DEMAND FLUCTUATIONS, INVENTORIES

AND FLEXIBILITY

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Abstract:

This paper considers a firm's choice of technique in the face of demand fluctuations. It reviews the standard result of the literature, that a more slowly-rising marginal cost function is preferred as the level of demand fluctuations increases, and presents a simple model where this result does not hold in the more general case where output is storable. In this case a firm's choice of technique includes a choice of whether to adjust sales to demand fluctuations by adjusting output or to invest in an inventory-holding facility and so use inventories to adjust sales. More general sets of assumptions are considered, the implication being that they favour the use of inventories to adjust sales to demand fluctuations.

I. Introduction

One branch of the literature on the Theory of the Firm has been much concerned with the relationship between demand fluctuations and the choice of technique by a firm.¹ This literature has been keen to develop analytically an intuitive link between greater flexibility and greater profitability of a technique of production in the face of demand fluctuations. By defining the degree of flexibility as the slope of the marginal cost function of a particular technique, the intuitive link is established analytically by this type of flexibility providing relative cheapness in adjusting sales to demand fluctuations.

A key assumption in this type of analysis is, however, that output be non-storable from period to period. With this assumption, the only way a firm can adjust sales to demand fluctuations is by adjusting output. While non-storability would seem an appropriate assumption in some cases, it is clearly very restrictive with respect to much of the manufacturing sector. In particular, holding inventories allows firms to adjust sales to demand fluctuations either by adjusting output or by selling inventories.

The main argument of this paper is that allowing a firm to hold inventories destroys the analytical link between the flexibility, defined as the slope of the marginal cost function, and the profitability of a technique. It is shown that, once inventories can be held, the more "flexible" of two techniques does not necessarily become the more profitable as the level of demand fluctuations increases.

However, because this is not a problem of intuition but rather of the limited definition of "flexibility," by resorting to a more general definition, the analytical link can be restored. In particular, by defining greater flexibility

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1. See Stigler (1939), Hart (1940), Nelson (1961), Marschak and Nelson (1962), Schwartzman (1963), Tisdell (1968), Turnovsky (1973), Mills (1981).

simply as relative cheapness in adjusting sales to output fluctuations, and by viewing the choice of technique as a choice both of a marginal cost function (with an associated minimum average cost) and of whether or not to hold inventories, then the more flexible of two techniques is that in which the marginal cost function and the use or not of inventories combine to give greater profitability in the face of fluctuations in demand.

More generally, this paper may be viewed as an attempt to synthesize two strands of literature in the Theory of the Firm: the choice of marginal cost function and the choice of whether or not to smooth production over time.²

The structure of the paper is as follows: Section II constructs a simple situation where inventories cannot be held and in which a choice between marginal cost functions is to be made. It presents the standard result of the literature: that the more flexible of two marginal cost functions, defined as that with the smaller slope (but with a greater minimum average cost), is preferred as the level of demand fluctuations increases.

Section III constructs a simple situation in which, for a given marginal cost function, a choice is to be made of whether or not to use inventories to smooth production in the face of demand fluctuations over time. It also presents the standard result of the literature; that as long as the marginal cost of holding inventories increases more slowly than that of adjusting output, the holding of inventories (and thus the smoothing of production over time) is preferred as the level of demand fluctuations increases.

Section IV brings the two decisions together and shows the distinction between the standard definition of flexibility and the profitability of a marginal cost function in the face of demand fluctuations when inventories can be held. It describes a variety of possible situations among which the more flexible

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2. See Abramovitz (1950), Modigliani and Hohn (1955), Lovell (1964), Ghali (1974, 1982).

marginal cost function is never preferred; inventories are never used; or one or the other case is true depending on the level of demand fluctuations.

It is thus shown that when inventories can be held, by defining "flexibility" more generally as cheapness of adjusting sales, and by referring to the choice of technique as the choice both of a marginal cost function and of whether or not to hold inventories, the analytical link between greater flexibility and greater profitability of a technique in the face of demand fluctuations can be restored.

Section V considers the implications of relaxing some of the assumptions made in the previous analysis. It is intended that this discussion will yield a clearer notion of which feature of the choice of technique--a slowly rising marginal cost function or the use of inventories--is likely to be dominant in terms of providing flexibility.

Section VI concludes the paper.

II. Choice of Marginal Cost Function

This section presents a simple model of a situation where no inventories can be held and in which a firm is to choose between two total cost functions (specified by a marginal cost function and a minimum average cost) in the face of fluctuations in demand.

It is assumed that the pattern of demand (x) follows a known cyclical pattern as specified by a rectangular distribution with:

$$\int_{\bar{x} - \frac{1}{2}M}^{\bar{x} + \frac{1}{2}M} x \cdot \frac{1}{M} dx = \bar{x} = \text{expected demand}$$

$$\bar{x} - \frac{1}{2}M = \text{minimum demand}$$

$$\bar{x} + \frac{1}{2}M = \text{maximum demand}$$

The two total cost functions ($C_I(x)$ and $C_F(x)$) are assumed to be quadratic so that:

$$E(C_I(x)) = C_I(\bar{x}) + d_I \text{Var}(x)$$

and:

$$E(C_F(x)) = C_F(\bar{x}) + d_F \text{Var}(x)$$

where:

$$E(C_i(x)) = \text{expected total cost for the } i\text{th total cost function}$$

$$\text{Var}(x) = \text{variance of demand} = \frac{M^2}{12}$$

Furthermore, $C_F(x)$ is assumed to have the more flexible marginal cost function in that:

$$d_I > d_F ,$$

but to have a higher minimum average cost, where this is assumed to occur for both total cost functions at $\bar{x}$:

$$C_I(\bar{x}) < C_F(\bar{x})$$

Finally, it is assumed that the price for selling output is fixed, and at such a level that the firm always finds it profitable to satisfy the maximum level of demand.³

Since the two total cost functions yield the same revenue in each period of production, their relative, average profitability as a function of the variance of demand ($M^2/12$) depends simply on the two cost characteristics, d_i and $C_i(\bar{x})$:

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3. This assumption, while also having some intuitive appeal, is employed largely as a means of simplifying the following analysis.

Figure 1

where:

$$\sigma_0^2 = \frac{C_F(\bar{x}) - C_I(\bar{x})}{d_I - d_F}$$

Figure 1 shows the standard result of the literature: that the more flexible of two marginal cost functions (in this case d_F) becomes the preferred choice as the extent of demand fluctuations increases (beyond σ_0^2). For small fluctuations in demand, the minimum average cost advantage of the inflexible marginal cost function is the dominating cost factor. As these fluctuations increase, however, the relative cheapness of adjusting output with the flexible marginal cost function proves to be the dominating cost factor. For a situation in which no inventories can be held, this result represents the analytical link between greater flexibility and greater profitability in the face of demand fluctuations.

III. Choice of Whether or Not to Hold Inventories

This section presents a simple model of a situation in which a firm already has its total cost function, and is considering the relative profitability of using inventories to smooth production in the face of demand fluctuations.

Further to the assumptions of the previous section concerning the pattern of demand, it is assumed that the firm is currently facing the commencement of the downward cycle of demand. In other words, were the firm to decide to smooth production, it would be accumulating inventories over the first half of the cycle, and decumulating over the second half.

The total cost of holding inventories to smooth production over the demand cycle is assumed to be quadratic, with a fixed cost of C_0 , and a per-period holding cost of:

$$\alpha N_j^2$$

where N_j is the level of inventories held in period j .

The expected total cost of holding inventories over the demand cycle ($E(G(N))$) is thus given by:

$$\begin{aligned} E(G(N)) &= C_0 + 2 \int_{\bar{x} - \frac{1}{2}M}^{\bar{x}} \alpha (\bar{x} - x)^2 \frac{1}{M} dx \\ &= C_0 + \alpha \text{Var}(x) \end{aligned}$$

By defining the length of the demand cycle as one unit, and recognizing that average revenue per period of production is the same whether or not production is smoothed, the relative profitability as a function of the variance of demand ($M^2/12$) of holding inventories and smoothing production or not holding inventories and adjusting production depends simply on the cost characteristics

d , $C(\bar{x})$, C_0 and α :

Figure 2

where:

$$\sigma_1^2 = \frac{C_0}{d - \alpha}$$

Figure 2 shows the standard result of the literature: that as long as the marginal holding cost of inventories increases more slowly than the marginal cost of adjusting production, holding inventories and smoothing production becomes the preferred choice as the extent of fluctuations in demand increases (beyond σ_1^2). Otherwise, inventories will never be held.

IV. Choice of Marginal Cost Function and of Whether or Not to Hold Inventories

Bringing together the analyses of the previous two sections, this section presents a model of a situation in which the firm is to make a decision concerning both the choice of a marginal cost function and of whether or not to hold inventories to smooth production. This joint decision will be referred to as a choice of technique.

Bearing in mind the assumptions made previously about the pattern of demand and the level of price, the technique preferred by the firm for any given level of demand fluctuations will depend on the characteristics of the three total cost functions involved in its decision: $C_I(x)$, $C_F(x)$ and $G(N)$. More specifically, the relative profitability of a particular technique depends on the values of $C_I(\bar{x})$, $C_F(\bar{x})$, C_0 , d_I , d_F and α .

For low levels of demand fluctuations, the firm will always choose the inflexible marginal cost function and prefer not to hold inventories. This follows from the assumptions that:

$$C_I(\bar{x}) < C_F(\bar{x})$$

and

$$C_0 > 0.$$

For larger levels of demand fluctuations, however, the advantages of satisfying demand either by using the flexible marginal cost function, or by holding inventories, become relevant. For this range of demand fluctuations, and depending on the characteristics of the total cost functions, there are three general classes of choice:

- (i) the flexible marginal cost function is never chosen, independent of the level of demand fluctuations

- (ii) the firm never chooses to hold inventories, independent of the level of demand fluctuations
- (iii) the firm's choice either of producing with the flexible marginal cost function and not holding inventories, or of producing with the inflexible marginal cost function and holding inventories, depends on the level of demand fluctuations.

Producing with the flexible marginal cost function or the holding of inventories to smooth production thus are seen to be alternative methods of adjusting to demand fluctuations. It is this observation which suggests the inadequacy of the standard definition of "flexibility" when output is storable.

In considering the case where inventories are never chosen to be held, two possible combinations of characteristics of the total cost functions will give this result:

$$(i.a) \quad C_F(\bar{x}) - C_I(\bar{x}) \leq C_0 \quad \text{and} \quad d_F \leq \alpha$$

$$(i.b) \quad C_F(\bar{x}) - C_I(\bar{x}) \geq C_0 \quad \text{and} \quad d_I \leq \alpha$$

These situations are depicted in figures 3(a) and 3(b) respectively:

In both cases, the firm prefers never to hold inventories, and prefers the more flexible marginal cost function if the variance of demand exceeds:

$$\sigma_2^2 = \frac{C_F(\bar{x}) - C_I(\bar{x})}{d_I - d_F}$$

For the case where the flexible marginal cost function is never chosen, there are once again two possible combinations of characteristics:

$$(ii.a) \quad C_F(\bar{x}) - C_I(\bar{x}) \geq C_0 \quad \text{and} \quad d_F \geq \alpha$$

$$(ii.b) \quad C_F(\bar{x}) - C_I(\bar{x}) \leq C_0, \quad d_F \geq \alpha \quad \text{and} \quad \frac{C_0}{d_I - \alpha} \leq \frac{C_F(\bar{x}) - C_I(\bar{x})}{d_I - d_F}$$

These situations are depicted in figures 4(a) and 4(b) respectively:

In both cases, the firm never prefers the more flexible marginal cost function, and prefers to hold inventories once the variance of demand exceeds:

$$\sigma_3^2 = \frac{C_0}{d_I - \alpha}$$

Two possibilities exist again in the final case, with the firm preferring either to produce with the flexible marginal cost function, or to hold inventories, depending on the level of demand fluctuations:

$$(iii.a) \quad C_F(\bar{x}) - C_I(\bar{x}) \leq C_0, \quad d_F \geq \alpha \quad \text{and} \quad \frac{C_0}{d_I - \alpha} > \frac{C_F(\bar{x}) - C_I(\bar{x})}{d_I - d_F}$$

$$(iii.b) \quad C_F(\bar{x}) - C_I(\bar{x}) \geq C_0, \quad d_F \leq \alpha$$

These situations are depicted in figures 5(a) and 5(b) respectively:

In the case depicted in figure 5(a), for increases in the variance of demand beyond:

$$\sigma_4^2 = \frac{C_F(\bar{x}) - C_I(\bar{x})}{d_I - d_F}$$

the firm prefers to produce with the flexible marginal cost function. However, for increases in the variance of demand beyond:

$$\sigma_5^2 = \frac{C_I(\bar{x}) + C_0 - C_F(\bar{x})}{d_F - \alpha}$$

the firm prefers to produce with the inflexible marginal cost function and to hold inventories to smooth production.

The reverse is true for the case depicted in figure 5(b). In this case the firm's preference initially switches to holding inventories when:

$$\text{Var}(x) = \sigma_6^2 = \frac{C_0}{d_I - \alpha}$$

and only after the variance of demand increases further to:

$$\sigma_7^2 = \frac{C_F(\bar{x}) - C_I(\bar{x}) - C_0}{\alpha - d_F}$$

does the firm prefer to produce with the flexible marginal cost function.

In summary, this section has demonstrated two main points. First, it has shown that once output is storable, it is not necessarily the case that, as the level of demand fluctuations increases, the firm will prefer to produce with the more flexible marginal cost function, a result which holds when output is not storable. The explanation for the new result is that once output is storable, inventories provide an alternative method of adjusting sales to demand fluctuations. Second, it has shown that the analytical link between greater flexibility and greater profitability in a technique of production can be re-stored simply by using a more general definition of flexibility: as cheapness in adjusting sales to demand fluctuations; and by defining a choice of technique more generally: as a choice both of a marginal cost function and of whether or not to hold inventories.

V. Complications

The previous section has shown that the slope of a firm's marginal cost function and the holding of inventories provide alternative sources of flexibility for the firm in the face of demand fluctuations. Given certain simplifying assumptions on the pattern of demand and on the shapes of the relevant total cost functions, it was also shown that the choice between these two sources of flexibility often depends only on specific characteristics of these total cost functions.

These simplifying assumptions, however, have served to eliminate two relevant possibilities:

- (a) that with more general assumptions the firm may prefer to utilise to some extent both sources of flexibility
- (b) that with more general assumptions the firm may prefer to utilise a particular source of flexibility, regardless of changes in the specific characteristics of the total cost functions.

The aim of this section is to investigate the implications of relaxing some of the simplifying assumptions, with a view towards establishing an understanding of the importance of these two possibilities.

Two aspects of the assumptions made about the pattern of demand seem particularly simplifying: the predictability of demand at any point in time and its cyclical regularity over time. The cyclical regularity of demand over time is an important feature of "the production smoothing hypothesis."⁴ In particular, it enables inventories to be accumulated during troughs and decumulated during peaks: "If firms do follow a production-smoothing policy, the inventory-

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4. See Ghali (1982).

sales ratio will exhibit an inverted cycle relative to that of sales."⁵ The cyclical pattern of demand thus allows firms to adjust sales by adjusting inventory holdings.

The extreme regularity assumed here, however, allows firms perfectly to smooth production with the minimum of inventory holdings at any point in the cycle. By eliminating the need for a buffer stock holding of inventories which guards against irregular fluctuations in demand,⁶ the analysis of the previous section underestimates the expected total cost of holding inventories to adjust sales to demand fluctuations.

In contrast, imposing this extreme regularity has no effect on the expected total cost of adjusting sales by adjusting output. The important assumption in this case is the predictability of demand at a point in time. By assuming perfect predictability of demand, it is a simple matter for the firm to adjust its output plans in advance, and thereby adjust its sales to the demand fluctuation. If there is only partial predictability, however, then the firm is likely to err in its adjustment of output plans and so either fail to fully adjust sales to demand, or over-adjust sales by over-producing. In any case, it is clear that assuming full predictability leads to an overestimation of the profitability of adjusting sales to demand fluctuations by adjusting output.⁷

Assuming full predictability of demand is also likely to lead to some underestimation of the expected total costs of holding inventories. As already seen, irregular fluctuations in demand will encourage the holding of a buffer stock

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5. Ghali (1982), p. 614.

6. A buffer stock holding will also be important for unforeseen fluctuations in demand. This will be discussed later in the section.

7. Nelson (1961) points out that an important determinant of the predictability of demand will be the source of the fluctuations. Exogenously determined fluctuations are thus likely to be difficult to predict.

of inventories. However, assuming full predictability of these irregular fluctuations serves to minimise the size of this holding. With less than full predictability, the firm will need to hold a buffer stock not just to cover itself against irregular fluctuations in demand, but rather to cover itself against unforeseen irregular fluctuations. The difference being that, in the latter case, the firm cannot plan perfectly the reduction of its buffer stock over the demand cycle and so must hold a larger stock to counter the risk of unfulfilled demand.

The special assumptions about the pattern of demand thus lead to a variety of biases in the estimation of the relative profitability of choosing to adjust sales either by holding inventories or by adjusting output. Consequently, it is not clear that more general assumptions about the pattern of demand fluctuations would favour the choice of either alternative.

One suggestion is that, in a situation with more general assumptions about the patterns of demand fluctuations, a firm might choose to adjust sales both by adjusting output and by holding inventories. Both methods of achieving flexibility would thus be used to some extent, depending on their relative cost.⁸

It is argued here, however, that two cost considerations, which to this point have been assumed to be unimportant, are actually important determinants of the relative profitability of adjusting sales by holding inventories, rather than by adjusting output.

The first of these cost considerations concerns the cost of short-run adjustments in output.⁹ Such short-run adjustments are achieved by more or less intensive use of the firm's existing labour force, plant and machinery. More

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8. Blinder (1981) examines this situation for a given marginal cost function.

9. Atkinson (1981) presents a clear analysis of the importance of this cost in influencing a firm's short-run behaviour.

specifically, if increases in the short-run rate of production are achieved "by the overtime use of existing labour and machinery," and short-run reductions in the rate of production are affected "by a policy of paid idle time,"¹⁰ then it is clear that the firm faces important short-run costs of adjusting output, costs which do not exist in the long run. As Atkinson (1981) shows for a situation where inventories can be held and the firm has a given (long run) marginal cost function, such costs encourage the short-run adjustment of inventories rather than output. It follows that these costs will also influence the firm's choice of technique, and in particular, will encourage the choice of an inflexible marginal cost function and the use of inventories to adjust sales to demand fluctuations.

Second, to this point the total cost function of holding inventories has been assumed to be quadratic. This implied the expected total cost of holding inventories increased linearly with the level of demand fluctuations, consistent with the expected cost of adjusting output to such fluctuations. It is argued here, however, that although the assumption of convex total costs seems appropriate in the case of output adjustments, linear or even concave total costs seems a more appropriate assumption in the case of inventory holdings. In particular, an assumption of linearly increasing holding costs has been standard in the inventory literature to date.¹¹ This assumption means that the expected total cost of holding inventories is a concave function of the level of

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10. Atkinson (1981), p. 319.

11. See, for example, Arrow, Harris and Marschak (1951), Modigliani and Hohn (1955) and Zabel (1972). Blinder (1981) assumes quadratic costs while Reagan (1982) assumes zero costs.

demand fluctuations. Alternatively, if there are economies of scale in the holding of inventories, expected total costs of holding inventories will actually decrease with increases in the level of demand fluctuations. Since both of these specifications seem to be more accurate representations of the holding costs of inventories, then, compared with the analysis of the previous section, the firm's choice of technique will be biased in favour of adjusting sales by the use of inventories, especially in situations where there is a high level of demand fluctuations.

Taking into account both the unambiguous encouragement to the holding of inventories of these two cost considerations, and the ambiguous implications of considering more general assumptions about the pattern of demand fluctuations, it would seem that the weight of the effects of these complications is in favour of the firm choosing to adjust sales by the use of inventories (and of choosing to produce with a quickly-rising marginal cost function). Furthermore, this seems especially so when there is a high level of demand fluctuations.

VI. Conclusion

This paper has developed two principal arguments. First, in a simple model of a situation in which a firm is to make a choice both of the shape of its marginal cost function and of whether or not to hold inventories, it was shown that, when faced with a regular, foreseeable cyclical pattern of demand fluctuations, the firm would plan to adjust sales to these demand fluctuations either by adjusting output or by adjusting inventory holdings, depending on cost considerations and the level of demand fluctuations. It was thus argued that, when output is storable, the appropriate way to refer to the choice of technique by a firm is to include a choice not only of a marginal cost function, but also of whether or not to hold inventories.

It was further argued that the standard approach of the literature on the choice of technique, which assumes output is non-storable, develops a concept of "flexibility" which is inadequate in situations where output is storable. In this literature, a firm which faces demand fluctuations is shown to prefer a flexible marginal cost function as the level of these fluctuations increases; where "flexible" implies that the slope of this function is slowly-rising (relative to some other function). For the firm, flexibility is thus viewed as relative cheapness of adjusting output levels in order to adjust sales to demand fluctuations. As was shown in section IV, however, when output is storable, the firm may choose to adjust sales to demand fluctuations either by adjusting output or by adjusting inventories. Therefore, in this more general situation, a more general definition of flexibility was shown to be needed. It was suggested that flexibility be viewed simply as relative cheapness in adjusting sales to demand fluctuations. The choice of a flexible technique could thus imply the choice either of a slowly-rising marginal cost function or of the holding of inventories.

The second principal argument concerned the effect on the choice of technique of complicating the previous analysis by relaxing some of its assumptions. It was shown that introducing a more general set of assumptions about the pattern of demand, in which the demand cycle was no longer perfectly regular and foreseeable, had ambiguous implications for the firm's relative preference between adjusting sales by adjusting output or by adjusting inventory holdings. Both methods were seen to be more costly with this specification of demand fluctuations.

The consideration of a more complicated structure of costs, however, yielded an unambiguous implication for the firm's preferred method of adjusting sales.

Taking into account the likely possibilities that short-run adjustments in output involved extra costs to the firm (e.g. higher wages for overtime work), and that the total cost of holding inventories was a linear or concave function of the size of this holding (e.g. economies of scale in building a warehouse) rather than a convex function (as had been assumed), clearly implied a greater preference for adjusting sales by adjusting inventories.

It was thus argued that the weight of the effects of these complications was in favour of firms choosing to adjust sales by the use of inventories (and of choosing to produce with a quickly-rising marginal cost function), especially in situations where there is a high level of demand fluctuations.¹²

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12. Two pieces of empirical research support the assertion that, as the level of demand fluctuations in an economy increases, firms are more likely to choose a technique where inventories are held to adjust sales to these fluctuations. Rubin (1980) demonstrates a positive correlation between the variation of sales and the level of inventory holdings for the period 1965 to 1978. Finally, Blinder (1979) demonstrates a rising trend in inventories-sales ratios during the period 1972 to 1976--a period noted for its unstable levels of demand.

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