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Output Persistence from Monetary Shocks with Staggered Prices or Wages under a Taylor Rule

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ABSTRACT

We analytically examine output persistence from monetary shocks in a DSGE model with staggered prices or wages under a Taylor Rule for monetary policy. The best known such model assumes Calvo-style staggering of prices and flexible wages and is known to yield no persistence under a Taylor Rule. Switching to Taylor-style staggering introduces lagged output into the model's 'New Keynesian Phillips Curve' equation. Despite this, we show it generates no persistence, whether staggering is in wages or prices. Surprisingly, however, Calvo-style staggering of wages does generate persistence, if there are decreasing returns to labour.

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1. Introduction

Considerable attention has been given to whether a DSGE model with staggered prices or wages can generate, in response to monetary shocks, something approaching the high level of ‘persistence’ observed in detrended quarterly GDP data.¹ Woodford (2003, Ch. 3) provides an authoritative exposition of the current state of understanding of this issue. To date, a feature of the literature on output persistence from monetary shocks is that the monetary policy regime assumed has almost always been one in which the money supply is the exogenous instrument of policy. Typically, the ‘monetary shock’ studied has been a once-and-for-all increase in the money supply. However, in parallel with this literature, and using the same kinds of DSGE model, there has been much research into the properties of ‘Taylor Rules’ for the conduct of monetary policy. The latter treat the nominal interest rate, rather than the money supply, as the instrument of policy. Indeed, a prominent exposition of such research is in the following chapter of the same book by Woodford (2003, Ch. 4). It seems surprising that, if some version of the Taylor Rule is now accepted as providing the best description of real-world monetary policy, the question of output persistence from monetary shocks has not been investigated under a Taylor Rule. Here we contribute to rectifying this omission.

The models we will use are all variants of a standard ‘New Neoclassical Synthesis’ (NNS) framework. Two types of staggering will be considered - Taylor’s (1979) and Calvo’s (1983) - and two alternatives for the staggered variable: wages and prices. In the canonical NNS model, Calvo-staggering of prices and flexible wages are assumed. Here it is well known that under the standard Taylor Rule the resulting reduced-form model is completely forward-looking. This immediately implies that the model cannot generate output persistence at all, in response to a purely temporary shock. The economy attains its new steady state as soon as the shock has passed. Although this feature is well known, the question of how robust it is has not received much attention.

One modification which looks promising for generating persistence is to switch from Calvo- to Taylor-staggering. This is because it is known that the ‘New Keynesian Phillips Curve’ (NKPC) associated with Taylor-staggering is no longer purely forward-looking (see, e.g., Roberts (1995)). Hence in Section 3 we investigate this. However we find that there is still no persistence. It turns out that, although the reduced-form of the model does have a

¹ There is a broader question of whether monetary shocks, rather than, e.g., technology or preference shocks, are the source of the observed output persistence. It is beyond our scope to address this here, a restriction which we share with several other contributions to the literature, such as Chari et al. (2000).

backward-looking element in this case, so that convergence following a shock takes time, the adjustment is oscillatory rather than monotonic. We also study whether putting the Taylor-staggering in prices rather than wages makes a difference to this result. We find that it does not. Against this background, one would expect that putting Calvo staggering in wages, rather than in prices, would also make little difference. We investigate this in Section 4.

Interestingly, it turns out to be wrong. Under Calvo-staggering of wages and a Taylor Rule, the reduced form of the model not only has a backward-looking element but also exhibits output persistence.

2. The Economy

Consider a monetary economy composed of a large number of industries, each of them producing a differentiated product from labour input. There is also a constant population of infinitely-lived households who have identical preferences over goods, real money balances and leisure. Households consume a non-durable final good, which is ‘assembled’ by perfectly competitive producers using all of the differentiated products and a constant-elasticity-of-substitution (CES) technology with constant returns to scale. Each household is a supplier of differentiated labour services to one specific intermediate goods industry.

In such an economy, the consumption good is produced using the CES technology:

$$Y_t = \left[\int_0^1 Y_t(i)^{(\theta_p-1)/\theta_p} di \right]^{\theta_p/(\theta_p-1)}, \quad (2.1)$$

where $Y_t(i)$ is the intermediate good produced by industry $i \in [0,1]$ and $\theta_p > 1$ is the elasticity of substitution between goods. Each unit of the final good is sold at unit cost:

$$P_t = \left[\int_0^1 P_t(i)^{1-\theta_p} di \right]^{1/(1-\theta_p)}, \quad (2.2)$$

where $P_t(i)$ is the price of the intermediate product of type i . P_t can also be thought of as the price index. The assumptions of a CES technology and perfect competition result in the following demand functions for the intermediate goods:

$$Y_t^d(i) = \left[\frac{P_t(i)}{P_t} \right]^{-\theta_p} Y_t, \quad i \in [0,1]. \quad (2.3)$$

Each firm k producing an intermediate good uses industry-specific labour and has the production function:

$$Y_t(k) = L_t(k)^\alpha, \quad (2.4)$$

where $0 < \alpha \leq 1$.

All households have the same preferences over consumption $C_t(j)$, real money balances $M_t(j)/P_t$ and labour supply $L_t(j)$. Household $j \in [0,1]$ supplies a differentiated labour type. When it has monopoly power, it should be interpreted as the union for that labour type. It chooses a sequence $\{C_t(j), M_t(j)/P_t, L_t(j)\}_{t=0}^\infty$ in order to maximise lifetime expected utility:

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t(j)^{(\sigma-1)/\sigma} - 1}{(\sigma-1)/\sigma} + \delta \frac{(M_t(j)/P_t)^{1-\rho} - 1}{1-\rho} - dL_t(j)^e \right) \right\}, \quad (2.5)$$

where $0 < \beta < 1$, $e > 1$, $\sigma, \delta, \rho, d > 0$, subject to a standard sequence of budget constraints (e.g., Ascari, 2000) and, possibly, other constraints depending on whether wages are flexible or not.

The first-order condition for optimal intertemporal consumption choice is given by:

$$I_t = \beta^{-1} \left\{ E_t \left[\frac{P_t C_{t+1}(j)^{-1/\sigma}}{P_{t+1} C_t(j)^{-1/\sigma}} \right] \right\}^{-1}, \quad (2.6)$$

where $I_t \equiv 1 + i_t$ is the gross nominal interest rate.

3. Taylor-Style Staggering

First consider the case where wages are staggered and prices are flexible. In the labour market, households are divided into two sectors of equal size. Each supplier of differentiated labour skill j acts as a monopolist in setting the wage $W_t(j)$. As in Taylor (1979), in one sector each household is allowed to adjust its wage in even periods, and in the other sector in odd periods. The wage is fixed during the life of the two-period ‘contract’. Goods markets are Walrasian. Each industry i is modelled by a representative firm, with technology as in (2.4), who is a price- and wage-taker. Industry i draws its labour only from household j , where $j = i$. Thus the labour market is segmented by industry, as in Ascari (2000).

Each household j chooses the sequence of optimal wages in order to maximise (2.5) subject every period to its budget constraint, the demand function for its labour and the constraint that nominal wages are fixed for two successive periods (i.e. for households in the

sector which adjusts wages in - say - even periods, $W_t(j) = W_{t+1}(j)$ for all even values of t).

The optimal ‘new’ wage, W_t^* , is given by

$$W_t^* = \left\{ \frac{\varepsilon}{\varepsilon - 1} de \frac{K_t^e + \beta E_t [K_{t+1}^e]}{K_t / (P_t C_t(j))^{1/\sigma} + \beta E_t [K_{t+1} / (P_{t+1} C_{t+1}(j))^{1/\sigma}]} \right\}^{1/(1+\varepsilon(e-1))}, \quad (3.1)$$

where $K_t \equiv \alpha^\varepsilon Y_t^{\varepsilon/\theta_p} P_t^\varepsilon$ and $\varepsilon \equiv \theta_p / [\alpha + (1-\alpha)\theta_p] > 1$ is the real wage elasticity of labour demand.

By evaluating equations (3.1), (2.2) and (2.6) at equilibrium and log-linearising them around the zero-inflation steady state, we obtain:

$$w_t^* = \frac{1}{1+\beta} (p_t + \gamma_w y_t) + \frac{\beta}{1+\beta} E_t [p_{t+1} + \gamma_w y_{t+1}], \quad (3.2)$$

$$p_t = \eta_{mpl,Y} y_t + \frac{1}{2} (w_t^* + w_{t-1}^*), \quad (3.3)$$

$$y_t = -\sigma (i_t - E_t \pi_{t+1}) + E_t y_{t+1}, \quad (3.4)$$

where $\gamma_w \equiv [\eta_{LL} / \alpha + (\theta_p \eta_{mpl,Y} + 1) / \sigma] / [\theta_p (\eta_{LL} / \alpha + \eta_{mpl,Y}) + 1] > 0$, $\eta_{mpl,Y} \equiv (1-\alpha) / \alpha \geq 0$ and $\eta_{LL} \equiv e - 1 > 0$. Equations (3.2) and (3.3) are essentially a microfounded version of the supply side of Taylor’s (1979) model. Equation (3.4), on the other hand, is the expectational IS curve (see, e.g., McCallum and Nelson, 1999).

It follows that the rate of aggregate price inflation $\pi_t \equiv p_t - p_{t-1}$ of the economy must satisfy:

$$\pi_t = k_{Tw} \left[y_t + \frac{\gamma_w}{k_{Tw}} (y_{t-1} + \beta E_t y_{t+1}) \right] + \beta E_t \pi_{t+1} + \beta (\eta_t^\pi + \gamma_w \eta_t^y), \quad (3.5)$$

where $k_{Tw} \equiv (\gamma_w + 2\eta_{mpl,Y})(1+\beta) > 0$, while $\eta_t^\pi \equiv E_{t-1} p_t - p_t = E_{t-1} \pi_t - \pi_t$ and

$\eta_t^y \equiv E_{t-1} y_t - y_t$ are (stationary) expectational errors. Equation (3.5) is an example of the NKPC (so-named by Roberts (1995)). Notice the presence of y_{t-1} . This means that the equilibrium cannot be entirely forward-looking. We might thus conjecture that, following a shock, output would adjust only gradually to its steady-state value, thereby exhibiting persistence.

The log-linearised, reduced-form model of the economy consists of equations (3.4), (3.5) and a Taylor rule of the form:

$$i_t = \phi_\pi \pi_t + \phi_y y_t + \bar{i}_t, \quad (3.6)$$

where $\phi_\pi \geq 0$, $\phi_y \geq 0$ ($\phi_\pi + \phi_y > 0$) and \bar{i}_t is an exogenous (stationary) shift term.

By manipulation of these equations, we obtain the following law of motion of output

$$p_0 E_t y_{t+2} + p_1 E_t y_{t+1} + p_2 y_t + p_3 y_{t-1} = \bar{i}_t - \beta E_t \bar{i}_{t+1} + \phi_\pi \beta (\eta_t^\pi + \gamma_w \eta_t^y), \quad (3.7)$$

where $p_0 = \beta(\gamma_w - \sigma^{-1})$, $p_1 = k_{Tw} + (1 + \beta)/\sigma - \beta\phi_\pi\gamma_w + \beta\phi_y$, $p_2 = \gamma_w - \sigma^{-1} - k_{Tw}\phi_\pi - \phi_y$, $p_3 = -\phi_\pi\gamma_w < 0$.

(3.7) is a third order difference equation where output is driven by the exogenous term \bar{i}_t and an expectational error term. However, if $\gamma_w = \sigma^{-1}$ (i.e. when $\sigma = \theta_p$), the order of the equation drops by one.

Regardless of the actual order of (3.7), one and only one of its three (or two) roots must be stable, i.e. inside the unit circle, in order for output's dynamic path to be bounded and uniquely determined, given its exogenous forcing term. This is the condition for saddlepoint stability (SPS) because current output is a 'jump' (nonpredetermined) variable, while the previous period's output y_{t-1} is given in any period t .² It can be shown³ that the necessary and sufficient condition for determinacy is given by:

$$\phi_\pi + \frac{1 - \beta}{k_{Tw} \left[1 + (1 + \beta) \frac{\gamma_w}{k_{Tw}} \right]} \phi_y > 1. \quad (3.8)$$

This is an example of the 'Taylor Principle', whose best-known form (which applies here too, when $\phi_y = 0$) is $\phi_\pi > 1$.

The persistence properties of output depend critically on the sign of the stable root. Only if its sign is positive is there monotonic convergence of output (and thus persistence) in response to a shock. We obtain⁴ that the stable root takes the sign of the following expression:

² We are thus adopting the standard rational expectations assumption and, correspondingly, the standard rational expectations solution concept, as found in Blanchard and Kahn (1980). 'Learning', such as in recent work by Bullard and Mitra (2002) or McCallum (2007), may also contribute to persistence, but this lies beyond what we can consider here.

³ The proof is available in Daros and Rankin (2009).

⁴ The proof is available in Daros and Rankin (2009).

$$-\frac{\phi_\pi \gamma_w}{(\phi_\pi - 1)k_{Tw} \left[1 + (1 + \beta) \frac{\gamma_w}{k_{Tw}} \right] + (1 - \beta)\phi_y}. \quad (3.9)$$

This shows how output persistence is determined by the sign of the inflation response coefficient ϕ_π , because $\gamma_w > 0$ and condition (3.8) ensure that the denominator in (3.9) is positive. More precisely, a Taylor rule of the form (3.6), where $\phi_\pi > 0$, produces a negative stable root and therefore output oscillations. Thus, despite the fact that Taylor-staggering introduces a backward-looking element into the NKPC through the presence of y_{t-1} , the model does not exhibit persistence.

It is natural to ask whether Taylor-style staggering of prices, rather than wages, would yield a different result. In the literature on output persistence under a money supply shock, after an initial debate it was concluded that whether staggering is in prices or wages makes little difference (see, e.g., Edge (2002)). To study this case we now assume firms are monopolistic competitors, while equilibrium in the labour market is Walrasian. Industries are divided into two sectors of equal size, which set prices in alternate periods à la Taylor.⁵ By analogous steps to those above, we obtain the following version of the NKPC in this case:

$$\pi_t = k_{Tp} \left[y_t + \frac{\gamma_p}{k_{Tp}} (y_{t-1} + \beta E_t y_{t+1}) \right] + \beta E_t \pi_{t+1} + \beta (\eta_t^\pi + \gamma_p \eta_t^y), \quad (3.10)$$

where $k_{Tp} \equiv (1 + \beta)\gamma_p$, $\gamma_p \equiv [\eta_{LL} / \alpha + \eta_{mpl,Y} + \sigma^{-1}] / [\theta_p (\eta_{LL} / \alpha + \eta_{mpl,Y}) + 1] > 0$. Note that if there are constant returns to labour ($\alpha = 1$, $\eta_{mpl,Y} = 0$) (3.10) is identical to (3.5), its counterpart under wage staggering. Even with decreasing returns to labour ($\alpha < 1$, $\eta_{mpl,Y} > 0$), it is qualitatively the same as (3.5): only the magnitudes of the coefficients differ. Hence the same reasoning applies as above, leading again to the conclusion of no persistence when monetary policy is conducted through a Taylor rule of the form (3.6).

4. Calvo-Style Staggering

⁵ To maintain the assumption that the labour market is segmented by industry, it is now necessary to assume - see Woodford (2003, Ch. 3) - that there is a double continuum of differentiated goods. Within each industry i , there is a continuum of firms $k \in [0, 1]$, each producing a differentiated good, substitutable for other goods in the industry with elasticity θ_p . This way, each firm can be a price-setter in the goods market but a wage-taker in the industry's labour market.

The canonical NNS model found in the literature assumes Calvo-staggering of prices and flexible wages. It exhibits no persistence under a Taylor Rule, as we have noted. Given the results of Section 3, a priori it seems unlikely that the case of Calvo-staggering of wages and flexible prices would alter this. Nevertheless for the sake of completeness we now consider it.

Under Calvo-style staggering, household j is allowed to change its money wage with probability $1 - \alpha_w$ in any period, while with probability α_w it must keep $W_t(j)$ fixed at its previous level. The structure is otherwise the same as in the model with Taylor-staggering of wages.

The reduced form of the supply side of the model is:

$$w_t^* = (1 - \alpha_w \beta)(p_t + \gamma_w y_t) + \alpha_w \beta E_t w_{t+1}^*, \quad (4.1)$$

$$w_t = (1 - \alpha_w) w_t^* + \alpha_w w_{t-1}, \quad (4.2)$$

$$p_t = \eta_{mpl,Y} y_t + w_t, \quad (4.3)$$

where γ_w is the same as in equation (3.2). From this we derive the following version of the NKPC:

$$\pi_t = k_{Cw} \left[y_t - \frac{\eta_{mpl,Y}}{k_{Cw}} (y_{t-1} + \beta E_t y_{t+1}) \right] + \beta E_t \pi_{t+1}, \quad (4.4)$$

where $k_{Cw} \equiv \alpha_w^{-1} [(1 - \alpha_w)(1 - \alpha_w \beta) \gamma_w + (1 + \alpha_w^2 \beta) \eta_{mpl,Y}] > 0$. Observe that under decreasing returns to labour ($\eta_{mpl,Y} > 0$) Calvo-staggering of wages causes a negative dependence of current inflation on past and expected future output. Interestingly, the NKPC is the same as under Taylor-staggering, except that, in the latter case, the dependence on past and expected future output is *positive* (cf. (3.5) and (3.10)). Constant returns to labour ($\eta_{mpl,Y} = 0$), on the other hand, cause y_{t-1} to drop out, reproducing the same purely forward-looking NKPC as in the canonical NNS model. Therefore we focus on decreasing returns here.

The complete model of the economy now consists of equations (3.4), (4.4) and the Taylor rule (3.6). From these we obtain the following law of motion of output:

$$p_0 E_t y_{t+2} + p_1 E_t y_{t+1} + p_2 y_t + p_3 y_{t-1} = \bar{i}_t - \beta E_t \bar{i}_{t+1}, \quad (4.5)$$

where $p_0 = -\beta(\eta_{mpl,Y} + \sigma^{-1}) < 0$, $p_1 = k_{Cw} + (1 + \beta)/\sigma + \beta \phi_\pi \eta_{mpl,Y} + \beta \phi_y > 0$, $p_3 = \phi_\pi \eta_{mpl,Y} > 0$,
 $p_2 = -(\eta_{mpl,Y} + \sigma^{-1} + k_{Cw} \phi_\pi + \phi_y) < 0$.

Output's dynamic path is bounded and uniquely determined from equation (4.5) if the associated characteristic polynomial has one and only one stable root. We obtain that the necessary and sufficient condition for SPS to hold is:

$$\phi_\pi + \frac{1-\beta}{k_{Cw} \left[1 - (1+\beta) \frac{\eta_{mpl,Y}}{k_{Cw}} \right]} \phi_y > 1. \quad (4.6)$$

Further, it can be shown that⁶, if SPS holds, the stable root takes the sign of the following expression:

$$\frac{\phi_\pi \eta_{mpl,Y}}{(\phi_\pi - 1) k_{Cw} \left[1 - (1+\beta) \frac{\eta_{mpl,Y}}{k_{Cw}} \right] + (1-\beta) \phi_y}. \quad (4.7)$$

Therefore the stable root is positive if $\phi_\pi > 0$. Hence, surprisingly, provided that there are decreasing returns to labour, Calvo staggering of wages does produce output persistence under a Taylor Rule.

To give a rough idea of magnitudes, suppose $\beta = 0.99$, $e = 1.1$, $\alpha = 0.75$, $\theta_p = 7.88$, $\sigma = 6.25$, $\phi_\pi = 1.5$, $\phi_y = 0.5$ and $\alpha_w = 0.66^7$. Then we find that the stable root is $\lambda_s = 0.31$. For sure, this is below the 'near unit root' behaviour observed empirically, but it is still a non-negligible contribution to persistence.

5. Conclusions

The use of a Taylor Rule for monetary policy does not necessarily eliminate output persistence in a basic DSGE model with staggered prices or wages. However it does completely alter the set of features of the model which are critical for persistence. Further research on this question seems desirable.

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⁶ The proof is available in Daros and Rankin (2009).

⁷ The Taylor rule's coefficients were chosen to be consistent with Taylor (1993), while the other parameter values are consistent with the corresponding values in the structural econometric model found in Rotemberg and Woodford (1997), once their assumption of staggered prices à la Calvo is replaced with staggered wages.

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