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PRICE MODELS

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Persistency in Sticky Price Models

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Abstract
Nominal rigidities imply that nominal shock have an impact effect which may be propagated by standard mechanisms. However, the nominal adjustment process may in itself be a propagation mechanism causing persistent effects of nominal shocks. This may be caused by inertia in nominal wage and price adjustment arising due to input-output networks or multiperiod nominal contracting as captured in models with staggered price/wage decisions. It has recently been contested whether staggering can account for persistency of any quantitative importance. This paper reviews the theory and empirical evidence on this issue and it is concluded that staggering may be a quantitative important propagation mechanism.

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1. Introduction

What role do nominal demand shocks play for business cycles? An important question of wide policy implications, but despite a continuous stream of new theoretical and empirical analyses, it remains an open question on which it is difficult to reach consensus.

For nominal shocks to play any real role it is necessary to break the classical neutrality result, that is some nominal rigidity is required. A voluminous literature has explored the extent to which imperfect information and adjustment costs can generate nominal stickiness of aggregate importance (for a survey see e.g. Andersen (1994)). While the literature first explored the basic mechanisms in partial models there has recently been a growing literature placing these aspects in a general equilibrium setting and thereby putting the issue in a more genuine business cycle perspective (see section 2).

Finding that nominal shocks can have important impact effects is only half of the story. Persistency in output adjustment is a crucial property of observed business cycle fluctuations and a convincing theory attributing an important role to nominal shocks needs also to be consistent with persistency in output fluctuations. The aim of this paper is to survey the literature on the relationship between price stickiness and persistency

The paper is organized as follows. Section 2 reviews models with nominal rigidities relying on real propagation mechanisms, while section 3 considers nominal propagation mechanisms arising via staggering. Finally, section 4 concludes.

2. Sticky prices and real propagation mechanisms

The role of nominal shocks has recently been explored in many quantified dynamic macroeconomic analyses. To set the scene money is introduced by appealing to its transactions role either by placing real balances as an argument in the utility function or by imposing a cash in advance constraint. Next nominal rigidities are brought in by assuming a nominal contracting process. The specific schemes explored spans from anticipatory price setting in which prices are pre-set for one or more periods at the level expected to clear the market (Cho (1993), Cooley and Hansen (1995), Ohanian et al. (1995), Christiano et al. (1997), Cho and Cooley (1995) to models of imperfect competition where price changes are costly (menu costs) (Rotemberg (1996), Hairault and Portier (1993) and King and Watson (1996)).

This literature has documented that by including nominal shocks it is possible to improve upon the ability of calibrated models to match selected second moments for observed business cycle fluctuations. In particular the finding that inclusion of monetary shocks resolve the problem that calibrated models tend to imply too low volatility in aggregate activity has been stressed as showing that monetary shocks matter for observed business cycle fluctuations.

Moreover, the explicit inclusion of monetary aspects has facilitated the explanation of observed business cycle properties of nominal variables, including in particular the cyclical properties of prices and inflation. Although there are still unresolved problems and a debate on whether this support monetary shocks as an exogenous source of business cycle fluctuations or whether it reflects the endogenous adaption of the monetary system to real changes (the inside money view).

It is also worth stressing that problems of the basic real business cycle model in replicating certain business cycle properties most notably related to the labour market are also present in models including nominal shocks.

Turning to the persistency issues it is important to note the difference between nominal and real shocks as it is only the unanticipated part of the former which have real effects, while even fully anticipated real shocks have real effects[1)]. This reflects that any model based on first principles has the classical neutrality property as a long-run property. Though this still leaves open how decisions depend on anticipations and how agents form their anticipations and what information they have access to.

If a (unanticipated) monetary shock has an impact effect it would be propagated as real shocks via the (real) propagation mechanism running through capital accumulation, intertemporal substitution and various kinds of adjustment lags or costs. That is, if output is temporary high, this will activate these mechanisms no matter whether the impulse is real or nominal in origin. This is brought out by the analysis in e.g. Bénassy (1995). This raises, however, a severe problem as the internal propagation mechanism is rather weak in the dynamic macromodels which hitherto have been analysed (see e.g. Cogley and Nason (1995)). Accordingly, the processes for real shocks have been specified in such a way as to include substantial persistence, that is, one has to bring in external sources of dynamics in order to replicate observed output dynamics. However, this will not do the trick for monetary shocks as it is only the unanticipated part which matters. Considering the impulse response functions to nominal shocks reveal that monetary shocks do not contribute in any significant way to output dynamics as they only have a temporary output effect (see e.g. Hairault and Portier (1993), Cooley and Hansen (1995), Ohanian et al.(1996)). This reflects that the internal propagation mechanism is too weak, a

[1] Disregarding super non-neutralities. Attempts to quantify e.g. the inflation tax (see e.g Cooley and Hansen (1995)) has shown this to have a very modest effect.

problem both for theories stressing real and nominal shocks as driving the business cycle. There is thus a need to consider propagation mechanisms further.

3. Nominal propagation mechanism

Could nominal inertia in itself be an important propagation mechanism? In a seminal paper Taylor (1980) argued that staggered wage setting could account for the observed persistency in output fluctuations in the US even for contracts lasting for as short as one year. The framework can be seen as a modified Philips curve in which nominal wage setting depends not only on an excess demand variable (captured by an output gap measure) but also on past and future wage rates to capture that current wages overlap with wages set in the past as well as with wages to be set in the future. This model has motivated a huge literature exploring the consequences of staggering of wages and prices (see e.g. Blanchard (1983,1986)). There is also a growing literature introducing staggered nominal contracts in explicit dynamic macromodels (Chari et al. (1996), Yun (1996) and Jeanne (1997)).

The explanatory power of staggered wage and price setting has recently been questioned on two scores. First, it has been pointed out that the Taylor model cannot explain inflation inertia and that is has the implausible implication that a credible disinflation programme can be implemented at no output costs (Fuhrer and Moore,1995). Secondly, it has been pointed out that the elasticity of labour supply with respect to the real wage is critical to the persistency result and for plausible values of the this parameter the model is not capable of generating persistency(Chari et al, 1996)

Both of these points are very important as they question the empirical relevance of models with staggering. The following aims at evaluating the strength of this criticism.

Whereas Taylor considered wage-staggering, the subsequent literature has tended to focus on price staggering. It is an implicit assertion in most of the literature that there is no qualitative difference between the two cases[2)], the following aims at showing that there is such a difference and that the criticism discussed above does not apply to wage staggering.

Consider a stripped down economy in which aggregate demand is determined by the quantity theory, i.e.

$$y_t = m_t - p_t \tag{1}$$

[2] Cho (1993) considers the difference between one-period setting of prices and wages and concludes that there is a qualitative difference.

All variables are in logs, and y_t is the output level, m_t the money stock and p_t the aggregate price level. In addition to simplicity, this assumption implies that other (real) propagation mechanisms are disregarded allowing a more direct focus on the implications of the nominal contracting process[3)].

Next we shall specify the supply side and since the focus is on wage and price formation, labour is assumed to be the only input. Let us consider in turn the cases where prices and wages are pre-set in a staggered way. This can arise due to asynchronization of multi-period contracts or due to the input-output network in case of production lags (Andersen (1994).

First we consider price staggering with flexible wages. Assume that nominal prices are set for two periods and in a staggered fashion such that half the firms set prices at the beginning of even periods and half the firms set prices at the beginning of odd periods. Denote by x_t the nominal price set at the beginning of period t conditional on the information set I_t (to be specified below). The price is assumed to be set as a mark-up on expected input cost, and neglecting constants and discounting, we have

$$x_t = \frac{1}{2}\left(E_t w_t + E_t w_{t+1}\right) \tag{2}$$

The aggregate price level is defined as

$$\begin{aligned} p_t &\equiv \frac{1}{2}\left(x_{t-1} + x_t\right) \\ &= \frac{1}{4}\left(E_{t-1} w_{t-1} + E_{t-1} w_t + E_t w_t + E_t w_{t-1}\right) \end{aligned} \tag{3}$$

Firms meet whatever demand is forthcoming at the quoted prices, i.e. output sales is demand determinated. Finally, we have to consider the labour market which is assumed to be competitive. Labour demand follows from the amount of labour needed to accommodate the output demand forthcoming at the quoted prices. Labour supply is modelled in a standard way as increasing in the real wage (w_t-p_t) and in output units it can be specified as

$$y_t = \alpha\left(w_t - p_t\right) \tag{4}$$

where α depends on the wage elasticity of labour supply[4)].

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[3] In Andersen (1997) a fully specified intertemporal model with wage staggering is analysed, and it is shown that the interplay between real and nominal propagation mechanisms can produce substantial persistence in the adjustment process.

[4] With a standard technology $\alpha \equiv \eta\beta$ where η is the elasticity of output wrt labour and β is the labour supply elasticity.

Combining (1) and (4) we get

$$m_t = \alpha w_t + (1-\alpha)p_t \tag{5}$$

which by use of (3) can be solved to yield the equilibrium distribution of wages.

Turn now to the opposite situation in which the output market is competitive while nominal wages are predetermined in a staggered fashion. Half of the wage contracts are signed at the beginning of even periods, and the other half at the beginning of odd periods. Denote by z_t the nominal wage set at the beginning of period t conditional on the information set I_t (to be specified below). This wage is assumed to be set so as to reach a real wage target, and neglecting constants and discounting, we have

$$z_t = \frac{1}{2}\left(E_t p_t + E_t p_{t+1}\right) \tag{6}$$

The aggregate wage level becomes

$$\begin{aligned} w_t &\equiv \frac{1}{2}\left(z_{t-1} + z_t\right) \\ &= \frac{1}{4}\left(E_{t-1}p_{t-1} + E_{t-1}p_t + E_t p_t + E_t p_{t+1}\right) \end{aligned} \tag{7}$$

Labour supply is assumed to adjust so as to accommodate whatever demand is forthcoming at the quoted wage.

Firms are price- and wage-takers producing subject to a traditional technology linking output to the use of labour. Maximization of profits yields a supply function of the form

$$y_t = \beta\left(p_t - w_t\right) \ , \beta > 0 \tag{8}$$

Combining (1) and (8) yields

$$m_t = (1+\beta)p_t - \beta w_t \tag{9}$$

which by use of (7) can be solved to yield the equilibrium distribution of prices.

Rather than solving these two models separately, it is useful to note that they have the same mathematical structure as they are both special cases of the model

$$m_t = \gamma q_t + (1-\gamma)s_t \tag{10}$$

$$s_t = \frac{1}{4}\left(E_{t-1}q_{t-1} + E_{t-1}q_{t-1} + E_t q_t + E_t q_{t+1}\right) \tag{11}$$

where q_t is the flexible variable, and s_t the staggered variable.

The model with staggered prices arises as the case where $q_t = w_t$, $s_t = p_t$, and $\gamma = \alpha$, while the model with staggered wage arises as the case there $q_t = p_t$, $s_t = w_t$, and $\gamma = 1+\beta$.

To solve the system (10) and (11) we need to specify a process for the money stock as well as the information set I_t. For the money stock we take the simple case where it follows a random walk, i.e.

$$m_t = m_{t-1} + \varepsilon_t \tag{12}$$

where ϵ_t is iid $N\left(0,\sigma_\varepsilon^2\right)$. Although counterfactual, it has the virtue of simplicity and of high-lighting how permanent monetary changes are transmitted into the economy.

It is assumed that $m_{t-j} \in I_t \ \forall j \geq 0$, that is, there is full information about past as well as the current money stock. The latter assumption removes information confusion as a source of business cycle fluctuations.

A solution to (10) and (11) given (12) is easily found by use of the undetermined coefficients method starting by conjecturing a solution of the form

$$q_t = \pi_0 q_{t-1} + \pi_1 m_t + \pi_2 m_{t-1} \tag{13}$$

Under the assumed information set we have

$$E_t q_t = q_t$$

reflecting that there is full current information and

$$E_t q_{t+1} = \pi_0 q_t + (\pi_1 + \pi_2) m_t$$

Inserting in (10) and (11) we get

$$\left(\gamma + \frac{1}{4}(1-\gamma)(1+\pi_0)\right)q_t$$

$$= m_t - \frac{1}{4}(1-\gamma)\left[(1+\pi_0)q_{t-1} + (\pi_1+\pi_2)m_t + (\pi_1+\pi_2)m_{t-1}\right]$$

which is consistent with (12) for the following parameter values

$$\pi_0 = -\frac{1}{4}(1-\gamma)\left(1+\pi_0\right)\chi$$

$$\pi_1 = \left[1-\frac{1}{4}\left(1-\gamma\right)\left(\pi_1+\pi_2\right)\right]\chi$$

$$\pi_2 = -\frac{1}{4}\left(1-\gamma\right)\left(\pi_1+\pi_2\right)\chi$$

where

$$\chi \equiv \left[\gamma+\frac{1}{4}\left(1-\gamma\right)\left(1+\pi_0\right)\right]^{-1}$$

The expression for π_0 can be rewritten as

$$\frac{1}{2}\left(1+\pi_0^2\right)+\rho\pi_0 = 0 \qquad \rho \equiv \frac{1+\gamma}{1-\gamma}$$

implying[5)]

$$\pi_0 = -\rho \pm \sqrt{\rho^2-1}$$

The stable solution ($|(\pi_0| < 1$) is given by

$$\pi_0 = \begin{cases} -\rho-\sqrt{\rho^2-1} & \text{for}\,\rho<0 \\ -\rho+\sqrt{\rho^2-1} & \text{for}\,\rho>0 \end{cases}$$

It follows that

$\rho > 0$ and $-1 < \pi_0 < 0$ for $\gamma < 1$

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5 Note that ρ^2-1 > 0.

$\rho < 0$ and $0 < \pi_0 < 1$ for $\gamma > 1$

We also find that

$$\frac{\partial \pi_0}{\partial \rho} > 0 \quad \text{or} \quad \frac{\partial \pi_0}{\partial \gamma} > 0$$

It is easily verified that

$$\pi_0 + \pi_1 + \pi_2 = 1 \tag{14}$$

reflecting that the model displays long-run neutrality wrt nominal changes. The interesting question is now the role of staggered price and wage decision for output persistence.

It can be shown (see appendix) that output can be written

$$y_t = \pi_0 y_{t-1} + \pi_3 \varepsilon_t \tag{15}$$

where $\pi_3 \equiv \frac{\alpha}{1-\alpha}\left(\pi_0 + \pi_2\right) > 0$ in the case of staggered price setting and $\pi_3 \equiv 1-\pi_1 > 0$ in the case of staggered wage setting.

Both models thus imply that nominal shocks have an expansionary effect ($\pi_3 > 0$) and that output follows a first order autoregressive process. Whether the model generates persistency (monotone damping) or oscillations in the adjustment path depends on the sign of π_0. If it is positive ($0 < \pi_0 < 1$) we get persistency while if it is negative ($-1 < \pi_0 < 0$), we get oscillations.

In the case of price staggering we have that the sign of π_0 depends on the sign of (α-1). If α>1, we have that $\pi_0 > 0$ and there is damped persistency in the adjustment process. On the other hand, $\pi_0 < 0$ for $\alpha < 1$ and the adjustment process is oscillating. This is the basis for the Chari et al. (1996) critique as empirical evidence suggests that the labour supply elasticity α is small and definitively below unity[6)7)]. The model must on this score be discharged as not being empirically plausible.

Interestingly, there is an important qualitative difference between staggered price and wage decisions. This is seen by noting that in the staggered wage model π_0 is always positive, that

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[6] With a standard technology $\alpha \equiv \eta\beta$, where $\eta \leq 1$, and hence $\beta > 1$ is a necessary condition for $\alpha > 1$.

[7] Jeanne (1997) shows that the supply elasticity needs not be interpreted as the labour supply elasticity if the labour market is non competitive. The size of this parameter is assessed by estimating the sensitivity of cyclical measures of wages on a cyclical measures for output for 6 countries for the period 1979:1 to 1992.4 he finds support that wage sensitivity is small and this supports the conclusion that nominal shocks have persistent effects even for moderate price stickiness.

is, there is no critical parameter deciding whether the model produces persistency or oscillations in the adjustment process. The staggered wage model cannot be discharged on the same score as the staggered price model.

The qualitative difference between price and wage staggering can be explained in the following way. With wage staggering the adjustment burden is borne by the price. In case of an expansionary shock, the price rises to equilibrate the market and in this process supply is increased (due to nominal wage stickiness) and demand is reduced. With price-staggering, the burden of adjustment rests on the wage. In e.g. the case of an expansionary shock, labour supply has to increase to match demand. This is ensured by a rise in the wage rate. However, this only has a supply effect, and it does not lower aggregate demand. If labour supply is very elastic, only a small wage increase is needed, and this will initiate moderate price revisions in subsequent periods[8)]. However, if labour supply is little responsive, a large wage increase is needed, and this will in turn lead to large price increases in the future making it possible that future output contracts. This explains the qualitative differences in the adjustment mechanism between the two cases.

As noted, the staggering model has been criticized for not being able to explain inflation inertia. Price stickiness is thus not necessarily causing inflation stickiness. It is easily seen that this problem does not arise in the model with wage staggering in which we have that

$$p_t - p_{t-1} = \pi_0\left(p_{t-1} - p_{t-2}\right) + \pi_1\left(m_t - m_{t-1}\right) + \pi_2\left(m_{t-1} - m_{t-2}\right)$$

Persistency in output movements ($0 < \pi_0 < 1$) also cause persistency in inflation. It is a model specific feature that the persistency parameter is the same in the output and the inflation equation. A credible reduction in the money growth rate will thus not bring inflation down immediately, and it will have an output cost.

The two models of staggering obviously differ in their implications for price and wage adjustment over the business cycle. More precisely we have that (see appendix)

$$\frac{\partial q_t}{\partial m_t} > \frac{\partial s_t}{\partial m_t}$$

that is, the flexible variable is always more sensitive to the shock than the staggered variable. The model with price staggering thus implies more wage than price variability over the business cycle. Empirical evidence indicates the opposite, and this points to a further empirical

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[8] Overshooting in the sense that $\partial w_t/\partial m_t = \pi_1 > 1$ is seen to arise when $\alpha < 1$.

weakness of the price staggering model. Obviously, the wage staggering model is consistent with this fact.

So far, the staggering process has been postulated, but what is the empirical evidence, and can such a process be given a theoretical justification.

There is ample empirical evidence showing that long-term wage contracts are predominant in the labour market. Contract duration is usually between 1 and 3 years and the contract usually stipulates a fixed wage over the contract period eventually allowing for mechanical (partial indexation) a fixed points in time. This is obvious in countries and industries with a high degree of unionization. This is the case for a number of Northern European Countries (see OECD1995) in which the bargaining power of unions remains high (Wallerstein et al. (1997)). But also in cases where the formal union density is low are long term, contracts dominating, partly because union settlements extend to non-unionized workers and partly because such contracts are also used in more decentralized labour markets[9)] Although long term contracts are also observed in product market (Carlton (1986) and Lach and Tsiddon (1994)), they are less widespread and mostly seen in contexts requiring substantial irreversible investments like natural resources (see e.g. Goldberg and Erickson (1987) and Joskow (1988)). Long term contracting is thus frequently observed and to a first approximation they are more important in the labour than in the product market.

There is a theoretical literature explaining whether asynchronization can arise endogenously for price-setting (see e.g. Ball and Cecchetti (1988), Maskin and Tirole (1988), Ball and Romer (1989)) and wage-setting (see e.g. Fethke and Policiano (1984), Freja (1993)). Asynchronization, because it facilitates dissemination of costly information, enhances market power or allows a more flexible adjustment to the different timing of sectoral shocks.

4. Concluding remarks

Price and wage staggering have been shown to have qualitatively different implications for output dynamics. Price staggering models have to rely on high labour supply elasticities to generate output persistency and moreover have difficulties in generating inflation inertia and the explanatory power of such models have accordingly been questioned. This criticism does not apply to wage staggering models. In such models nominal shocks would not only be non-neutral but they would also have a persistent effect on output. Wage staggering models thus hold the potential of being able to generate a quantitative important nominal propagation me-

[9] For evidence on the US labour market see e.g. Beaudry and DiNardo(1991),Chen (1988) andVroman (1989) .

chanism which can strengthen the (weak) real propagation mechanisms.

There is a need to further explore this issue both theoretically and empirically. This applies both to the microfoundations for nominal staggering but also to the integration of this aspect in fully specified dynamic macromodels. Despite the voluminous literature on labour contracts, it is surprising to find that empirical literature in this issue is very scart. This calls not only for attempt to quantify the macroeconomic effects of wage staggering but also for further empirical evidence and econometric analyses of labour contracts.

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Appendix

A: Equilibrium output

(I) Staggered Prices

From the equilibrium wage function (13) it follows that

$$w_t - m_t = \pi_0 \left(w_{t-1} - m_{t-1} \right) - \left(\pi_0 + \pi_2 \right) \varepsilon_t$$

From (5) we have that

$$m_t - w_t = \left(1 - \alpha \right) \left(p_t - w_t \right)$$

Using these in the output equation (4), we find

$$y_t = \alpha \left(w_t - p_t \right) = \frac{\alpha}{1-\alpha} \left(w_t - m_t \right)$$

$$= \pi_0 y_{t-1} - \frac{\alpha}{1-\alpha} \left(\pi_0 + \pi_2 \right) \varepsilon_t$$

Note that

$$\pi_0 + \pi_2 = \frac{-\frac{1}{2}\left(1-\gamma\right)}{\gamma + \frac{1}{4}\left(1-\gamma\right)\left(1+\pi_0\right)}$$

since $\gamma + \frac{1}{4}\left(1-\gamma\right)\left(1+\pi_0\right) > 0$, it follows that

$$\pi_3 \equiv \frac{\alpha}{1-\alpha} \left(\pi_0 + \pi_2 \right) > 0$$

for all values of α.

(II) Staggered Wages

From the equilibrium price function (13), it follows that

$$m_t - p_t = \pi_0 \left(m_{t-1} - p_{t-1} \right) + \left(1 - \pi_1 \right) \varepsilon_t$$

Using the output equation (8), we have

$$y_t = m_t - p_t = \pi_0 y_{t-1} + \left(1 - \pi_1 \right) \varepsilon_t$$

vp

B: Proof that $\pi_1 > 1/4(\pi_1 + \pi_2)$.

From the definition of π_1 the inequality can be rewritten

$$1 > \frac{1}{2}\left(\pi_1 + \pi_2\right)\left(D + \left(1 - \gamma\right)\right) \qquad \text{(A-1)}$$

where $D \equiv \gamma + 1/4(1-\gamma)(1+\pi_0)$.

Using that

$$\pi_1 + \pi_2 = \frac{1 - \frac{1}{2}\left(1-\gamma\right)\left(\pi_1 + \pi_2\right)}{D} = \frac{1}{D + \frac{1}{2}\left(1-\gamma\right)}$$

we can rewrite (A-1) as

$$1 > \frac{1}{4}\frac{D + \left(1-\gamma\right)}{D + \frac{1}{2}\left(1-\gamma\right)}$$

Next we shall show that

$$\left(D + (1-\gamma)\right)\left(D + \frac{1}{2}\left(1-\gamma\right)\right)^{-1} < 1$$

Using that $1 = \pi_0 + \pi_1 + \pi_2$, it follows that $\pi_1 + \pi_2 \in [0,1]$ and that $D + ½(1-\gamma) > 0$ for $\gamma > 1$ and $\pi_0 \in [0,1]$ and $\pi_1 + \pi_2 \in [-1,0]$ and that $D + ½(1-\gamma) < 0$ for $\gamma < 1$ and $\pi_0 \in [-1,0]$. Using these findings, the inequality follows straightforward.

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