Macroeconomic Dynamics, **23**, 2019, 1703–1719. Printed in the United States of America.
doi:10.1017/S1365100517000402

NOTE

A NOTE ON TREND GROWTH, UNEMPLOYMENT, AND OPTIMAL MONETARY POLICY

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We analyze the implications of trend growth for optimal monetary policy in the presence of search and matching unemployment. We show that trend growth interacts importantly with the inefficiencies stemming from the labor market. Higher trend growth exacerbates the inefficiencies of the labor market and therefore calls for larger deviations from price stability. Our analysis implies that lower trend growth reduces not only the level but also the optimal volatility of the nominal interest rate.

Keywords: Trend Growth, Unemployment, Optimal Monetary Policy, Labor Market Frictions, Policy Trade-Off

1. INTRODUCTION

The slow recovery after the Great Recession experienced in many countries sparked a new debate about whether gross domestic product (GDP) growth has declined permanently. Some economists argue that the slowdown in GDP growth is not a recent phenomenon but a trend that has started long before that [see, e.g., Fernald (2014) and Gordon (2014) for a US perspective and OECD (2015) for a global perspective on past and future productivity growth]. In this paper, we show that changes in trend growth have an impact on business cycle dynamics, on the inefficiencies of the labor market and thereby on optimal monetary policy.

We build on known results from the literature on optimal monetary policy in the presence of labor market frictions [e.g., Thomas (2008), Faia (2009), Ravenna and Walsh (2011), Lechthaler and Snower (2013), Faia et al. (2014)]. The main finding in this literature is that optimal monetary policy deviates from price stability in response to inefficient employment fluctuations implied by labor market distortions. In the special case where labor market outcomes are efficient, maintaining price stability is optimal. We show that higher trend growth exacerbates the effects of labor market distortions, thus calling for larger deviations from price stability.

Financial support from the German Research Foundation within the project "Trend Productivity Growth and Labor Market Frictions in a New Keynesian Business Cycle Model" is gratefully acknowledged. We would like to thank Eric Schaling, Christian Merkl, Ignat Stepanok, and Carl Walsh for helpful comments. All the remaining errors are ours. Address correspondence to: Mewael F. Tesfaselassie, Kiel Institute for the World Economy, Kiellinie 66, 24105 Kiel, Germany; e-mail: mewael.tesfaselassie@ifw-kiel.de.

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https://doi.org/10.1017/S1365100517000402 Published online by Cambridge University Press

When labor market outcomes are efficient, maintaining price stability is optimal regardless of trend growth.

We demonstrate our results in a model with search and matching unemployment, disembodied technological progress [see, e.g., Pissarides (2000)], and Calvo-type nominal price rigidity, [see, e.g., Walsh (2005)].[1] In this framework, we study Ramsey optimal monetary policy in the presence of temporary shocks to productivity and to government spending. As is standard, we consider two sources of labor market distortions—unemployment benefits and the violation of the so-called Hosios condition.[2] Unlike Pissarides (2000), who assumes an exogenous and constant real interest rate, we consider an endogenous real interest rate as a result of intertemporally optimizing, risk-averse consumers.[3]

In our model, higher trend productivity growth affects pricing and employment decisions of forward-looking agents by raising the real rate of interest. The intuition is that, along a balanced growth path higher trend productivity growth implies a steeper consumption profile over time. Given diminishing marginal utility of consumption, households wish to move forward consumption, which puts upwards pressure on the real interest rate.[4] This has two opposing effects. On the one hand, a higher real interest rate (or a higher discount rate) reduces the present discounted value of a worker-firm match, which makes wages less responsive to future labor market tightness. More rigid wages imply more volatile employment, thus exacerbating the inefficiency stemming from the labor market. On the other hand, a higher real interest rate reinforces the markup distortion and the relative price distortion of a given level of inflation. As a result, higher trend growth makes fighting the labor market distortion through monetary policy more costly. The first (second) effect calls for larger (smaller) deviations from price stability.

Under various calibrations of the model, we find that the first effect dominates and thus optimal inflation volatility increases with trend productivity growth. For instance, in our benchmark calibration, which follows Hagedorn and Manovskii (2008) and Arsenau and Chugh (2012), and in the presence of productivity shocks, the optimal reduction in output volatility rises from 4.5% for zero growth to almost 6% for 4% growth.[5]

While our analysis abstracts from issues related to the zero lower bound, our results have some bearing on how trend growth is likely to affect the likelihood of hitting the zero lower bound. As explained above, lower trend growth leads to a lower steady-state real interest rate. Given a constant level of inflation, this also implies a lower nominal interest rate. This has led many to argue that the possible decline in trend growth in the aftermath of the recent financial crisis will raise issues for the average nominal interest rate if inflation targets remain too low, given the constraint associated with the zero lower bound. Our analysis provides a counter-weight to this argument. In the presence of real shocks, we find that the lower the trend growth rate the smaller the optimal volatility in the nominal interest rate, suggesting that, given the average level of the nominal interest rate, the zero lower bound is less likely to be binding when trend growth slows down.[6]

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Apart from the literature on optimal monetary policy in the presence of labor market frictions, our paper is related to a recent literature that analyzes the consequences of trend growth in a business cycle setting. For instance, Amano et al. (2009) examine the effect of productivity growth on the optimal steady-state inflation rate in the presence of Calvo-type nominal wage and price staggering. In a similar New-Keynesian model with nonseparable utility, Tesfaselassie (2013) studies the effect of productivity growth on the government spending multiplier, while Snower and Tesfaselassie (2017) analyze the joint effect of trend growth and job turnover on the optimal steady-state inflation rate. In contrast to these papers, we analyze optimal monetary policy over the business cycle, i.e., in response to temporary shocks.

The rest of the paper is structured as follows. Section 2 describes the model, including the optimization problem of households and firms. Section 3 compares the equilibrium outcomes under the decentralized economy with flexible prices and under the social planner. Section 4 discusses the Ramsey optimal monetary policy and presents the main results of the paper under our benchmark calibration. Section 5 contains our sensitivity analysis. Section 6 provides concluding remarks and suggestions for future work.

2. THE MODEL

We use a standard New-Keynesian model augmented by search and matching frictions in the labor market and exogenous trend growth in labor productivity A_t. In the following, we will only give a brief, intuitive description of the model and discuss the main equations that are relevant for our analysis. For further details, the interested reader is referred to the working paper version—Lechthaler and Tesfaselassie (2015).

The representative household maximizes the lifetime utility

$$E_t \sum_{i=0}^{\infty} \beta^i \frac{C_{t+i}^{1-\sigma}}{1-\sigma}, \tag{1}$$

where β is the subjective discount factor, C_t household consumption, and σ the intertemporal elasticity of substitution. Household members are either employed or unemployed. As in Andolfatto (1996) workers are organized in large household so that consumption of a worker is independent of her employment status.

Production is organized in two sectors. Firms in the intermediate goods sector hire workers subject to search and matching labor frictions and sell their product in a perfectly competitive market to the final goods sector. Firms in the final goods sector produce slightly differentiated consumption goods and sell them under monopolistic competition to the households.

To be able to hire a worker, firms in the intermediate goods sector need to post a vacancy at a cost $A_t\kappa$. Vacancy-posting costs are proportional to labor productivity because otherwise unemployment would converge toward zero in the

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long run (jobs become more and more profitable while the cost of a vacancy stays constant). Free entry of firms implies the following vacancy creation condition:

$$\frac{\kappa}{q(\theta_t)} = a_t p_t^I - \frac{w_t}{A_t} + \beta(1-\delta)\Gamma^{-\sigma} E_t \left[\left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \frac{\Gamma\kappa}{q(\theta_{t+1})} \right], \qquad (2)$$

where $q(\theta_t) = \mu\theta_t^{-\alpha}$ is the probability of a firm to fill a vacancy with θ_t being the tightness of the labor market, the ratio of open vacancies V_t to unemployed workers U_t. Thus, $\kappa/q(\theta_t)$ is the expected cost of hiring a worker. a_t is a temporary productivity shock, p_t^I is the price of the intermediate good, w_t is the wage of the worker, δ is the separation rate, Γ is one plus the growth rate of labor productivity γ, and $c_t = C_t/A_t$. Equation (2) says that in equilibrium the cost of hiring a worker must equal the contemporaneous profits generated by a worker plus the discounted saved hiring costs of the next period, where $\beta(1-\delta)\Gamma^{-\sigma} E_t(c_{t+1}/c_t)^{-\sigma}$ is the effective discount factor, taking account of growth and the risk of separation.

There are two counteracting effects of higher trend growth on the firm's hiring policy for a given level of the relative price p_t^I. On the one hand, it raises the returns from current hiring because, along the balanced growth path, vacancy-posting costs grow at the same rate as labor productivity. So with higher trend growth, hiring today implies larger savings in future hiring costs. On the other hand, higher trend growth lowers the returns from current hiring because higher trend growth lowers the stochastic discount factor or raises the real interest rate, implying that the savings of future vacancy posting costs are discounted more heavily.

Wages are set by Nash-bargaining implying

$$w_t^d = \nu u_b + (1-\nu)\left\{ a_t p_t^I + \beta(1-\delta)\kappa\Gamma^{1-\sigma} E_t \left[\left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \theta_{t+1} \right] \right\}, \qquad (3)$$

where $\nu > 0$ is the bargaining power of the firm and u_b represents unemployment benefits. Given $\sigma > 1$, higher growth has similar effects on the wage as does a lower discount factor or a higher job separation rate, diminishing the surplus of a match and thus the negotiated wage.

Firms in the final goods sector are monopolistic competitors. Thus, they have price setting power. However, price setting is assumed to be subject to Calvo-type price staggering, where ω is the fraction of firms whose prices are fixed in any given period. Those firms that are able to reset their price choose the optimal price

$$p_t^* = \mu_p \frac{E_t \sum_{i=0}^{\infty} \omega^i \beta^i \Gamma^{-\sigma i} \left(\frac{c_{t+i}}{c_t} \right)^{-\sigma} (1-\tau) p_{t+i}^I \Gamma^i \frac{y_{t+i}}{y_t} \left(\frac{P_{t+i}}{P_t} \right)^{\epsilon}}{E_t \sum_{i=0}^{\infty} \omega^i \beta^i \Gamma^{-\sigma i} \left(\frac{c_{t+i}}{c_t} \right)^{-\sigma} \Gamma^i \frac{y_{t+i}}{y_t} \left(\frac{P_{t+i}}{P_t} \right)^{\epsilon-1}}, \qquad (4)$$

where $p_t^* \equiv P_t^*/P_t$, $y_t = Y_t/A_t$, and μ_p is the price markup in the absence of price staggering.

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Under nonzero inflation, trend growth has two counteracting effects on price setting. On the one hand, higher trend growth implies a smaller stochastic discount factor and therefore a lower weight on future variables. On the other hand, higher trend growth implies faster aggregate demand growth. The corresponding optimal relative price depends more on future variables to counteract a potential variation in the markup. Under the assumption $\sigma > 1$, the first effects dominates.

Finally, we allow for government spending that is financed by a lump-sum tax, implying the aggregate resource constraint $y_t = c_t + g_t + \kappa V_t$.

3. EFFICIENCY OF FLEX-PRICE EQUILIBRIUM

This section compares the solution of the social planner economy with the equilibrium allocation under the decentralized economy with flexible prices and where subsidies are used to eliminate the monopolistic distortion in the final goods sector (the optimal level of the subsidy rate τ is set equal to $1/\epsilon$ and implies $p_t^I = 1$). The latter assumption allows us to concentrate on the potential distortions stemming from the labor market. The purpose of this exercise is to show under which conditions the first best outcome is feasible, and to identify the role of trend growth for potential inefficiencies. If the first best outcome is feasible, this implies that zero inflation is optimal at any time, and that the central bank does not face a trade-off.

The social planner's problem is to maximize household utility (1) subject to the employment dynamics equation and the aggregate resource constraint. The optimum implies

$$\frac{\kappa}{q(\theta_t)} = a_t (1-\alpha) + \beta (1-\delta) \Gamma^{1-\sigma} E_t \left[\frac{\kappa}{q(\theta_{t+1})} \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \left(1 - \alpha \frac{M_{t+1}}{U_{t+1}} \right) \right], \tag{5}$$

where M_t is the number of new matches.

For the decentralized economy, using equation (3) in equation (2) and $p^I = 1$ implies

$$\frac{\kappa}{q(\theta_t)} = \nu(a_t - u_b) + \beta(1-\delta)\Gamma^{1-\sigma} E_t \left[\left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \frac{\kappa}{q(\theta_{t+1})} \left(1 - (1-\nu) \frac{M_{t+1}}{U_{t+1}} \right) \right]. \tag{6}$$

Comparing equations (5) and (6), it is clear that the decentralized economy yields the same outcome as the social planner economy if and only if $\nu = 1 - \alpha$ (the so-called Hosios condition) and $u_b = 0$. Under these assumptions, the economy under flexible prices is efficient, and the best that the Ramsey planner can do is to keep inflation at zero at any time to avoid the price distortions that would follow from nonzero inflation. This is so irrespective of the trend growth rate.

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TABLE 1. Parameter configuration

Parameter		Calibrated values
β	Discount factor	0.99
σ	Coefficient of relative risk aversion	5
ω	Fraction of nonoptimizing firms	0.75
ϵ	Elasticity of substitution between final goods	11
Γ	Trend growth	1.005
μ	Scale parameter of the matching function	0.81
α	Elasticity of the matching function	0.4
κ	Cost of posting a vacancy	0.99
δ	Job separation rate	0.1
ν	Firm's share of surplus	0.95
u_b	Unemployment benefits	0.82

However, whenever unemployment benefits are positive and/or the Hosios condition is violated, the labor market does not function efficiently. This implies that the Ramsey planner will have an incentive to deviate from price stability in response to temporary shocks. Put differently, the Ramsey planner will trade off higher price distortions against lower labor market distortions by following activist monetary policy. Interestingly, trend growth interacts with the labor market distortions in a nontrivial way, thus affecting the trade-off faced by the Ramsey planner. In the following, we explore this trade-off in more detail.

4. RAMSEY OPTIMAL MONETARY POLICY

This section looks at the Ramsey optimal monetary policy, whereby the Ramsey planner maximizes household utility subject to the competitive equilibrium under nominal price rigidity and labor market frictions, i.e., the Ramsey planner takes the distortions on the labor market as given. As is standard, we assume that in steady state the monopolistic distortion is eliminated by the use of an appropriate subsidy. This is to ensure that deviations from price stability are only driven by distortions in the labor market.

Table 1 shows the calibration of the model to a quarterly frequency. In this case, the discount factor β is set to 0.99. The elasticity of substitution between final goods and the fraction of nonoptimizing firms are set to values that are standard in the literature. The coefficient of relative risk aversion is within the range of values used in the related literature [see, e.g., Tesfaselassie (2013) and the references therein]. We provide robustness checks with respect to these parameters in Section 5. The trend growth rate in our benchmark calibration is assumed to be 2% (annualized).

To generate the large fluctuations in unemployment found in the data, we follow the calibration approach of Hagedorn and Manovskii (2008). Their calibration approach is based on the idea of shrinking the firm's surplus, thus making hiring more susceptible to business cycle shocks (a shock of the same size leads to a

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larger relative change in the surplus if the steady-state surplus is smaller). The same calibration approach is used in the related literature, e.g., in Arsenau and Chugh (2012) who analyze optimal fiscal policy in the search and matching model. Specifically, we use $\nu = 0.95$ and $u_b = 0.82$, which implies that the steady-state return to nonmarket activity represents 95% of the real wage in the steady state. The quarterly job separation rate δ is equal to 0.1. The scale parameter in the matching function μ and the cost of posting a vacancy κ are set such that the job-finding rate is 0.7 [see, e.g., Blanchard and Gal (2010)] and the job-filling rate is 0.9 [see, e.g., Andolfatto (1996), Arsenau and Chugh (2012)]. Assuming a steady-state unemployment rate U of 12% [see, e.g., Krause and Lubik (2007)], the steady-state mass of vacancies V is pinned down by the definition of θ.

Regardless of the presence of trend growth under the Ramsey optimal policy, the steady-state inflation rate is zero. The reason is that the presence of trend growth does not introduce another distortion. Given zero steady-state inflation, higher trend growth implies lower steady-state employment, as higher trend growth raises the effective discount rate [see, e.g., Tesfaselassie (2014) and the references therein].

The results are shown in terms of impulse responses to a temporary but persistent shock to the economy and under alternative trend growth rates. As in related studies two types of shocks are considered: a shock to transitory productivity a_t and a shock to government spending, both of which are assumed to follow an AR(1) process (i.e., an autoregressive process of order 1). To be specific, $g_t/g = (g_{t-1}/g)^{\rho_g} u_{gt}$, $0 < \rho_g < 1$, and $a_t = a_{t-1}^{\rho_a} u_{at}$, $0 < \rho_a < 1$. In line with previous studies, the autocorrelation coefficients ρ_g and ρ_a are set equal to 0.9, while the standard deviation of the innovations u_{gt} and u_{at} are set equal to 0.01. Moreover, steady-state government spending g represents 20% of aggregate output y.

Figure 1 shows baseline (i.e., assuming 2% annualized trend growth rate) impulse responses of output, unemployment, inflation rate, the nominal rate of interest, labor market tightness and the wage rate to a positive shock to productivity under the Ramsey optimal policy (solid line), the zero-inflation policy (dashed line), and the efficient economy, i.e., under $u_b = 0$ and $\nu = 1 - \alpha$ (dot–dashed line). In the absence of labor market distortions, all three lines would coincide with each other, because then zero inflation would be optimal, but this is not the case in the presence of labor market distortions.

Let us first focus on the efficient economy and the economy under zero inflation (i.e., the decentralized economy). For the reasons given above, the efficient economy exhibits much smaller fluctuations in all quantity allocations, especially the ones related to the labor market, the employment rate, and the tightness of the labor market. In contrast, the wage rate is much more volatile in the efficient economy. The calibration approach of Hagedorn and Manovskii (2008) is designed to generate relatively stable wages by shrinking the surplus of a firm-worker match through a very high threat point of the worker (high unemployment benefits, u_b). The comparison with the efficient economy reveals that this implies inefficiently large fluctuations in employment.[7]

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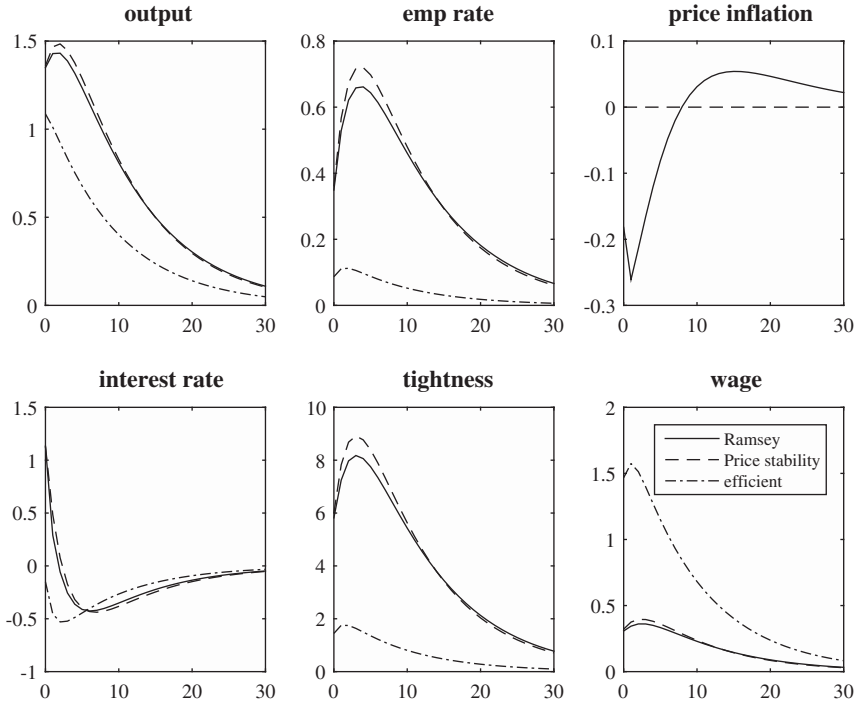


FIGURE 1. Impulse responses to a positive productivity shock under Ramsey optimal policy, zero-inflation policy, and efficient economy.

Thus, the decentralized economy features excess volatility of quantity allocations in response to productivity shocks, which gives the Ramsey planner an incentive to reduce the volatility of the economy. Indeed, in reaction to the rise in labor productivity, the Ramsey planner deviates from price stability and allows a reduction in the inflation rate (by inducing a rise in the real interest rate) so as to smooth output and employment fluctuations.[8] That is, in the presence of nominal price rigidity, the Ramsey planner uses the aggregate demand channel to reduce demand for the final good and in turn demand for the intermediate good. The resulting reduction in the relative price of the intermediate good p_t^I implies that, given the productivity shock a_t and the wage rate w_t, the marginal revenue product of labor, and in turn the match surplus, also decline. At the same time, a reduction in p_t^I implies a reduction in the real marginal cost of final good producers and therefore a corresponding reduction in the optimal relative price p_t^*. Finally, a reduction in p_t^* implies, by definition, lower inflation.

The deviation from price stability is due to the presence of labor market distortions associated with the violation of the Hosios condition (in particular, $\nu > 1-\alpha$—bargaining power of firms is larger than the elasticity of matches with respect to vacancies) and the presence of unemployment benefits ($u_b > 0$). As

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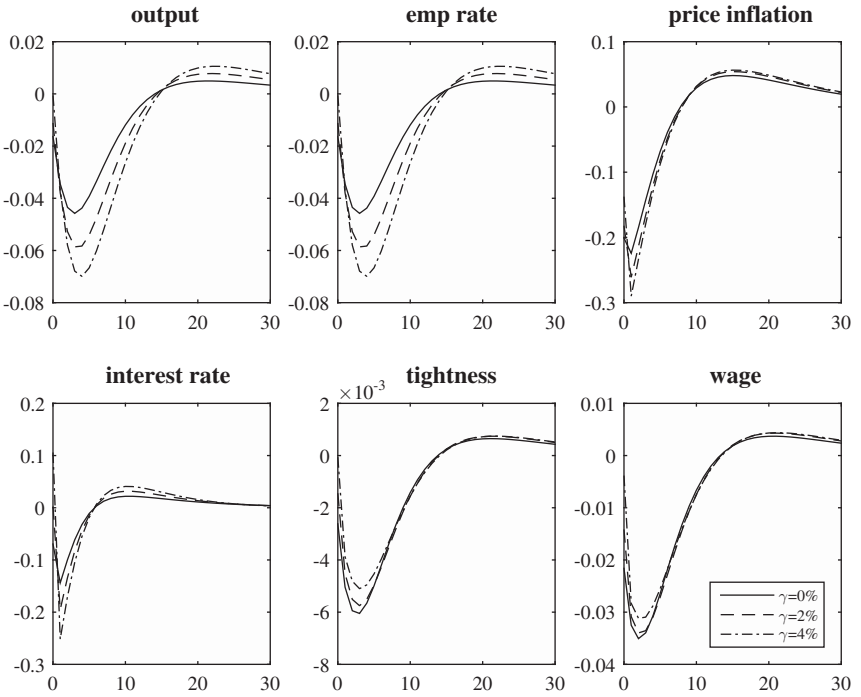


FIGURE 2. Impulse responses to a positive productivity shock and alternative trend growth rates. Deviation of the Ramsey optimal policy from price stability.

we demonstrate in the robustness section, the presence of unemployment benefits is especially important. It implies that the wage rate is relatively insensitive to the rise in productivity and therefore job creation and employment are relatively excessive. In order to partially offset the resulting distortions, the Ramsey planner deviates from price stability and induces a smaller rise in match surplus than is the case under price stability. This in turn implies that the wage rate is more stable under the Ramsey planner than under price stability.

Turning next to the effect of trend growth on the optimal plan, Figure 2 shows the gap between the Ramsey optimal plan and the zero-inflation policy under alternative values for the annualized trend growth rate—namely, 0%, 2% (baseline), and 4%. We see that the Ramsey planner induces the largest fall in inflation, and correspondingly the largest fall in the output and employment volatilities relative to the case of price stability, under the 4% growth rate (dashed line).[9]

This is the outcome of two opposing effects of higher trend growth. On the one hand, higher trend growth reinforces the excessive job creation, in response to positive productivity shocks, stemming from firms having excessive bargaining power. As discussed above, this excessive bargaining power of firms implies that the wage rate is relatively insensitive to a given rise in future labor market tightness

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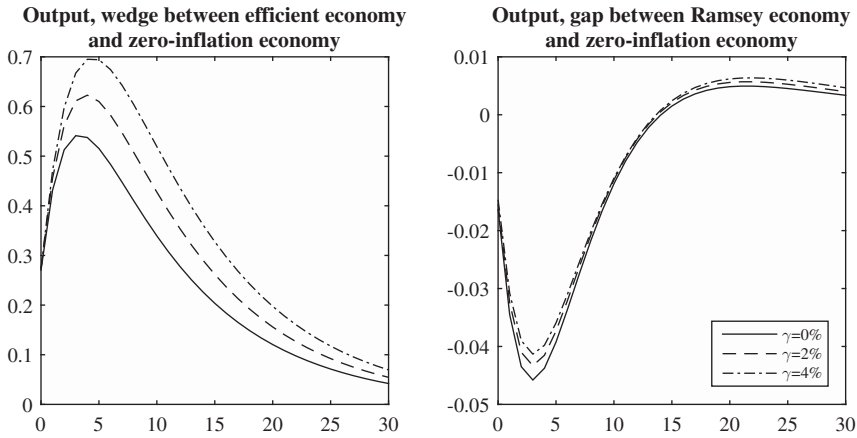


FIGURE 3. The dynamic output wedge (i) between the efficient economy and the zero-inflation economy in the baseline model (left panel) and (ii) between the Ramsey economy and the zero-inflation economy in the counterfactual model (right panel).

associated with the persistent rise in productivity. This, in turn, makes the surplus of the firm, which is driving firm hiring, excessively volatile. By raising the effective discount rate, higher trend growth reduces the surplus of the firm, and strengthens the insensitivity of the wage rate to a given productivity shock, which results in an increase in the output wedge between the efficient economy and the zero-inflation economy.[10] This effect is illustrated by the left panel of Figure 3, which shows that higher trend growth increases the wedge between output under the efficient economy and the corresponding one under zero-inflation policy. This increase in the output wedge reflects the strengthening of labor market distortions due to higher trend growth.

On the other hand, higher trend growth reinforces the markup distortion and relative price distortion of a given rise in the real interest rate (a given fall in aggregate demand). As discussed above, the Ramsey planner dampens the response of employment to higher productivity by raising the nominal interest rate so as to reduce demand for the final good and in turn demand for the intermediate good. The latter effect lowers p_t^I (which is the current real marginal cost) and thus lowers the optimal relative price p_t^*. By raising the effective discount rate, higher growth raises the sensitivity of p_t^* (and in turn inflation) to a given reduction in p_t^I, and therefore raises the cost (in terms of markup distortion) of mitigating a given degree of labor market distortion.[11]

Interestingly, while our analysis abstracts from issues related to the zero lower bound, our results have some bearing on how lower trend growth is likely to affect the likelihood of hitting the zero lower bound. As can be seen from Figure 2, the lower the trend growth rate, the smaller the optimal volatility in the nominal interest rate, suggesting that, given the average level of the nominal interest rate,

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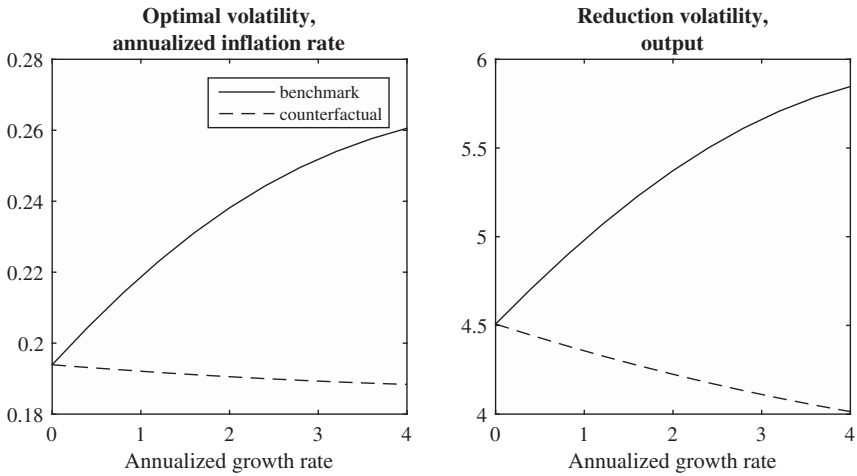


FIGURE 4. The effect of trend growth on the optimal inflation volatility and the optimal reduction in output volatility in the baseline model (solid lines) and the counterfactual model (dashed lines).

the zero lower bound is less likely to be binding when trend growth slows down.[12] This result is novel and shows that the link between trend growth and the nominal interest rate goes beyond the steady-state relationship.

In order to illustrate the reinforcement of the markup distortion by trend growth, the right panel of Figure 3 shows the gap in output between the Ramsey economy and the zero-inflation economy in a counterfactual scenario where the labor market effect of trend growth is suppressed—i.e., the degree of labor market distortion is unchanged as trend growth rises. This is achieved by assuming that the trend growth rate does not show up in the wage equation and the value of a filled job. We see that the gap in output is now smaller at higher levels of trend growth, while it is the opposite in the baseline model. In line with our discussion above, the higher markup distortion associated with higher trend growth, given an unchanged degree of labor market distortion, moves the Ramsey plan toward price stability—thus the smaller the deviation of output relative to the zero-inflation policy.

Figure 4 shows the optimal inflation volatility and the optimal reduction in output volatility as a function of the annualized trend growth rate over the interval [0%, 4%]. The dashed lines illustrate what happens under the counterfactual scenario, where trend growth does not affect the labor market distortions, while the solid lines illustrate our baseline case, taking into account the strengthening of labor market distortions due to higher trend growth. We see that in the counterfactual scenario there is a negative relationship between trend growth and inflation volatility. Consistent with this outcome, there is a negative relationship between trend growth and the magnitude of the reduction in output volatility relative to the zero-inflation economy.

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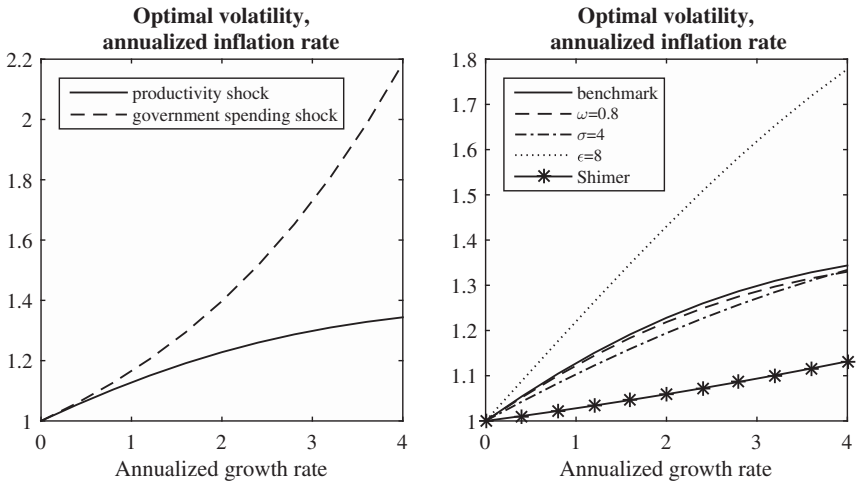


FIGURE 5. The effect of trend growth on the optimal inflation volatility. Sensitivity.

The solid lines in Figure 4 show contrasting outcomes to those in dashed lines—i.e., in the baseline model there is a positive relationship between trend growth and inflation volatility and between trend growth and the magnitude of the reduction in output volatility. This result indicates that the strengthening, due to higher trend growth, of labor market distortions dominates the corresponding strengthening of markup distortions. The figure also illustrates that the effect of trend growth is quantitatively important. Under zero growth, the reduction in output volatility induced by the Ramsey planner is 4.5%, while it is about 6% under a growth rate of 4%, an increase of one third.

5. SENSITIVITY ANALYSIS

Our benchmark result regarding the optimal deviation from price stability is not specific to the presence of a productivity shock. Other types of shocks, such as a government spending shock, that take the economy off steady state also imply deviations from price stability. To illustrate this, the left panel of Figure 5 shows the effect of trend growth on the optimal inflation volatility under a positive productivity shock (solid line, which replicates the benchmark case shown in the left panel of Figure 4, with the difference that it shows inflation volatility relative to the zero growth level) and a positive government spending shock (dashed line). As with the productivity shock, the higher the trend growth rate, the larger the deviation from price stability.[13]

The right panel of Figure 5 shows sensitivity of our benchmark result under alternative calibrations of some model parameters—the Calvo parameter ω, the risk aversion parameter σ, and the elasticity of substitution parameter ϵ. Moreover, we also consider an alternative calibration as in Shimer (2005)—which involves

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changing the firms's share of surplus ν and the unemployment benefits u_b. As can be seen from the figure, the baseline result that higher trend growth is associated with higher optimal inflation volatility holds under the alternative calibrations, even though to a different degree depending on the particular parameter.

First, relative to the benchmark calibration ($\omega = 0.75$), the alternative calibration $\omega = 0.8$ represents a stronger degree of nominal price rigidity, because the firm has a lower probability to reset its price. Considering the effect on the optimal volatility of inflation, a rise in ω has two opposing effects. On the one hand, the co-movement between the optimal price of a firm and marginal cost is strengthened. On the other hand, the co-movement between the optimal price of a firm and inflation is weakened.

More rigid prices imply that an optimizing firm worries more about having a markup that is relatively high, in the face of a declining price level induced by lower aggregate demand. In this case, the optimal relative price is less sensitive to a reduction in the current real marginal cost, which implies lower markup distortions. Put differently, a given movement in the marginal cost is associated with a larger movement in the optimal relative price. This effect alone calls for more inflation volatility, but is weaker when the trend growth rate is higher. However, the larger is ω, the smaller is the implied (mechanical) drop in inflation of a given fall in the optimal relative price around the initial steady state. This effect calls for lower inflation volatility, and dominates the first effect, the markup effect. Furthermore, the second effect is independent of trend growth and, thus, the line under $\omega = 0.8$ is flatter than in the benchmark case.

Analogous effects are at play in the case of changes in the value of ϵ. The alternative calibration $\epsilon = 8$ represents a weaker degree of substitution between final goods than in the benchmark $\epsilon = 11$. On the one hand, it implies that relative demand is less price elastic so that an optimizing firm worries less about having a markup that is relatively high, in the face of a declining price level induced by lower aggregate demand, in case the firm does not get a chance to reset its price. In this case, the optimal relative price is more sensitive to a reduction in real marginal cost. It implies larger markup distortions and calls for lower inflation volatility. As before, this effect is weaker at higher trend growth rates. On the other hand, the smaller is ϵ, the larger is the implied drop in inflation of a given fall in the optimal relative price around the initial steady state. This effect calls for larger inflation volatility and is independent of trend growth. Therefore, the line under $\epsilon = 8$ is steeper than the corresponding one under the benchmark case.

Next, the alternative calibration $\sigma = 4$ represents a lower degree of consumption smoothing than the benchmark case with $\sigma = 5$ and thereby implies higher sensitivity of consumption and aggregate demand to changes in the real interest rate. In this case, the Ramsey planner is able to stabilize the economy with a smaller deviation from price stability than implied by the benchmark calibration. At the same time, a lower degree of consumption smoothing weakens both the labor market and markup distortions. This implies less inflation volatility because a lower degree of consumption smoothing has effects similar to lower trend

https://doi.org/10.1017/S1365100517000402 Published online by Cambridge University Press

growth. Moreover, from the definition of the stochastic discount factor, this effect is stronger at higher trend growth rates. Therefore, the line under $\sigma = 4$ is flatter than the corresponding one under the benchmark case.

Finally, under a Shimer-like calibration—$\nu = 0.5$ (symmetric bargaining power) and $u_b = 0.36$, implying a relatively low replacement rate of 40%—labor market inefficiencies are less severe than implied by the baseline case. As a result, the optimal inflation volatility is lower. Moreover, smaller values of ν and u_b imply that the relationship between higher trend growth and a more rigid wage rate is somewhat weaker. Therefore, the line under the Shimer-like calibration is flatter than its counterpart under the benchmark case.

To summarize, while changes in the considered parameters have quantitative implications, the main result of the paper, that higher trend growth optimally implies larger inflation volatility, is robust to these changes.

6. CONCLUDING REMARKS

We study the implications of trend productivity growth for Ramsey optimal monetary policy in the presence of nominal rigidity and search and matching frictions in the labor market. We build on insights from two strands of the recent literature, one of which incorporates trend growth in the standard New-Keynesian model but abstracts from Ramsey optimal monetary policy or labor market frictions, while the other studies Ramsey optimal monetary policy in the presence of labor market frictions but abstracts from considerations of trend growth.

We show that higher productivity growth lowers the effective discount factor and thereby amplifies the inefficiencies due to labor market distortions (arising from the presence of unemployment benefits and higher wage bargaining power of firms). In this environment, the higher the trend growth rate, the less responsive is the wage rate, and the more excessive is job creation, to aggregate shocks (e.g., productivity and government spending shocks). As a result, the Ramsey planner deviates further from price stability so as to stabilize job creation and employment. The deviation from price stability is somewhat weakened by a second effect of trend growth, which amplifies the inefficiencies due to markup distortions (arising from monopolistic competition and nominal price staggering). By calibrating the model to the US economy, we show that, under zero growth, the reduction in output volatility induced by the Ramsey planner is 4.5%, while it is about 6% under a growth rate of 4%, an increase of one third.

In our analysis, productivity growth arises from disembodied technological progress. Aghion and Howitt (1994) analyze the steady-state effect of growth on unemployment and identify a creative destruction effect brought about by embodied technological progress. They show that by reducing the duration of an existing job match faster growth leads to higher job destruction and therefore higher long-run unemployment. A possible extension of our analysis is thus to allow for embodied technological progress and thus endogenous job destruction. We consider this a potential topic for future research.

https://doi.org/10.1017/S1365100517000402 Published online by Cambridge University Press

Another potential topic for future research is the incorporation of the zero lower bound on the nominal interest rate. Many have argued that the possible decline in trend growth in the aftermath of the recent financial crisis will raise issues for the average nominal interest rate if inflation targets remain too low, given the constraint associated with the zero lower bound. While our analysis abstracts from issues related to the zero lower bound, our results have some bearing on how trend growth is likely to affect the likelihood of hitting the zero lower bound. Interestingly, in the presence of real shocks, we find that the lower the trend growth rate, the smaller the optimal decline in the nominal interest rate, suggesting that, given the average level of the nominal interest rate, the zero lower bound is less likely to be binding when trend growth is low. It would be interesting to explore whether this holds in a model with explicit consideration of the zero lower bound constraint.

NOTES

1. In the presence of disembodied technological progress, trend productivity of workers increases each period at an exogenous rate, and all workers operate with the same, most recent technology. This is in contrast with embodied technological progress, under which only newly hired workers can use the latest technology. Pissarides and Vallanti (2007) provide empirical evidence in favor of disembodied technological progress.

2. According to Hosios (1990), the labor market works efficiently if the bargaining power of firms equals the elasticity of the matching function.

3. See Tesfaselassie (2014) for a discussion and additional references.

4. This is in line with the empirical evidence in, e.g., Hamilton et al. (2015) who find that the growth rate is one of the factors affecting the natural interest rate, although not the only one.

5. As is well known, [see, e.g., Shimer (2005) and Costain and Reiter (2008)] the standard calibration of the search and matching model is not able to generate the large fluctuations in employment observed in the data. Hagedorn and Manovskii (2008) suggest an alternative calibration strategy that is based on a very high threat-point of the worker and a very high bargaining power of the firm. This shrinks the surplus of a match and makes the wage rate relatively rigid over the business cycle, because it now depends primarily on the threat-point of the worker. A more rigid wage in turn implies large fluctuations in employment. However, as already demonstrated by Arsenau and Chugh (2012), these fluctuations are largely inefficient, calling for business cycle stabilization. More specifically, monetary policy can use inflation to dampen markup fluctuations, and thus make employment more stable [see Faia (2009)]. In our sensitivity analysis, we also consider government spending shocks and find similar qualitative results.

6. We thank Carl Walsh for pointing out the implication of our analysis for the zero lower bound. Needless to say, one has to exercise care in interpreting this result. Whether the zero lower bound binds also depends critically on the size of the shocks hitting the economy. Indeed, the large negative shocks that led to the recent financial crisis have led to a binding zero lower bound.

7. This is in line with Arsenau and Chugh (2012) who also use a search and matching model under the Hagedorn-Manvoskii calibration but analyze optimal fiscal policy.

8. The magnitude of inflation volatility is low but in line with similar studies [see, e.g., Faia (2009) or Ravenna and Walsh (2011)].

9. Note that a larger negative gap in Figure 2 implies larger negative deviation from the zero-inflation economy and thus lower volatility.

10. Put differently, the Hagedorn Manovskii calibration approach generates large volatility in unemployment by reducing the surplus of the firm. Higher trend growth pushes down the surplus of the firm even more and thus makes unemployment more volatile.

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11. Note that a stronger reduction in p_t^* due to higher trend growth also implies higher price dispersion. This effect alone, which increases relative price distortion and thereby lowers output, partly mitigates the excessive rise in output implied by the rise in the markup distortion.

12. The overall effect of a lower trend growth rate on the likelihood of the zero lower bound depends on the interaction between the well-known steady-state effect, as implied by the consumption Euler equation, and the business cycle effect shown in Figure 2.

13. We remark that, in line with previous studies [see, e.g., Faia (2009), Faia et al. (2014), or Lechthaler and Snower (2013)] the optimal inflation volatility in our model is smaller under a government spending shock than under a productivity shock. For instance, under a zero trend growth rate, the optimal volatility with a government spending shock is about 0.04 compared to about 0.2 under a productivity shock. The reason is that higher government spending crowds out household consumption so that aggregate output, and in turn employment, rises less strongly than under a positive productivity shock, which implies that the output wedge moves by less.

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