POSTPONEMENT, PRODUCT CUSTOMIZATION, AND MARKET-ORIENTED SUPPLY CHAIN MANAGEMENT

by

Matthew A. Waller
The University of Arkansas

Pratibha A. Dabholkar
The University of Tennessee

and

Julie J. Gentry
The University of Arkansas

Market-oriented organizations often segment the markets and differentiate products and services to create and retain satisfied customers and surpass the competition. Scholarly work in this area suggests that market-oriented firms: (1) put the customer first;[1] (2) generate, disseminate, and respond to market intelligence;[2] and, (3) have the capability to use their resources to produce premium customer value.[3] A market orientation is critical to business performance, and one would expect superior performance from firms that also adopt market-oriented supply chain management. Such an approach requires the cooperation of various members of the supply chain in order to deliver products and services of superior value as determined by the end customer, while minimizing total costs across the functions of procurement, transformation of materials into intermediate and finished products, and storage and distribution of the various products to end customers.

Companies that can engage in market segmentation and product customization while maintaining reasonable cost levels are expected to have exemplary profitability and market share.[4] Product customization, demand function modification, and market segmentation may entail changes in physical or nonphysical product characteristics.[5] When these market oriented strategies involve changes in physical product characteristics, new options or versions of the product may be offered to customers. These often increase inventory carrying costs and transportation costs[6] which further accentuates the importance of a supply chain management approach.

Although there have been substantive advances in research in the area of supply chain management, several subjects remain unexplored. There is limited literature, for example, on the tradeoffs between market-oriented strategies, supply chain costs, and innovative solutions to surmounting those costs. Day provides a framework for this through what he classifies as a spanning process

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capability (i.e., coordination of external and internal emphases).[7] He gives as an example a company that used a rigid manufacturing process designed for repetitive production with low variety. The firm recognized the changing market requirements (Day referred to this as an outside-in process) that demanded custom production, reconsidered its existing production process (inside-out process), and looked for ways to make it more flexible. A discussion of spanning process capabilities apropos of inside-out and outside-in processes can be found in Day.[8]

We investigate the concept of market-oriented supply chain strategies that result in a wider variety of product options/versions (outside-in processes) and internal capabilities (inside-out processes) to provide cost effective coordination of functional activities (spanning processes) in order to meet external demand. We focus on the relationship between postponement and product customization.[9] Postponement can be viewed as a competency or capability in an inside-out process and product customization can result from a competency in an outside-in process. We also investigate the coordination of these as one aspect of effective supply chain management. It is demonstrated that postponement may be a meaningful and innovative approach for facilitating market-oriented supply chain management.

We begin with the constructs of product customization and postponement. We then extend the latter (originally introduced by Alderson[10]) to include production postponement, up/downstream postponement, and distribution postponement. This expanded concept encompasses different strategies along the total supply chain that may be employed to meet customer demands while controlling costs. Next, we discuss the relationship between product customization and postponement and its potential for developing alternative market-oriented supply chain management strategies. Finally, we provide deductive mathematical models to illustrate the relationship between postponement and product customization. Extensive graphical illustrations extend the model's usefulness. The mathematical proofs are given in the appendix; they are not necessary for a complete understanding of this research but are provided for further evidence and support of the logic.

CONCEPTUAL DEVELOPMENT

Product Customization

The extension of options and characteristics of a product is referred to as product customization.[11] If a product has only one possible configuration, it cannot be customized, if there are many possible configurations, then the product has high customization potential. Henry Ford's first automobile could not be customized, whereas General Motor's newest minivan has high product customization because there are many possible configurations, depending on customer choice/selection.

Kotha discusses the benefits and costs associated with mass customization based on a case study of the National Bicycle Industrial Company[12]. He describes mass customization and compares it to mass production on the basis of its focus, goal, features, product characteristics, and organizational structure. He also outlines conditions that increase the probability of successful implementation of

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mass customization in terms of the following: (1) industry and competitive conditions, (2) culture and organizational design, (3) resources and capabilities, and (4) inter- and intra-organizational coordination.

Historical Perspective of Postponement

To offer high product customization without incurring immense costs, as first recommended by Alderson in 1950, producers should add options or make differentiating changes to the product close to the time of purchase by the end-use customer. The approach is referred to as postponement, that is, the extent to which production and distribution are delayed.[13] For example, suppose that a product requires fifty steps in manufacturing and assembly. If a company builds the product up to the 40th step and then puts it in inventory until a customer places an order, then the company is using postponement; it is postponing ten steps in production. If the company makes its end products to inventory, then it is not using postponement in production. If the company does absolutely no manufacturing or assembly until a customer order is received, then it is exercising the highest possible level of postponement.

Alderson's concept of postponement was visionary for its time and has broad applications to business. Alderson recognized that offering product options to customers was inherently beneficial because it allowed a company to meet customer needs more closely. He argued that by postponing a necessary stage to produce different final versions of the product, costs would be reduced. However, he did not address other issues associated with postponing such as the potential of losing customers or the impact postponement has on various costs.

When a firm postpones, customers may have to wait longer for the product and may switch to a competitor's product. Also, there is greater risk of not being able to fulfill a customer's order at the time quoted. For example, if products are held in a warehouse instead of a retail outlet and weather makes transportation impossible, certain customer orders may be delayed. Furthermore, every step in production and distribution has a probability distribution representing the time that step takes. All the variances of these steps accumulate the further production and distribution is postponed.[14] Consequently, without effective supply chain management, the more postponement is used, the less certain is the quoted delivery date, an outcome of some annoyance to a number of customers.

In 1965, Bucklin's rigorous analysis of postponement made it a more useful concept.[15] Bucklin viewed postponement as a means by which a supplier may shift risk to the buyer. He made a distinction between postponement and speculation; postponement involves delaying value-adding activities until a customer order is received, and speculation involves adding value before the order is received. In accord with that perspective, we view postponement as a continuum, with speculation defined as zero postponement. Our analysis below differs from Bucklin's in that it does not focus on the risk aspect of postponement; instead we examine the strategic aspects and the relationship between postponement strategies and product customization as well as the associated costs. This allows

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us to focus on issues related to market-oriented supply chain strategies that may enhance the ability to create superior customer value.

After 1965, little was written on postponement until 1988, when Zinn and Bowersox presented a framework to suggest conditions in which postponement is justified.[16] The most important of these conditions are (1) high unit value of the product, (2) high sales fluctuations in the industry, (3) a company with a large number of distribution warehouses, and (4) a company that offers several versions of the product (i.e., high product customization). In this article we examine an alternative way to study the issue. We develop a model that suggests an optimum level of postponement given other conditions, such as a planned level of product customization or throughput time (i.e., time that the product is in production).

Value of Postponement

Postponement allows a company to be flexible in developing different versions of the product as needed, to meet changing customer needs, and to differentiate a product or to modify a demand function. For example, Benetton's innovative postponement strategy allows product customization to be economically maximized. In the clothing industry, traditionally the yarn is first dyed and then knitted into garments, which is a lengthy process; Benetton first knits garments using bleached yarn and postpones dyeing until a latter step of production.[17] Before postponement was used, there were always too many garments in colors customers did not want, whereas colors in demand were always sold out. The new strategy allows Benetton to be extremely responsive to rapid changes in customer demand for different colors in clothing. It also permits higher customer service levels. Benetton's market-oriented supply chain management is illustrated through the ability to adapt internal processes to create superior customer value based on information about customer demand generated at the store level.

Postponement can be extended further upstream in the supply chain to suppliers of components and raw materials, or downstream in the delaying of transportation costs, warehousing and storage costs. According to Alderson's definition, postponement also can be used in distribution if the company delays transporting the finished product to the retail store until the order is received. Whirlpool uses postponement in its downstream supply chain by delaying the shipping of a product to a Sears distribution center until a customer order is received (with the exception of the floor display models).[18] Prior to this, large inventories of appliances were maintained in store locations. Marketing research revealed that most customers did not want the appliances the same day they purchased them—they were willing to wait several days. In many cases, the purchase was for a new home that was not yet ready for appliance installation. The ability to postpone distribution resulted in significant savings inventory and transportation costs. Whereas Whirlpool used information about customer needs to reduce inventory and transportation costs, Benetton used information to reduce inventory and stockout costs and to improve customer service. Both examples illustrate the value of a market-oriented supply chain management.

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Differentiating Features of Postponement

Although postponement allows a company greater flexibility, it differs from JIT and flexible manufacturing in several ways, as shown in Figure 1. Many companies are now implementing JIT to reduce inventory costs and improve quality,[19] and several empirical studies have found evidence that JIT does improve quality.[20] Firms employing JIT hold only enough inventory to satisfy immediate demand. Therefore, JIT often results in postponement, to some extent, because it entails using demand to "pull" production, as opposed to the traditional approach of "pushing" production based upon demand forecasts. Nevertheless, it is possible to use postponement and not use JIT. For example, a retail firm that keeps only displays in its outlets and holds many months of inventory in its warehouses is employing postponement but not JIT because of the large amounts of inventory. Similarly, it is possible to use JIT without postponement as when products are made to inventory but only in anticipation of daily demand. Toyota automobile manufacturing is an example of this strategy.

FIGURE 1

COMPARISON OF APPROACHES TO FLEXIBILITY

	Postponement	**Just In Time**	**Flexible Manufacturing Systems**
Concept	Delay Strategy	Material Flow System	Flexible Automation
Information System Investment Required	low	low	high
Enhancement of Flexibility	varies	low	high
Requires Level Demand	no	yes	no
Relative % Technical Employees Required	low	low	high
Opposite Strategy	Speculation	Make to Inventory	Dedicated Equipment

Postponement also differs from flexible manufacturing systems.[21] The latter involve programmable automation that allows for greater flexibility than the dedicated equipment typical of most repetitive manufacturing environments. Although such systems result in more flexibility, they are extremely expensive and require months or years to become fully operational. Consequently, their adoption continues to be slow. The use of postponement in the supply chain may be an appropriate and inexpensive alternative. This will be illustrated in several examples throughout this article.

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Extending the Concept of Postponement

Our typology of postponement builds on the work of Zinn and Bowersox, in particular (viz., (1) form postponement in labeling, packaging, assembly, and manufacturing, and (2) time postponement), by incorporating strategies that involve other companies in the supply chain.[22] Typically, discussions of postponement in the literature refer to delaying production, where production may include manufacturing, assembly, packaging, and labeling. Any of these steps can be postponed if customers have a range of needs in this product type. We recognize that *production postponement* can be an important market-oriented supply chain strategy and is used by many firms. We propose, however, that postponement also may occur at other stages and involve different supply chain members. Such strategies include upstream postponement, downstream postponement, and distribution postponement.

Upstream postponement extends up the supply chain. Manufacturers can wait to order raw materials from suppliers until they receive customer orders. This is likely for job shops that use expensive raw materials, such as companies that make highly specialized industrial ultrasonic transducers. A primary component of the piezoelectric element, which is expensive and fragile and comes in many different sizes, and shapes, and frequencies. Upstream postponement would be likely for certain project-oriented firms, such as builders of nuclear reactors. Most of the critical components in nuclear reactors have exacting specifications that result in very high costs, which makes them too expensive to hold as inventory.

Postponement also may include value-adding activities from supply chain members closer to the end-use customer. *Downstream postponement* delays some sort of physical change to the product after it leaves the primary manufacturing stage, such as further processing, adding features, mixing and sorting, or performing some other value-adding function to the product *for a specific supply chain.* The key difference between production postponement and up or downstream postponement is the degree of coordination and strategic management among firms in the supply chain and the unique customer service requirements of individual supply chains.

Further postponement may occur after the product has all value-added features and is in the form in which it will remain until the end-user takes possession. The simplest type is distribution or place postponement.[23] The manufacturer waits to ship the product until the order is received. Although such postponement does not affect product customization, it influences inventory carrying and transportation costs. In case of the Sears/Whirlpool, transportation savings were achieved primarily because fewer transshipments were necessary. That is, before postponement there were times when some Sears warehouses needed inventory from others. By postponing distribution to warehouses until orders were received, transshipments could be eliminated, which resulted in savings in transportation.

The Relationship Between Product Customization and Postponement

Decisions concerning product customization and postponement are related, but they are still separate. It is possible for a company to choose high product customization but very little postponement within the supply chain. For example, suppliers of car stereos produce a wide variety of models and

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options and hold them in inventory in anticipation of demand. Occasionally, they may not have a particular stereo that a customer wants, but usually they can fill most orders from inventory.

The opposite strategy is no product customization but the highest level of postponement. This is the case for a company that offers only one product with no variations and does not manufacture or assemble it until an order is received. French nuclear reactors are an example. In the United States, many different types of nuclear reactors can be produced, but in France they are standardized and they are not produced until an order is received.

Our focus is on the relationship between product customization and postponement in order to emphasize the inside-out and outside-in spanning processes that are necessary in order to implement a successful market-oriented supply chain strategy. The managers we interviewed knew intuitively that there is a relationship but admitted they did not understand it well enough to incorporate it into their decision making. This enigma served as the primary impetus for the research. To approach the problem, we developed the concept of product customization and extended the concept of postponement to incorporate the various approaches that businesses use in manufacturing and distribution. We then investigated the relationship between product customization and postponement in order to determine how various conditions affect optimal postponement strategies. This third element is of primary interest because it involves theoretical constructs that represent possible results of outside-in and inside-out processes as well as their coordination in developing alternative strategies for market-oriented supply chain management.

MODELING ALTERNATIVE STRATEGIES FOR MARKET-ORIENTED SUPPLY CHAIN MANAGEMENT

Operational Definition of Postponement

To model optimal postponement within a market-oriented supply chain, a more concise definition is necessary. We measure postponement as the number of stages of production and distribution that are delayed until the order is received. These stages include everything that occurs before the customer takes possession. Other definitions could be used but might lead the discussion in a different direction. For example, if postponement is defined as the length of time between order placement and customer receipt. The result would be a tautology in a later section, where we discuss the effects of decreased cycle time in manufacturing on postponement strategies. If the time-oriented definition is used, by definition a decrease in manufacturing cycle time automatically decreases postponement. The "stages" definition of postponement circumvents such a tautology.

Postponement Strategies and Costs

Articles that discuss costs associated with postponement include the work of Bucklin,[24] Zinn and Bowersox,[25] and Zinn.[26] Bucklin categorized costs into those incurred by the supplier and those incurred by the buyer.[27] Supplier costs include inventory, transportation, handling, uncertainty, and

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marketing expenses associated with the use of an intermediary. Buyer costs result from holding inventory and stockouts. Taken together, these costs determine whether postponement will occur in the supply chain. Bucklin provides a clear explanation of the tradeoffs affecting whether postponement will be used. We build on Bucklin's work by addressing many of the same costs but investigating how extensively postponement will be used given various conditions, such as degree of product customization and speed of production. The results not only are useful from a theoretical perspective but also serve as heuristics for successful market-oriented supply chain management.

Zinn and Bowersox categorize costs associated with postponement into inventory carrying costs, processing costs, transportation costs, and the cost of lost sales,[28] and Zinn suggests ways to determine safety stock levels for a postponement strategy.[29] According to Zinn and Bowersox, inventory carrying costs decline, and the costs of processing and lost sales rise when there is postponement. We agree that carrying partially finished goods (rather than finished) and shipping unassembled units (rather than assembled) will reduce inventory carrying costs and transportation costs, although the latter could increase due to potential smaller shipment sizes and the need for expedited shipments. As such, we will not consider transportation costs in our models since these would have to be investigated with respect to the specific product and transport characteristics unique to each supply chain.

Processing costs will only be higher in a traditional manufacturing setup that achieves economies of scale.[30] In the newer flexible factories with modules that can come together as needed to assemble and manufacture products,[31] or with a computerized design and manufacturing setup, processing costs will not necessarily be higher with postponement. Furthermore in the Zinn and Bowersox framework, the cost of lost sales is defined as mean sales lost due to an increase in delivery time, but sales also can be lost because a company does not offer a sufficient level of product customization. If the company increases delivery time because it offers more options, it is not easy to predict how sales will react. Therefore, we refer to these as costs associated with increased delivery time rather than lost sales. In other words, we examine the effect of postponement and product customization on inventory carrying costs and costs associated with increased delivery time. The usual premise is that the primary goal of supply chain management is to meet customer service objectives while simultaneously minimizing inventory and associated logistics costs.[32]

Inventory Holding Costs

It is less expensive to hold components and raw materials than it is to hold finished products because the latter contain more labor and material inputs. Therefore, for a given level of product customization, as postponement increases, inventory holding costs decrease as shown in Figure 2. The nature of the relationship is explained as follows. The beginning of the supply chain is the point at which the product is first produced and distributed. As the product is developed throughout the supply chain, it picks up more and more labor and manufacturing content, even if no more components are added. Thus, inventory carrying costs are higher toward the end of the supply chain than at the beginning.[33] Consequently, the marginal benefit of postponing a step at the end of the supply

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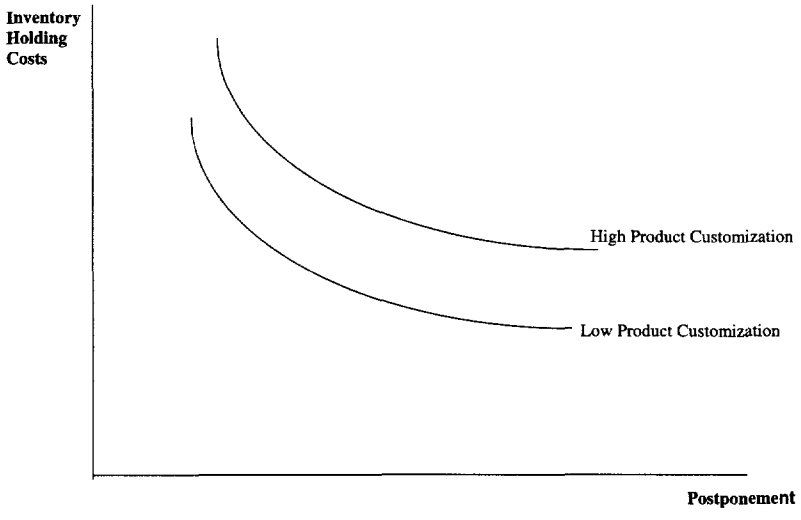
chain is greater than the marginal benefit of postponing a step at the beginning. This implies that inventory carrying costs decline at a decreasing rate the more extensively postponement is used.

FIGURE 2

EFFECT OF POSTPONEMENT AND PRODUCT CUSTOMIZATION ON INVENTORY HOLDING COSTS



Note: Higher levels of postponement lead to lower inventory holding costs. For a given level of postponement, however, higher levels of product customization lead to higher inventory holding costs.

EFFECT OF PRODUCT CUSTOMIZATION ON INVENTORY HOLDING COSTS.

For a given level of postponement, if product customization increases, inventory holding costs will increase (see Figure 2). This happens because when customers are allowed more options, a wider variety of components and raw materials must be purchased, held, and transported and a wider variety of products must be manufactured, held, and transported.

Costs Associated with Delivery Lead Time

For a given level of product customization, higher levels of postponement lead to higher costs attributable to the longer lead times as shown in Figure 3. When customers must wait for a product, a certain number of them will turn to a competitor. Also customers are willing to pay less for a product due to the longer wait. It is assumed that the relationship between lead time costs and post-

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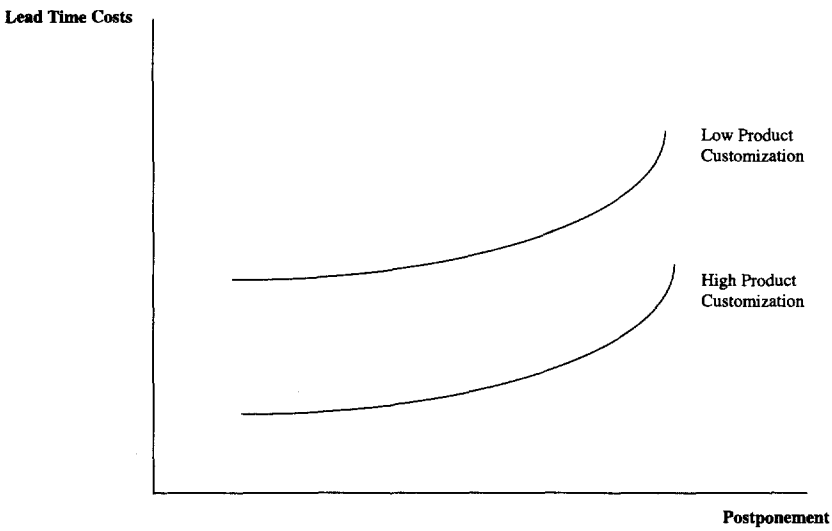
ponement is convex; if a company postpones too long, it will eventually lose all its customers, making the opportunity cost extremely high (see Figure 3). Alternatively, customers will not be willing to pay anything if they have to wait too long. An exception would be a monopolistic supplier, whose customers have no choice but to wait.

FIGURE 3

EFFECT OF POSTPONEMENT AND PRODUCT CUSTOMIZATION ON LEAD TIME COSTS



Note: Higher levels of postponement have higher lead time costs. For a given level of postponement, however, higher levels of product customization are associated with lower lead time costs.

If customers are given more product customization, then they may be willing to wait without switching to a competitor. Therefore, for a given level of postponement, increasing product customization reduces costs associated with lead time (see Figure 3). This reasoning is based on the assumption that customers are willing to sacrifice certain benefits such as short waiting time (i.e., less postponement)—for more options (i.e., higher product customization). Little research has been conducted on this issue, but a recent study examines the relationship between service delays and the customer's perception of service.[34] With regard to delays in airline flight service, Taylor found that if customers perceive delays as preventable (or under the control of the service provider), then they are more likely to feel angry. Our assumption about the relationship between postponement and lead

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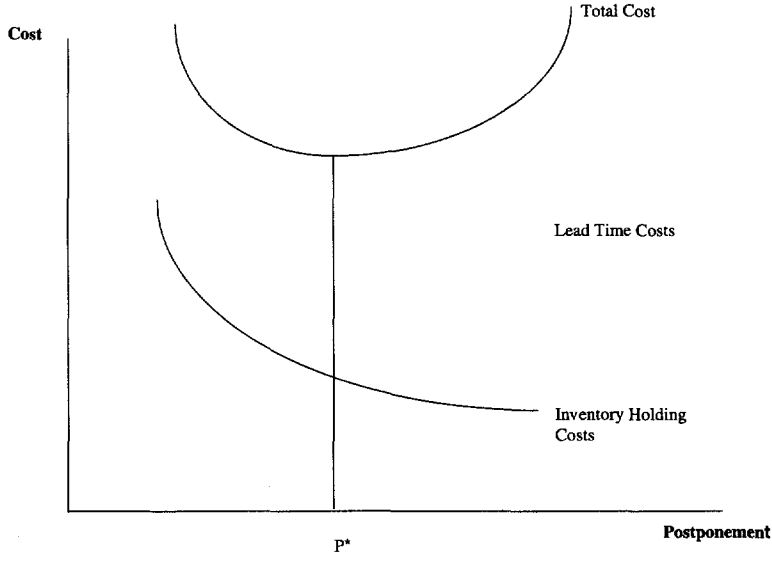
time costs is similar, but this has yet to be substantiated empirically. Nevertheless, it is intuitively appealing.

Adding the lead time cost function to the inventory carrying cost function gives total cost as a function of various levels of postponement within the supply chain as shown in Figure 4 which holds for a given level of product customization.

FIGURE 4

OPTIMAL POSTPONEMENT



Note: The optimal level of postponement is the sum of lead time costs and inventory holding

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Based on the preceding discussion, several propositions are developed below to investigate the relationship of postponement with product customization and various relevant costs. Optimal coordination of postponement with product customization would be characteristic of market-oriented supply chains. In applying propositions 1 through 3, the types of postponement the supply chain should use will depend on the options available to the various firms from which it is configured.

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Optimal Postponement though an Outside-In Process

Propositions 1 through 3 examine coordinative strategies relating postponement to product customization using an outside-in process. In other words, the supply chain leader assumes a level of product customization based on market needs and then determines optimal postponement by examining the associated costs within various supply chain configurations.

P1: For a given level of product customization, there exists an optimal level of postponement at which total costs are minimized. (See the Appendix for a mathematical proof.)

Proposition 1 is illustrated in Figure 4. A decrease in inventory holding costs is associated with an increase in costs associated with lead time, such that for a certain level of postponement, the marginal cost associated with delivery lead time is equal to the marginal benefit of lower inventory holding costs. This implies that there is some optimal level of postponement, given various costs. Market sensing and customer linking capabilities allow the firm to select a level of product customization. Supply chain management capabilities direct and coordinate various functions toward the optimal level of postponement. Inside-out capabilities allow the firm to respond by implementing the optimal level of postponement. Thus, with market-oriented supply chain management strategies, firms can select a high level of product customization (if necessary to meet customer needs) and do so in a cost feasible way by determining the optimal level of postponement for that product customization.

P2: The optimal level of postponement is positively related to the level of product customization. (See the Appendix for a mathematical proof.)

Proposition 2 is illustrated in Figure 5. An increase in product customization has two effects. First, it causes the lead time cost curve to shift downward because customers are given more product customization. Second, it causes the inventory holding cost curve to shift upward because higher levels of product customization increase overall inventory levels due to the greater variety. This causes the intersection of these two cost curves to shift to the right. The optimal level of postponement corresponds to this intersection.

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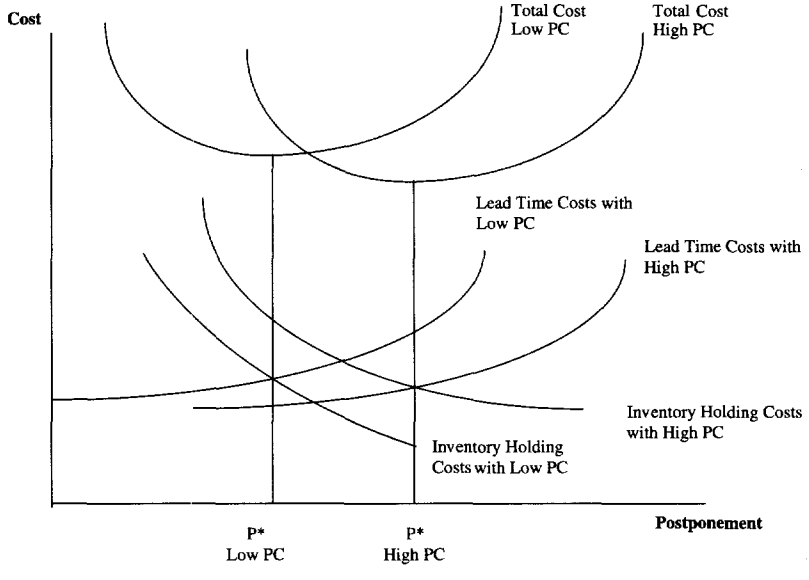
FIGURE 5

OPTIMAL POSTPONEMENT AND PRODUCT CUSTOMIZATION (PC): TOTAL COST DECREASE



Note: The optimal level of postponement is positively related to the level of product customization.

Proposition 2 suggests that more extensive postponement in the supply chain will be observed in firms that use advances in product customization to create superior customer value. This can only be expected in firms with distinct competencies in supply chain management, however many firms will not be capable of interfirm coordination necessary to implement these changes.

P3: The change in total cost at the optimal level of postponement is indeterminate when the level of product customization changes. (See the Appendix for a mathematical proof.)

Proposition 3 is illustrated by comparing Figures 5 and 6. If the magnitude of the increase in the inventory holding cost curve due to the increased product customization is greater than the magnitude of the decrease in the lead time cost curve, then total costs will increase (see Figure 6). If the reverse is true, then total costs will decrease (see Figure 5).

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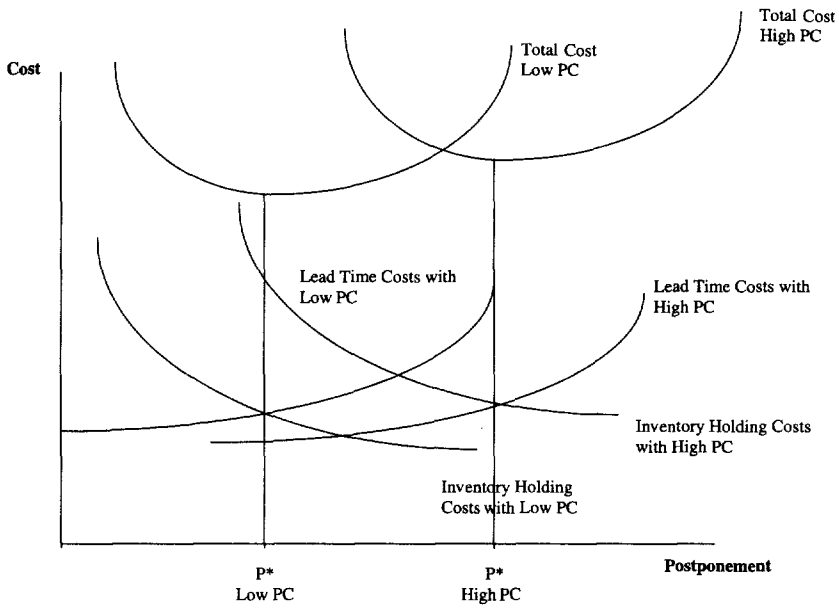
FIGURE 6

OPTIMAL POSTPONEMENT AND PRODUCT CUSTOMIZATION (PC): TOTAL COST INCREASE



Note: The optimal level of postponement is positively related to the level of product customization.

A marketing strategy may entail increasing product customization. This proposition suggests it should not be assumed that costs will definitely increase as a result. Greater product customization may allow the firm to increase postponement to such an extent that total supply chain costs decrease.

Optimal Postponement through an Inside-Out Process

Speed of production has been taken as a constant up to this point, but many firms attempting to reengineer their business processes are reducing their manufacturing cycle time.[35] Propositions 4 and 5 below examine market-oriented supply chain management using an inside-out process. In other words, the focus is on how improvements in manufacturing cycle time are related to postponement and product customization strategies.

The ability to reduce cycle time in manufacturing is an inside-out process capability that can only enhance a firm's marketing effectiveness if it is coordinated with various outside-in processes. Speed of production is an important variable that can affect costs associated with postponement.

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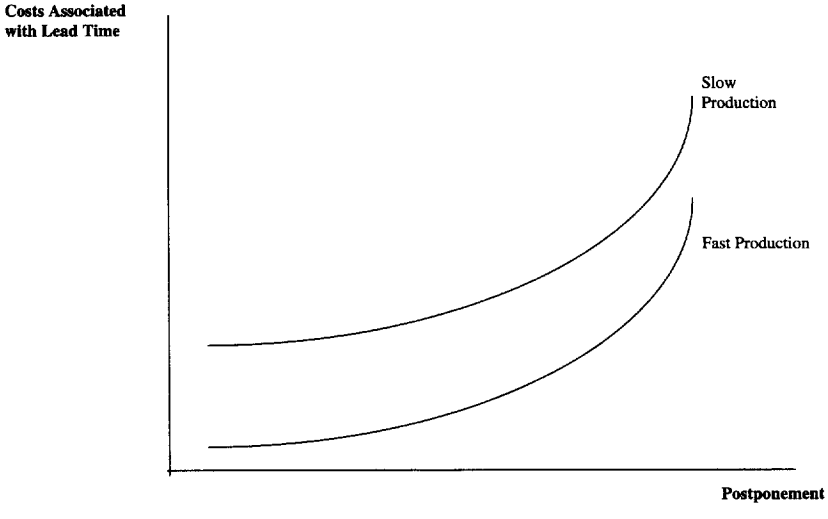
Figure 7 illustrates that, for a given level of postponement, faster production will lower costs associated with lead time. This is because customers will not have to wait as long, even though postponement may not have changed. Figure 8 illustrates that, for a given level of postponement, faster production will lower inventory holding costs. The less time raw material, components, sub assemblies, and finished products stay in the supply chain, the lower are total inventory holding costs.

FIGURE 7

EFFECT OF SPEED OF PRODUCTION AND POSTPONEMENT ON COST ASSOCIATED WITH LEAD TIME



Note: For a given level of postponement, faster production is associated with lower lead time costs.

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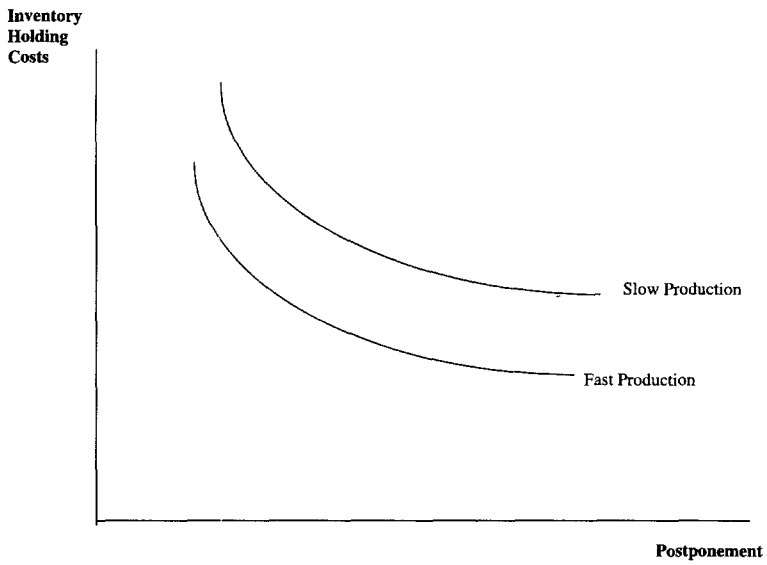
FIGURE 8

EFFECT OF SPEED OF PRODUCTION AND POSTPONEMENT ON INVENTORY HOLDING COSTS



Note: For a given level of postponement, faster production leads to lower inventory holding costs.

P4: An increase in the speed of production will decrease total costs. (See the Appendix for a mathematical proof.)

Proposition 4 is illustrated in Figure 9. The proposition is true because, unlike a change in product customization, an increase in the speed of production decreases both the inventory holding and lead time cost curves. From the viewpoint of market-oriented supply chain management, the more quickly the firm can get the material from production to the customer, the lower are expenses associated with inventory. Customers are not aware of the extent of postponement in terms of the number of steps of production, but they are aware of its effects on lead time. From their perspective, shorter lead time is an improvement in the value associated with a company's product offering. Thus, a cost-oriented "internal" process can lead to a market-oriented "external" process.

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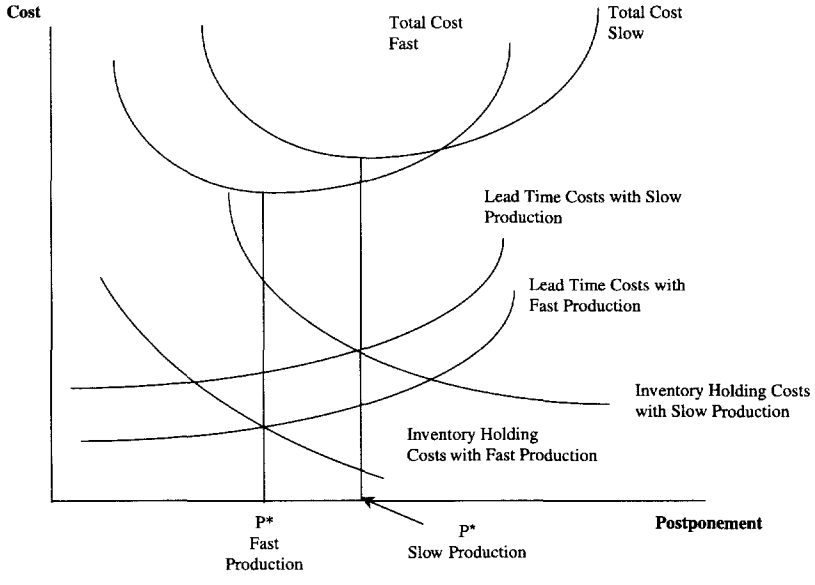
FIGURE 9

REDUCTION IN TOTAL COST AND DECREASE IN OPTIMAL LEVEL OF POSTPONEMENT



Note: An increase in speed of production reduces total cost and reduces optimal level of postponement.

Despite the benefits of reducing throughput time, there are costs associated with greater speed of production. Production speed can be increased by purchasing faster equipment, reducing setups, and rationalizing factory layout. Furthermore, distribution speed can be increased by changing the mode of transportation (e.g., switching from rail to motor carriage), but faster modes have higher costs per ton-mile. Thus, firms will have to trade off these one-time production costs or on-going distribution costs against cost reductions due to faster production/distribution speed. In this section, costs or cost savings take into consideration direct costs associated with increasing the speed of production or distribution.

The relationship between speed of production and product customization, although not precise, can be bi-directional. Faster production can reduce costs sufficiently to allow firms to offer greater product customization. In some situations, however, decreasing product customization can increase speed of production because the processes can be streamlined with standard procedures, moving more toward the assembly line than job shop mode. For example, in the automobile industry, different options require different assembly procedures and components. If only one option is available, the assem-

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bly procedures often can be automated, increasing the speed. Yet, this will only be true in special cases. There are many situations in which greater or lesser product customization will have no effect on production pace. For example, a personal computer may be available with Microsoft Word or WordPerfect preloaded on the hard drive. Since both take about the same amount of time to load, decreasing product customization by making only WordPerfect available will not speed up production. Similarly, offering one more alternative word processing package will not decrease production speed. These examples illuminate why market-oriented supply chain management requires an understanding of a company's internal processes. To coordinate outside-in processes with inside-out processes, the implications of changes in one must be understood in order for the other to be managed.

P5: An increase in the speed of production may increase or decrease the optimal level of postponement. (See the Appendix for a mathematical proof.)

Proposition 5 is illustrated by comparing Figures 9 and 10, which illustrate that increasing the speed of production reduces total cost but has an indeterminate effect on the optimal level of postponement. If the magnitude of the decrease in inventory holding costs is greater than the magnitude of the decrease in lead time costs, then the optimal level of postponement will decrease with an increase in the speed of production (see Figure 9). This is most likely when the costs added in production are extremely high. In a sense, production speed substitutes for postponement in this situation. If the reverse is true, then the optimal level of postponement will increase. A salient implication is that, just because production speed increases, postponement should not necessarily be used more extensively. Specifically, Figure 9 illustrates that when the magnitude of the decrease in inventory holding costs overcomes the effects of the decrease in lead time costs, the optimal level of postponement declines. Figure 10 shows that when the magnitude of the decrease in lead time costs overcomes the decrease in inventory holding costs, the optimal level of postponement raises. To understand why a situation similar to that illustrated in Figure 10 might occur, consider the case in which production speed increases so much that the customer does not notice additional postponement. In fact, from the customer's perspective, delivery occurs sooner than it would have otherwise.

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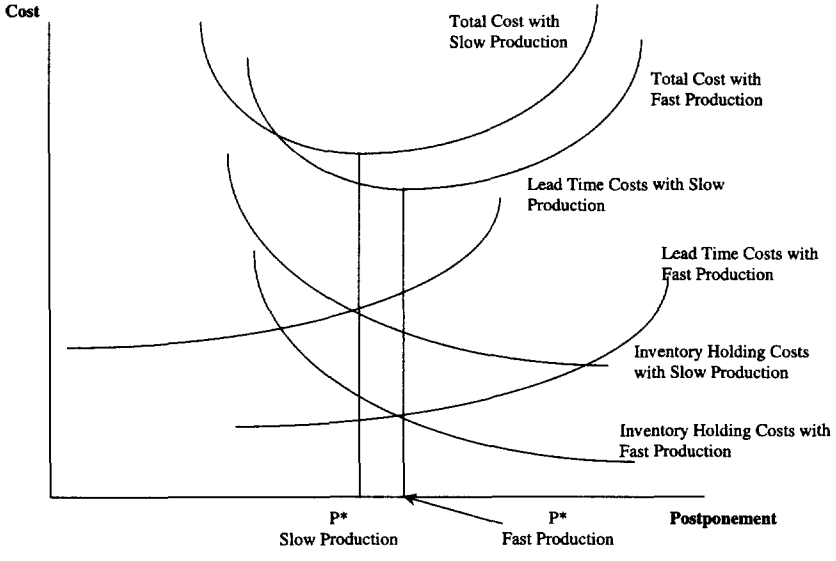
FIGURE 10

REDUCTION IN TOTAL COST AND INCREASE IN OPTIMAL LEVEL OF POSTPONEMENT



Note: Here an increase in speed of production reduces total cost and increases the optimal level of postponement.

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FIGURE 11

SUMMARY OF CONDITIONS, EFFECTS, AND DRIVERS

	Affected Area	
Condition	**Optiomal Level of Postposement**	**Inventory Holding Cost plus Lead Time Costs**
Increasing Level of Product Customization	Increases	Indeterminate[a]
Increasing the Speed of Production and Distribution	Indeterminate[b]	Determinate

Note: The conditions that lead to intermediate effects have drivers that may make them increase or decrease.
[a]Driver: If the magnitude of the increase in the inventory holding cost curve due to the increased product customization is greater than the magnitude of the decrease in the lead time cost curve, then total costs will increase. If the reverse is true, then total costs will decrease.

[b]Driver: If the magnitude of the decrease in inventory holding costs is greater than the magnitude of the decrease in lead time costs, then the optima level of postponement will decrease with an increase in the speed of production. If the reverse is true, then the optimal level of postponement will increase.

SUMMARY AND CONCLUSIONS

The results of the propositions are summarized in Figure 11, which reveals the effects of changing conditions. These conditions include product customization and speed of production and distribution. The optimal level of postponement and changes in total cost are the areas summarized. For indeterminate effects, the drivers are discussed in the note to the figure.

Day and Wensley suggest that competitive advantage arises from a combination of superior customer value and lower costs relative to the competition.[36] Using postponement to provide product customization may help achieve that end. Postponement helps manage costs and product customization allows customers to get more precisely what they want. Thus, using both can be a market-oriented supply chain strategy to gain competitive advantage.

In terms of theory development, this research examines the construct of postponement, differentiates it from similar concepts, and extends it to include different types of postponement within the supply chain: production, down/upstream, and distribution postponement. We show that although product customization and postponement are separate decisions, they should be made with respect to each other (market-oriented supply chain management).

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Management Implications

Important implications for supply chain management in market-oriented organizations can be derived from our study which illustrates that the impetus for changes in the level of postponement can come from changes in external as well as internal processes. A firm with a distinctive competency in market sensing may discover it should increase product customization. If that firm has a distinct supply chain management capability, then it can coordinate appropriate changes in postponement with various members of the chain.

A firm with a distinctive competency in manufacturing processes may discover ways to increase speed of production. If that firm embraces a supply chain management approach, it can coordinate appropriate changes in postponement. For example, it could decrease postponement (if that were optimal) and pass the benefit on to customers through faster delivery. Or it could increase postponement (if that were optimal), in which case, customers might not perceive a delay (due to the time savings achieved by faster production), and the company could save money.

The company may also elect to increase product customization rather than change the level of postponement, since faster production makes any level of customization less expensive. Greater customization might be desirable but too costly without an increase in speed of production. Another example of an inside-out process would be a move to a flexible manufacturing process to increase product customization. Many managers regard standardization and flexibility as tradeoffs.[37] As a result, they view postponement and high product customization as expensive. Yet, it is possible and ideal to have both standardization and flexibility so that the company can build a variety of products from a small number of standardized parts to match customer needs more closely. Of course, any product modifications should be considered carefully with respect to market demand and present and future moves by competitors.

Research Directions

We provide a framework for future investigation of market-oriented supply chain management. Our approach is primarily deductive theoretical modeling,[38] which provides a basis for more inductive empirical research concerning postponement, product customization, and time-based competition. The use of both deductive and inductive approaches will provide greater assurance that results will not be method-related.[39]

Empirical research has shown a positive relationship between market orientation and performance,[40] but more work is needed on market-oriented supply chain management. Several research questions need to be investigated. For example, do firms with distinctive market-oriented supply chain management competencies perform better than firms that are just market oriented? Do firms that are competent not only in terms of outside-in and inside-out processes, but also in supply chain management capabilities (i.e., spanning process capability) perform better and provide greater customer value? What *type* of competency allows a firm an advantage in translating market and competitive information into changes in product customization?

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There are several issues to be researched regarding the effects of various types of postponement on different supply chain relationships. What effects does upstream postponement have on supplier relationships? What effects does distribution postponement have on customers and distributors? Feitzinger and Lee note that "clashing priorities make it hard to create the most efficient supply network." [41]

Finally, this article raises a critical question regarding the strategic tradeoff between product customization and cost minimization. Does the use of both postponement and product customization allow firms to overcome this classic tradeoff? Market strategists consistently suggest that organizations must choose among the three divergent strategies of product customization, cost minimization, and concentration (i.e., focus on a few customers, markets, or products). They further suggest that it is very difficult, if not impossible, to succeed at more than one of these strategies at a time.[42] Empirical research supports this thinking and shows that firms which select one of these three strategies are more likely to be successful than those which try to combine two or more strategies.[43] Yet, we show that if a firm has superior spanning process capabilities and develops a distinctive competency in applying postponement, along with a continuous drive toward shorter cycle times, then it can engage in more extensive product customization. Future researchers can use this framework as a starting point to reexamine the issue of the strategic tradeoffs between product customization and cost minimization with regard to market-oriented supply chain management. Specifically, firms will have to trade-off one-time production costs or on-going distribution costs against cost reductions due to increased product/distribution speeds. Therefore, at this point we must be cautious about deducing that cost minimization and customization can be achieved simultaneously.

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APPPENDIX

PROOFS OF THE PROPOSITIONS

Let Ci be the inventory holding cost as a function of postponement, C_L be the cost associated with lead time as a function of postponement, $C_T = C_i + C_L$ be the total cost, and p be the level of postponement. Then based on the discussion $\partial C_i/p < 0$, and $\partial C_L/\partial p > 0$. In the paper, it was argued that the marginal benefit of postponing one more day at the end of the supply chain is greater than the marginal benefit of postponing one more day at the beginning of the supply chain. In mathematical notation this relationship is described as $\partial C_i^2/\partial^2 p > 0$. Taken together, $\partial C_i/\partial p < 0$ and $\partial C_i^2/\partial^2 p > 0$ suggests the inventory carrying costs decrease at a decreasing rate the more extensively postponement is used.

As contended in the paper, it is assumed that $\partial C_L^2/\partial^2 p > 0$ because if a company postpones too long, they will eventually lose all of their customers, making the opportunity cost extremely high.

Proof of Proposition 1

$C_T = C_i + C_L$ is total cost as a function of postponement.

The first order condition for the optimal solution is

$\partial C_T/\partial p = 0,$

$\partial C_i/\partial p + \partial C_L/\partial p = 0,$

$-\partial C_i/\partial p = \partial C_L/\partial p.$

$\partial C_L/\partial p$ is the marginal cost associated with delivery lead time, and $-\partial C_i/\partial p$ is the marginal benefit associated with lower inventory holding costs.

The second order condition is

$\partial C_T^2/\partial^2 p > 0$

$\partial C_i^2/\partial^2 p + \partial C_L^2/\partial^2 p > 0$

As discussed earlier $\partial C_i^2/\partial^2 p > 0$ and $\partial C_L^2/\partial^2 p > 0$.

Thus, there exists an optimal level of postponement where the total cost function is minimized (see Figure 4).

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Proof of Proposition 2

Proposition 1 showed that optimum postponement P* depended on C_L and C_i, i.e., $P^*(C_i, C_L)$. It has also been argued that C_i is a function of product customization (PC) and C_L is also a function of PC. Therefore, taking the total derivative of P*

$$\partial P^*/\partial(PC) = \{\partial P^*/\partial C_i \bullet dC_i/d(PC)\} + \{\partial P^*/\partial C_L \bullet dC_L/d(PC)\}.$$

To prove Proposition 2, it must be shown that $\partial P^*/\partial(PC) > 0$.

$\partial P^*/\partial C_i > 0$ because, ceteris paribus, if the cost of holding inventory increases, then higher levels of postponement will be optimal.

The argument for $dC_i/d(PC) > 0$ is the same argument for Figure 2—namely, higher levels of PC result in higher inventory holding costs due to increased variety. Thus, since $\partial P^*/\partial C_i > 0$ and $dC_i/d(PC) > 0$, it is true that

$$\{\partial P^*/\partial C_i \bullet dC_i/d(PC)\} > 0.$$

$\partial P^*/\partial C_L < 0$ because, if the lead time costs increase, lower levels of postponement will be preferred, other things being equal. The argument for $dC_L/d(PC) < 0$ is the same argument for Figure 3, namely, if customers are given more product customization, they may be willing to wait without switching to a competitor. Therefore,

$$\{\partial P^*/\partial C_L \bullet dC_L/d(PC)\} > 0.$$

Since $\{\partial P^*/\partial C_i \bullet dC_i/d(PC)\} > 0$ and $\{\partial P^*/\partial C_L \bullet dC_L/d(PC)\} > 0$, then $\partial P^*/\partial(PC) > 0$. This means the optimal level of postponement is positively related to the level of product customization.

Proof of Proposition 3

To prove this proposition it must be shown that $\partial C_T/\partial(PC)$ can be greater than, less than or equal to zero.

$$\partial C_T/\partial(PC) = \{\partial C_T/\partial C_i \bullet dC_i/d(PC)\} + \{\partial C_T/\partial C_L \bullet dC_L/d(PC)\}$$

Since $\partial C_T/\partial C_i = \partial(C_L + C_i)/\partial C_i$ and $\partial C_L/\partial C_i = 0$, and

$\partial C_T/\partial C_L = \partial(C_L + C_i)/\partial C_L$ and $\partial C_i/\partial C_L = 0$, therefore,

$$\{\partial C_T/\partial C_i \bullet dC_i/d(PC)\} + \{\partial C_T/\partial C_L \bullet dC_L/d(PC)\}$$

$$= \{\partial C_i/\partial C_i \bullet dC_i/d(PC)\} + \{\partial C_L/\partial C_L \bullet dC_L/d(PC)\}$$

$$= \{1 \bullet dC_i/d(PC)\} + \{1 \bullet dC_L/d(PC)\}$$

$$= dC_i/d(PC) + dC_L/d(PC)$$

As discussed above, $dC_i/d(PC) > 0$ and $dC_L/d(PC) < 0$, therefore,

$\partial C_T/\partial(PC) > 0$ if $|dC_i/d(PC)| > |dC_L/d(PC)|$,

$\partial C_T/\partial(PC) < 0$ if $|dC_i/d(PC)| < |dC_L/d(PC)|$,

and $\partial C_T/\partial(PC) = 0$ if $|dC_i/d(PC)| = |dC_L/d(PC)|$.

Thus, the change in total cost at the optimal level of postponement is indeterminate as product customization changes.

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Proof of Proposition 4

Let σ represent the speed of production. As explained in relation to Figure 7, for a given level of postponement, faster production will lower costs associated with lead time, $dC_L/d\sigma < 0$. This is due to the fact that customers will not have to wait as long, even though postponement may not have changed. Figure 8 and the corresponding discussion showed that for a given level of postponement, faster production will lower inventory holding costs, $dC_i/d\sigma < 0$. The less time raw material, components, sub assemblies, and finished products stay in the supply chain, the lower the total inventory holding costs.

To prove Proposition 4, it must be shown that $\partial C_T/\partial\sigma < 0$.

$\partial C_T/\partial\sigma = \{\partial C_T/\partial C_i \bullet dC_i/d\sigma\} + \{\partial C_T/\partial C_L \bullet dC_L/d\sigma\}$

Since $\partial C_T/\partial C_i = \partial(C_L + C_i)/\partial C_i$ and $\partial C_L/\partial C_i = 0$, and

$\partial C_T/\partial C_L = \partial(C_L + C_i)/\partial C_L$ and $\partial C_i/\partial C_L = 0$, therefore,

$\{\partial C_T/\partial C_i \bullet dC_i/d\sigma\} + \{\partial C_T/\partial C_L \bullet dC_L/d\sigma\} = \{1\ dC_i/d\sigma\} + \{1 \bullet dC_L/d\sigma\}$

As discussed above $dC_i/d\sigma < 0$ and $dC_L/d\sigma < 0$, therefore, $\partial C_T/\partial\sigma < 0$.

Therefore, an increase in the speed of production will decrease total costs.

Proof of Proposition 5

Taking the total derivative of P*

$\partial P^*/\partial\sigma = \{\partial P^*/\partial C_i \bullet dC_i/d\sigma\} + \{\partial P^*/\partial C_L \bullet dC_L/d\sigma\}$.

To prove this proposition it must be shown that $\partial P^*/\partial\sigma$ can be greater than, less than or equal to zero.

As explained in the proof of Proposition 2, $\partial P^*/\partial C_i > 0$. Also, as explained in the proof of Proposition 4, $dC_i/d\sigma < 0$. Therefore,

$\{\partial P^*/\partial C_i \bullet dC_i/d\sigma\} < 0$.

Similarly, $\partial P^*/\partial C_L < 0$ was shown in the proof of Proposition 2 and $dC_L/d\sigma < 0$ was discussed in the proof of Proposition 4. Therefore,

$\{\partial P^*/\partial C_L \bullet dC_L/d\sigma\} > 0$.

Therefore:

$\partial P^*/\partial\sigma > 0$ if $|\{\partial P^*/\partial C_L \bullet dC_L/d\sigma\}| > |\{\partial P^*/\partial C_i \bullet dC_i/d\sigma\}|$,

$\partial P^*\partial\sigma/ < 0$ if $|\{\partial P^*/\partial C_L \bullet dC_L/d\sigma\}| < |\{\partial P^*/\partial C_i \bullet dC_i/d\sigma\}|$,

and $\partial P^*/\partial\sigma = 0$ if $|\{\partial P^*/\partial C_L \bullet dC_L/d\sigma\}| = |\{\partial P^*/\partial C_i \bullet dC_i/d\sigma\}|$.

Thus, an increase in the speed of production has an indeterminate effect on the optimal level of postponement.

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