Annicchiarico, Barbara; Pelloni, Alessandra; Rossi, Lorenza

Working Paper

Endogenous Growth, Monetary Shocks and Nominal Rigidities

Quaderni di Dipartimento, No. 120

Provided in Cooperation with:
University of Pavia, Department of Economics and Quantitative Methods (EPMQ)

Suggested Citation: Annicchiarico, Barbara; Pelloni, Alessandra; Rossi, Lorenza (2010) : Endogenous Growth, Monetary Shocks and Nominal Rigidities, Quaderni di Dipartimento, No. 120, Università degli Studi di Pavia, Dipartimento di Economia Politica e Metodi Quantitativi (EPMQ), Pavia

This Version is available at:
https://hdl.handle.net/10419/95315

Quaderni di Dipartimento

Endogenous Growth, Monetary Shocks and Nominal Rigidities

Barbara Annicchiarico
(Università Tor Vergata di Roma)

Alessandra Pelloni
(Università Tor Vergata di Roma)

Lorenza Rossi
(Università di Pavia)

120 (08-10)

Dipartimento di economia politica
e metodi quantitativi
Università degli studi di Pavia
Via San Felice, 5
I-27100 Pavia

Agosto 2010

Endogenous Growth, Monetary Shocks and Nominal Rigidities*

Barbara Annicchiarico† Alessandra Pelloni‡ Lorenza Rossi§

August 2010

Abstract

We introduce endogenous growth in an otherwise standard NK model with staggered prices and wages. Some results follow: (i) monetary volatility negatively affects long-run growth; (ii) the relation between nominal volatility and growth depends on the persistence of the nominal shocks and on the Taylor rule considered; (iii) a Taylor rule with smoothing increases the negative effect of nominal volatility on mean growth.
Keywords: Growth, volatility, business cycle, monetary policy.
JEL codes: E32, E52, O42.

1 Introduction

Traditionally, macroeconomists considered growth and business cycles are separated research areas. However, following the seminal paper by Ramey and Ramey (1995) many theoretical and empirical contributions have studied the relationship between volatility and long-run growth (for a comprehensive treatment of the literature see Steindl and Tichy 2009). The existence of a relationship between growth and volatility has important policy implications as it suggests the possibility that policies designed to stabilize short-run fluctuations might affect the long-run performance of the economy.

In this paper we study the relationship between output growth and volatility of money shocks in a New Keynesian (NK) model characterized by endogenous growth *à la* Romer (1986) and

*A detailed appendix is available from the authors upon request.

†Corresponding Author: Department of Economics, University of Rome 'Tor Vergata', via Columbia 2, 00133 Roma, Italy. E-mail: Barbara.Annicchiarico@uniroma2.it. Phone: +390672595731.
‡Department of Economics, University of Rome 'Tor Vergata'.
§Department of Economics and Quantitative Methods, University of Pavia.

nominal rigidities due to both staggered price and wage setting.[1] The monetary rule is of the Taylor-type. To the best of our knowledge we are the first to study the relationship between volatility and growth using this setup. Indeed, very few papers analyze this relationship in the context of monetary models, thus taking into account the implications of nominal volatility (see e.g. Evans and Kenc 2003, Dotsey and Sarte 2000 and Varvarigos 2008). An even smaller subset introduce nominal rigidities (see e.g. Blackburn and Pelloni 2004, 2005 and Annicchiarico *et al.* 2010), but only in the form of one-period nominal wage contracts. Third, we are the first to consider staggered prices together with staggered wages. In this way, we are able to distinguish the role the two rigidities play in affecting the relationship between nominal volatility and growth. Finally, as far as we know, our paper is the first to study the relationship between volatility and growth with a monetary authority which smooths the business cycle by adopting a Taylor-type rule. Our main results are: (i) the model implies a non-negligible negative relationship between nominal volatility and growth; this is interesting because explaining the negative correlation between the volatility and the mean rate of output found in the data has proved a challenge for the theoretical literature.[2] This is true even if we adopt a logarithmic specification of utility under which precautionary saving induces, by itself, a positive effect of uncertainty on growth;[3] (ii) this effect depends upon the type of the Taylor rule considered and upon the interaction between the two staggering mechanisms; (iii) by implementing a Taylor-rule with smoothing the monetary authority increases the (negative) effects of nominal volatility on long-run growth. The key point is that the literature on monetary policy cannot disregard the role that nominal rigidities and the type of monetary rule adopted have in the transmission of uncertainty on long-term growth.

The paper is organized as follows: section two describes the model setup. Section three analyzes the relationship between nominal rigidities and growth under different Taylor-type rules and concludes.

[1] Vaona (2010) also uses a NK model with endogenous growth to study the relationship between inflation and growth.

[2] For different but by no means not alternative explanations, see Aghion *et al.* (2010), who introduce credit constraints, and Krebs (2003), who introduces idiosyncratic shocks to human capital accumulation.

[3] See de Hek and Roy (2001) and Jones *et al.* (2005).

2 The model

The economy is described by a standard NK model with prices and wage rigidities (see Galí 2008), extended to include endogenous capital accumulation, convex investment adjustment costs and an endogenous growth mechanism with serendipitous learning by doing *à la* Romer (1986). The monetary authority follows a Taylor-type rule.

2.1 Firms and Endogenous Growth

In each period, the final good Y_t is produced by perfectly competitive firms, using the intermediate inputs produced by the intermediate sector, with the standard technology: $Y_t = \left[\int_0^1 Y_{j,t}^{(\theta_p-1)/\theta_p} dj\right]^{\theta_p/(\theta_p-1)}$, with $\theta_p > 1$. There is a continuum of monopolistic competitive intermediate good-producing firms $j \in (0,1)$ each of which produces a differentiated output $Y_{j,t}$ using the following technology

$$Y_{j,t} = AK_{j,t}^{1-\alpha} \left(Z_t N_{j,t}\right)^{\alpha}, \quad \alpha \in (0,1), \, A > 0. \tag{1}$$

$K_{j,t}$ is physical capital (final good) and $N_{j,t}$ are labor hours from the aggregator combining household-specific labor services supplied in a monopolistic competitive market. A is a constant term. Z_t represents an index of knowledge, taken as given by each firm, which is freely available to all firms and which is acquired through learning-by-doing. In particular we assume $Z_t = K_t$, where $K_t = \int_0^1 K_{j,t} dj$.

Prices are modeled *à la* Calvo (1983). In each period there is a fixed probability $1 - \xi_p$ a firm in the intermediate sector can set its optimal price $P_{j,t}^*$ otherwise the price is unchanged. The

first-order conditions of the firm's problem with respect to $K_{j,t}$, $N_{j,t}$, and $P^*_{j,t}$ are:

$$R^K_t = (1-\alpha) MC^N_{j,t} \frac{Y_{j,t}}{K_{j,t}}, \tag{2}$$

$$W_t = \alpha MC^N_{j,t} \frac{Y_{j,t}}{N_{j,t}}, \tag{3}$$

$$P^*_{j,t} = \frac{\theta_p}{\theta_p - 1} \frac{E_t \sum_{i=0}^{\infty} \xi_p^i Q_{t,t+i} MC^N_{j,t+i} P^{\theta_p}_{t+i} Y_{t+i}}{E_t \sum_{i=0}^{\infty} \xi_p^i Q_{t,t+i} P^{\theta_p}_{t+i} Y_{t+i}}, \tag{4}$$

where R^K_t is the nominal rental rate of capital, $MC^N_{j,t}$ denotes the nominal marginal cost, W_t is the nominal wage rate and $Q_{t,t+i}$ is the stochastic discount factor used at time t by shareholders to value date $t+i$ profits. The zero-profit condition in the final good sector is respected as the price of the final good (aggregate price index) is defined as $P_t = \left(\int_0^1 P_{j,t}^{1-\theta_p} dj \right)^{1/(1-\theta_p)}$.

2.2 Households

The typical household $h \in (0,1)$ maximizes the following lifetime utility:

$$\begin{aligned} & E_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_{h,t} - \mu_n \frac{{N_{h,t}}^{1+\phi}}{1+\phi} \right), \ \phi, \ \mu_n > 0 \text{ and } \beta < 1, \\ & s.t. \ \ P_t C_{h,t} + Q_{t,t+1} B_{h,t} = B_{h,t-1} + W_t(h) N_{h,t} + D_{h,t} + R^K_t K_{h,t} - P_t \left[\Gamma_I \left(I_{h,t} \right) + I_{h,t} \right] - T_{h,t}, \end{aligned} \tag{5}$$

where $C_{h,t}$ is consumption and $N_{h,t}$ denotes specific labor services of type h at time t. In each period t the representative household h carries $K_{h,t}$ units of physical capital from the previous period. $Q_{t,t+1}$ is a vector of prices of state-contingent assets that will pay one unit of currency if a particular state of nature occurs in period $t+1$, while each corresponding element of the vector $B_{h,t}$ represents the quantity of such contingent claims purchased at time t. Given the current state of nature, $B_{h,t-1}$ is the market value of such claims. $T_{h,t}$ denotes lump-sum taxation. Firms are owned by consumers, and $D_{h,t}$ are dividends in nominal terms. Finally, physical capital accumulates according to: $K_{h,t+1} = (1-\delta) K_{h,t} + I_{h,t}$. The investment decisions are subject to convex adjustment costs $\Gamma_I \left(I_t \right)$ given by: $\Gamma_I \left(I_t \right) = \frac{\varphi_I}{2} \left(\frac{I_t}{K_t} - \delta \right)^2 K_t$ with $\varphi_I > 0$. From the first

order conditions, dropping index h:

$$\frac{1}{R_t} = \beta E_t \left\{ \frac{C_t P_t}{C_{t+1} P_{t+1}} \right\}, \tag{6}$$

$$\varphi_I \left(\frac{I_t}{K_t} - \delta \right) = q_t - 1, \tag{7}$$

$$C_t^{-1} q_t = \beta E_t C_{t+1}^{-1} \left\{ \tilde{R}_t^k + (1-\delta) q_{t+1} + \frac{\varphi_I}{2} \left(\delta + \frac{I_{t+1}}{K_{t+1}} \right) \left(\frac{I_{t+1}}{K_{t+1}} - \delta \right) \right\}, \tag{8}$$

where $R_t = 1/E_t Q_{t,t+1}$ is the nominal interest factor on an asset that pays one unit of currency under every state of nature in period $t+1$, $\tilde{R}_t^k = R_t^k / P_t$ and q_t denotes the Tobin's marginal q.

As in Erceg *et al.* (2000), households supply differentiated labor services to the intermediate good-producing sector and set nominal wages in staggered contracts *à la* Calvo. A representative labor aggregator combines households' labor hours in the same proportions firms would choose, $N_t = \left[\int_0^1 N_{h,t}^{(\theta_w - 1)/\theta_w} dh \right]^{\theta_w/(\theta_w - 1)}$ with $\theta_w > 1$. In each period a constant fraction $1 - \xi_w$ of households reset their wage contracts. Households maximize their utility function subject to the budget constraint and the labor demand schedule. Let W_t^* denotes the value of W_t set by an household that can reoptimize its wage at time t, we then have:

$$\frac{W_t^*}{P_t} = \frac{\theta_w}{\theta_w - 1} \frac{E_t \sum_{i=0}^{\infty} (\beta \xi_w)^i \mu_n N_{t+i}^{1+\phi}}{E_t \sum_{i=0}^{\infty} (\beta \xi_w)^i N_{h,t+i} P_t / C_{t+i} P_{t+i}}, \tag{9}$$

where we use the fact that all households resetting their wage at time t will choose the same wage, since they face and identical optimization problem given the existence of a complete set of securities market.

2.3 Aggregation

In equilibrium all markets clear. The aggregate resource constraint and the aggregate production function are:

$$Y_t = C_t + I_t + G_t + \frac{\varphi_I}{2}\left(\frac{I_t}{K_t} - \delta\right)^2 K_t, \tag{10}$$

$$Y_t = AK_t N_t^{\alpha} \left(D_{p,t} D_{w,t}\right)^{-1}, \tag{11}$$

where $D_{p,t} = \int_0^1 \left(\frac{P_{j,t}}{P_t}\right)^{-\theta_p} dj$ and $D_{w,t} = \int_0^1 \left(\frac{W_{h,t}}{W_t}\right)^{-\theta_w} dh$ measure price and wage dispersion and G_t denotes public spending fully financed by lump-sum taxes and assumed to be equal to a constant fraction of income.

2.4 Monetary Policy

The monetary policy is described by a Taylor-type interest rate rule subject to exogenous disturbances, i.e.:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\iota_r} \left[\left(\frac{\pi_t}{\pi}\right)^{\iota_\pi} \left(\frac{\hat{y}_t}{\hat{y}}\right)^{\iota_y} \left(\frac{\pi_t^w}{\pi^w}\right)^{\iota_w}\right]^{1-\iota_r} u_t, \tag{12}$$

where $\pi_t = \frac{P_t}{P_{t-1}}$, π is the deterministic balanced growth path (BGP) value of π_t, $\hat{y}$ is the deterministic BGP value of $\hat{y}_t = Y_t/K_t$, π_t^w is wage inflation and π^w its deterministic steady state value. R is the deterministic BGP value of R_t and ι_r, ι_π, ι_y, ι_w and are policy parameters. The term u_t is defined as $u_t = \exp\left[\xi_{u,t} - \frac{\sigma_{\varepsilon_u}^2}{2(1-\rho_{\xi_u}^2)}\right]$, $\xi_{u,t+1} = \rho_{\xi_u}\xi_{u,t} + \varepsilon_{u,t+1}$, and $\varepsilon_u \sim N\left(0, \sigma_{\varepsilon_u}^2\right)$. The specification of the exogenous process u_t is relatively standard and allows us to study the effects of a mean-preserving spread increase in the volatility of the monetary shock since $E(u_t) = 1$.

3 Price and Wage Rigidities, Nominal Volatility and Growth

To evaluate the effects of the volatility of monetary shock on output growth we solve the model by following the 'pure' perturbation method by Schmitt-Grohé and Uribe (2004). As a number of variables, such as output, consumption, investments and wages are not stationary along the BGP,

we first perform a change of variables, so to obtain a set of equilibrium conditions involving only stationary variables. We set the benchmark parameter in line with the existing literature. The quarterly discount factor β equals 0.99, the inverse of the Frisch elasticity ϕ is set equal to 1, the capital depreciation rate δ equals 0.025 and the labor share α is 2/3. The steady-state inflation is equal to zero, $\pi = 1$, $N = 0.3$ while $\theta_p = \theta_w = 5$. We calibrate the remaining parameters to have $I/Y = 0.2$ and $C/Y = 0.65$ in steady state and an annual growth rate of output of 2% along a BGP.

To disentangle the role of nominal rigidities we consider three alternative economies: i) a NK model with staggered prices and flexible wages ($\xi_p = 2/3$, $\xi_w = 0$); ii) a model with staggered wages and flexible prices ($\xi_p = 0$, $\xi_w = 2/3$); iii) a model which embeds both staggered prices and staggered wages ($\xi_p = \xi_w = 2/3$).

Our variable of interest is the mean rate of output growth, that is $Mean(y_t - y_{t-1})$ where $y_t = \log(Y_t)$. We conduct two types of sensitivity analysis: we vary the standard deviation, σ_{ε_u}, and the persistence, ρ_{ξ_u}, of the monetary shocks. Finally, to better understand the interaction between nominal rigidities, monetary shocks volatility and monetary policy rules, six different Taylor rules, as indicated in Table 1, will be considered.

- Table 1 about here -

Figures 1 and 2 show the mean annual rate of output growth for increasing from 0 to 4% monetary policy variability σ_{ε_u} under sticky prices and flexible wages (solid lines), flexible prices and sticky wages (dotted lines) and sticky prices and wages (dashed lines). The persistence of the monetary shock is set to $\rho_{\xi_u} = 0.5$ in Figure 1 and to $\rho_{\xi_u} = 0$ in Figure 2. The monetary authority follows the rules indicated in Table 1.

- Figures 1 and 2 about here -

Monetary policy volatility always decreases the expected long-run growth: however the magnitude of the effect is very different depending on the source of nominal rigidities and on the conduct

of the monetary authority: in particular it is negligible with staggered wages and strong with staggered prices.

In the case of an economy with staggered prices and flexible wages, Figure 1 shows that an increase in the volatility of the monetary policy shock increases the volatility of prices and, therefore, price dispersion. This will increase firms uncertainty on the future value of the aggregate price index. With monopolistic competition and price staggering firms will try to reduce the risk of uncertainty by increasing their desired markup. Therefore, firms markup increases and real wages, output and investment decrease. This will translate into a reduction in average growth by virtue of a fall in the rate of knowledge accumulation.

With staggered wages and flexible prices the stochastic growth rate of output is not particularly affected by the volatility of the monetary policy shocks. In this case firms markup is constant and therefore firms are not able to reduce the risk of uncertainty by reducing their desired markup. On the other hand, uncertainty will induce agents to desire a higher real wage rate, thus pushing the average employment down: however for realistic values of the compensated elasticity of labor supply the effect will be small.[4]

With staggered prices and wages a higher nominal uncertainty increases both prices and wages dispersion inducing firms and workers to increase their desired markups, so implying a lower level of economics activity, a lower accumulation of capital and slower growth. On the other hand, given that both prices and nominal wages are staggered, real wages become more sluggish and less volatile and, as a consequence, the impact on the real marginal costs is lower and so the effects on output growth. Depending on which of the two effects prevails, the increase in the volatility of the shocks may have stronger or weaker effects on growth than those observed in an economy with sticky prices only.

Remarkably, rules characterized by interest rate smoothing strongly amplify the effects of uncertainty. This is due to the fact that by smoothing the interest rate, the monetary authority is much more accommodative and therefore its stabilizing effect is lower. This last result seems to

[4]This result is consistent with Blackburn and Pelloni (2004), Galindev (2009), Annicchiarico *et al.* (2010).

be of particular interest since, as documented by many empirical papers (among others Sahuc and Smets 2008, Smets and Wouters 2003) both the FED and the ECB seem to adopt Taylor rule with very high degree of smoothing- approximately equal to 0.8, as in our benchmark calibration.

Further, notice that a lower persistence of the monetary shock implies a lower negative effect on expected growth (see Figure 2). This is explained by the fact that in a model where prices and/or wages are set in a staggered fashion, a lower serial correlation implies less persistent effects of monetary shocks reducing the effects on nominal uncertainty.

Overall, we observe the following. Monetary shocks volatility has negative effects on the stochastic growth of output. Rules targeting both price and wage inflation reduce the negative impact of volatility on growth through the moderating effects these rules have on price and wage dispersion.

References

Aghion, P., Angeletos G.M., Banerjee, A., Manova, K., 2010. Volatility and Growth: Credit Constraints and the Composition of Investment, Journal of Monetary Economics, 57, 246–265.

Annicchiarico, B., Corrado, L., Pelloni, A., 2010. Long-Term Growth and Short-Term Volatility: The Labour Market Nexus, Manchester School, forthcoming.

Blackburn, K. Pelloni, A., 2004. On the Relationship Between Growth and Volatility, Economics Letters, 83, 123-127.

Blackburn, K. Pelloni, A., 2005. Growth, Cycles, and Stabilization Policy, Oxford Economic Papers, 57, 262-282.

Calvo, G., 1983. Staggered Prices in a Utility Maximizing Framework, Journal of Monetary Economics, 12, 383-398.

de Hek, P., Roy, S., 2001. On Sustained Growth under Uncertainty, International Economic Review, 42, 801-13.

Dotsey, M., Sarte, P.D., 2000. Inflation Uncertainty and Growth in a Cash-in- Advance Economy, Journal of Monetary Economics, 45, 631-655.

Erceg, C.J, Henderson, D.W, Levin, A.T., 2000. Optimal Monetary Policy with Staggered Wage and Price Contracts, Journal of Monetary Economics, 46, 281-314.

Evans, L., Kenc, T., 2003. Welfare Cost of Monetary and Fiscal policy Shocks, Macroeconomic Dynamics, 7, 212-238.

Galí, J., 2008. Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework. Princeton University Press, Princeton and Oxford.

Galindev, R., 2009. Note on 'Growth, cycles, and stabilization policy', Oxford Economic Papers, 61, 201-206.

Jones, L., Manuelli, R., Siu, H., Stacchetti, E., 2005. Fluctuations in Convex Models of Endogenous Growth I: Growth Effects, Review of Economic Dynamics, 8, 780-804.

Krebs, T., 2003. Growth and Welfare Effects of Business Cycles in Economies with Idiosyncratic Human Capital Risk, Review of Economic Dynamics, 6, 846–868.

Ramey, G., Ramey, V.A., 1995. Cross-Country Evidence on the Link Between Volatility and Growth', American Economic Review, 85, 1138-1152.

Romer, P.M., 1986. Increasing Returns and Long-Run Growth, Journal of Political Economy, 94, 1002-1037.

Sahuc, J-G, Smets, F., 2008. Differences in Interest Rate Policy at the ECB and the Fed: An Investigation with a Medium-Scale DSGE Model, Journal of Money, Credit and Banking, 40, 505-521.

Schmitt-Grohé, S., Uribe, M., 2004. Solving Dynamic General Equilibrium Models Using a Second-Order Approximation to the Policy Function, Journal of Economic Dynamics and Control, 28, 755-775.

Smets, F., Wouters, R., 2003. An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area, Journal of the European Economic Association, 1, 1123-1175.

Steindl, S. Tichy, G., 2009. Cycles and Growth: an Introduction, Empirica, 36, 159-164.

Vaona ,A., 2010. Inflation and Growth in the Long Run: A New Keynesian Theory and Further Semiparametric Evidence, forthcoming in Macroeconomic Dynamics.

Varvarigos, D., 2008. Inflation, Variability, and the Evolution of Human Capital in a Model with Transactions Costs, Economics Letters, 98, 320-326.

Table 1: Taylor Rules Parameters

Taylor Rules	ι_π	ι_y	ι_w	ι_r
1	1.5	0	0	0
2	0	1.5	0	0
3	1.5	0	1.5	0
4	1.5	0	1.5	0.8
5	1.5	0.125	0	0
6	1.5	0.125	0	0.8

Figure 1: Mean Annual Rate of Output Growth and Monetary Volatility, $\rho_{\xi_u} = 0.5$

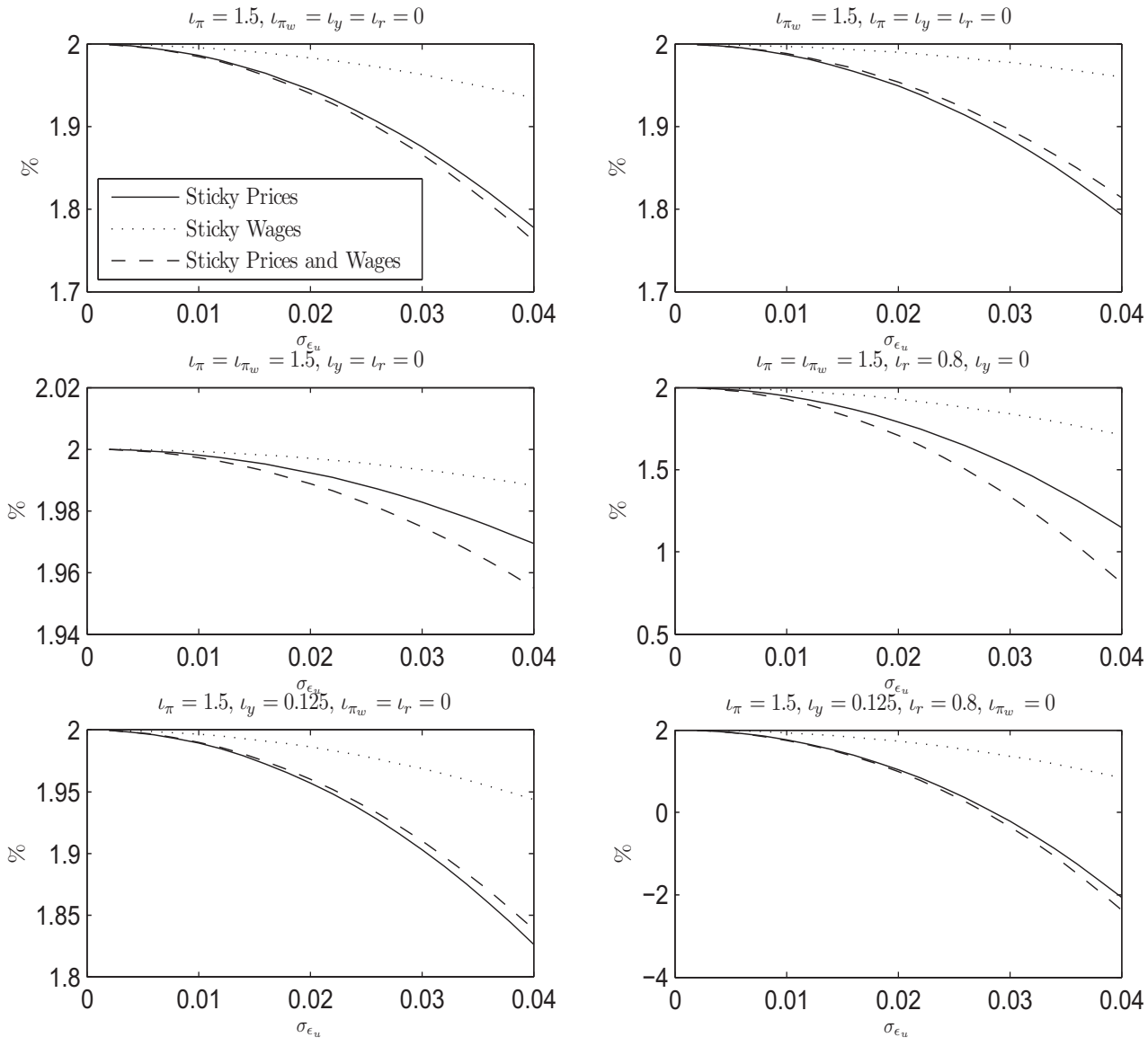

Figure 2: Mean Annual Rate of Output Growth and Monetary Volatility, $\rho_{\xi_u} = 0$