Trend Growth, Job Turnover and Phillips Curve Tradeoffs

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Abstract

The paper reexamines the long-run Phillips curve in a New Keynesian model with job turnover and trend productivity growth. It shows that (i) job turnover flattens the long-run Phillips curve (a permanent change in the money growth rate has a significantly positive real effects for low inflation rates), (ii) trend productivity growth flattens the long-run Phillips curve if the consumption smoothing motive is sufficiently strong, and (iii) optimal inflation is higher in the presence of job turnover, as job turnover reinforces the effect of trend growth on consumption more than it does on employment.

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

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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), Ascari (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]

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 impart 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 on employment, and due to this the 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

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[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 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 labour types. Since 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."

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 in terms of discounting and Rotemberg nominal adjustment costs: (a) When agents have positive rates of time discounting, current wage and price adjustments costs receive more weight that 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, since discount rates are low in practice (say, between 2 and 7 percent), the resulting asymmetry is negligible for standard calibrations. (b) With Rotemberg nominal adjustment costs, the size of the costs depend on the magnitude of nominal adjustment. Thus, the greater the rate of inflation, the greater the nominal adjustment costs. Thus a permanent increase in inflation leads to a permanent increase in real macroeconomic activity.

The first major rationale (that is neither well-known nor trivial) rests on an intertemporal weighting asymmetry arising from job turnover. The greater is the rate of job turnover, the less likely it becomes that the future wage adjustment costs, incurred by a particular labour type, materialize. Thus, when the current wage is set, a worker attaches greater weight on current wage adjustment costs than on future wage adjustment costs. The effect is a lower wage markup. The average monthly job separation rate in the U.S. has exceeded 3 percent for much of the past decade.[4] Since a 3 percent monthly rate corresponds to a 30.6 percent 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, leading to trend growth in real wages. This has the following effects: (1) The real interest rate effect: In a balanced growth path productivity growth increases the real interest rate, the effect of which is larger the stronger is the degree of consumption smoothing. Higher real interest rate leads to a stronger discounting of future payoffs. (2) The wage adjustment cost effect: Trend productivity growth increases future wage adjustment costs relative to present ones, inducing households to raise their wage markup. (3) The nominal wage growth effect: Trend productivity growth increases both

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[4]Using the Bureau of Labour Statistics' Job Openings and labour Turnover Survey (JOLTS), which begins in December 2000, Hall (2003) reports that the monthly separation rate was 3.4 percent 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.

current and future nominal wage growth. The former effect implies lower wage markup while the latter effect implies higher wage markup. The former effect dominates due to time discounting. 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 implication for the optimal steady state inflation rate. Section 6 concludes.

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) and Bilbiie (2009) and Tesfaselassie (2013)). For simplicity, we assume labour to be the only input in the production function and monetary policy is characterize by a choice of the inflation target, which in turn pins down the level of steady state inflation.[5] 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

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[5]While we are following 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.

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, Plosser and Rebelo (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.[6] This utility function encompasses the log-separable utility as a special case (see, e.g., Guerron-Quintana (2008) and the 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 labour markets of measure one, each indexed by j. In each labour 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 leaves their jobs.[7] 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 below). Consequently, all workers who separate from their jobs are replaced by new hires during each period of analysis.[8] We choose to model employment in this way, since our analysis is meant to include job turnover into an otherwise standard DSGE model.[9]

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

[7]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 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)).

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

[9]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

We assume that, each labour market type faces an exogenous probability of exit δ. Furthermore, we assume a deterministic growth in labour 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 $\Pi_w = \Gamma \Pi_p$.

We introduce nominal wage and price rigidity by assuming quadratic adjustment costs to wage-price changes.[10] 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 labour 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 labour 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, Gironi and Melitz (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 increases 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 (see equation (5) below). 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.[11]

The household faces labour demand in market j

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

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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 analogous effects on the Phillips curve as those outlined in this paper.

[10] A nice feature of this assumption is that the price and wage setting problems are symmetric across all differentiated goods and across all labour types. In an appendix, available upon request, 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.

[11] As is shown below, the price adjustment cost takes the same form as the wage adjustment cost.

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 labour demand (derivation of which is given in section 2.2).

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

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

and the resource constraint

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

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where we have substituted out N_t^j using equation (3). The sum of each labour 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.

In each period, the household sets the wage in each labour 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, Gironi and Melitz (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 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 Eq. (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 balance growth, the real interest rate increases with consumption growth (the relationship is stronger the stronger is 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 labour 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.

Detrending equation (13) (i.e., dividing it through by A_t) leads to[12]

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

where $c_t \equiv C_t/A_t$ and $\phi_t \equiv W_t/(A_t P_t)$. The steady state of Eq. (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, due to 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). Due to 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 labour services

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

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

where $\mu_w = \theta_w/(\theta_w - 1)$ with θ_w being the elasticity of substitution between any two different labour types. Minimizing firm k 's total wage bill $\int_0^1 W_t^j N_{k,t}^j dj$ subject to (ref firmkempl) leads to the labour 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 labour demand for labour type j, namely (3), where $N_{d,t} = \int_0^1 N_{k,t} dk$, and the aggregate wage index is given by (4).

Pricing decision of firm k is subject to quadratic price adjustment costs, pac_k,

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

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 Eq. (18) is analogous to Eq. (2), which defines wage adjustment costs.

Firm k maximizes the expected lifetime profit

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

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 $Y_t = C_t + AC_t$ and

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

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

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

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

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 Eq. (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 $y_t = N_t$.

3 Steady-state Growth

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

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

Job turnover unambiguously decreases the steady state wage markup (the ratio ϕ/MRS, where $MRS \equiv (1-\alpha)c/(\alpha(1-N))$), while 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 is $\alpha(1-\sigma)$ in absolute value (the stronger is the consumption smoothing motive) the larger is the negative effect of trend growth on the wage markup.

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

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

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

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

Equation (27) shows that, due to price adjustment costs the average price markup differs from the desired level, $\theta_p/(\theta_p - 1)$. Similar to the wage setting problem, there are two countervailing effects of trend growth. On the 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 $\phi = \mu_p^{-1}$ (real wage equals the inverse of the price markup). In this case Eq. (25) and Eq. (26) can be combined to yield

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

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) while $Q_\Gamma > 0$ (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 Eq. (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 so as to restore equilibrium.

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

4 Calibration and Numerical Analysis

We now examine the properties of the macroeconomy above by calibrating the model to the US economy (see Table 1). Most of the calibrated parameters are within a range of values used in the literature (see, e.g., Erceg, Henderson and Levin (2000), Smets and Wouters (2007) and Graham and Snower (2008)). The values of σ and α are taken from Guerron-Quintana (2008) while the values of κ_p and κ_w are calibrated such that they correspond to their Calvo price and wage stickiness parameters, respectively (see, e.g., Chugh (2006), Keen and Wang (2007) and Lombardo and Vestin (2008)), whose estimate is reported in Smets and Wouters (2007). The productivity growth rate is set to be 2% (annualized) while the implied annualized job turnover rate is 0.3, which is consistent with empirical estimates.

Table 1: Parameter configuration

Parameter		Calibrated values
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 labour	5

The calibrated value of Γ implies an annualized productivity growth rate of 2%. The value of σ is set such that the degree of consumption smoothing is at the lower end of reported estimates in the literature with nonseparable utility. For instance, Guerron-Quintana (2008) reports values of σ as large as 23 in a New-Keynesian model with Calvo-type price and wage staggering. Inline with Graham and Snower (2008) we set $\theta_w = 5$ as a baseline value and assume $\theta_p = \theta_w$.[13] 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 below.

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

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

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 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).
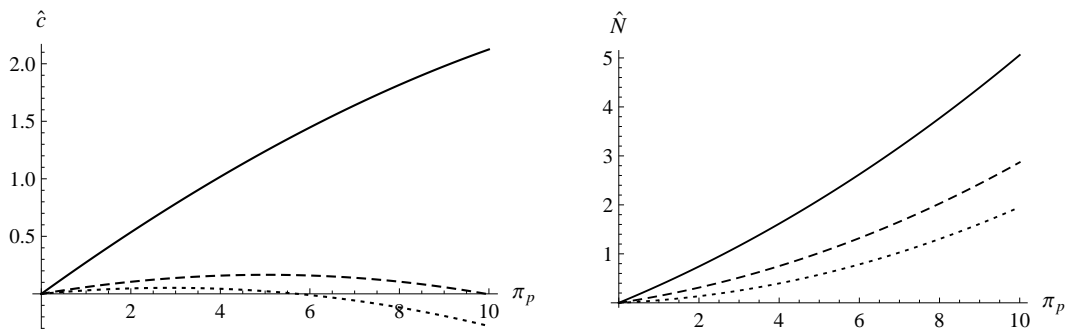

Figure 1: The steady-state relation between real variables and inflation (i) in the absence of trend growth and job turnover ($\gamma = 0\%, \delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%, \delta = 0$, dashed line) and (iii) in the presence of trend growth and job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

Figure 1 shows our main result. The left panel of the figure shows the relation 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.

Note that the relationship between inflation and consumption is concave while that between inflation and employment is convex. The reason behind this result is the convex nature of price and wage adjustment costs. A given rise in the 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 is 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,

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consumption is lower the higher is 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 the inflation rate 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 Eq. (25)), the wage markup ϕ/MRS (see Eq. (27))as well as the consumption-employment wedge N/c (see Eq. (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 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, the wage markup and the consumption-employment wedge, shown, respectively, in the left, middle and right panel of the figure, decrease 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 markups raise employment given consumption, while the fall 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 discussion above, 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.[14] In the presence of trend growth but in the absence of job turnover the magnitude of the decline in the price and wage markups are quantitatively similar. For e.g., a rise in inflation from zero to 10 percent lowers the price markup by 0.34 percent and the wage markup by 0.54 percent.

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[14]Note that since 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.
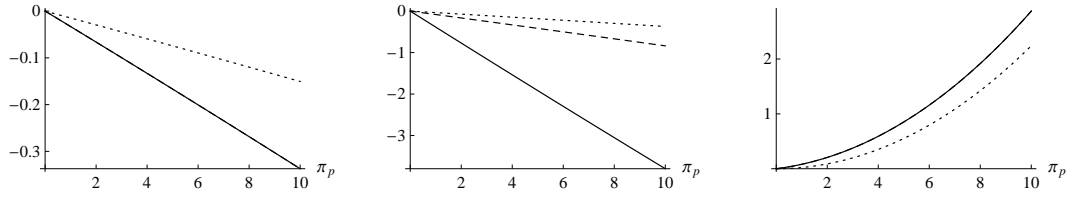
Figure 2: Steady state price markup (left panel), wage markup (middle panel) and consumption-employment wedge (right panel) (i) in the absence of trend growth and job turnover ($\gamma = 0\%, \delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%, \delta = 0$, dashed line) and (iii) in the presence of trend growth and job turnover ($\gamma = 2\%, \delta = 0.3$, solid line).

In the presence of both trend growth and job turnover the corresponding drop in the wage markup, 2.5 percent, 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.
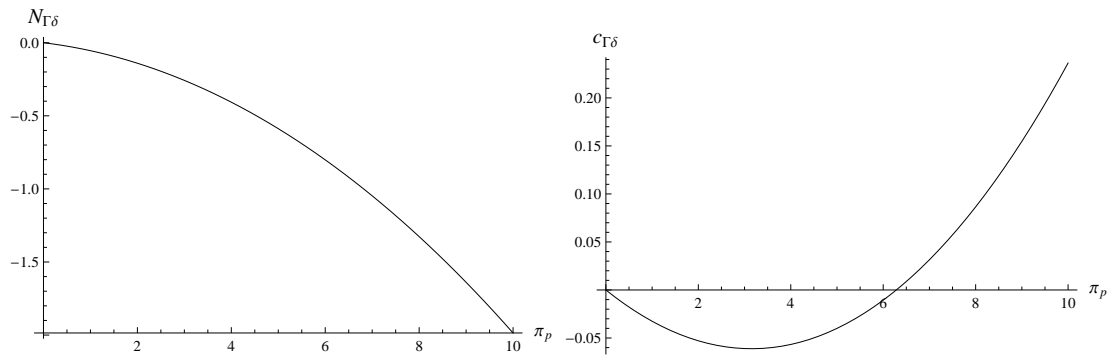

Figure 3: Complementarity between trend growth and job turnover in employment (left panel) and consumption (right panel).

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

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complementary.

4.3 The Influence of Consumption Smoothing

In order to see how the degree of consumption smoothing matters for our results, Figure 4 shows the relationship between output and inflation as well as between 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 the resource cost effect of trend growth dominates the wage markup effect.
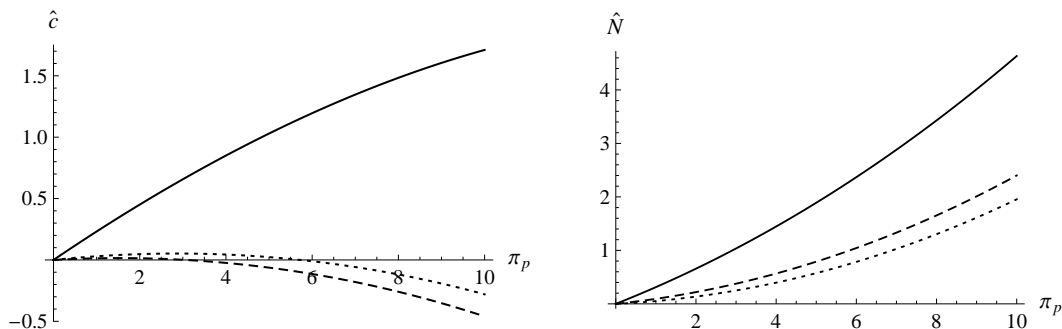

Figure 4: The steady-state relation between real variables and inflation under log separable utility (i) in the absence of trend growth and job turnover ($\gamma = 0\%, \delta = 0$, dotted line), (ii) in the presence of trend growth only ($\gamma = 2\%, \delta = 0$, dashed line) and (iii) in the presence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

4.4 Price and Wage Indexation

Figure 5 shows the relationship 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).
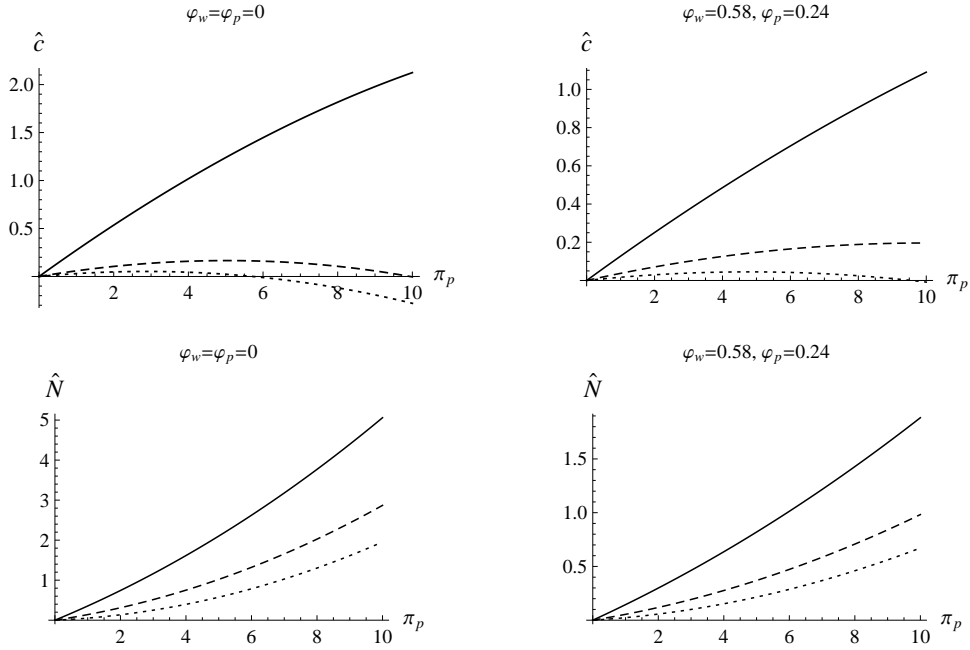
Figure 5: The steady-state relation between real variables and inflation with and without partial indexation.

As can be seen from the figure the presence of indexation does not alter qualitatively the long-run relationships under discussion. 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 resulting that the presence of indexation weakens the response of real variables to inflation is a general feature of models with nominal rigidity.

4.5 The Elasticity of Substitution Between Goods and Between Labour Services

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

In the figure $\theta_p = \theta_w$ take 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 larger is the elasticity of substitution between goods and between
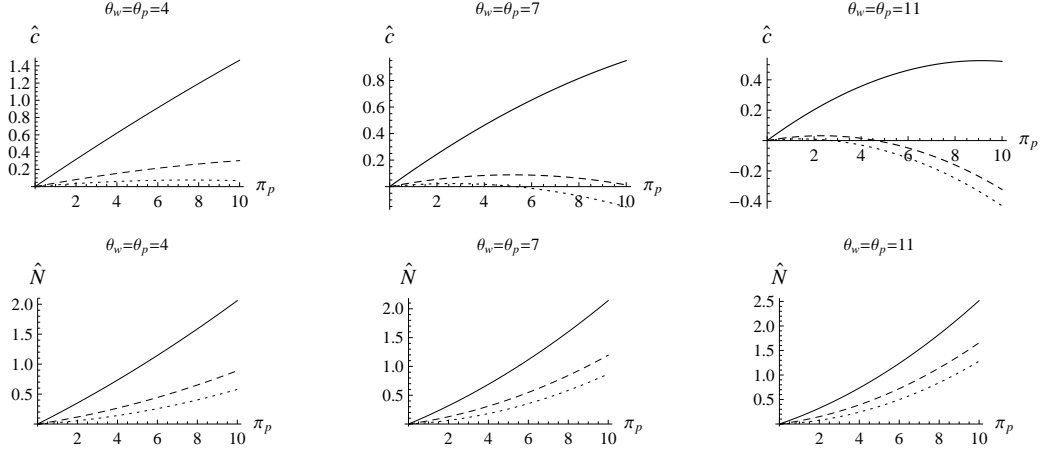
Figure 6: The steady-state relation between real variables and inflation under alternative values of the elasticity of substitution between goods θ_p and labour services θ_w.

labour 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 sub-section 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 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 while higher trend growth lowers the wage and price markups if the degree of consumption smoothing is large 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[15]

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

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[15]For simplicity we abstract from wage and price indexation.

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

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,

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

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

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 labour types whose wages are set in the past (as captured by Eq. (30)). In anticipation, wage setters choose a higher markup than is implied by zero wage inflation, as is shown in Eq. (29). The result is higher wage dispersion across differentiated labour types and more inefficiency associated with imperfect substitutability among these labour types labour types, as shown in Eq. (31). Equations (32), (33) and (34) show analogous effects when steady state price inflation is positive.

Next, Eq. (29) shows that by reinforcing time discounting higher job turnover δ lowers the optimal wage markup. It also shows that the higher trend growth lowers the optimal wage markup if the degree of consumption smoothing is large enough. From Eq. (29) higher wage inflation increases the optimal wage markup while higher consumption growth has two opposing effects. On the one hand, it implies higher growth of the marginal rate of substitution between consumption and labour, and thus higher optimal wage markup, as it reinforces the markup-eroding effect of positive wage inflation. This effect is stronger the larger is the elasticity of substitution between differentiated labour types θ_w. On the

other hand, it implies higher real interest rate, and thus lower optimal wage markup, as it reinforces time discounting. This effect is stronger the larger is the degree of consumption smoothing (i.e., the value of α or σ is larger).

From Eq. (32) higher consumption growth also has two opposing effects on the optimal price markup. On the 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 higher real interest rate and thus 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 due to higher wage dispersion. The wage dispersion effect depends crucially on the elasticity of substitution between differentiated labour 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 under the Rotemberg model.

As pointed out, for e.g., by Bakhshi et al. (2003) and Graham and Snower (2008), a drawback of Calvo nominal staggering is that 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 Inflation Rate

In this section we discuss the optimal level of 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 an optimal inflation is given by $\partial U(c(\Pi_p), N(\Pi_p))/\partial \Pi_p = 0$, implying

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

Since c and N are non-linear 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%.[16]

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 Eq. (25)). The result is that, employment rises less strongly to a given rise in price inflation (see Figure 1) and so does consumption (see Eq. (26)). The result that the optimal inflation rate is lower in the absence of job turnover implies that the consumption effect dominates the employment effect of removing the job turnover channel.

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 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.[17] In the model, the absence of trend growth has two implications (i) as is the case of no job turnover, the intertemporal asymmetry due to discounting becomes weaker implying higher wage markup (Eq. (25)) and higher price markup (Eq. 27)), and (ii) wage growth, and thus the resource cost of wage adjustments, is lower at any given price inflation so that consumption is higher at any given employment (Eq. (26)). Thus, unlike the case of no job turnover, here the resource cost effect dampens the discounting effect on

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

[17]See Kiley (2003) for a detailed discussion of the postwar relationship between productivity growth and inflation in the U.S.

consumption.[18] This explains why the optimal inflation rate is higher in the absence of trend growth—the employment effect dominates the consumption effect 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.

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 Eqs. (25) and (27)) and so does consumption (see Eq. (26)). However, the effect on consumption is more muted, since the less costly are price and wage adjustments, the higher is consumption given employment (see Eq. (26)). The optimal inflation rate is thus higher in the presence of indexation.

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

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 above (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.

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

6 Concluding remarks

In the standard New Keynesian model higher trend inflation (equivalently, higher long-run money growth) imparts contractionary long-run effect on real macroeconomic activity except at level 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) are shown to impart a substantial expansionary influence on 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 effects, trend growth and job turnover are substitutes when inflation is low enough and complementary when inflation is high enough.

Finally, in the presence of trend growth and job turnover and under 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.

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.

Wage setting. From 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

while the first order condition for optimal wage setting is given by

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

where W_t^*/W_t is the optimal relative wage and $MRS_t = (1-\alpha)C_t/(\alpha(1-N_t))$.[19]

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 with respect to $P_{k,t} = P_t^*$ (because all optimizing firms face 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 non-optimized wages[20]

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

The aggregate price level can also be expressed in terms of optimized and non-optimized 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 labour market clearing, we get a relationship between N_t and y_t,

$$N_t = \int_0^1 N_t^j dj$$

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[19] Note that, since all labour types whose wages are reset face an identical optimization problem, all set an identical relative wage.

[20] We assume that among the newly opened labour 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 labour market types is identical to that across existing labour market types.

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

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

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

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

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

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 ($\phi_t = W_t/P_t A_t$, $c_t = C_t/A_t$, $y_t = Y_t/A_t$) 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) of the main text. Moreover, in steady state, market clearing for all goods implies $c = y$ so that $N = (\Delta_w \Delta_p)c$.

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