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ADOPTING FLEXIBLE TECHNOLOGY FOR MULTIPLE PRODUCT-LIFE-CYCLES: THE ECONOMY-OF-SCOPE ADVANTAGE

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ABSTRACT

One of the principal benefits of flexible technology is the benefit of economy of scope of joint production. We examine the situation of a firm having to adopt either dedicated or flexible technology for simultaneous production of multiple products with overlapping product life cycles. Economies of scope of joint production are assumed to operate during the overlapping part of the life cycles of the products. We formulate the problem for the two product case, and analyze for the benefits of economies of scope of process flexibility. We arrive at a condition that can help the firm decide between dedicated and flexible technology for producing several new products.

1. INTRODUCTION

Proponents of flexible manufacturing technology highlight many benefits that such technology could have over dedicated technology. One of the suggested sources of benefit is the economy of scope arising from having the capability of simultaneous production of more than one product on the same system, compared to isolated dedicated production of the same products. In this paper, we examine this potential source of benefit in detail, and relate economic benefits of scope to investment parameters in technology.

The scenario is that of a firm facing a decision concerning technology selection. The firm possesses dedicated technology for producing one type of product, and now wants to enter the market with a second product. The choice for the firm is to either acquire dedicated technology for production of the second product and operate the two dedicated technologies in parallel, or to acquire a flexible technology capable of producing both products together and simultaneously, with no significant changeover cost between the two products. The acquisition cost of the flexible technology needs to be considered, and typically is higher than the cost of the dedicated technology required for the second product.

A product life cycle describes a sequence of stages that a product goes through over time from its initial market entry, through rising sales culminating in a peak, to finally exit from the market (Bass, 1969). Economies of scope from joint production can occur only during the overlapping period of the life cycles of the two products. In order to understand how flexible technology might provide such an economy of scope, one needs to have a specific idea about the types of flexibility of concern as well as the particular source of economy of scope. We examine the question of adoption of flexible versus dedicated technology for overlapping product life cycles of multiple products under economy of scope.

The plan of the paper is as follows. The past and current research in the modeling of technology choice are reviewed in Section 2. Then in Section 3, both the economy of scope and the *degree* of economy of scope are precisely and mathematically defined. Also in Section 3, the two-product situations where these products can be produced using dedicated or flexible technology are formulated and analyzed. Finally, in Section 4, we consider the flexibility type appropriate for our analysis and then arrive at a condition relating the degree of economy of scope to investment and production costs and the extent of overlap between products. The validity or otherwise of this condition can aid in the decision of whether to adopt dedicated or flexible technology in order to manufacture multiple products with overlapping product life cycles.

2. LITERATURE REVIEW

Flexibility in manufacturing has been studied recently. A comprehensive review of the analytical and empirical research can be found in Fine (1990). Another excellent survey of the existing literature can be found in Sethi and Sethi (1990). Without reviewing all of these, here only those analytical works that address the issue of interest here, that of adopting flexible technology in relation to product life cycle, are discussed.

Hutchinson and Holland (1982) determine what factors affect relative profitability of both flexible and dedicated technologies. They consider two types of production technologies, one dedicated and one flexible (FMS), to make two products. The FMS costs more but can produce these two products efficiently. They assume that technology can be added incrementally and that demand follows a product life cycle pattern of starting low, increasing over time to a peak and then gradually declining. The authors show through a simulation study that the advantage of FMS over a dedicated technology increases as the rate of new product introductions increases and as the maximum capacity of the FMS increases, and decreases as the interest rate decreases and as the average volume per period produced decreases.

Lederer and Singhal (1988) use the capital asset pricing model to show how cost structure affects the risk adjustment which in turn affects the technology choice decision. Empirical evidence provided by the authors suggests that an FMS has lower fixed period costs as well as lower unit variable costs compared to conventional technologies, and is therefore a less risky technology choice.

Fine and Li (1988) examine the case of adopting either flexible or dedicated technology for multiple products with very low overlap of product life cycles and without any economy of scope of joint production. Demand deterministically follows the classic product life cycle pattern. Conditions are established under which a firm would switch from a labor-intensive technology to a capital-intensive one, as well as conditions under which no switch occurs or the reverse switch occurs. Conditions for adoption of either technology are based on investment costs and profit streams from the technologies. Rajagopalan (1993) also studies the technology-choice issue and establishes conditions for adoption based on demand patterns, costs, and benefits.

Jordan and Graves (1991) analyze the decision mathematically in a broader context of multi-plant flexibility and develop principles about how process flexibility should be introduced into a network of facilities producing many different products. They conclude that there is not one, but many ways to assign products to plants that will achieve most of the benefits of total flexibility.

Gupta and Buzacott (1993) present a first-pass decision model to help a firm narrow down the options in finding the optimum sizes of dedicated and flexible facilities and the degree of flexibility for the flexible facility under the objective of minimizing operational costs. Two models are offered to deal with constant and random product-demands for the two-product case.

The question of technology choice has been addressed in the economics literature as well, particularly in the context of the supply of new technologies. Schumpeterian competition, which portrays a firm allocating resources to technological innovation to gain a competitive advantage in the market, is the basis of most of the analyses. Kamien and Schwartz (1972) build a model that assumes no fixed operating costs and find that in choosing between competing technologies, the relatively capital-intensive technology becomes more attractive as its variable cost advantage increases, its capital cost disadvantage decreases, the interest rate falls, the appearance of superior technology is delayed, and the improvement provided by the future technology is reduced. The thrust of the economics literature is on the flexibility of changing the scale of production. We do not go into a detailed review here, but note for the interested reader that a good survey of the topic can be found in Carlsson (1989).

Another flexibility type, that of having the flexibility to shift between products, has been examined by Fine and Freund (1990). They mathematically analyze the optimal investment in flexible technology. Cohen and Halperin (1986) presents a single-product, stochastic, dynamic model to link production planning with technology selection. Optimal production plans are completed in the face of uncertain demand. The authors reduce the problem of optimal technology choice to the selection of a pair of fixed and variable costs from sets of available pairs of the same. It is shown that if the mean value of demand is increasing, under certain conditions, the firm will never switch to a higher variable cost technology. Also, conditions are established under which the firm will switch to a lower variable cost technology. These conditions, stated in terms of demand, cost, and contribution margin, help link the question of technology choice to the notion of product life cycle.

Motivation for the current work stems from that of Fine and Li (1988). We study a situation similar to theirs in the number of products, product life cycles, and technology choices. However, our scenario differs from theirs in two aspects. To describe these differences, we resort to the follwing notation. Let us denote the first product as Product 1 and the second product as Product 2. Let

S1= Start of life cycle of product 1

P1= Peak of life cycle of product 1

E1= End of life cycle of product 1

S2= Start of life cycle of product 2

P2= Peak of life cycle of product 2

E2= End of life cycle of product 2.

Then the first extension of Fine and Li (1988) is as follows. The earliest time that product 2 can come into profitable production is after the beginning of the life cycle of product 1 but long before the demand of product 1 has reached its peak. This ensures an early beginning of the time-period during the rising period in the product life cycle of product 2 over which economies of scope of joint rather isolated dedicated production can operate. Mathematically, this can be stated as :

$$S1 < Inf\,\{S2: \text{Product 2 is profitable}\} << P1.$$

The second extension, in a similar vein, is as follows. The products are such that the end of the product life cycle of product 1 is before the end of the product life cycle of product 2 but is long after the peak demand period in the life cycle of product 2, allowing a considerable overlap during the declining demand stage in the life cycle of product 1. This can be stated mathematically as:

$$E2 > Sup\,\{E1: \text{Product 1 is profitable}\} >> P2.$$

This scenario is depicted in Figure 1.

******** [*Figure 1 here*] *********

Figure 1. Product life cycles of product 1 and product 2.

An FMS is one example of a system that can produce the two products of Figure 1 simultaneously. Product 1 and product 2 can then be two products within the same product family, offered to increase product diversity in the market. Such is often the case with FMSs. The potential for joint production of these two products on the FMS provides a case for examining the economy of scope arising out of such joint production.

3. ECONOMY OF SCOPE AND THE DEGREE OF ECONOMY SCOPE

The economy of scope can be defined (Baumol et al., 1975) as the cost savings arising from joint production rather than isolated dedicated production of several different products. Notation required to mathematically define these savings is given in Table 1.

Table 1. Notation.

N= Number of products

Q_i= The output of product i, i=1,...,N, for N products

Q= The n-dimensional production vector of outputs

V= The cost function

Ψ= Degree of economy of scope

$\Psi_{1,2}$= Degree of economy of scope for the two-product case

$V_{Average}$= Average cost of production

Δ_t= Period of overlap of product life cycles of products 1 and 2

Δ_I= Additional investment in flexible technology over dedicated technology

Formally, the economy of scope can be interpreted as a restricted form of subadditivity. That is, for the set of N products, economies of scope of joint production exist if

$$V(\mathbf{Q}) < \Sigma_i V(Q_i), \text{ for } i = 1,...,N.$$

For a two-product case with products 1 and 2, the economy of scope exists if,

$$V(Q_1, Q_2) < V(Q_1, 0) + V(0, Q_2). \quad (1)$$

That is, the cost of joint production of product 1 and product 2 is less than the sum of the isolated dedicated production of the individual products.

For a subset of M products out of total of N products, the degree of economy of scope relative to the subset of M products measures the relative increase in cost that would result from partitioning the production of the set of N products into two product-subsets of M and N-M products. Such partitioning will increase, decrease, or not affect the total cost of production depending on whether the degree of economy of scope is greater than, less than, or equal to zero, respectively.

Formally, the degree of economy of scope can be mathematically described as:

$$\Psi = \frac{\text{Cost of dedicated production - Cost of joint production}}{\text{Cost of joint production}}$$

$$= \frac{\text{Additional cost of dedicated production}}{\text{Total cost of joint production}}$$

$$= \frac{V(Q_M) + V(Q_{N-M}) - V(Q)}{V(Q)}.$$

For a two-product case, degree of economy of scope, $\Psi_{1,2}$, is

$$\frac{V(Q_1,0) + V(0,Q_2) - V(Q_1, Q_2)}{V(Q_1,Q_2)}.$$

That is, the degree of economy of scope between product 1 and product 2 is given by the ratio of the additional cost of the isolated dedicated production of the products to the cost of joint production of these products.

If the economy of scope exists for products 1 and 2 with flexible technology, then from equation (1),

$$V(Q_1, Q_2) < V(Q_1,0) + V(0,Q_2). \qquad (2)$$

This provides us with the basis for capturing the savings due to the economy of scope. The difference between the left hand side and the right hand side of equation (2) is the benefit from the economy of scope. These savings will accrue as long as the economy of scope is in effect, i.e., as long as both product 1 and product 2 can be manufactured jointly on the flexible technology on a profitable basis.

Therefore,the *benefits* of flexible technology over isolated dedicated technologies due to economy of scope is

$$V(Q_1,0) + V(0,Q_2) - V(Q_1, Q_2).$$

The total benefit over the period through which economies of scope are present is equal to the total savings due to economy of scope during the overlap of product life cycles. That is, the total benefit is

$$\int_{S2}^{E1} [V(Q_1,0) + V(0,Q_2) - V(Q_1, Q_2)]\, dt. \qquad (3)$$

The benefits of using the flexible technology must outweigh the costs of using it in order for it to be viable for a firm to acquire. As stated earlier, the firm possesses dedicated technology for product 1. It now has to choose between either dedicated technology for product 2 in parallel with that for product 1 or a flexible technology for producing both. We assume that the acquisition cost of the flexible technology is more than that of the dedicated technology for product 2 and that this additional acquisition cost of the flexible technology represents the cost of the decision to adopt it. The operating costs are captured in the analysis of the benefit as given in equation (3). If the firm adopts the flexible technology and wants to salvage its old technology, the possible salvage value of the dedicated technology for product 1 is assumed to be zero.

Then the total costs are:

= Cost of acquiring flexible technology - Cost of acquiring dedicated technology

= Additional cost of adopting flexible technology

= Δ_I.

The decision will be to adopt flexible technology over dedicated technology if the total benefits (equation 3) exceed total costs. The benefits are obtained from the economies of scope of the flexible technology. Flexible technology can provide flexibilities of many types, however, and there may be many potential sources of flexibility within the technology that may provide additional economies of scope.

4. FLEXIBLE TECHNOLOGY AS A SOURCE OF ECONOMY OF SCOPE

In order to analyze the economy-of-scope benefits of flexible technology, it is necessary to be more specific about the source of this economy of scope. It is important to explain how flexible technology provides economy of scope. Specifically, one can ask which flexibility type, i.e., mix flexibility, and/or changeover flexibility, and/or volume flexibility and/or any other flexibility provide a manufacturing system with economies of scope? We have seen that in order for flexible technology to be more appropriate than dedicated technology, the total benefits must exceed total costs, i.e., (from equation 3)

$$\int_{S2}^{E1} [V(Q_1,0) + V(0,Q_2) - V(Q_1, Q_2)]\, dt > \Delta_I. \qquad (4)$$

Also, for a two-product case, the degree of economy of scope is

$$\Psi_{1\text{-}2} = \frac{V(Q_1,0) + V(0,Q_2) - V(Q_1, Q_2)}{V(Q_1,Q_2)}. \qquad (5)$$

Combining inequality (4) and equation (5), we see that flexible technology will be preferred to dedicated technology if

$$\int_{S2}^{E1} \Psi_{1\text{-}2} [V(Q_1, Q_2)]dt > \Delta_I.$$

Expanding, $\int_{S2}^{E1} \Psi_{1\text{-}2} [V(Q_1, Q_2)]dt$

$$= \Psi_{1\text{-}2} \int_{S2}^{E1} [V(Q_1, Q_2)]\, dt - \int_{S2}^{E1} [\frac{d}{dt}\Psi_{1\text{-}2} \int_{S2}^{E1} \{V(Q_1, Q_2)\}\, dt]\, dt. \qquad (6)$$

The time rate of change of the degree of economy of scope can be examined as follows. Our scenario describes the steady-state joint production of two or more products on the same technology. Related to this, Goldhar and Jelinek (1983), say that "A plant with mix flexibility ... can make a range of items at a lower cost than separately focused plants each producing a single item".

The capability for concurrent or intermittent production of multiple products in a steady-state operating mode can be called mix flexibility or process flexibility. Process flexibility is obtained by performing similar operations or producing similar part types on expensive capital equipment, with the objective of concurrent production of a proliferated product line (Carter, 1986), as in the current two-product case. Browne, Rathmill, Dubois, Sethi, and Stecke (1984) and Sethi and Sethi (1990) relate the process flexibility of a manufacturing system to the set of part types that the system can produce without major set-ups. One purpose of process flexibility is to be able to reduce batch sizes and inventory costs when there are shifts in the product mix in the markets. Carter (1986) calls this short-term insurance. Carter (1986) also says that process flexibility allows machines to be shared which can decrease the need for duplicate machines, similar to the situation of joint production of products 1 and 2 that is examined here. Gerwin (1989) describes process flexibility as the capability to be able to offer a range of products manufactured simultaneously.

This capability can be contrasted to volume flexibility or product flexibility. Volume flexibility refers to the ability to economically change the output level upwards or downwards. It is not concerned with economies of scope of joint production. Product flexibility, on the other hand, is essentially a transient flexibility and does not capture the short-term production requirement of the current scenario. Further, an empirical study by Kekre and Srinivasan (1990), based on the PIMS database, shows that for some industrial product companies, product-line breadth has a positive association with profitability and a significant negative association with manufacturing costs. This empirical evidence seems to bolster the claim of mix flexibility being a provider of economies of scope. However, care must be taken to not state this as a proof of the same. Thus we see that the appropriate flexibility type of concern here is process flexibility. In concurrent production in the short-term, the degree of economy of scope provided by process flexibility can depend on the flexible technology itself and the production and processing requirements of product 1 and product 2. Since these factors are all given, the degree of economy of scope, under the scenario, is a function of factors which are time-invariant and therefore, is itself time-invariant and we can neglect the second term of equation (6) and simplify our expression of the required condition to:

$$\Psi_{1\text{-}2} \int_{S2}^{E1} [\, V(Q_1, Q_2)]dt \;>\; \Delta_I.$$

In practice, one way to estimate $\int_{S2}^{E1} [\, V(Q_1, Q_2)]dt$ will have to be through cost accounting data, Specifically, one may know (or can estimate) the period of overlap of the products and the average product cost over this period. The average product cost, $V_{Average}$, may be obtained by an appropriate weighted measure of individual period costs of the products. Then

$$\int_{S2}^{E1} [\, V(Q_1, Q_2)]\, dt \;=\; V_{Average}\,(E_1 - S_2) \qquad (7)$$

= Average Cost of Production x Period of Overlap.

Therefore, the condition for adopting flexible technology becomes:

$$\Psi_{1\text{-}2}\;\; V_{Average}\,\Delta_t \;>\; \Delta_I, \qquad (8)$$

where Δ_t = Period of overlap of product life cycles.

The results can be easily extended to multiple products. In fact, as suggested by Fine and Li (1988), multiple products will likely favor flexible technology even more than the two product case just examined.

5. CONCLUSIONS AND FURTHER EXTENSIONS

Rearranging inequality (8), adopting flexible rather than dedicated technology is preferred if the following condition (9) holds true:

$$\Psi_{1\text{-}2} \;>\; \frac{\Delta_I}{V_{Average}\;\Delta_t}, \qquad (9)$$

where

$\Psi_{1\text{-}2}$ = Degree of Economy of Scope

$V_{Average}$ = Average Cost of Production

Δ_t = Period of Overlap of Product Life Cycles

Δ_I = Additional investment in flexible technology over the dedicated technology.

Note that the values of all of the terms on the right hand side of the inequality may be available within a firm. The average cost of production can be calculated as a weighted measure from the cost accounting data in the system. The period of overlap of the product life cycles could be estimated by the marketing function for their own purposes and hence be readily available. The additional cost of acquiring the flexible technology over the dedicated one will be known precisely by the firm. Thus it is possible to relate the degree of economy of scope provided by the flexible technology to variables that are measurable and already available in different systems within the business.

Condition (9), not surprisingly, says that a decrease in the additional acquisition cost of the flexible technology over the dedicated technology increases its probability of being adopted. It also says that an increase in the overlapping period of the product life cycles of product 1 and product 2 increases the chance of acceptance of the flexible technology. The higher the economy of scope of the process flexibility for the two products, the lower the overlap required between them. What is not intuitively evident, though, is that an increase in the average cost of production seems to increase the chances of adopting flexible technology. A possible explanation of this is that the economies of scope available from the process flexibility operate significantly only when the batch sizes are very small (Carter, 1986). Additional research is needed to further understand this.

We have examined only one aspect of flexibility - that of process flexibility - and its associated economy of scope. Other types of flexibility can be examined for potential economies that they may offer over dedicated equipment. Process flexibility itself is a component of some of the system level flexibilities. The benefits of these flexibilities and other aggregate level flexibilities may be different from those of process flexibility since they are also affected by other flexibilities. Our work provides a new link between the notion of economy of scope and flexible manufacturing technology, but an actual decision undoubtedly has to take into consideration many additional complex aspects. We formalize the benefit of process flexibility in economic and business system variables in the decision of technology choice, and note that economy of scope is but one benefit in a complex cost-benefit analysis.

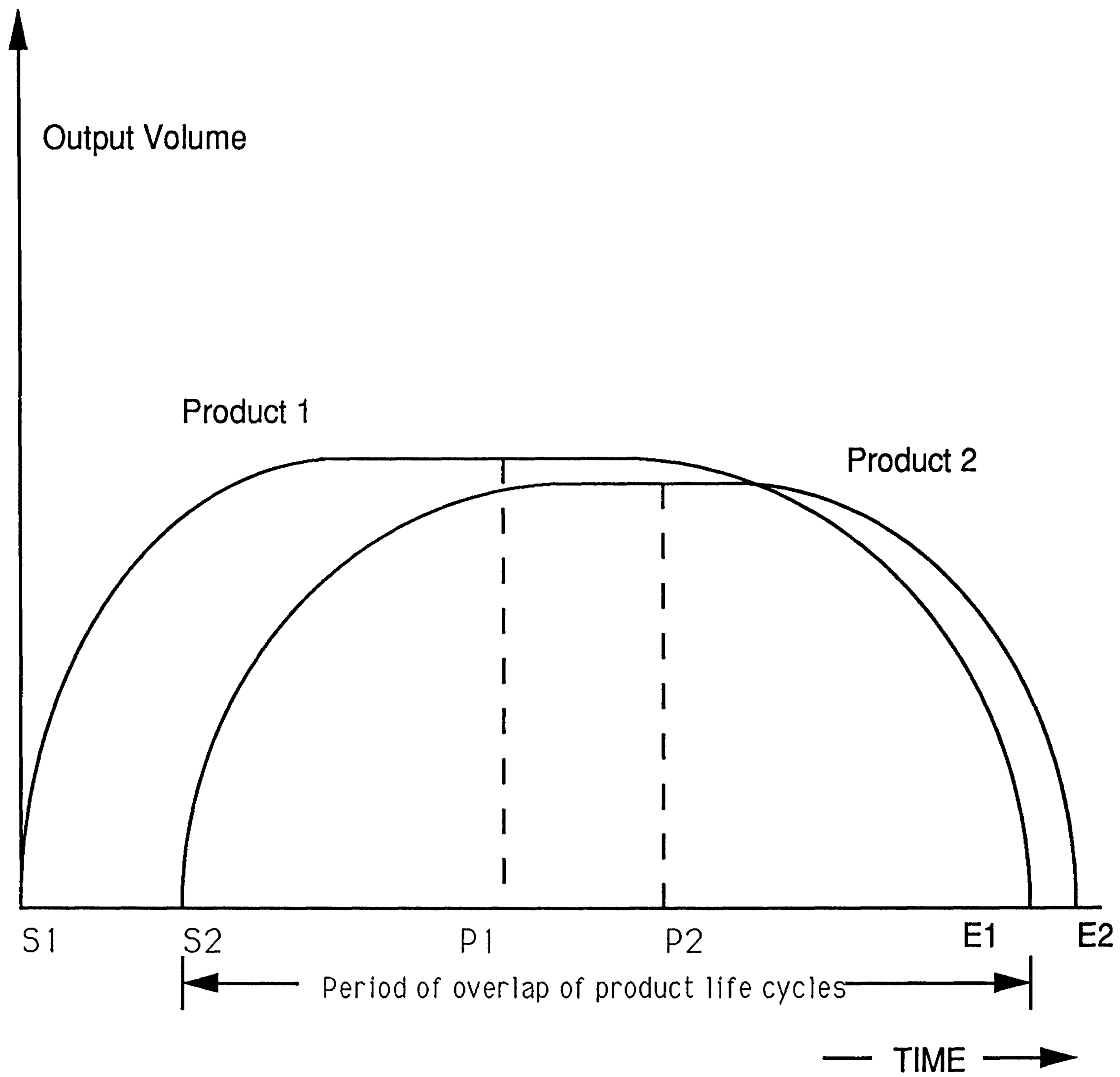

Figure 1. Product Life Cycles of Products 1 and 2.

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