rises more strongly [equation (26)], for a given rise in price inflation. Here the resource cost effect associated with removing trend growth dampens the discounting effect outlined in (i), so that the overall effect on consumption is less pronounced than the effect on employment of removing trend growth. This explains why the optimal inflation rate is higher in the absence of trend growth—the rise in household utility due to lower employment dominates the fall in household utility due to lower consumption of removing the trend growth channel.

No job turnover and no trend growth. Finally, in the absence of both job turnover and trend growth (case 4 of Table 2), the optimal inflation rate is 0.4%, which is much lower than that implied in the baseline case. The optimal inflation rate lies between that implied in the absence of job turnover (case 2) and that implied in the absence of trend growth (case 3). This is to be expected, given that the optimal inflation rate is lower in the absence of job turnover but is higher in the absence of trend growth.

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TABLE 3. Indexation and optimal inflation (%)

	φ_w		
φ_p	0	0.5	0.58
0	1.8	2.7	2.8
0.24	2.0	3.6	3.8
0.5	2.2	4.9	5.5

Nominal indexation. The analysis of the optimal inflation rate is done in the context of the baseline model, which abstracts from price and wage indexation. How is the presence of indexation likely to affect the optimal inflation rate? As we discussed in the previous section, price and wage adjustments are less costly in the presence of nominal indexation, so that employment responds less strongly to changes in inflation [see equations (25) and (27)] and so does consumption [see equation (26)]. However, the effect on consumption is more muted, because the less costly are price and wage adjustments, the higher is consumption given employment [see equation (26)]. The optimal inflation rate is thus higher in the presence of indexation.

Table 3 shows the optimal inflation rate for alternative degrees of price and wage indexation. The parameter values $\varphi_p = 0.24$ and $\varphi_w = 0.58$ have been used in our numerical analysis (see Figure 5) and imply an optimal inflation rate of 3.8%. The values $\varphi_p = 0.5$ and $\varphi_w = 0.5$ represent the special case of symmetric indexation and imply an optimal inflation rate of 4.9%. The general picture from the table is that the stronger is price or wage indexation, the higher is the optimal inflation rate.

6. CONCLUDING REMARKS

In the standard New Keynesian model, higher trend inflation (equivalently, higher long-run money growth) imparts a contractionary long-run effect on real macroeconomic activity, except at very low levels of trend inflation. Our analysis calls this conventional result into question by showing that trend inflation can have significant positive effects on macroeconomic activity over a wide range of positive inflation rates. The reason is that job turnover and trend productivity growth (important aspects of macroeconomic activity in practice) impart a substantial expansionary influence to the effect of trend inflation on real macroeconomic activity.

Job turnover and trend productivity growth flatten the long-run Phillips curve (in the sense that an increase in trend inflation is associated with a larger percentage increase in steady state employment and consumption). Moreover, with regard to employment effects, trend growth and job turnover are substitutes: their joint effect is smaller than the sum of the individual effects. Regarding consumption

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effects, trend growth and job turnover are substitutes when inflation is low enough and complements when inflation is high enough.

Finally, in the presence of trend growth and job turnover and under a reasonable calibration of the model, the optimal steady state inflation lies within what Fed officials judge as the "comfort zone" for core inflation. The analysis shows that trend growth and job turnover are key determinants of the optimal inflation rate.

NOTES

1. For a recent survey of the empirical and theoretical literature on trend inflation see Ascari and Sbordonne (2014).

2. There are few exceptions. Yun (1996) and Sbordone (2002) allow for trend growth in the New Keynesian model, but abstract from job turnover and focus on short-run dynamics. Whereas Yun (1996) assumes full indexation to trend inflation, Sbordone (2002) examines short-run dynamics around the zero-inflation steady state. Closer to our paper, Amano et al. (2009) study the steady state effects of trend productivity growth but abstract from job turnover and the role of consumption smoothing. They focus on the effect of productivity growth on nominal wage growth and in turn wage dispersion. As is well known [see, e.g., Graham and Snower (2004)], wage dispersion leads to *employment cycling*—firms substitute among different labor types. Because different types are imperfect substitutes in production, employment cycling is inefficient.

3. For instance, Mortensen (2005) studies an endogenous growth model along the lines of Grossman and Helpman (1991) and Aghion and Howitt (1998), in which a fraction of product types are replaced by more productive ones so that "job creation and job destruction are the two sides of the same coin."

4. Using the Bureau of Labor Statistics' Job Openings and Labor Turnover Survey (JOLTS), which begins in December 2000, Hall (2003) reports that the monthly separation rate was 3.4% in December 2000, 3.2% in December 2001, and 3.0% in December 2002. See also Blanchard and Diamond (1990), who examine household data in the Current Population Survey as well as the manufacturing turnover survey from 1968 through 1981.

5. Optimal consumption smoothing results from risk-averse households. In this case, households require a higher real interest rate in order to support faster consumption growth because faster growth implies a decline in the marginal utility of future consumption relative to current consumption, the decline being stronger the higher is the degree of risk aversion.

6. The intuition regarding these effects is as follows. As is standard, Rotemberg nominal adjustment costs are modeled as purchases of a bundle of differentiated goods, which implies that each firm must be facing higher demand for its good when current nominal wage growth is higher. Each firm must be accommodating higher demand by raising output, and in turn labor demand, because price adjustment is costly. By accommodating higher demand instead of raising its price (as would be the case under flexible prices), each firm accepts a lower price markup. In turn, each household accommodates higher labor demand, despite the implied rise in the marginal rate of substitution between consumption and leisure, because wage adjustment is costly. Thus households must also be accepting a lower wage markup. In contrast, higher future nominal wage growth implies that each firm anticipates higher future demand for its good, which it expects to accommodate, and therefore raise future labor demand, in light of price adjustment costs. In anticipation of this, households raise their wage markup to economize on the expected rise in future wage adjustment costs associated with higher future labor demand.

7. Although we are taking a short cut, the analysis is consistent with monetary policy that is implemented with, say, an appropriate money growth rule. In our discussion later in the paper we use the words inflation rate and money growth interchangeably.

8. A limiting case is when $\sigma = 1$, so that $U(C_t, N_t) = \alpha \log C_t + (1 - \alpha) \log(1 - N_t)$.

9. In particular, these separations may be viewed as occupational switches or other job changes, occasioned by promotions and job shifts within the same firm or worker moves from one firm to

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another. These are documented in the extensive literature on job creation and destruction as well as on occupational switches [see, e.g., Davis and Haltiwanger (1990) and Kambourov and Manovskii (2008)].

10. For simplicity, we assume no labor market frictions, such as hiring and firing costs, so that all vacant jobs are immediately filled.

11. See, e.g., Aghion (2002) for a model of growth with creative job destruction in a neoclassical labor market. An alternative way of constructing our model would be to introduce a matching function (in which hiring is a function of unemployment and vacancies) to replace our labor demand equation. Along the lines of Pissarides (2000), the firm would maximize profits with respect to hiring and vacancies, and wages could be determined through Nash bargaining. In this context, it is straightforward to show that productivity growth and job turnover have effects on the Phillips curve analogous to those outlined in this paper.

12. A nice feature of this assumption is that the price and wage setting problems are symmetric across all differentiated goods and across all labor types. In the Appendix, we discuss the issue in the alternative framework of Calvo price and wage staggering, which points to a similar conclusion regarding the long-run Phillips curve.

13. As is shown later, the price adjustment cost takes the same form as the wage adjustment cost.

14. As firms are assumed to be symmetric, the aggregate production function implies that $N_{d,t} = Y_t / A_t$ (see Section 2.2).

15. The chosen baseline values are within the range used in the literature. For instance, Erceg et al. (2000) set $\theta_p = \theta_w = 4$, Huang and Liu (2002) set $\theta_p = 10$, $\theta_w \in \{2, 4, 6\}$, and Graham and Snower (2008) set $\theta_w = 5$ in a model with only nominal wage rigidity, whereas Amano et al. (2009) set $\theta_p = \theta_w = 11$.

16. Note that because the job turnover does not affect the price markup as well as the consumption–employment wedge, the dashed and solid lines in the left and right panels of the figure overlap.

17. For simplicity we abstract from wage and price indexation.

18. This value is within the Fed's "comfort zone" for core inflation. According to Kliesen (2010), former Fed Governor Ben Bernanke publicly stated in 2005 that his comfort zone was between 1 and 2%.

19. See Kiley (2003) for a detailed discussion of the postwar relationship between productivity growth and inflation in the United States.

20. The discounting effect alone implies lower employment and (from the aggregate resource constraint) lower consumption.

21. Note that, because all labor types whose wages are reset face an identical optimization problem, all set an identical relative wage.

22. We assume that among the newly opened labor markets in period t a fraction $1 - \omega_w$ set a new wage while a fraction ω_w pick a wage randomly from period $t - 1$ distribution of wages. This assumption implies that the distribution of wages among newly opened labor market types is identical to that across existing labor market types.

REFERENCES

Aghion, P. (2002) Schumpeterian growth theory and the dynamics of income inequality. *Econometrica* 70, 855–882.

Aghion, P. and P. Howitt (1998) *Endogenous Growth Theory.* Cambridge, MA: MIT Press.

Amano, R., K. Moran, M. Murchison, and A. Rennison (2009) Trend inflation, wage and price rigidities, and productivity growth. *Journal of Monetary Economics* 56, 353–364.

Ascari, G. (1998) Superneutrality of money in staggered wage-setting models. *Macroeconomic Dynamics* 2, 383–400.

Ascari, G. (2004) Staggered prices and trend inflation: Some nuisances. *Review of Economic Dynamics* 7, 642–667.

https://doi.org/10.1017/S136510051500070X Published online by Cambridge University Press

Ascari, G. and L. Rossi (2012) Trend inflation and firms price-setting: Rotemberg versus Calvo. *Economic Journal* 122, 1115–1141.

Ascari, G. and A. Sbordonne (2014) The macroeconomics of trend inflation. *Journal of Economic Literature* 53, 679–739.

Bakhshi, H., P. Burriel-Llombart, H. Kahn, and B. Rudolf (2003) Endogenous Price Stickiness, Trend Inflation, and the New Keynesian Phillips Curve. Working paper 191, Bank of England.

Basu, S. and M. Kimball (2002) Long-Run Labor Supply and the Elasticity of Intertemporal Substitution for Consumption. Unpublished manuscript, Boston College and University of Michigan.

Bilbiie, F. (2011) Non-separable preferences and Frisch labor supply: One solution to a fiscal policy puzzle. *Journal of Money, Credit and Banking* 43, 221–251.

Bilbiie, F., F. Gironi, and M. Melitz (2007) Monetary policy and business cycles with endogenous entry and product variety. *NBER Macroeconomics Annual* 22, 299–353.

Blanchard, O. and P. Diamond (1990) The cyclical behavior of the gross flows of U.S. workers. *Brookings Papers on Economic Activity* 2, 85–143.

Blanchard, O. and J. Gali (2010) Labour markets and monetary policy: A New Keynesian model with unemployment. *American Economic Journal: Macroeconomics* 2, 1–30.

Chugh, S. (2006) Optimal fiscal and monetary policy with sticky wages and sticky prices. *Review of Economic Dynamics* 9, 683–714.

Davis, S. and J. Haltiwanger (1990) Gross job creation and destruction: Microeconomic evidence and macroeconomic implications. *NBER Macroeconomics Annual* 5, 123–168.

Erceg, C., D. Henderson, and A. Levin (2000) Optimal monetary policy with staggered wage and price contracts. *Journal of Monetary Economics* 46, 281–313.

Graham, L. and D. Snower (2004) The Real Effects of Money Growth in Dynamic General Equilibrium. Working paper 412, European Central Bank.

Graham, L. and D. Snower (2008) Hyperbolic discounting and the Phillips curve. *Journal of Money, Credit and Banking* 40, 427–448.

Grossman, G. and E. Helpman (1991) *Innovation and Growth in the Global Economy*. Cambridge, MA: MIT Press.

Guerron-Quintana, P. (2008) Refinements on macroeconomic modeling: The role of non-separability and heterogeneous labour supply. *Journal of Economic Dynamics and Control* 32, 3613–3630.

Hall, R. (2003) Modern theory of unemployment fluctuations: Empirics and policy applications. *American Economic Review* 93, 145–150.

Huang, K. and Z. Liu (2002) Staggered price setting, staggered wage setting and business cycle persistence. *Journal of Monetary Economics* 49, 405–433.

Ireland, P. (2011) A New Keynesian perspective on the Great Recession. *Journal of Money, Credit and Banking* 43, 31–54.

Kambourov, G. and I. Manovskii (2008) Rising occupational and industry mobility in the United States: 1968–1997. *International Economic Review* 49, 41–79.

Keen, B. and Y. Wang (2007) What is a realistic value for price adjustment costs in New Keynesian models? *Applied Economics Letters* 14, 789–793.

Kiley, L. (2003) Why is inflation low when productivity growth is high? *Economic Inquiry* 41, 392–406.

King, R., C. Plosser, and S. Rebelo (1988a) Production growth and business cycles: I. The basic neoclassical model. *Journal of Monetary Economics* 21, 195–232.

King, R., C. Plosser, and S. Rebelo (1988b) Production growth and business cycles: II. New directions. *Journal of Monetary Economics* 21, 309–341.

King, R. and A. Wolman (1996) Inflation targeting in a St. Louis model of the 21st century. *Federal Reserve of St. Louis Review* 78, 83–107.

Kliesen, K. (2010) Is the Fed's Definition of Price Stability Evolving? Economic synopsis 33, Federal Reserve Bank of St. Louis.

Lombardo, G. and D. Vestin (2008) Welfare implications of Calvo vs. Rotemberg-pricing assumptions. *Economics Letters* 100, 275–279.

https://doi.org/10.1017/S136510051500070X Published online by Cambridge University Press

Mankiw, G. (2001) The inexorable and mysterious tradeoff between inflation and unemployment. *Economic Journal* 111, 45–61.
Monacelli, T. and R. Perotti (2009) Fiscal Policy, Wealth Effects, and Markups. NBER working paper 14584.
Mortensen, D. (2005) Growth, unemployment, and labour market policy. *Journal of the European Economic Association* 3, 236–258.
Pissarides, C. (2000) *Equilibrium Unemployment Theory*, 2nd ed. Cambridge, MA: MIT Press.
Rotemberg, J. (1982) Monopolistic price adjustment and aggregate output. *Review of Economic Studies* 49, 517–531.
Sbordone, A. (2002) Prices and unit labor costs: A new test of price stickiness. *Journal of Monetary Economics* 49, 265–292.
Schmitt-Grohe, S. and M. Uribe (2006) Comparing Two Variants of Calvo-Type Wage Stickiness. Working paper 12740, NBER.
Smets, F. and R. Wouters (2007) Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review* 97, 586–606.
Tesfaselassie, M.F. (2013) Trend productivity growth and the government spending multiplier. *Journal of Macroeconomics* 37, 197–207.
Wolman, A. (2001) A primer on optimal monetary policy with staggered price-setting. *Federal Reserve Bank of Richmond Economic Quarterly* 87(4), 27–52.
Yun, T. (1996) Nominal price rigidity, money supply endogeneity, and business cycles. *Journal of Monetary Economics* 37, 345–370.

APPENDIX: WAGE AND PRICE SETTING IN THE CALVO MODEL

In this Appendix we derive optimal wage and price setting under the Calvo model of nominal staggering, where in any given period a fraction ω_w (ω_p) of wages (prices) are not reset.

A.1. WAGE SETTING

Wage setting is based on the household's optimization problem given in the main text with the budget constraint amended as

$$C_t + \frac{B_t}{P_t} = N_{d,t}\int_0^1 \frac{W_t^j}{P_t}\left(\frac{W_t^j}{W_t}\right)^{-\theta_w} dj + R_{t-1}\frac{B_{t-1}}{P_t} + \frac{D_t}{P_t}.$$

The first-order conditions for C_t and N_t are identical to the ones given in the main text, whereas the first-order condition for optimal wage setting is given by

$$\frac{W_t^*}{W_t} = \mu_w \frac{E_t \sum_{i=0}^{\infty}[\beta(1-\delta)\omega_w]^i \frac{U_{C,t+i}}{U_{C,t}} \mathrm{MRS}_{t+i} N_{d,t+i}\left(\frac{W_{t+i}}{W_t}\right)^{\theta_w}}{(W_t/P_t)E_t \sum_{i=0}^{\infty}[\beta(1-\delta)\omega_w]^i \frac{U_{C,t+i}}{U_{C,t}} N_{d,t+i}\left(\frac{W_{t+i}}{W_t}\right)^{\theta_w}\frac{P_t}{P_{t+i}}},$$

where W_t^*/W_t is the optimal relative wage and $\mathrm{MRS}_t = (1-\alpha)C_t/[\alpha(1-N_t)]$.[21]

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A.2. PRICE SETTING

Price setting by firms is analogous to wage setting by households. Firm k maximizes the expected lifetime profit $E_t \sum_{i=0}^{\infty} \omega_p^i Q_{t,t+i}(P_{k,t}/P_{t+i} - \phi_{t+i})C_{k,t+i}$. Using the demand function (6) in the profit function and differentiating with respect to $P_{k,t} = P_t^*$ (because all optimizing firms face an identical maximization problem) gives

$$\frac{P_t^*}{P_t} = \mu_p \frac{E_t \sum_{i=0}^{\infty} (\beta\omega_p)^i \frac{U_{C,t+i}}{U_{C,t}} \frac{C_{t+i}}{C_t} \phi_{t+i} \left(\frac{P_{t+i}}{P_t}\right)^{\theta_p}}{E_t \sum_{i=0}^{\infty} (\beta\omega_p)^i \frac{U_{C,t+i}}{U_{C,t}} \frac{C_{t+i}}{C_t} \left(\frac{P_{t+i}}{P_t}\right)^{\theta_p - 1}},$$

where P_t^*/P_t is the optimal relative price. The aggregate wage level can be expressed in terms of optimized and nonoptimized wages:[22]

$$\begin{aligned} W_t^{1-\theta_w} &= \int_0^1 W_t^{j(1-\theta_w)} dj \\ &= (1-\omega_w) W_t^{*(1-\theta_w)} + (1-\delta)\omega_w \int_0^1 W_{t-1}^{j(1-\theta_w)} dj + \delta\omega_w \int_0^1 W_{t-1}^{j(1-\theta_w)} dj \\ &= (1-\omega_w) W_t^{*(1-\theta_w)} + \omega_w W_{t-1}^{(1-\theta_w)}. \end{aligned}$$

The aggregate price level can also be expressed in terms of optimized and nonoptimized prices:

$$P_t = \left[(1-\omega_p) P_t^{*1-\theta_p} + \omega_p P_{t-1}^{1-\theta_p}\right]^{\frac{1}{1-\theta_p}}$$

Next, using the aggregate resource constraint and imposing goods and labor market clearing, we get a relationship between N_t and y_t:

$$\begin{aligned} N_t &= \int_0^1 N_t^j dj \\ &= \int_0^1 \left(\int_0^1 N_{k,t}^j dj\right) dk \\ &= \Delta_{w,t} \Delta_{p,t} y_t, \end{aligned}$$

where $\Delta_{w,t}$ denotes wage dispersion and is given by

$$\begin{aligned} \Delta_{w,t} &= \int_0^1 \left(\frac{W_{jt}}{W_t}\right)^{-\theta_w} dj \\ &= (1-\omega_w)(W_t^*/W_t)^{-\theta_w} + \omega_w \Pi_{w,t}^{\theta_w} \Delta_{w,t-1}, \end{aligned}$$

whereas $\Delta_{p,t}$ denotes price dispersion and is given by

$$\begin{aligned} \Delta_{p,t} &= \int_0^1 \left(\frac{P_{k,t}}{P_t}\right)^{-\theta_p} dk \\ &= (1-\omega_p)(P_t^*/P_t)^{-\theta_p} + \omega_p \Pi_{p,t}^{\theta_p} \Delta_{p,t-1}. \end{aligned}$$

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Along a steady state growth path, consumption growth Γ_C is equal to productivity growth Γ, $\Pi_w = \Gamma\Pi_p$, and all detrended real variables ($\phi_t = W_t/P_tA_t$, $c_t = C_t/A_t$, $y_t = Y_t/A_t$) are stationary. The steady state optimal wage setting, aggregate wage level, wage dispersion, optimal price setting, aggregate price level, and price dispersion are given, respectively, by equations (29), (30), (31), (32), (33), and (34). Moreover, in the steady state, market clearing for all goods implies that $c = y$, so that $N = (\Delta_w\Delta_p)c$.

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