The Suntory and Toyota International Centres for Economics and Related Disciplines

Price Inertia in a Macroeconomic Model of Monopolistic Competition
Author(s): Th. van de Klundert and P. Peters
Source: *Economica*, New Series, Vol. 55, No. 218 (May, 1988), pp. 203-217
Published by: Blackwell Publishing on behalf of The London School of Economics and Political Science and The Suntory and Toyota International Centres for Economics and Related Disciplines
Stable URL: http://www.jstor.org/stable/2554468
Accessed: 24/08/2011 09:25

Economica, **55**, 203–17

Price Inertia in a Macroeconomic Model of Monopolistic Competition

By TH. VAN DE KLUNDERT and P. PETERS

Tilburg University and Nijmegen University

Final version received 30 March 1987. Accepted 30 April 1987.

The paper discusses the consequences of price-setting by firms under monopolistic competition in dynamic models. It is assumed that costs of price adjustment are speed-dependent. The Keynesian regime prevails when firms choose a point on the demand curve. If real labour costs are relatively high, customers may be rationed. After analysing firm behaviour in a partial equilibrium setting, demand is made endogeneous in a full-scope macroeconomic model. Numerical examples are worked through by applying the technique of multiple shooting. It is found that relatively small costs of price adjustment give rise to substantial macroeconomic effects.

INTRODUCTION

The time-honoured question of price-setting remains an important issue in economic theory. Market-clearing conducted by a Walrasian auctioneer does not provide us with a realistic picture for most markets. A natural way out is to assume oligopoly or monopolistic competition among firms. As is well known, imperfect competition leads to inefficiency. Macroeconomic models based on monopolistic competition even exhibit Keynesian features, as shown in a seminal paper by Hart (1982). However, this is not the complete story. There is ample evidence that prices react with a lag to changes in demand. Price inertia can be explained in several ways. One way to do so is to assume that price changes are costly, as emphasized by Barro (1972), Rotemberg (1982) and others.

The present paper discusses the consequences of monopolistic competition and costly price adjustment in a dynamic macroeconomic model. Firms are supposed to have perfect foresight. It is shown that a demand shock has a substantial effect on output in the short run even if the costs of price adjustment are moderate. This can be explained by demand externalities in case of monopolistic competition, as emphasized in recent papers by Akerlof and Yellen (1985a, b) and by Blanchard and Kiyotaki (1985). Supply shocks give rise to a similar impact in the short run. In both cases, the economy adjusts towards a Nash–Cournot equilibrium in the long run.

Restrictions on the flexibility of prices may lead to rationing in markets. If firms produce according to demand, the situation can be characterised as 'Keynesian'. A 'classical regime' would prevail if *customers* are rationed by firms to avoid losses in production. It is found that in the present model rationing of customers is less likely in comparison with the case of perfect competition because monopoly profits form a buffer in the event of unexpected shocks. There remains the possibility of rationing of firms in the market for labour. However, following Blanchard and Sachs (1982), the regime of 'repressed inflation' will be eliminated by postulating that households supply all the labour demanded by firms. On the other hand, involuntary unemployment is taken into account by assuming sluggish wage adjustment.

The paper is organized as follows. In Section I the optimal behaviour of firms under monopolistic competition and perfect foresight is analysed. Section II builds on the results of this analysis by incorporating the behavioural equations in a model of the whole economy. Since the choice of the paper is to focus on the role of firms, demand for money and goods will be modelled as simply as possible. Simulation results of this macroeconomic model are discussed in Section III. The paper closes with some conclusions.

I. Optimal Behaviour of Firms under Perfect Foresight

Output of firm j, say y_j, is non-storable and can be produced by a neoclassical production function

$$(1) \qquad y_j = f(l_j, k_j), \qquad f_l, f_k, f_{kl} > 0; \qquad f_{ll}, f_{kk} < 0$$

where l_j denotes labour and k_j stands for the capital stock of firm j. The production function is linear homogeneous. Both consumers and producers demand good j. The demand function for the product of firm j is of the constant elasticity form

$$(2) \qquad y_j = a_j\left(\frac{p_j}{\bar{p}}\right)^{-\eta_j}, \qquad \eta_j > 1$$

where p_j is the (nominal) price of the good produced by firm j, $\bar{p}$ is the average price level and a_j is a constant determining the position of the demand curve for good j.

Capital accumulation depends on gross investment, i_j, and depreciation:

$$(3) \qquad \dot{k}_j = i_j - \delta k_j, \qquad \delta \geq 0.$$

Depreciation is exponential at a rate δ. To derive a well-behaved investment function, installation costs of capital are introduced. The investment expenditure function including these costs is written as

$$(4) \qquad g_j = g(i_j, k_j), \qquad g_i > 0, \qquad g_k < 0, \qquad g_{ii} > 0.$$

The function is assumed to be convex in i_j and homogeneous of degree 1 in its arguments i_j and k_j.

The adjustment of prices may be costly for two reasons. First, there are administrative costs of changing price lists, informing dealers, etc. These costs are independent of the direction or magnitude of the price change; they are a lump-sum type of costs. Administrative cost or 'small menu' cost, as they have been recently termed, will not be taken into account here. Second, there is the implicit cost resulting from unfavourable reactions of customers to large price changes. Such price changes may harm the reputation of firms. These costs, which are called information cost by Barro (1972), are speed-dependent (say, quadratic), as customers may well prefer small and recurrent price changes to more infrequent but larger ones. In reality, both types of cost may have some significance. Here, we take company with Rotemberg (1983) in arguing that information costs are probably more important in an environment in which the price level moves little. However, further empirical research may be needed to solve the issue. Casual observation of actual price changes is not a substitute for adequate testing.

Information costs may be conceived as a temporary shift of the demand curve facing a firm. Such temporary shifts in the demand curve can be allowed for by adapting the demand function (2) as follows:[2]

$$\text{(2a)} \qquad y_j = a_j\left(\frac{p_j}{\bar{p}}\right)^{-\eta_j}\left\{1-\phi_j\left(\frac{\dot{p}_j}{\bar{p}}\right)^2\right\}, \qquad \phi_j > 0.$$

As an alternative, let us consider the following argument. Firms may prefer to avoid temporary shifts of demand in the face of price changes. This may be realized at the expense of costly information to convince customers of the necessity of the change in prices. Moreover, firms may prevent temporary shifts in demand by increasing normal advertising. Larger price changes would require a larger effort on the part of firms. This line of reasoning implies a separate cost of adjustment function, which, bearing in mind equation (2a), would be

$$\text{(5)} \qquad h_j = a_j\phi_j\left(\frac{p_j}{\bar{p}}\right)^{1-\eta_j}\left(\frac{\dot{p}_j}{\bar{p}}\right)^2.$$

To make the analysis more tractable, we shall assume that firms ignore the dependency on the relative price level. The cost of adjustment function can then be written as

$$\text{(5a)} \qquad h_j = \frac{1}{2\psi_j}s_j^2$$

where $s_j = \dot{p}_j/\bar{p}$ and $\psi_j = 1/2a_j\phi$. A similar specification can be found in, among others, Rotemberg (1982), Henin and Zylberberg (1984) and Broer (1986).

Denoting the discount factor by

$$\rho(t) \equiv \exp\left(-\int_0^t r_s\, ds\right),$$

the value of the firm to be maximized is

$$V_j(0) = \int_0^\infty \left\{y_j(t)\frac{p_j(t)}{\bar{p}(t)} - l_j(t)\frac{w(t)}{\bar{p}(t)} - g_j(t) - h_j(t)\right\}\rho(t)\, dt$$

where $w(t)$ is the nominal wage rate paid by firms. For the time being, we assume that the supply of labour is infinitely elastic. Investment expenditure and adjustment costs are valued at the average price level. Decisions made by the representative firm with regard to prices are supposed to have only an indirect effect on these amounts. Firms maximize V subject to the constraints (1)-(5). As observed in the Introduction, it may be optimal for the representative firm to ration its customers. The constraint (2) should therefore be written as

$$a_j\left(\frac{p_j}{\bar{p}}\right)^{-\eta_j} \geq y_j$$

or

$$\frac{p_j}{\bar{p}} \leq \left(\frac{y_j}{a_j}\right)^{-(1/\eta_j)}$$

Multiplying both sides of the inequality by y_j finally results in

$$(2b) \qquad \bar{p}a_j\left(\frac{y_j}{a_j}\right)^{1-(1/\eta_j)} \geq y_j p_j.$$

The model has the format of an optimal control problem with instrument variables *l*, *i*, *s* and state variables *k*, *p*. The Hamiltonian of this problem dropping firms' subscripts is

$$(6) \qquad H = \rho\left[y\frac{p}{\bar{p}} - l\frac{w}{\bar{p}} - g(i,k) - \frac{1}{2\psi}s^2 + q(i-\delta k) + us + \lambda\left\{a\left(\frac{y}{a}\right)^{1-(1/\eta)} - y\frac{p}{\bar{p}} - z^2\right\}\right].$$

The costate variables q and $u/\bar{p}$ are adjoint to the state variables k and p. The symbol z indicates a slack variable connected with inequality (2b). The Lagrangean multiplier λ relates to this demand constraint and can be interpreted as the shadow price of sales revenue.[3]

Necessary first-order conditions for an optimum dividing out equal terms are:[4]

$$(7) \qquad (p+\lambda\Phi)f_l(k,l) = w$$

with

$$\Phi \equiv \left(1-\frac{1}{\eta}\right)\bar{p}\left(\frac{y}{a}\right)^{-1/\eta} - p$$

$$(8) \qquad g_i(i,k) = q$$

$$(9) \qquad s = \psi u$$

$$(10) \qquad \lambda z = 0$$

$$(11) \qquad \dot{q} = (r+\delta)q - \left(\frac{p+\lambda\Phi}{\bar{p}}\right)f_k(k,l) + g_k(i,k)$$

$$(12) \qquad \dot{u} = (r+\pi)u - (1-\lambda)y$$

where $\pi = \dot{\bar{p}}/\bar{p}$.

The complementary slackness condition (10) implies that $\lambda > 0$ if $z=0$. We then have: $\Phi = -(p/\eta)$. Substituting this result in (7) and (11) gives, for the case that consumers are not rationed,

$$(7a) \qquad \left(1-\frac{\lambda}{\eta}\right)pf_l = w$$

$$(11a) \qquad \dot{q} = (r+\delta)q - \left(1-\frac{\lambda}{\eta}\right)\frac{p}{\bar{p}}f_k(k,l) + g_k(i,k).$$

If $z > 0$ we have $\lambda = 0$ and equations (7a) and (11a) are still valid. The full model describing optimal behaviour by firms consists of equations (1), (2a), (3), (7a), (8), (9), (11a), (12) and the complementary slackness condition (10) with $\lambda \geq 0$.

Given the time paths of w, $\bar{p}$, r and initial values $k(0)$, $p(0)$, the model gives a solution for y, l, k, i, p, q, u, λ and z for $t > 0$. There are two regimes possible, depending on the values of the exogenous variables and the parameters of the model. When $\lambda = 0$ we have $z > 0$, and the firm is not operating on the demand curve for its product in the short run. Consumers are rationed, because labour is too expensive to produce according to demand. Under these circumstances demand is not binding and firms equate the marginal product of labour with the real wage rate. Such a situation of excess demand may arise because it takes time to adjust prices. In the terminology of Malinvaud (1977), the economy is in the 'classical regime' under these circumstances. As the price of output rises producers increase the supply of goods and sooner or later the demand constraint will be binding ($z = 0$ and $\lambda > 0$). When this point is reached the price will go up further to exploit the monopolistic position of the firm. When demand determines what can be supplied, the 'Keynesian regime' prevails.

The possibility of rationing in case prices change over time is illustrated in Figure 1. Demand in the initial equilibrium is given by the curve D, whereas the marginal cost curve is indicated by MC. For simplicity, these curves are assumed to the linear. The initial equilibrium price p_1^* and equilibrium output y_1^* are found from the equality of marginal cost and marginal revenue (MR). Upon impact of a demand shock from D towards D', firms will produce up to the point where the price equals marginal cost ($y = y_2$). With the price of output unchanged, consumers demand the quantity $y = y_3$. This results in excess demand for goods to the amount of $y_3 - y_2$.

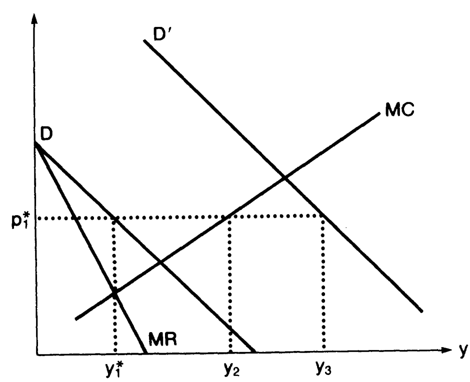

FIGURE 1

Dynamic price and quantity adjustment can be analysed more rigorously by ignoring for the time being capital accumulation and assuming that the stock of capital is constant. It then follows from equations (9) and (12), taking account of the definition of s, that, for the case of a long-run equilibrium with $\dot{p} = \dot{u} = 0$, we have $\lambda = 1$. Therefore in a long-run equilibrium situation demand will be binding and producers will exploit their monopoly position according to the static theory of profit maximization. Now consider the dynamics in case

λ remains positive ($\lambda > 0$, $z = 0$). From equations (2a), (7a), (9) and (12), the following system of differential equations in p and u can then be derived:[5]

$$(13) \qquad \dot{u} = r_m u - \left\{1 - \eta\left(1 - \frac{w}{pf_l}\right)\right\} a\left(\frac{p}{\bar{p}}\right)^{-\eta}$$

$$(14) \qquad \dot{p} = \bar{p}\psi u$$

where $r_m (\equiv r + \pi)$ denotes the nominal rate of interest, which firms take as given.

The phase diagram of the system is given in Figure 2(a). The line $\dot{p} = 0$ coincides with the horizontal axis. The expression for $\dot{u} = 0$ is more complicated. As shown in Appendix 1, the slope is negative for low values of p but is positive at high values of p. The main characteristics of the function are captured by the line shown in Figure 2(a). As appears from inspection of (13) and (14), the long-run solution is a saddlepoint with the stable arm indicated by SS' in Figure 2(a). The phase diagram for the 'classical regime' ($\lambda = 0$) is given in the left part of Figure 2(b). The expression for $\dot{u} = 0$ now equals $u = y/r_m$. Because in this situation there is a positive relationship between y and p, the slope of the curve for $\dot{u} = 0$ is also positive.

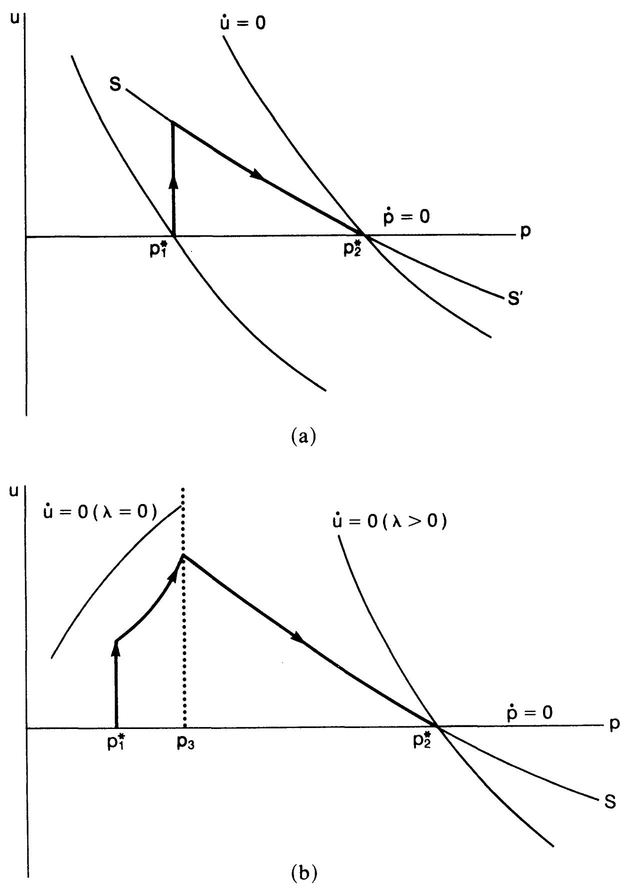

FIGURE 2

Let us now consider the case of an outward shift of the demand curve starting from a long-run equilibrium at p_1^* in Figures 2(a) and 2(b). If the demand constraint bites less, λ will fall. However, λ has a lower bound of zero, and when this is attained there will be some slack. In Figure 2(a) it is assumed that λ remains strictly positive. Therefore, the system of differential equations (13) and (14) determines the adjustment process from the old equilibrium indicated by p_1^* towards the new long-run value p_2^*. Following the shock, the costate variable u jumps to a point on the stable arm of the saddlepoint p_2^*. Output is raised to meet demand at the existing price p_1^*. After this initial adjustment, firms gradually increase prices and output declines until the new equilibrium is attained. The movement along the stable manifold SS' can be described by the differential equation

$$\dot{p}=\xi_1\left\{\frac{w}{(1-1/\eta)f_l}-p\right\} \tag{15}$$

where $\xi_1<0$ is the stable root.

In the case presented in Figure 2(b), the increase in demand is assumed to be larger and λ has to be set at zero initially. There is still a jump in output at $t=0$, but the rise in output is not enough to meet demand at the existing price level; consumers are rationed in the market for goods. The 'classical regime' prevails, and the real wage rate equals the marginal product of labour. Firms adjust prices gradually and at $p=p_3$ in Figure 2(b) a situation is reached where demand and supply are again equal.[6] From then on λ rises towards its equilibrium value unity and firms are able to exploit their monopoly position. It should be observed that the initial jump in u must be such that the stable arm of the saddlepoint p_2^* must be attained when p equals p_3.

Changes in the nominal wage rate w can be analysed in a similar way. However, in this case there is no initial change in output unless the change in w is large enough to lead to a regime switch. An increase in the wage rate, for example, leads to an upward adjustment of the output price over time and a decline in output. If the wage shock is relatively large, there may be a period of rationing of consumers to begin with.

Things are different if capital accumulation is taken into account. Because the production function and the cost of the adjustment function for capital are linear homogeneous, an increase in demand induces a proportional rise in l and k in the long run. Therefore, the long-run equilibrium price remains unchanged. An increase in nominal wages induces capital-deepening. As can be easily seen from equations (7a) and (11), the long-run equilibrium value of the price level will now be higher. Assuming saddlepoint stability, the dynamics of the system can be described in a way analogous to our previous analysis with constant k. Upon impact of a shock, the costate variables q and u will jump to the stable arm (for $\lambda>0$) and adjustment towards the new long-run values will take place smoothly. In case the demand constraint is not binding initially things are more complicated, of course.

II. A Macroeconomic Model with Endogeneous Price Adjustment

Before a macroeconomic model can be developed, something has to be said about aggregation. To simplify, we assume that demand elasticities are uniform across firms. Equation (2) can then be rewritten as

$$(16) \qquad y_j = \frac{y}{n}\left(\frac{p_j}{\bar{p}}\right)^{-\eta}, \qquad \eta > 1, j = 1, \dots, n$$

with $(\sum_{j=1}^{n} p_j y_j)/\bar{p}$ and n denoting the number of firms. Following Iwai (1981), Blanchard and Kiyotaki (1985) and Svensson (1986), the formula for the average price index can be represented by[7]

$$(17) \qquad \bar{p} = \left(\frac{1}{n}\sum_{j=1}^{n} p_j^{1-\eta}\right)^{1/(1-\eta)}.$$

It can be shown that the system of demand equations defined by (16) and (17) is consistent with maximization of the utility function:

$$(18) \qquad U = \sum_{j=1}^{n} y_j^{(\eta-1)/\eta}$$

subject to the expenditure constraint

$$(19) \qquad \sum_{j=1}^{n} p_j y_j = \bar{p}y.$$

In equilibrium all firms choose the same price; hence $p_j = \bar{p}$ for all j. Firms consider the prices of other firms as given. The equilibrium could therefore be called a Nash-rational expectations equilibrium as suggested by Rotemberg (1982). The necessary condition for an optimum at the firm level can now also be applied on the macroeconomic level, where total demand (y) equals the sum of aggregate consumption (c) and aggregate investment expenditure (g).[8]

To complete the macroeconomic model with endogenous price changes, we need a consumption function and equations for the money market. Consumer behaviour will not be modelled explicitly and is therefore not necessarily consistent with (18). Instead, we postulate a standard consumption function:

$$(20) \qquad c = c(y, r, \Omega), \qquad c_y > 0, \qquad c_\Omega \geq 0, \qquad c_r \leq 0$$

where Ω symbolizes real wealth:

$$\Omega = k + \frac{M}{p}.$$

The supply of money (M) is exogenous, while the demand for money follows from the standard specification:

$$(21) \qquad \frac{M}{p} = m(y, r, \Omega), \qquad m_y > 0, \qquad m_\Omega \geq 0, \qquad m_r < 0.$$

The nominal interest rate rather than the real interest rate should be in equation (21). As observed by Blanchard (1983), the present specification eliminates the 'Mundell effect'. Labour supply is exogenous. The nominal wage rate responds to excess demand in the market for labour over time (see equation (22p)). Following Blanchard and Sachs (1982), we assume that households supply all the labour demanded by firms, which means that firms are never constained in the market for labour. The regime of 'repressed inflation' is therefore eliminated.

The full macroeconomic model can now be formulated as follows:

(22a)	$y_d = c_d + g(i, k)$	effective demand
(22b)	$l_d = l_d(y_d, k)$	Keynesian demand for labour
(22c)	$l_w = l_w\left(\frac{w}{p}, k\right)$	demand for labour in case of rationing in the goods market
(22d)	$y_w = f(l_w, k)$	output in case of rationing in the goods market
(22e)	$y = \min(y_d, y_w)$	actual output
(22f)	$l = \min(l_d, l_w)$	actual employment
(22g)	$c_d = c_d(y, r, k)$	consumption function
(22h)	$g_i(i, k) = q$	investment function
(22i)	$\frac{M}{p} = m(y, r)$	*LM* curve
(22j)	$\lambda = \max\left[0, \eta\left\{1 - \frac{w}{pf_l(k, l_d)}\right\}\right]$	shadow price of the sales constraint
(22k)	$c = c_d - (y_d - y)$	rationing rule for consumption
(22l)	$\dot{k} = i - \delta k$	accumulation of capital
(22m)	$\dot{q} = (r + \delta)q - \left(1 - \frac{\lambda}{\eta}\right)f_k(k, l) + g_k(i, k)$	costate variable for k
(22n)	$\dot{p} = \psi up$	price formation
(22o)	$\dot{u} = \left(r + \frac{\dot{p}}{p}\right)u - (1 - \lambda)y$	costate variable for p
(22p)	$\dot{w} = \beta w(l - l_s)$	wage formation

Equation (22b) is the inverted production function determining labour demand if consumers are not rationed in the goods market. When rationing prevails, labour demand is obtained by equating the marginal product of labour and the real wage rate, which follows from equation (7a) when $\lambda = 0$. Labour demand is then given by equation (22c). The corresponding output volume is found by substituting l_w in the production function as shown in equation (22d).

In models with monopolistic competition, it can be shown that the employment function has the real wage rate and effective demand as explanatory variables, ıı the elasticity of demand with respect to the relative price depends on output (see for instance Layard and Nickell, 1985). In our model the employment function depends upon the prevailing regime as follows from equations (22b) and (22c). The assumption of a constant elasticity of demand is immaterial to this result. In the 'classical regime', effective demand has no influence on employment. In the 'Keynesian regime', the influence of the wage rate on labour demand is only indirect. The reason for this is that output prices are fixed in the short run.

It is assumed that only consumers are rationed in the market for goods. If total effective demand exceeds actual output, then actual consumption falls short of effective consumers' demand by the same amount, as can be seen from equation (22k).

If the demand constraint is binding ($\lambda > 0$), combining (22j) and (22m) gives

$$(22\text{m}_1) \quad \dot{q} = (r+\delta)q - \frac{w}{p}\frac{f_k}{f_l} + g_k.$$

Fims invest to save labour costs. This result corresponds with the outcome in case of a Keynesian regime under perfect competition as discussed in Blanchard and Sachs (1982) and Van de Klundert and Peters (1986). For $\lambda = 0$, we get

$$(22\text{m}_2) \quad \dot{q} = (r+\delta)q - f_k + g_k.$$

This is the classical outcome: investment is governed by the return to capital. As shown by Hayashi (1982), the shadow price q is then equal to the observable average value of capital (Tobin's q).[9]

In a stationary state we: $\dot{k} = \dot{q} = \dot{p} = \dot{u} = \dot{w} = 0$. Substituting these conditions in equations (22l)–(22p) gives the following long-run solutions: $u^* = 0$, $\lambda^* = 1$, $l^* = l^s$, $i^* = \delta k^*$. It should be recalled that in the long-run equilibrium situation the demand constraint is binding ($\lambda = 1$).

The comparative statics of the long-run model are rather straightforward if the functions are properly specified.[10] A change in labour supply (measured in efficiency units) then leads to a proportional mutation in the equilibrium value of the stock of capital. In this case the long-run rate of interest remains unaffected. An increase in the money stock induces an increase in the nominal price level with all other variables maintaining their value. Money is neutral in the long run.

The impact of a shock depends among other things on the non-predetermined state variables q and u. The short-run impact of changes in exogenous variables and the process of adjustment towards a (new) long-run equilibrium can be traced by numerical examples. Applying the method of multiple shooting as explained in Lipton, *et al.* (1982), this will be done in the next section. The specification of functions applied and the chosen parameter values are given in Appendix 2.

III. Simulation Results on a Macroeconomic Level

The results of a once and for all 5 per cent decrease in the money stock at $t = 0$ are presented in Table 1. All variables (except λ and u) are measured as percentage deviations from the original steady-state values. There are three roots with negative real parts and two roots with positive real parts corresponding to the number of, respectively, predetermined and non-predetermined state variables. Therefore the model exhibits saddlepoint stability.

Money is not neutral in the short run if price changes are costly. Firms accept lower profits from operations because it pays to let prices decrease slowly. The resulting price rigidity causes a recession with a substantial decline in output and employment. A higher value for λ ($\lambda > 1$) points to a more binding demand constraint. These results are remarkable, because the costs

TABLE 1
A 5 PER CENT DECREASE IN MONEY

Variable	Period 0	1	2	5	10	SS
c	−4·1	−2·4	−1·4	−0·3	−0·1	0
i	−3·1	−1·9	−1·1	−0·3	−0·2	0
y	−4·1	−2·4	−1·4	−0·3	−0·1	0
l	−6·5	−3·7	−2·0	−0·2	0·0	0
r	6·4	4·0	2·7	0·8	0·3	0
λ*	1·10	1·07	1·05	1·01	1·00	1
k	0	−0·2	−0.4	−0·4	−0·3	0
q	−1·6	−0·8	−0·4	0·1	0·1	0
p	0	−2·0	−3·3	−4·7	−4·8	−5
u*	−0·3	−0·2	−0·1	−0·0	0·0	0
w	0	−2·5	−3·8	−5·0	−5·0	−5

* Level.

of price adjustment are moderate. From equation (5a), the adjustment costs of a 5 per cent change in price with $\psi = 0{\cdot}1$ amount to 0·0125 in real terms. The cumulative loss in output exceeds this number by far. Over the first ten periods, the cumulative output gap is already equal to 10 per cent of the initial steady-state value, which in the present example comes down to an absolute amount of 0·12.

There is of course no contradiction involved. The number of firms is large and each firm must incur the cost of price adjustment. To put it differently, the output figures in Table 1 are macroeconomic results, which must be split up among a large number of firms. There is no monopoly of supply on the macroeconomic level. Instead, there are many firms observing their own demand curve. As our numerical example, based on reasonable values of parameters, shows, small costs of price adjustment under these circumstances have important consequences for output and employment. A similar argument has been put forward by Blanchard and Kiyotaki (1985) with regard to the significance of administrative cost or small menu cost. Following a suggestion in Akerlof and Yellen (1985a, b), the envelope theorem is applied to argue that second-order menu costs will prevent each firm from changing its price, given the prices of other firms. It should be clear that the interpretation of macroeconomic results does not depend on the cause of adjustment costs. Essential in both cases is a demand externality related to the market form of monopolistic competition. By changing the prices of their own good, firms can move along the demand curve facing them, but they can not alter the position of the curve: only if other firms change their prices will the demand curve shift.

Changes in the stock of capital are of minor importance. The decline in capacity raises marginal labour cost in the medium run, but the fall in real wages has an opposite effect. Not much harm would be done if in the present case capital accumulation would be left out.

Ignoring the possibility of 'repressed inflation', the result of an increase in money is the exact image of the result presented in Table 1. It pays again to adjust prices slowly. Profits from operations are below their long-run equilibrium level, which is now reflected in a value of λ below unity. Consumers are not rationed unless λ falls below zero. Things would be different in the case of perfect competition and price formation based on excess demand. Then, a positive demand shock leads upon impact to a 'classical disequilibrium', because meeting demand would mean suffering a loss. In case monopolistic competition prevails, monopoly profits serve as a buffer, which enables firms to meet demand. It is only when the shock is very large that producing according to demand may imply that the price of output does not cover marginal (labour) cost. In such a situation, firms decide to ration their customers until prices have risen sufficiently. The mainly symmetrical output response in the case of imperfect competition gives the model a more Keynesian flavour compared with the competitive model. Our next example of a negative supply shock also illustrates this point.

The results presented in Table 2 relate to a permanent decline in total factor productivity of 5 per cent at $t=0$. This corresponds to a decline in labour quality of 7·9 per cent for a Cobb–Douglas production function with an elasticity of production with regard to labour of 0·625. As shown in Section II, the capital stock decreases at the same rate in the long run, whereas the long-run rate of interest does not change. With the stock of money given, the price level increases to compensate for the fall in output in the long term. The real wage rate falls because the supply of labour is perfectly inelastic.

TABLE 2

A 5 PER CENT DECREASE IN PRODUCTIVITY

	Period					
Variable	0	1	2	5	10	SS
c	−2·7	−4·8	−5·7	−6·0	−6·1	−7·9
i	−2·0	−3·7	−4·5	−5·0	−5·4	−7·9
y	−2·7	−4·8	−5·7	−6·0	−6·1	−7·9
l	4·0	0·6	−0·7	−0·7	0·0	0
r	−16·5	−12·3	−10·1	−7·7	−6·7	0
λ*	0·73	0·86	0·93	1·00	1·00	1
k	0	−0·3	−0·7	−1·7	−3·1	−7·9
q	−1·0	−1·7	−1·9	−1·7	−1·2	0
p	0	3·0	4·3	5·1	5·4	8·6
u*	0·4	0·2	0·1	0·0	0·0	0
w	0	1·0	0·9	−0·5	−1·1	0

* Level.

Things are different in the short run. The lower productivity level reduces the profitability of investment. Effective demand is even further depressed by the multiplier mechanism. The demand constraint bites, however, less ($\lambda < 1$) because there is a downward pressure on supply in case of an increase in cost. As long as λ is positive, firms produce what can be sold at the going price even if they have to hire more labour. The rise in employment underlines the demand-oriented character of the model. In a competitive world with price inflexibility, an adverse supply shock may lead to classical unemployment (see for instance Blanchard and Sachs, 1982).

The development of employment over time is governed by demand and supply factors. As effective demand decreases employment declines, and in period $t=2$ there is even some unemployment. Capital decumulation in combination with a fall in real wages reverses the situation, and from period $t=0$ onward labour demand and labour supply are more or less balanced. As appears from Table 2, the process of adjustment towards the new long-run equilibrium lasts some time in the present case.

IV. Conclusions

It is interesting that the results of our model are in a number of ways qualitatively different from those of disequilibrium models presented by Blanchard and Sachs (1982) and by Van de Klundert and Peters (1986). In the present analysis, rationing of consumers seems a somewhat remote possibility, at least starting from a long-run equilibrium position. A macroeconomic demand pull leads to an increase in output in the short run, because firms change prices slowly while at the same time wanting to sell more at the going price.

As emphasized by Rotemberg (1982), when prices adapt without a time lag, changes in the quantity of money have no effect on real variables even if firms are monopolists. It is interesting to compare this result with the view expressed by Hart (1982) that imperfect competition induces Keynesian features in a model that has no money in the usual sense. Hart analyses imperfectly competitive equilibria where demand shocks relate to a shift in demand for the produced good versus the non-produced good.

The *ad hoc* modelling of the labour market remains an unsatisfactory aspect of the model presented here. To deal with this problem, one could opt for a model of wage-setting by firms or labour unions. As suggested in Iwai (1981), costs of wage adjustment could then be introduced to allow for disequilibrium in the labour market. Extensions like these are certainly on our agenda.

APPENDIX 1

From (14) we get, for $\dot{u}=0$,

$$u=\left\{1-\eta\left(1-\frac{w}{pf_l}\right)\right\}\frac{a}{r_m}p^{-\eta}. \tag{A1}$$

Differentiating with regard to p gives

$$\frac{du}{dp}=\eta\underset{+}{\frac{a}{r_m}p^{-(\eta+1)}}\left\{\underset{+}{(\eta-1)}-(\eta+1)\frac{w}{pf_l}+\underset{-}{\frac{w}{f_l}\frac{f_{ll}}{f_l^2}}\eta\underset{-}{\frac{a}{r_m}p^{-(\eta+1)}}\right\}. \tag{A2}$$

Inspection of equation (A2) reveals that the derivative is negative for low values of p and positive for high values of p. From (A1) it follows that $u\to 0$ for $p\to\infty$ and $u\to\infty$ for $p\to 0$. The function (A1) is therefore of the form as shown in Figure 3. The number of inflection points or turning points cannot be determined.

APPENDIX 2

In the numerical exercises of Section III, the following specifications are applied:

$c_d=\gamma y$ consumption function

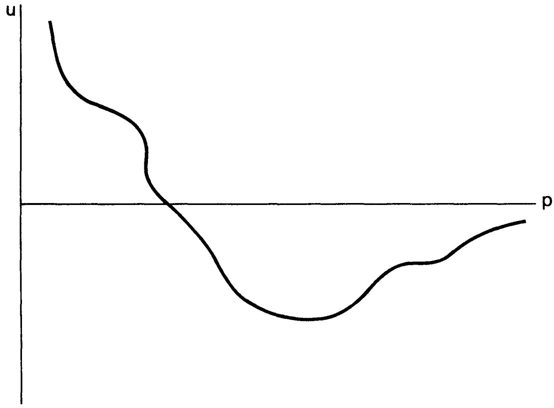

FIGURE 3

$y = \varepsilon l^{\alpha} k^{1-\alpha}$ production function

$g = i\left(1 + \theta \frac{i}{k}\right)$ investment expenditure function

$\frac{M}{p} = \chi y r^{-\zeta}$ liquidity preference function

Parameter values should be based on empirical estimates and lead to reasonable outcomes for important ratios in the economy.

The full set of parameter values used in computations is given by

$$\alpha = 0{\cdot}625 \quad \beta = 0{\cdot}5 \quad \gamma = 0{\cdot}8 \quad \delta = 0{\cdot}1 \quad \varepsilon = 1$$

$$\zeta = 0{\cdot}15 \quad \eta = 5 \quad \theta = 5 \quad \chi = 0{\cdot}25 \quad \psi = 0{\cdot}1.$$

The chosen values of the exogenous variables are

$$l^s = 1, \qquad M = 100.$$

ACKNOWLEDGMENTS

We would like to thank Lex Meydam, Rick van der Ploeg and two anonymous referees for their valuable comments on a previous version of this paper. Computational assistance by G. Staarink is gratefully acknowledged.

NOTES

1. With lump-sum type costs of price adjustment, it is straightforward that, in response to a shock, adjustment for the individual firm would occur either all at once or not at all. Of course, with a large number of different firms the economy may still display smooth behaviour.
2. The specification of equation (2a) is reminiscent of the dynamic monopoly problem introduced by Evans (1924) and discussed in Allen (1938).
3. Our treatment of the inequality constraint on demand is based on Broer (1986, Chapter 3). For a more general discussion of inequality constraints in optimal control problems, see for instance Hadley and Kemp (1971, Chapter 5).
4. In addition, we have the usual transversality conditions:

$$\lim_{t\to\infty} \rho(t)q(t)k(t) = 0 \quad \text{and} \quad \lim_{t\to\infty} \rho(t)p(t) = 0.$$

5. The marginal product of labour f_l depends upon p through y and l.
6. The value of p_3 can be found from equations: $f_l(l, k) = w/p$ and $f(l, k) = a(p/\bar{p})^{-\eta}$.
7. In Svensson (1986) there is a continuum of firms defined by the unit interval $0 \leq j \leq 1$, where each firm is indexed by j.

8. The implication of this approach is that investment goods are of different quality, and qualities are chosen according to preferences specified in equation (18). This is the 'price' to be paid if one wants to avoid the modelling of a two-sector economy.
9. It should be noted that this result is obtained under the condition of constant returns to scale both in production and installation: the functions f and g are linear homogeneous. Costs of price adjustment ought to be ignored.
10. According to Rose (1966), the consumption function should be homogeneous of the first degree in y and k.

REFERENCES

AKERLOF, G. A. and YELLEN, J. L. (1985a). Can small deviations from rationality make significant differences to economic equilibria? *American Economic Review*, **75**, 708-21.

—— (1985b). A near-rational model of the business cycle, with wage and price inertia. *Quarterly Journal of Economics*, **100**, 823-38.

ALLEN, R. G. D. (1938). *Mathematics for Economists.* London: Macmillan.

BARRO, R. J. (1972). A theory of monopolistic price adjustment. *Review of Economic Studies*, **39**, 17-76.

BLANCHARD, O. J. (1983). Dynamic effects of a shift in savings: the role of firms. *Econometrica*, **51**, 1583-91.

—— and KIYOTAKI, N. (1985). Monopolistic competition, agregate demand externalities and real effects of nominal money. NBER Working Paper no. 1770.

—— and SACHS, J. (1982). Anticipations, recessions and policy: an intertemporal disequilibrium model. *Annales de l'INSEE*, **47-8**, 117-44.

BROER, D. R. (1986). *Neoclassical Theory and Empirical Models of Aggregate Firm Behavior.* The Hague: Martinus Nijhoff.

EVANS, G. C. (1924). The dynamics of monopoly. *American Mathematical Monthly*, **31**, 77-83.

HADLEY, G. and KEMP, M. C. (1971). *Variational Methods in Economics.* Amsterdam: North-Holland/American Elsevier.

HART, O. (1982). A model of imperfect competition with Keynesian features. *Quarterly Journal of Economics*, **97**, 109-38.

HAYASHI, F. (1982). Tobin's marginal q and average q; a neoclassical interpretation. *Econometrica*, **50**, 213-24.

HENIN, P. Y. and ZYLBERBERG, A. (1984). Sur la comptabilité à long terme d'un ajustement partiel des prix avec l'hypothèse de prévisions rationelles. *Revue d'Economie Politique*, **94**, 792-807.

IWAI, K. (1981). *Disequilibrium Dynamics. A Theoretical Analysis of Inflation and Unemployment.* New Haven and London: Yale University Press.

VAN DE KLUNDERT, TH. and PETERS, P. (1986). Tax incidence in a model with perfect foresight of agents and rationing in markets. *Journal of Public Economics*, **30**, 37-59.

LAYARD, R. and NICKELL, S. (1985). The causes of British unemployment. London School of Economics, Centre for Labour Economics, Discussion Paper no. 209.

LIPTON, D., POTERBA, J., SACHS, J. and SUMMERS, L. (1982). Multiple shooting in rational expectations models. *Econometrica*, **50**, 1329-33.

MALINVAUD, E. (1977). *The Theory of Unemployment Reconsidered.* Oxford: Basic Blackwell.

ROSE, H. (1966). Unemployment in a theory of growth. *International Economic Review*, **7**, 260-82.

ROTEMBERG, J. J. (1982). Monopolistic price adjustment and aggregate output. *Review of Economic Studies*, **49**, 517-31.

—— (1983). Aggregate consequences of fixed costs of price adjustment. *American Economic Review*, **73**, 433-36.

SVENSSON, L. E. O. (1986). Sticky goods prices, flexible asset prices, monopolistic competition, and monetary policy. *Review of Economic Studies*, **53**, 385-406.