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FACTOR PRICE STABILIZATION WITH FLEXIBLE PRODUCTION

BY RICHARD J. GILBERT*

Firms may adapt to factor price uncertainty by choosing a production technology that permits flexibility in the choice of inputs. This paper shows that under some conditions, including rational expectations on the part of decision-makers, adjustments in the choice of technique may neutralize the effect of a buffer stock on the long-run price distribution of a commodity used as a factor of production. Nonetheless, a stabilization program could have desirable welfare effects if producers are risk-averse and if the cost of the stabilization program is not too large.

1. INTRODUCTION

The literature on commodity price stabilization programs deals primarily with their objectives and design. The problem of formulating policy objectives includes the analysis of distributional impacts of stabilization programs (Massell [1969], Tisdell [1969], Turnovsky [1976], Newbery [1976,7], i.e. whether producer or consumers gain from the program, and by how much. McKinnon [1967] and Newbery [1977] have explored the general consequences of alternative stabilization schemes such as buffer stocks and forward markets, and a number of authors have applied stochastic control techniques to simulate the outcome of particular stabilization programs (e.g. Kim, Goreux and Kendrick [1974] for cocoa and Pindyck [1973]).

This paper examines a component of the market that has been largely ignored in discussions of commodity stabilization policies, namely the interaction between the stabilization program and a firm's efficient production technology. The result is simple, but not without some importance. The production technology employed by firms in general depends on the distribution of input prices. If input prices fluctuate widely, a technology that affords some flexibility may be used. A program that reduces this price variability may also reduce the incentive to employ a flexible process. The result may be a less elastic derived demand for the primary commodity, which would increase its price variability.

This is a very loose statement of the results. Section 2 presents a model based on a fixed proportions production technology. Conditions on alternative production processes are derived for which attempts at

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partial stabilization by means of a buffer stock has no effect on the equilibrium price distribution. The equilibrium price distribution after implementation of a buffer stock is identical to the distribution before the stabilization program, although in the short run the buffer stock may be effective in reducing price fluctuations. This is not a general result, but rather an example whose purpose is to alert those involved in the design of commodity stabilization programs to the potential importance of input substitution in production.

2. The Model

Since the point of this paper is to illustrate the possible extent of factor substitution in production and its consequences for stabilization programs, it is sufficient to consider a simple atemporal model. We make the following assumptions.

A.1 *Factor Supply*

There is only one risky factor of production. The supply uncertainty is multiplicative, and given by

(1)
$$\tilde{V}_a = V_a(p)\tilde{\theta},$$

where $\tilde{\theta}$ is a random variable with mean equal to one.

The next assumption concerns the production possibility set of each firm that uses the risky factor of production. Restricting attention to one industry with identical firms simplifies accounting, although the results depend on induced substitution by firms in all industries.

A.2 *Production*

All firms have the same technology set for production of the output, q. There are two fixed proportions techniques:

(2a)
$$q = \min(a_K K_a, a_V V_a)$$

(2b)
$$q = \min(b_K K_b, b_V V_b).$$

Each technique makes use of a separate capital and variable input. The technology is putty-clay: capital is variable ex ante but frozen in place ex post. The industry is assumed competitive, so that each agent takes prices as given. Define the normalized prices.

$$r_a = \frac{p(K_a)}{a_K}, \quad \text{normalized price of } K_a$$

$$r_b = \frac{p(K_b)}{b_K}, \quad \text{normalized price of } K_b$$

$$\tilde{p}_a = \frac{p(V_a)}{a_1}, \quad \text{normalized price of } V_a$$

$$p_b = \frac{p(V_b)}{b_1}, \quad \text{normalized price of } V_b.$$

By assumption, only $\tilde{p}_a$ is a random variable, and all other prices are constant. That is, the supply of all other factors is infinitely elastic. This assumption will be reconsidered in the discussion that follows.[1]

Agents maximize profits taking prices as given, and it is assumed that the distribution of prices is known. If the nature of the stochastic disturbances is stationary, it is not unreasonable to expect that the industry will achieve an equilibrium that is consistent, or rational, in the sense suggested by Muth [1961] and described by Radner [1971] and Grossman [1975]. The equilibrium is such that the price distribution generated by the aggregate decisions of the agents is the same distribution each took as given in the production decision. In this case, the price $\tilde{p}_a$, depends on the state of nature, $\tilde{\theta}$, and the total industry demand for the factor. It simplifies matters to assume that $\tilde{\theta}$ takes on only two values, θ_1 with probability α and θ_2 with probability $1 - \alpha$, where $\theta_2 > \theta_1$.

Suppose the equilibrium is such that some of the time $\tilde{p}_a$ exceeds p_b and some of the time the converse is true. If firms had installed any capacity of type (2b), it would be used whenever $\tilde{p}_a > p_b$. Assume for the moment that industry output is fixed at Q_0. Each firm and therefore the total industry, must decide on the amount of capacity, X_a and X_b (where X_a is the total output from process (2a) and similarly for X_b) in order to minimize expected total costs.

$$(3) \quad C(Q_0) = \min_{X_a, X_b} \{r_a X_a + r_b X_b + \alpha(p_b X_b + p_a(\theta_1, Q_0 - X_b)(Q_0 - X_b)) + (1 - \alpha)(p_a(\theta_2, X_a)X_a + p_b(Q_0 - X_a))\},$$

The minimization is subject to the constraint that

$$(4) \quad X_a + X_b \geq Q_0.$$

The problem described by (3) requires some explaining. It is assumed that

$$p_a(\theta_1, Q_0 - X_b) > p_b$$

[1]The textile industry is an illustration of the general problem considered in this paper. The use of cotton as opposed to synthetic materials calls for somewhat different machinery. The investment in capital equipment of either type will depend on the relative prices of cotton and synthetic yarn. In recent years, the supply of cotton has been more volatile than that of synthetics.

Another example is electricity generation plants that may be designed to burn either coal or oil with different capacities, but once constructed the capacities cannot be changed in the short run.

and

$$p_a(\theta_2, X_a) < p_b.$$

Of course this need not hold, but without this assumption for some X_a, X_b there is no possibility for flexible production. It is also understood that

$$0 < X_a < Q_0$$

$$0 < X_b \leq Q_0$$

The necessary conditions for efficient production are $X_a^* > 0$ if

(5) $$r_a + (1 - \alpha)(p_a(\theta_2, X_a^*) - p_b) \leq \lambda$$

and $X_b^* \geq 0$ if

(6) $$r_b + \alpha(p_b - p_a(\theta_1, Q_0 - X_b^*)) \leq \lambda,$$

where λ is the shadow price of the capacity constraint, (4).

There are a number of process configurations that could be efficient. If the industry is the sole user of the input, it is reasonable (but of course not necessary) to expect an interior solution where

$$X_a^* < Q_0 \quad \text{and} \quad X_b^* < Q_0.$$

This would imply equality in (5) and (6). If

$$X_a^* + X_b^* > Q_0,$$

there is excess capacity in the industry. Note that whether or not there is excess capacity,

$$r_a + \bar{p}_a = r_b + p_b$$

at an interior solution, where $\bar{p}_a$ is the expected equilibrium price of V_a. The expected cost of using either technology to produce a given output, q, is the same, which suggests that it is not necessary for any individual firm to employ both processes. If there is excess capacity at the industry equilibrium some firms must invest in more capacity than is necessary to produce the desired output by either employing both techniques or one with excess capacity. In either case, at the efficient equilibrium any one firm would have an incentive to trim away the excess fat, but if all firms eliminated excess capacity, there would be an incentive to reinvest in either one process or the other. In other words, with excess capacity, the rational expectations equilibrium is stable; but if agents' behavior were Nash, taking prices as given and ignoring the effects of total industry demand, the equilibrium would not be stable. If individual production units each purchase a large share of the total output of V_a, the Nash instability with its consequent loss of efficiency is less likely because each firm would be more aware of the effects of its demand on the price distribution. For this reason, there may be a bias toward horizontal integration when the environment and technology are such that excess capacity affords cost-reducing flexibility.

3. Effects of Buffer Stocks

A buffer stock generally refers to a program of open market purchases and sales with the intent of reducing the variability of supply or market price. A more precise description of a buffer stock program is a policy function. $B(p, \tilde{\theta})$, which gives the net purchase of the buffer stock as a function of the market price and the observable state of nature. A balanced buffer stock leaves the mean market supply unchanged, and it is clear from the elementary theory of random walks that a buffer stock must be balanced if it is to remain operative indefinitely (this is proved formally in Townsend [1977]).

If the buffer stock policy function is $B(p, \tilde{\theta})$, the net market supply of the variable factor is

$$V_a^S(p, \tilde{\theta}) = V_a(p)\tilde{\theta} - B(p, \tilde{\theta}). \tag{7}$$

where $V_a(p)\tilde{\theta}$ is the assumed factor supply function and $B(p, \tilde{\theta})$ is the net purchase of the buffer stock. One possible policy function is

$$B(p, \tilde{\theta}) = \begin{cases} \delta_1 V_a(p_1)\theta 1 & \text{if } \tilde{\theta} = \theta_1 \\ \delta_2 V_a(p_2)\theta_2 & \text{if } \tilde{\theta} = \theta_2. \end{cases} \tag{8}$$

with $\delta_1 < 0$ and $\delta_2 > 0$. This policy injects a constant fraction of the total supply at the equilibrium market price in bad times and purchases a constant fraction in good times. The buffer stock is balanced if

$$\alpha\delta_1 V_a(p_1)\theta_1 + (1 - \alpha)\delta_2 V_a(p_2)\theta_2 = 0.$$

One could propose alternatives to the policy given by (8): for example, a policy of a fixed net purchase in each state, or a policy that bounds the movement of the equilibrium price. The policy described by (8) has the desirable property that market supply may be expressed as

$$V_a^S(p)\tilde{\theta} = \begin{cases} V_a(p_1)\theta_1(1 - \delta_1) & \text{if } \tilde{\theta} = \theta_1 \\ V_a(p_2)\theta_2(1 - \delta_2) & \text{if } \tilde{\theta} = \theta_2. \end{cases} \tag{9}$$

The effect of the buffer stock is a mean-preserving reduction of risk (in the sense of Rothschild and Stiglitz [1970]) associated with the factor supply. The optimality of this buffer stock policy is a question that is beyond the scope of this paper.

A buffer stock stabilizes the supply of the variable factor, but the equilibrium price distribution depends on derived demand as well as supply. Consider the case where the industry equilibrium capacity choice is an interior solution to the cost minimization problem both before and after implementation of the buffer stock program and there is excess capacity. This requires that the buffer stock only partially stabilize the supply of the factor. Before the buffer stock program, we have

$$r_a + (1 - \alpha)(p_a(\theta_2, X_a^*) - p_b) = 0 \tag{10}$$

and

$$r_b + \alpha(p_b - p_a(\theta_1, Q_0 - X_b^*)) = 0. \tag{11}$$

If efficient production remains interior with excess capacity after the buffer stock is implemented, it must be true that $p_a(\theta_2, X_a)$ and $p_a(\theta_1, Q_0 - X_b)$ are unchanged. The buffer stock effectively changes θ_1 and θ_2, but in equilibrium X_a^* and X_b^* may change so that (10) and (11) still hold. This could only occur in the long-run given the putty-clay technology assumption. In the short-run, both X_a^* and X_b^* are fixed and the buffer stock would be effective in partially stabilizing prices. The derived demands would change over time until prices returned to the original distribution.

Figure 1 illustrates a potential consequence of the buffer stock under the assumed production conditions. Before the stabilization program, the supply of the factor is $\tilde{V}_a(\theta_1)$ in the low state of nature and $\tilde{V}_a(\theta_2)$ in the high state. The buffer stock reduces the variability of supply to $\tilde{V}_a(\theta_1')$ and $\tilde{V}_a(\theta_2')$. In the absence of a buffer stock, the input price alternates between p_a^l and p_a^h, and the efficient levels of industry capacities are X_a^* and X_b^*. In the short-run these capacities are fixed and the buffer stock is effective in reducing the price variance. Indeed, in this example, if demand for $\tilde{V}_a$ continued at X_a^* in the high state and $Q_0 - X_b^*$ in the low state the factor price would be "high" when supply is high and "low" when supply is low.[2] With excess capacity, demand can be reduced in the high state and increased in the low state. The factor price would be stabilized at price p_b, which is the value that minimizes costs given X_a^* and X_b^*.

When the price of the variable input $\tilde{V}_a$ is p_b, it is not profitable to install additional capacity for either process (cf. equations (6) and (7)). Capital that deteriorates with the passage of time would not be replaced until the levels of capacities reached X_a' and X_b'. If

$$X_a' + X_b' > Q_0.$$

[2]This situation is analogous to the peak-load reversal problem in utility pricing, where a tariff at the time of maximum demand may shift the peak to a different time (see, e.g. Bailey and White [1974]).

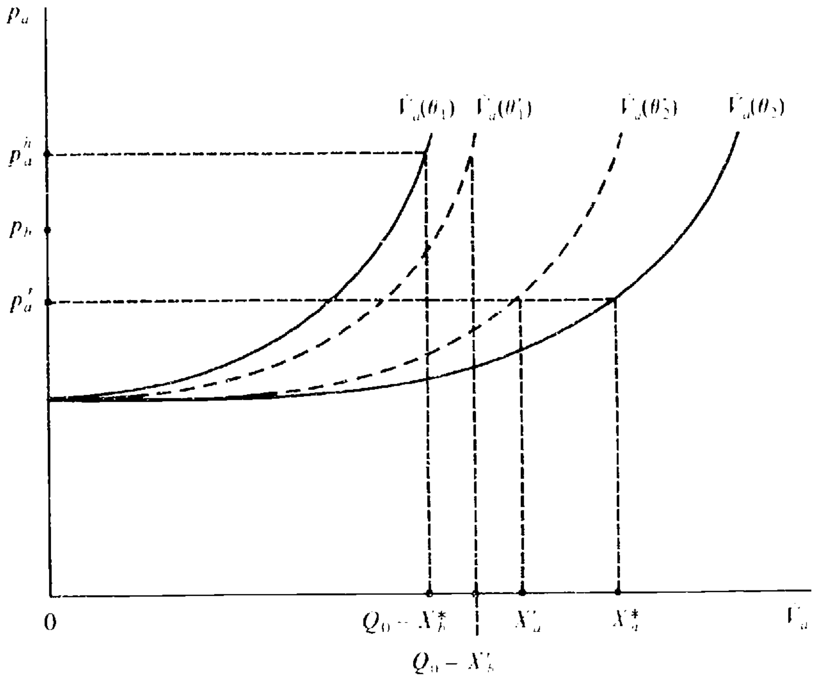

Figure 1.

equations (10) and (11) still apply and the price of the variable factor would alternate between p_a^l and p_a^h. The time path of the price distribution is illustrated schematically in figure 2, where τ is the implementation date of the buffer stock.

The case described is special in that firms invest in excess capacity until the marginal cost of the capacity equals the expected marginal benefit from flexible production. There is no reason to expect this to be typical. If there is no excess capacity in the industry that uses the variable factor, the derived demand for the input would be independent of the state of nature and a buffer stock would succeed in reducing the variance of the factor price. In this case, cost-minimization per se is not a motive for factor substitution in response to price variability, although the desire to avoid risk may cause entrepreneurs to reduce the employment of a factor with a highly variable price.

We have assumed in the previous analysis that the efficient capacity levels X_a^* and X_b^* were interior solutions to the cost-minimization problem. Of course it may be that either X_a or X_b or both equal total output, Q_0. If both X_a and X_b equal Q_0, a buffer stock would succeed in reducing the price when supply is low and raising the price when supply is high.

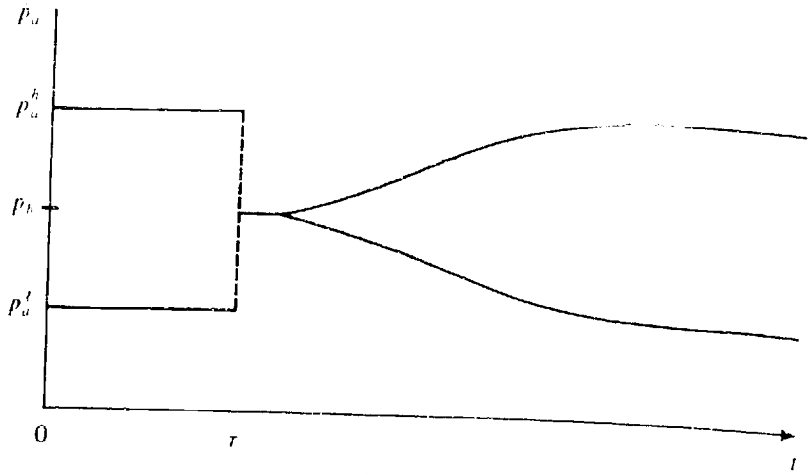

Figure 2.

If only X_a equals Q_0, the price when supply is low would remain stationary in the long-run, and a buffer stock would raise the price when supply is high. If only X_b equals Q_0, a buffer stock would succeed only in lowering the long-run price of the variable factor when supply is low. In these cases, a buffer stock would be effective in changing the price in good or bad times, but not both.

Implicit in the preceding discussion is the assumption that the buffer stock is sufficiently small that it does not lead to a discontinuous change in the production process. In other words, if there is excess capacity before the stabilization program, excess capacity continues to be efficient afterwards. An obvious exception to this is a buffer stock that perfectly stabilizes market supply. Such a program clearly succeeds in stabilizing the factor price.

The results depend on the assumption that supply elasticities of the other inputs are very large. Perhaps most important is the supply elasticity of the alternative variable input V_b. The demand for this factor may vary widely over a short period of time, and in the short-run the supply elasticity may be quite inelastic. A buffer stock will always partially stabilize the price of the uncertain factor, $\tilde{V}_a$, if the supply elasticity of V_b is finite. This may be seen from equation (11), noting that p_b may depend on total demand, X_b^*. The buffer stock effectively increases θ_1 and therefore reduces the demand for the alternative input factor. In doing so, the buffer stock also lowers the long-run input price in the low state of nature, $p_a(\theta_1, Q_0 - X_b^*)$. The buffer stock has no effect in the long-run if p_b is independent of total demand. This suggests that important parameters in empirical studies of stabilization programs are the supply elasticities of alternative variable inputs.

4. Distributional Impacts

The effect of a buffer stock program on production costs will be considered for the case in which the capacity levels X_a and X_b are positive but less than Q_0, and the sum of X_a plus X_b exceeds Q_0. This is the interior solution with excess capacity. Referring to figure 1, a (small) buffer stock changes the long-run efficient capacity levels from X_a^* to X_a' and from X_b^* to X_b'. If the supply of the alternative variable factor is perfectly elastic, the buffer stock has no effect on the price distribution after X_a and X_b are adjusted to their efficient levels. The actual magnitudes of X_a and X_b are determined by the conditions

$$p_a(\theta_1, Q_0 - X_b^*) = p_a(\theta_1', Q_0 - X_b')$$

and

$$p_a(\theta_2, X_a^*) = p_a(\theta_2', X_a').$$

provided the solution remains interior with excess capacity.

The effect of the buffer stock on the total production cost may be determined by rewriting equation (3) as

$$\begin{aligned} C(Q_0) = {} & \{r_a + (1 - \alpha)[p_a(\theta_2, X_a) - p_b]\}X_a \\ & + \{r_b + \alpha[p_b - p_a(\theta_1, Q_0 - X_b)]\}X_b \\ & + \{\alpha p_a(\theta_1, Q_0 - X_b) + (1 - \alpha)p_b\}Q_0. \end{aligned} \tag{12}$$

When there is an interior solution with excess capacity, equations (10) and (11) hold and the first two bracketed terms in equation (12) are zero. Total production costs are simply

$$C(Q_0) = \{\alpha p_a(\theta_1, Q_0 - X_b) + (1 - \alpha)p_b\}Q_0.$$

The total cost of production is not affected by a small buffer stock program if the price, p_b, is independent of the industry derived demand. The total installed capacity is lower with a buffer stock. This lowers total capacity costs, but the variable cost of production is increased because there is less input flexibility when installed capacity is reduced. In equilibrium, the savings from the reduction of installed capacity are just offset by the increase in expected operating costs from reduced flexibility.

5. Industry Equilibrium

There has been no mention as yet of equilibrium in the market for the industry's output. This is somewhat perverse, since most discussions of flexibility are concerned with the cost of varying the level of output rather than the cost of adapting to fluctuating input prices. Output variability was the motivation for Stigler's [1939] discussion of static efficiency versus flexibility, and the work on inventory theory and models, of which Mills [1962], Orr [1967] and Arrow [1958] are but a very small sample, is largely concerned with this issue. A production technology with output flexibility has a relatively "flat" short-run average cost curve, so that adjustments in output can be made without appreciably changing average production costs.[3]

A production technology that affords output flexibility does not necessarily offer flexibility with regard to factor price changes. There may be a positive correlation in the two kinds of flexibility if an increase (decrease) in the supply of an input factor leads to a large increase (decrease) in the efficient level of industry output, since this may limit the fluctuations in the input price. Whether this is so depends, however, on the demand elasticity for industry output and the level of the derived demand for the factor.

Solutions to the cost-minimization problem (3) that have excess capacity clearly exhibit some output flexibility. Let $Q(P)$ be the demand function for industry output, where P is the price of output. If there is excess capacity, the marginal cost of output is p_b if $\tilde{\theta} = \theta_2$ and $p_a(\theta_1, Q_0 - X_b)$ otherwise. Writing p_a^1 for $p_a(\theta_1, Q_0 - X_b)$ and p_a^2 for $p_a(\theta_2, X_a)$, expected profits are

$$\text{(13)}\qquad \Pi = \alpha\{p_a^1 Q(p_a^1) - (p_b X_b + p_a^1(Q(p_a^1) - X_b))\}$$
$$+ (1 - \alpha)\{p_b Q(p_b) - (p_a^2 X_a + p_b(Q(p_b) - X_a))\}$$
$$- (r_a X_a + r_b X_b).$$

Provided there is an interior solution with excess capacity, so that

$$X_a^* + X_b^* > Q(p_b) > Q(p_a^1),$$

the necessary conditions for profit-maximization are given by (10) and (11), with $Q(p_a^1)$ replacing Q_0 in (11). There is now the additional condition that capacity increase until expected profits are zero.

A market equilibrium is illustrated in figure 3. The curves S_1 and S_2 are short-run supply functions corresponding to $\tilde{\theta} = \theta_1$ and θ_2. The capacities X_a^* and X_b^* are the long-run equilibrium solutions to (3). For $\tilde{\theta} = \theta_1$, the output price cannot exceed p_b for $Q < X_b^*$ (although it could be less). For $Q > X_b^*$, the output price is $p_a(\theta_1, Q - X_b^*)$ as long as there is excess capacity. Similarly, when $\tilde{\theta} = \theta_2$, the output price is bounded above by $p_a(\theta_2, Q)$ for $Q \leq X_a^*$, and equals p_b for $Q > X_a^*$ as long as total capacity is not exceeded.

If a buffer stock changes the distribution of $\tilde{\theta}$, but the cost-minimizing solution for X_a^* and X_b^* remain interior with excess capacity, there is again no effect on the equilibrium price distribution. In general, the arguments made previously for the case of a constant output also apply when

[3]More precise statements about the quantitative implications of the static efficiency flexibility tradeoff can be made by applying quantitative methods developed by Fuss and McFadden [1971].

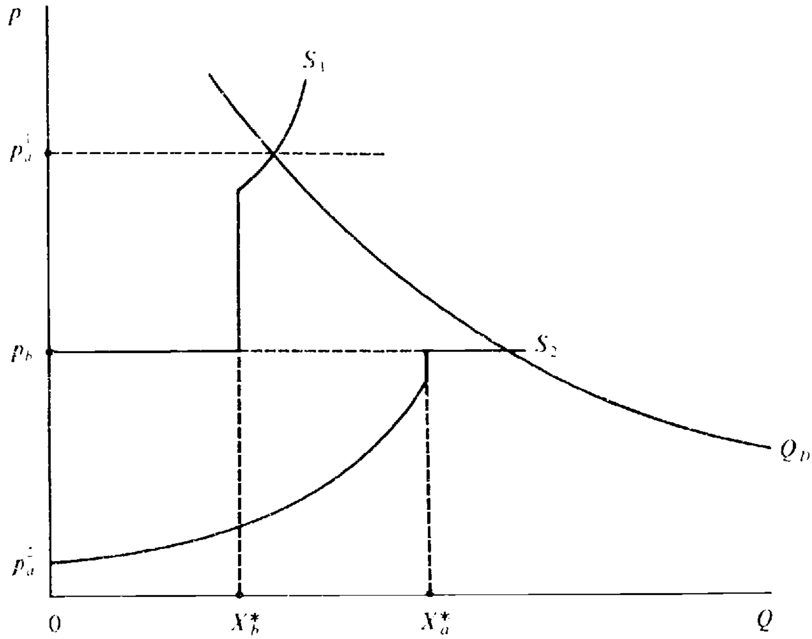

Figure 3.

industry output adjusts to a zero expected profit equilibrium. The only difference is that the price of the input depends on output demand elasticity as well as on the factor supply elasticity, and the derived demand for the fixed factor is more elastic than in the case of a fixed output.

6. SUMMARY

In the long-run, both the level of derived demand for a particular factor and the elasticity of substitution between the factor and others depend on the expected distribution of input prices and demand. The distribution of prices, in turn, depends on both factor supply and aggregate derived demand. The main point of this paper is to illustrate the potential importance of these relations in the design of commodity price stabilization programs. We have shown that in some cases, a buffer stock may have a negligible impact on prices in the long run, although there may be important welfare implications. The results presented in this paper clearly depend on the assumption of rational expectations on the part of producers. The consequences of rational expectations for a stabilization program using buffer stocks parallel the effects of rational expectations on the adjustments to monetary policy, described by Lucas [1972], Sargent and Wallace [1975] and others.

There are two directions in which this work should be extended. The first concerns the objectives of a commodity stabilization program. It has been implicitly assumed that reduction of price volatility is the objective of a stabilization program, although it is clear that price stabilization does not imply the stabilization of incomes. The consequences of alternative programs, such as forward markets and tariffs, should be considered.[4] A program that does not interfere with commodity prices or total supplies will have no effects on the choice of production technique, and therefore will not give firms any incentive to shift the burden of risk-bearing. However, alternative programs will have differential effects on total welfare and the distribution of gains between producers and consumers. Secondly, the distinction between the short and long run has not been made precise. This is particularly important when the distribution of prices is not known and additional information may become available that is relevant to the choice of technique. At issue here is the meaning of rational expectations in a world of imperfect and changing information, and considerable work remains to be done in modelling the dynamics of economically efficient process change under these conditions.

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[4] The results presented in this paper do not hinge on the absence of forward markets. The maintenance of excess capacity may allow the risk-neutral firm to benefit from input price variability. A firm may have no incentive to contract at a guaranteed forward price.

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