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# Aggregate Consequences of Fixed Costs of Price Adjustment

By JULIO J. ROTEMBERG\*

This paper studies the general equilibrium consequences of monetary growth in an economy in which firms must pay a fixed cost every time they change their price. Hence it presents an extension of the partial equilibrium models of Eytan Sheshinski and Yoram Weiss (1977), and Michael Mussa (1981). A substantial part of this paper is devoted to criticizing Mussa's paper. He claims to have shown that under these conditions the change in the price level depends both on the change in the price level that would have prevailed in the absence of costs of changing prices (the equilibrium rate of change in prices) and on the difference between the actual and the equilibrium price levels. I show that, under his assumptions, the actual and equilibrium price levels always coincide. This is a consequence of his assumption that equilibrium prices grow at a constant rate. Moreover, I argue that in environments like those of Sections I and III of his 1981 paper and those of his 1982 paper in which equilibrium prices do not grow at a constant, his rationale does not justify the use of his formula (18).<sup>1</sup>

Section I of this paper presents the maximization problem of a representative firm, while Section II discusses the ensuing equilibrium.

## I. Firms

The firms in this economy are indexed by  $i$  and produce differentiated products. They face identical demand and cost functions.

\*Sloan School of Management, Massachusetts Institute of Technology. This paper is a revised version of chapter V of my Ph.D. dissertation presented at Princeton University. I thank my advisor William Branson, as well as Alan Blinder and Robert Porter for helpful comments and suggestions.

<sup>1</sup>It must be noted, however, that Bennett McCallum (1980) presents an alternative rationale for an equation like Mussa's equation (18).

The demand curve facing firm  $i$  at time  $t$  is

$$(1) \quad Q_{it} = \left( \frac{P_{it}}{P_t} \right)^{-b} \left( \frac{M_t}{P_t} \right)^f; \quad i \in [0, 1],$$

where  $b$  and  $f$  are parameters. At time  $t$ ,  $Q_{it}$  and  $P_{it}$  are, respectively, the quantity demanded and the price of good  $i$ , while  $P_t$  and  $M_t$  are the price level and the size of the money stock. The quantity demanded of any good depends not only on its relative price, but also on real money balances. As suggested in my 1982 paper, this dependence will arise if real money balances are a direct source of utility. The price level at  $t$  is given by

$$(2) \quad P_t = \exp \left\{ \int_0^1 \log(P_{it}) \, di \right\}.$$

The cost to firm  $i$  of producing  $Q_{it}$  is

$$(3) \quad C(Q_{it}) = UP_t Q_{it}^2 / 2,$$

where  $U$  is a parameter. This cost function can arise, as shown in my 1982 paper, both when only goods are required to produce goods and when labor is a factor of production traded in a classical market. Equation (3) guarantees that, in the short run, marginal cost curves slope upwards.

In absence of costs of changing prices, firms would charge a price whose logarithm is  $\bar{p}_{it}$ :

$$(4) \quad \bar{p}_{it} = \phi + F(m_t - p_t) + p_t,$$

where lower case letters represent the logarithm of the respective upper case letters.  $\phi$  and  $F$  are constants given by

$$\phi = \frac{1}{1+b} \log \left( \frac{b}{b-1} \right); \quad F = \frac{f}{1+b}.$$

As suggested by Mussa (1981) and shown in my earlier paper, the instantaneous loss in

profits to firm  $i$  from charging a price different from  $\bar{P}_{it}$  can be approximated by

$$(5) \quad B(p_{it} - \bar{p}_{it})^2,$$

where  $B$  is equal to  $B = \phi b(1+b)\bar{Q}_{it}^2$  and

$$\bar{Q}_{it} = \left( \frac{2bU}{b-1} \right)^{-b/(1+b)} \left( \frac{M_t}{P_t} \right)^{f-bf/(1+b)}.$$

Here,  $\bar{Q}_{it}$  is the quantity firm  $i$  would sell at  $t$  if it charged  $\bar{P}_{it}$ , and  $B$  will be assumed to be constant. In the model studied below, money balances will be constant, therefore  $B$  will also be constant. As in Sheshinski and Weiss's paper and Mussa's (1981) paper, firms incur a fixed cost,  $A$ , every time they change their prices.

Price-setting firms face two types of costs of price adjustment. First, there are the administrative costs which ensue from printing new price lists, informing salesmen of the new prices, etc. Second, there are costs that result from the damage to the reputation of the firm that changes prices often and by large amounts. These latter costs are probably more important in an environment in which the price level moves little, as in the United States.

While the first type of cost is undoubtedly a fixed cost per price change, the second type of cost is, arguably, convex in the size of the price change since customers do not seem to react strongly to small price increases. When the cost of adjustment is convex, a solution to the firm's optimal control problem is guaranteed to exist (see Harold Kushner for a proof) and, furthermore, the solution is easily computed when the cost of adjustment can be approximated by a quadratic function. This approach is taken in my earlier paper.

Instead, only special cases of the control problem when the cost of adjustment is concave can be solved. Here, the objective of the firms is assumed to be the maximization of average real profits per unit of time. This, as shown by Kushner, is equivalent to the limit of the maximization of discounted profits as the discount factor tends to one. Moreover, as in the analysis of Sheshinski and Weiss,

and Mussa (1981), I solve the firm's problem only for the case in which the target price,  $\bar{p}_{it}$ , grows at a constant rate. I will then show that this is a property of the equilibrium when there is a constant rate of monetary growth.

Because there are fixed costs to changing prices, the firms will not change their prices continuously. Instead, they will keep their prices constant for discrete intervals of time. During each interval, they will charge an optimal price that minimizes average losses during the interval. Given the rule for choosing these optimal prices, the intervals themselves can be chosen to minimize losses per unit of time. It is the second part of this optimization that yields computable solutions only in simple cases.

Mussa (1981) considers the case in which  $\bar{p}_{it}$  grows at a constant rate,  $\bar{\Pi}_i$ :

$$(6) \quad \bar{p}_{it} = \bar{p}_{i0} + \bar{\Pi}_i t,$$

where  $\bar{p}_{i0}$  is a constant.

As shown by Mussa (1981), firms for which  $\bar{p}_{it}$  is given by (6) who minimize average costs per unit of time and keep their price constant between  $t$  and  $t+T$  will charge the price  $p_{it}$  given by

$$(7) \quad p_{it} = \bar{p}_{i0} + \bar{\Pi}_i t + \bar{\Pi}_i T/2$$

during this interval. An argument similar to Mussa (1981) establishes that, if the firm expects  $\bar{\Pi}_i$  to be the rate at which  $\bar{p}_{it}$  will grow forever, the value of  $T$  which minimizes average losses per unit of time is

$$(8) \quad \bar{T}_i = \left( \frac{12B}{A} \right)^{1/3} \bar{\Pi}_i^{-2/3}.$$

## II. Equilibrium

Following Mussa (1981), I assume that firms are uniformly distributed over the time of their last price change. He also assumes that "all commodities have the same frequency of price change [i.e., the same  $T_i$ ], that price adjustments are evenly spaced and that the rates of change of the equilibrium prices [given by (6)] of all commodities are all the same" (1981, p. 1023). Even though

these assumptions imply that  $\bar{\Pi}_i$  is the same for all firms, he writes the price level at  $t$  as

$$(9) \quad p_t = \frac{1}{T} \int_{t-T}^t \left( \bar{p}_i + \frac{T\bar{\Pi}_i}{2} \right) di.$$

He then assumes that  $\bar{p}_i + (T/2)\bar{\Pi}_i$  is "close to a linear function of  $i$ ." Hence  $\bar{p}_i + (T/2)\bar{\Pi}_i \approx \alpha + i\bar{\Pi}$ , where  $\alpha$  and  $\bar{\Pi}$  are constants. But, for the rate of equilibrium inflation faced by each firm to be unchanging:

$$\bar{\Pi}_i = \bar{\Pi}_{i+nT}; \bar{p}_{i+nT} = \bar{p}_i + n\bar{\Pi}_i,$$

where  $n$  is any integer. It is easy to establish that these conditions ensure that  $\bar{\Pi}_i = \bar{\Pi}$ .

It is important to stress that Mussa's assumptions repeatedly imply that  $\bar{\Pi}_i = \bar{\Pi}$  because this leads to conclusions which are much stronger than Mussa's. In particular, he shows that

$$(10) \quad dp_t/dt = \bar{\Pi} + \delta(p_t - \bar{p}_t),$$

where  $\delta$  is a constant. However, his assumptions imply Proposition 1.

**PROPOSITION 1:** *When  $\bar{\Pi}_i = \bar{\Pi}$  for all  $i$  and, without loss of generality  $\bar{p}_{i0} = \alpha$ , while firms are uniformly distributed over the time of their last price change:*

$$(11) \quad p_t = \bar{p}_t$$

**PROOF:**

Using (2), (6), and the fact that firms are uniformly distributed over the time of their last price change:

$$\begin{aligned} p_t &= \frac{1}{T} \int_{t-T}^t \left( \alpha + \bar{\Pi}u + \frac{T}{2}\bar{\Pi} \right) du \\ &= \alpha + \bar{\Pi}t = \bar{p}_t. \end{aligned}$$

Therefore under Mussa's (1981) assumptions, the price level is equal to the equilibrium price level. This conclusion depends crucially on the constancy of the rate of growth of the equilibrium prices. However, Mussa (1981) provides no evidence that (10) holds for more general paths of  $\bar{p}$ . Moreover,

it is obvious that for a variety of paths of  $\bar{p}$ , (10) is false. In particular, consider Robert Barro's case in which  $\bar{p}$  follows a random walk. Then, when there is a shock to  $\bar{p}$ , some firms adjust their price because their relative price has now fallen below some critical level  $s$ . However, after the shock, prices will stay constant until the next shock. There is no continuing tendency for the price level to come back to the equilibrium price level. Moreover, the effect of the shocks on the price level is not simply a function of the average discrepancy ( $\bar{p}_i - p_t$ ). Instead, it depends on the whole distribution of prices at the time of the shock.

It must be noted that Mussa (1981, 1982) and Bennett McCallum (1978) apply equation (10) to models in which  $\bar{p}_i$  does not grow at a constant rate. Mussa's (1981) rationale does not provide any microfoundation for the use of equation (10) in these contexts.

I now establish that (11) is a property of an equilibrium in which  $\bar{p}$  is given by (4) and money grows at the rate  $\bar{\Pi}$ .

**PROPOSITION 2.** *When the evolution of the money stock is given by  $m_t = m_0 + \bar{\Pi}t$  and firms are uniformly distributed over the time of their last price change, an equilibrium price level is given by*

$$(12) \quad p_t = \frac{\phi}{F} + m_0 + \bar{\Pi}t.$$

**PROOF:**

My 1982 paper establishes that in an economy such as this one, equilibrium in the goods markets is sufficient for overall equilibrium. Here an equilibrium is a perfect foresight path for the price level such that, given that firms expect this path to prevail, their optimal plans are consistent with this equilibrium. At this equilibrium firms are willing to supply the quantities given by (1).

Suppose (12) is an equilibrium. Then, using (4):

$$\begin{aligned} \bar{p}_{it} &= \phi + F \left\{ m_0 + \bar{\Pi}t - \left( \frac{\phi}{F} + m_0 + \bar{\Pi}t \right) \right\} \\ &\quad + \phi/F + m_0 + \bar{\Pi}t \\ &= \phi/F + m_0 + \bar{\Pi}t. \end{aligned}$$

So the price charged between  $i$  and  $i + T$  by the firm which changes its price at  $i$  is given by (7) with  $\bar{p}_{i0}$  equal to  $m_0 + \phi/F$ . Therefore,

$$p_t = \frac{1}{T} \int_{t-T}^t \left( \frac{\phi}{F} + m_0 + \bar{\Pi}u + \frac{\bar{\Pi}T}{2} \right) du \\ = \phi/F + m_0 + \bar{\Pi}t$$

Note that, at this equilibrium ( $m_t - p_t$ ) is constant. This establishes that  $B$  is a constant in (5). More importantly, it establishes that the index of aggregate output  $q_t$  given by<sup>2</sup>

$$q_t = \int_0^1 q_{it} di = f(m_t - p_t)$$

does not depend on the rate of monetary growth  $\bar{\Pi}$ . It is interesting to note that my 1982 analysis establishes that  $q_t$  is also unaffected by the rate of steady monetary growth when firms maximize expected profits per unit of time and face quadratic costs of changing prices.

<sup>2</sup>Indices, like  $q_t$ , which is equal to the logarithm of the product of outputs in all sectors, are widely used (see, for instance, Robert Lucas 1973). They behave like *GNP* when output in the different sectors exhibit a high degree of coherence. Such coherence does indeed seem to characterize business cycles (Lucas, 1977).

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