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RESEARCH MEMORANDUM

TILBURG UNIVERSITY

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Price Inertia in a Macroeconomic Model
of Monopolistic Competition

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Price Inertia in a Macroeconomic Model of Monopolistic Competition*)

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1. Introduction

If one accepts the view that prices are not fully flexible macroeconomic analysis has a long way to go. First, with prices fixed in the short run rationing in markets becomes a central issue. Second, if price adjustment takes time the question is how price levels are determined in the course of time. Models with quantity rationing and price adjustment based on excess demand functions have been investigated by a number of authors. As shown among others by McCurdy and Yannelis [1985] and van de Klundert and Peters [1985] stability of the Walrasian equilibrium may cause problems if the time path of prices crosses the boundary between the regime of Keynesian Unemployment and the regime of Repressed Inflation. Proposed solutions to this problem lead to an extension of ad-hoc procedures. Such procedures are criticized fundamentally by Fisher [1983]. Price adjustment according to excess demand functions implicitly assumes a Walrasian auctioneer. There is no agent who actually sets prices.

In this paper we aim at an analysis of optimal price inertia in a macroeconomic context. Entrepreneurs are supposed to maximize the present value of their firm at each point in time. In the output market the firm envisages monopolistic competition, because of product differentiation. There are costs attached to price changes as discussed in a well-known paper by Barro [1972]. Further, we assume that entrepreneurs have perfect foresight. This set of assumptions corresponds with that of Rotemberg [1982] with three not unimportant exceptions. First, Rotemberg

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eliminates the possibility that firms ration their customers in the market for goods. Following Broer [1985] we take account of the possibility of a classical disequilibrium under monopolistic competition. The second difference with Rotemberg's analysis concerns the problem of capital accumulation. Here again we keep company with Broer by analysing the long-run adjustment of the capital stock along the lines set out by Hayashi [1982] and others. Whereas Broer sticks to partial equilibrium analysis we want to consider the effects of macroeconomic shocks in a model with endogenous output price adjustments. Third, Rotemberg assumes that the labour market is competitive: wages are fully flexible and demand always equals supply. In this paper we assume that it takes some time to clear the labour market.

The assumption of monopolistic competition implies that long-run equilibria are non-Walrasian. A discussion of the welfare implications would require a choice-theoretic specification of consumer behaviour as for instance in Calvo and Phelps [1983]. Here we shall restrict our analysis to macroeconomic issues. For this purpose a standard specification of the consumption function and the liquidity preference function will do in order to close our model.

The paper is organized as follows. In section 2 the optimal behaviour of firms under monopolistic competition and perfect foresight is analysed. Section 3 builds upon the results of this analysis by incorporating the behavioural equations in a model for the whole economy. Simulation results of this macroeconomic model are discussed in section 4. The paper closes with some conclusions.

2. Optimal behaviour of firms under perfect foresight

Output of firms (y_j) is non-storable and can be produced by a neo-classical production function:

$$(1) \quad y_j = f(\ell_j, k_j), \quad f_\ell, f_k, f_{k\ell} > 0; f_{\ell\ell}, f_{kk} < 0$$

, where ℓ denotes labour and k stands for the capital stock. The production function is linear homogeneous. Both consumers and producers demand good j . The demand function is of the constant elasticity form:

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

where p_j is the (nominal) price of good 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) and depreciation:

$$(3) \quad \dot{k}_j = i_j - \delta k_j$$

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

$$(4) \quad e_j = g(i_j, k_j), \quad g_i > 0, g_k < 0, g_{ii} > 0$$

, where e is real investment expenditure. The function is assumed to be convex in i and homogeneous of degree one in its arguments i and k .

Price adjustment may be costly for two reasons. First, there are administrative costs when prices are changed. Second, there are implicit cost that result from unfavourable reactions of consumers to frequent and large price changes. The latter are coined information cost by Barro [1972]. Administrative cost can be considered as lump-sum amounts, independent of the direction or magnitude of the price change. Information cost may give rise to speed-dependent adjustment costs as in the case of capital accumulation, discussed above. Ignoring administrative costs of price adjustment and normalizing prices changes on $\bar{p}$ ($s \equiv \frac{\dot{p}}{\bar{p}}$) the cost of adjustment function reads:

$$(5) \quad n_j = h(s_j), \quad h' > 0, h'' > 0$$

, where n stands for the cost of price adjustment in real terms. The function is assumed to be convex.

Denoting the discount factor by $\rho(t) \equiv e^{-\int_0^t r_s ds}$ and dropping firm subscripts the value of the firm to be maximized is:

$$V_0 = \int_0^{\infty} [y(t) \frac{p(t)}{\bar{p}(t)} - \ell(t) \frac{w(t)}{\bar{w}(t)} - e(t) - n(t)] \rho(t)$$

, where $w(t)$ is the 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_0 subject to the constraints (1) - (5). As observed in section 1 it may be optimal for the representative firm to ration its customers. The constraint (2) should therefore be written with an inequality sign:

$$(2a) \quad y(t) \leq a_t \left(\frac{p(t)}{\bar{p}(t)} \right)^{-\eta}$$

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 time subscripts is:

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

The costate variables q and $\frac{u}{p}$ are adjoint to the state variables k and p . The Lagrangean multiplier λ relates to the demand constraint (2a). This constraint is written as an equality by applying the slack variable z .*) The symbol λ can be interpreted as the shadow price of sales revenue.

*) For an analysis of inequality constraints in optimal control problems see Hadley and Kemp [1971, ch. 5].

Necessary first order conditions for an optimum dividing out equal terms are^{*}):

$$(7) \quad (p + \lambda \Phi) f_{\ell}(k, \ell) = w$$

$$, \text{ with } \Phi \equiv (1 - \frac{1}{\eta}) \bar{p} (\frac{y}{a})^{-1/\eta} - p$$

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

$$(9) \quad h'(s) = u$$

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

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

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

, where $\pi = \frac{\dot{\bar{p}}}{\bar{p}}$.

The complementary slackness condition (10) implies $\lambda > 0$ if $z = 0$. In this case: $\Phi = -\frac{p}{\eta}$. Substituting this result in (7) and (11) gives:

$$(7a) \quad (1 - \frac{\lambda}{\eta}) p f_{\ell} = w$$

$$(11a) \quad \dot{q} = (r + \delta)q - (1 - \frac{\lambda}{\eta}) \frac{p}{\bar{p}} f_k(k, \ell) + g_k(i, k)$$

If $z > 0$ we have $\lambda = 0$ and equations (7a) and (11a) are still valid.

Existence of an optimal policy can be proven along the lines set out in Broer [1985].

To simplify a little bit we assume that the adjustment function with regard to prices is quadratic:

$$(5a) \quad n = \frac{1}{2\psi} s^2$$

^{*}) In addition we have the usual transversality conditions:

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

The full model describing optimal behaviour by firms can then be written as:

$$(13a) \quad y = f(\ell, k)$$

$$(13b) \quad f_{\ell} = \frac{w}{p} \left(\frac{n}{n-\lambda} \right)$$

$$(13c) \quad g_i(i, k) = q$$

$$(13d) \quad \bar{p} a \left(\frac{y}{a} \right)^{1-\frac{1}{n}} - y p - z^2 = 0$$

$$(13e) \quad \lambda z = 0$$

$$(13f) \quad \dot{k} = i - \delta k$$

$$(13g) \quad \dot{p} = \bar{p} \psi u$$

$$(13h) \quad \dot{q} = (r+\delta)q - \left(1 - \frac{\lambda}{n}\right) \frac{p}{\bar{p}} f_k + g_k(i, k)$$

$$(13i) \quad \dot{u} = (r+\pi)u - (1-\lambda)y$$

For given w and $\bar{p}$ the model gives a solution for $y, \ell, k, i, p, q, u, \lambda, z$. There are two regimes depending on $\lambda = 0$ or $\lambda > 0$. In case $\lambda = 0$ we have $z > 0$ and the firm is not operating on the demand curve for its product on 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. 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.

The possibility of rationing in case prices change over time is illustrated in figure 1. Demand in the initial equilibrium is given by

Figure 1

the curve D , whereas the marginal cost curve is indicated by MC . For simplicity these curves are assumed to be 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 $y_3 - y_2$.

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 equation (13g) and equation (13i) that in 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 exploit their monopoly position according to the static theory of profit maximization. Now consider the dynamics in case λ remains positive ($\lambda > 0, z = 0$). Substituting λ from (13b) and y from (13d) in (13i) results in:

$$(14) \quad \dot{u} = r_m u - \left[1 - \eta \left(1 - \frac{w}{p f_l} \right) \right] a \left(\frac{p}{p} \right)^{-\eta}$$

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

$$(13g) \quad \dot{p} = \bar{p}\psi u$$

we have a system of two interdependent differential equations in u and p .*) The phase diagram of the system is given in figure 2a. The line $\dot{p} = 0$ coincides with the horizontal axis. The expression for $\dot{u} = 0$ is

Figure 2a

Figure 2b

*) The marginal product of labour f_ℓ depends upon p through y and ℓ .

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 2a.

As appears from inspection of (13g) and (14) the long-run solution is a saddlepoint with the stable arm indicated by SS' in figure 2a. The phase diagram for the case $\lambda = 0$ is given in figure 2b. The expression for $\dot{u} = 0$ now equals $u = \frac{y}{r}$. 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.

The case of an outward shift of the demand curve is presented in figure 3. If the demand constraint bites less λ will fall and become eventually negative. However λ has a lower bound of zero and in that case there will be some slack. In figure 3a it is assumed that λ remains positive. Therefore, the system of differential equations (13g) 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:

Figure 3a

Figure 3b

$$(15) \quad \dot{p} = \xi_1 \left[\frac{w}{(1 - \frac{1}{\eta}) f_\ell} - p \right]$$

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

In the case presented in figure 3b there is a larger increase in demand 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 real wage rate equals the marginal product of labour. Firms adjust prices gradually and at $p = p_3$ in figure 3b a situation is reached where demand and supply are again equal.*) 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. An increase in the wage rate for example leads to an upward adjustment of the

*) The value of p_3 can be found from equations: $f_\ell(\ell, k) = \frac{w}{p}$ and $f(\ell, k) = a \left(\frac{p}{w} \right)^{-\eta}$.

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 homogenous 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 (13b) and (13h) 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 complicate of course.

3. A macroeconomic model with endogenous 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:

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

, with $y = \sum_{j=1}^n y_j$ and n denoting the number of firms.*) Following Iwai [1981] and Svensson [1985] the formula for the average price index can be represented by:

$$(17) \quad \bar{p} = \left[\sum_{j=1}^n p_j^{1-\eta} \right]^{1/(1-\eta)}$$

*) In Svensson [1985] there is a continuum of firms defined by the unit interval $0 \leq j \leq 1$, where each firm is indexed by j .

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

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

, subject to the expenditure constraint:

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

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 coined a Nash-Rational Expectations Equilibrium as suggested by Rotemberg [1982]. The necessary condition for an optimum at the firm level can now be applied also on the macroeconomic level where total demand (y) equals the sum of aggregate consumption (c) and aggregate investment expenditure (e).*)

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. Instead we postulate a standard consumption function:

$$(20) \quad c = c(y, r, k) \quad , \quad c_y > 0 \quad , \quad c_k > 0 \quad , \quad c_r < 0$$

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

$$(21) \quad \frac{M}{p} = m(y, r) \quad , \quad m_y > 0 \quad , \quad m_r < 0$$

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".

*) 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.

Labour supply is exogenous. The nominal wage rate responds to excess demand in the market for labour over time. Following Blanchard and Sachs [1982] we assume that households supply all the labour demanded by firms, which means that firms are never constrained 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) $\ell_d = \ell_d(y_d, k)$ Keynesian demand for labour
- (22c) $\ell_w = \ell_w(\frac{w}{p}, k)$ demand for labour in case of rationing in the goods market
- (22d) $y_w = f(\ell_w, k)$ output in case of rationing in the goods market
- (22e) $y = \min(y_d, y_w)$ rationing rule for goods
- (22f) $\ell = \min(\ell_d, \ell_w)$ rationing rule for labour
- (22g) $c_d = c_d(y, r, k)$ consumption function
- (22h) $g_1(i, k) = q$ investment function
- (22i) $\frac{M}{p} = m(y, r)$ LM-curve
- (22j) $\lambda = \max(0, \eta(1 - \frac{w}{pf_\ell(k, \ell_d)}))$ 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) $\dot{q} = (r + \delta)q - (1 - \frac{\lambda}{\eta})f_k(k, \ell) + g_k(i, k)$
costate variable for k

$$(22n) \quad \dot{p} = \psi u p \quad \text{price formation}$$

$$(22o) \quad \dot{u} = (r + \frac{p}{u})u - (1-\lambda)y \quad \text{costate variable for } p$$

$$(22p) \quad \dot{w} = \beta w (\ell - \ell_s) \quad \text{wage formation}$$

It is assumed that only consumers are rationed in the market for goods and in the labour market.

In models with monopolistic competition it can be shown that the employment function has the real wage rate and effective demand as explanatory variables, if 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.

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

$$(22m_1) \quad \dot{q} = (r+\delta)q - \frac{w}{p} \frac{f_k}{f_\ell} + g_k$$

Firms 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], van de Klundert and Peters [1985]. For $\lambda = 0$ we get:

$$(22m_2) \quad \dot{q} = (r+\delta)q - f_k + g_k$$

This is the classical regime: 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).*)

In a stationary state we have: $\dot{k} = \dot{q} = \dot{p} = \dot{u} = \dot{w} = 0$. Substituting these conditions in equations (22l)-(22p) gives the following long-run solutions: $u^* = 0$, $\lambda^* = 1$, $\ell^* = \ell^S$, $i^* = \delta k^*$. It should be noted that in the long-run equilibrium situation the demand constraint is binding ($\lambda=1$). In case λ would be zero, y would be zero too, which does not make economic sense. It will be assumed that the marginal valuation of present consumption in terms of future consumption is independent of the absolute size of the consumption stream. As observed by Rose [1966] the consumption function is then homogeneous of the first degree in y and k :

$$(23) \quad \frac{c_d}{k} = \psi^1\left(\frac{y}{k}, 1, r\right)$$

To simplify further we assume: $\psi_r^1 = 0$. The long-run model may now be written as:

$$(24a) \quad \frac{y^*}{k^*} = \frac{c^*}{k^*} + \bar{g}(\delta)$$

$$(24b) \quad \frac{c^*}{k^*} = \psi^1\left(\frac{y^*}{k^*}\right)$$

$$(24c) \quad q^* = g_1(\delta)$$

$$(24d) \quad \frac{y^*}{k^*} = \psi^2\left(\frac{a\ell^S}{k^*}\right)$$

$$(24e) \quad w^* = \left(1 - \frac{1}{\eta}\right) p^* f_\ell\left(\frac{k^*}{a\ell^S}\right)$$

$$(24f) \quad \frac{M^*}{p} = m(y^*, r^*)$$

$$(24g) \quad (r^* + \delta) q^* = \left(1 - \frac{1}{\eta}\right) f_k\left(\frac{a\ell^S}{k^*}\right) - g_k(\delta)$$

*) 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.

, with the symbol a indicating a quality index for labour. Inspection of the model reveals that q^* is determined by equation (24c), whereas the capital output ratio follows from equations (24a) and (24b). If the solution for y^*/k^* is substituted into equation (24d) the capital-labour ratio is found. The equilibrium value of the capital-labour ratio determines the long-run solution of the rate of interest r^* according to equation (24g). With the rate of interest known the price level follows from equation (24f). Finally the (nominal) wage rate is obtained from equation (24e).

It is now possible to study the comparative statics of the long-run model. It appears that a change in effective labour supply (al^S) 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 leads to an increase in the nominal price level with all other variables maintaining their value. Money is therefore 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.

4. Simulation results on a macroeconomic level

The results of a once and for all 5% 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 with the number of respectively the predetermined and the non-predetermined state variables. Therefore the model exhibits saddle-point stability.

Table 1: A 5% 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
$\lambda^*)$	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.

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 of price adjustment are moderate. From equation (5a) the adjustment costs of a 5% change in price with $\psi = 0.1$ amount to 0.0125 in real terms. The cumulative loss in output exceeds this number by far. Over the first 10 periods the cumulative output gap is already equal to 10% 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.

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. No 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 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 case of imperfect competition gives the model a more Keynesian flavour compared with the competitive model. Our next example of a negative supply shock illustrates this point still further.

Table 2: A 5% decrease in productivity

variable \ period	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
$\lambda^{*})$	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.

The results presented in table 2 relate to a permanent decline in total factor productivity of 5% at $t=0$. This corresponds to a decline in labour quality of 7.9% in case the production function is Cobb-Douglas and the elasticity of production with regard to labour amounts to 0.625. As shown in section 3 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 on long term. The real wage rate falls because the supply of labour is perfectly inelastic.

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 $t=10$ 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 last some time in the present case.

5. Conclusions

It is interesting to note that the results of our model are in a number of ways qualitatively different from those of disequilibrium models as for instance presented by Blanchard and Sachs [1982], van de Klundert and Peters [1985]. 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 they want to sell more at the going price.

As emphasized by Rotemberg [1982] in case prices adapt without a time lag changes in the quantity of money have no effect on real variables even if firms are monopolists. It should be noted that this result differs from the view expressed by Hart [1982] that imperfect competition as such implies a model with Keynesian features. However, 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. Costs of wage adjustment could then eventually 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 $\dot{u} = 0$:

$$(A1) \quad u = \left[1 - \eta \left(1 - \frac{w}{p f_\ell} \right) \right] \frac{a}{r_m} p^{-\eta}$$

Differentiating with regard to p gives:

$$(A2) \quad \frac{du}{dp} = \underbrace{\eta \frac{a}{r_m} p^{-(\eta+1)}}_{+} \underbrace{\left\{ (\eta-1) - (\eta+1) \frac{w}{p f_\ell} + \frac{w}{f_\ell} \frac{f_{\ell\ell}}{f_\ell^2} \eta \frac{a}{r_m} p^{-(\eta+1)} \right\}}_{-}$$

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 $u \rightarrow 0$ for $p \rightarrow \infty$ and $u \rightarrow \infty$ for $p \rightarrow 0$. The function (A1) is therefore of the form as shown in figure 4. The number of inflection points or turning points cannot be determined.

Figure 4

Appendix 2

In the numerical exercises of section 4 the following specifications are applied:

$$c^d = \gamma y \quad \text{consumption function}$$

$$y = \epsilon \ell^\alpha k^{1-\alpha} \quad \text{production function}$$

$$e = i(1+\theta \frac{i}{k}) \quad \text{investment expenditure function}$$

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

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:

$$\alpha = 0.625 \quad \beta = 0.5 \quad \gamma = 0.8 \quad \delta = 0.1 \quad \epsilon = 1$$

$$\zeta = 0.15 \quad \eta = 5 \quad \theta = 5 \quad \chi = 0.25 \quad \psi = 0.1$$

The chosen values of the exogenous variables are:

$$\ell^S = 1, M = 100$$

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Summary

by

Th. van de Klundert and P. Peters

In macroeconomic models with quantity rationing price changes, if any, are frequently based on ad-hoc assumptions. In the present model changes in the price of output are the result of choice-theoretic considerations. It is supposed that price changes are costly and that costs are speed-dependent.

Ignoring labour scarcity there are two regimes. If real labour costs are relatively high firms may not operate on their demand curves. This situation is reminiscent of classical disequilibrium. Otherwise firms produce according to demand, but may not realize the preferred position in the short run. In section 2 of the paper these problems are analysed from a microeconomic perspective.

In section 3 the model is extended to a full macroeconomic model by making demand endogenous. Wage formation is modelled in a traditional way by assuming that wages respond to excess demand in the market for labour. Because the model becomes rather complex full analytical solutions are now out of reach. Instead numerical exercises are worked through by applying the technique of multiple shooting.

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