PRODUCT SUBSTITUTION AND CUSTOMER SERVICE: A SIMULATION STUDY

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ABSTRACT

This paper illustrates the effect of product substitutability on customer service. A situation is considered in which we have two products, which could serve as substitutes for one another. This means that in the case of a retailer, if product A runs out of stock, then customers purchase product B instead. In such a system, intuitively, one would expect that such substitutable demand should affect the inventory control of the related items. We find that, as expected, product substitution does indeed result in the improvement of customer service. However, the importance of these improvements is dependent on the existing levels of customer service. In addition, we find that the benefits of product substitution outweigh the loss. In fact, we find that we are never worse off as a result of product substitution.

Keywords: product substitution, customer service, inventory management, operations management

INTRODUCTION

Product substitution occurs in a number of practical situations. A customer at a store desiring to buy a particular brand of color paint might end up buying some other brand if the originally desired brand is out of stock. A passenger at a travel agent might change plans of travelling by air and travel by rail if tickets for airlines are unavailable. A customer desiring a carton of one-gallon milk might be willing to accept two cartons of milk of half gallon each in case the one-gallon cartons are out of stock. For example, Anupindi, Dada, and Gupta (1998) found that about 82%-88% of customers are willing to buy substitute products if their preferred product is not in stock. In such a situation, intuitively, one would expect that such substitutable demand should affect the customer service of the related items. This paper investigates the effects of substitutable demand on customer service.

The paper is organized as follows. The first section outlines the relevant literature on product substitutability and motivates the research issues. The next section describes research methodology employed. Next follows the results of the research, which is followed by the managerial implications. The paper concludes by outlining the possibilities for further research.

LITERATURE REVIEW

As will be described in more detail later, our research addresses the impact of product substitution on safety stock. There are two streams of literature in operations management, which are of relevance to our research. Inventory management/optimization models dealing with the impact of product substitution and inventory consolidation or pooling models dealing with the statistical economies of scale arising out of inventory centralization/consolidation.

At an abstract level, the extant literature in inventory management/optimization models dealing with the impact of product substitution have addressed a wide spectrum of research questions. From specific inventory model perspective, existing literature deals with reorder-point/economic order quantity models, newsboy models, periodic order quantity models etc. Some papers focus on cycle stock inventory while others focus on safety stocks. Some articles use joint product replenishments while others do not. From the objective function perspective, some focus on profit maximization while others focus on cost minimization. Some articles attempt to use optimization modeling while others use approximation heuristics/algorithms. So the existing research deals with a myriad of issues and the papers focus on some aspect of the inventory substitution effect. We would present a brief sampling of this existing research starting with the earliest of such efforts to the more recent ones.

One of the earliest studies is McGillivray and Silver (1978). This research investigated the impact of substitutability on the inventory levels of two substitutable items. They considered the (R, S) system or the periodic review system of inventory control, where inventory is reviewed every R periods and units are ordered to restore the inventory levels to the order up-to levels S. They showed that in case of perfect substitution of one product for another, the best policy is to stock only the substitutable item. They assumed the two units to be identical in all respects, i.e. inventory carrying cost, profits, etc. They came up with a heuristic to arrive at the optimal values of safety stock to achieve a desired level of customer service, as measured by stock out probability.

Some other studies analyzed the effect of product substitutability in the context of single period inventory or newsboy models. Parlar and Goyal (1984) studied the two-product single period newsboy problem with product substitutability. The model had an objective function for expected profit per period, and they analyzed necessary conditions to obtain approximate values of the optimal order quantities. Parlar (1988) used game theory to model the substitution of demand in a single period newsboy problem. He assumed that the two decision-makers (players) that make the ordering decisions know the substitution rates and the demand densities for both products. Since each player's decision affects the other's single-period expected profit, game theory was used to find the order quantities under different strategies of co-operation, irrational competition, and Nash equilibrium. Parlar showed the existence of unique Nash solution. He demonstrated that in case of irrational competition on the part of one player, the optimal solution for the other player reduces to the classical single period newsboy solution. Also, he demonstrated that the joint optimal solution is achieved when the two players co-operate, and that both players are better off, or at least not worse off as compared to Nash solution. Parlar (1984) formulated a two-period perishable inventory problem as a Markov decision model to generate optimal ordering policies. In this case, the fresh product and the one period old product serve as substitutable products. Pasternack and Drezner (1991) developed a model to describe the total expected profit from stocking two short-lived commodities (single period inventory structure) with stochastic demands in which substitutability between products may be possible. They assumed that revenues obtained from substitution would be different than the price of either of the products. They derived formulas for optimal stocking levels and showed that in the case where either of the two products can be used as a substitute, inventory levels for the two products move in the opposite direction with changes in the transfer revenue. In other words, as the transfer revenue increases, the inventory levels of the substitutable item increases and of the other item decreases.

More recently, Chen, Feng, Keblis, and Xu (2015) addressed product substitution as a supplier driven phenomenon in a single period inventory model context. An example would be when a customer books a compact car from a rental company (the supplier), if the car type is unavailable, the rental car company may instead offer the customer a full-size car. Here, the substitution is carried out by the supplier instead of the customer. The supplier comes up with profit maximizing inventory levels for the products in question in with and without customer service objectives (in terms of in-stock probability of the concerned products). Krommyda et. al. (2015) considered the case of two substitutable products in the context of demand stimulation where the existing inventory levels of the two products impact the product demand. The objective was profit maximization. Orders for the two products are placed jointly. They demonstrated that effects of product substitution and demand stimulation are two important factors that should be considered by the retailer when making inventory decisions. When the demand stimulation effect is taken into account, it led to significant increase in retailer's profits. Further, it was found that it is always profitable to let the less profitable product stock-out first. Zhang, Huang, Cheng, Want, and Fernandez (2016) investigate the phenomenon of probabilistic selling through product substitution in situations where a customer may make a purchase decision based on imperfect information e.g. buying airline tickets on priceline.com where the specific airline is revealed after the customer purchases the product. Their results showed the probabilistic selling through product substitution may benefit a seller with higher expected profits and lower inventory. Maddeh, Kharbeche, Pokharel, and Ghoniein (2016) model a situation of multiple substitutable products in the context of classical economic order quantity model with joint replenishment where they arrive optimal ordering quantities with the objective of minimizing costs. Some of the interesting findings are that high holding cost of one product may lead to higher order quantity for another product, high shortage cost of one product may lead to lower order quantities for another product. The numerical analysis indicated significant cost improvements in the situation of joint order replenishment with substitution over the case of no substitution. Khishtandar and Zandieh (2017) used a multi-objective optimization formulation in the context of the classical economic order quantity reorder point model with product substitution. The paper compares various algorithms with the objectives of: minimizing total cost, the frequency of stock outs, and the number of items stocked out. Mishra (2017) investigated the case of two substitutable products in the context of a single period inventory model with joint replenishments and with the objective of cost minimization. As one may expect, the results of the analysis showed that the total optimal costs were significantly lower in the case of inventory substitution over without substitution. Basiri and Heydari (2017) model a two stage supply chain where a green or environmentally friendly product may be substituted for a traditional product. The retailer sets the price and decides the sales efforts while the manufacturer controls the products green quality. They find that offering a green substitutable product may create a win-win situation for both retailer and manufacturer possibly in terms of higher sales volume and more profits.

RESEARCH QUESTIONS

Thus, as discussed above, the existing literature does deal with some of the interesting issues arising out of product substitution. However, there still are many interesting questions left unanswered. For example, when does product substitution give you a significant benefit? More specifically, is product substitution equally worthwhile for various levels of customer service? In other words, is the effect of product substitution significant when your present level of customer service is low or high? Another issue is, if you allow a particular product to substitute for some other product to enhance its customer service, does the customer service of the product being substituted suffer? In such a situation, does the loss offset the benefit of product substitution? There are some significant gaps in the literature that this research seeks to address.

THE SIMULATION MODEL

The problem considered in the study is shown in Figure 1 (See Appendix A). We consider two products, Product A and Product B. Both the products can substitute for each other, in case either product is out of stock, with some given probability of substitution. First, a demand for a given product is met out of the existing inventory of the product being demanded. Should the product being demanded be out of stock, the other product substitutes for the demand, with some pre-specified probability. If the other product is also out of stock, then a stock out results. In this paper, our objective is to illustrate the effect of product substitutability on customer service as measured by the fill rate. Fill rate is essentially the percentage of product demand met out of safety stock while the next replenishment order is yet to be received.

Thus, our focus is primarily on how demand is met out of the safety stock. We are not interested in that part of order fulfillment when demand is being met out of the cycle stock. Hence, the simulation begins with the start of lead-time, or when the product order is placed with the supplier. Every simulation replication starts with a product order being placed with the supplier, with the inventory on hand being equal to the reorder point and safety stock for both of the products. At the start of the day, first the incoming shipments are received, if any. Daily customer demands are first fulfilled from the existing product inventory of the product being demanded. In case of product stock out, a portion of the daily demand, determined by the probability of substitution for the concerned product is transferred to the other product, and the other portion of the demand, which can't be transferred, is stocked out. Based on the availability of the other product, the transferred demand is met through the inventory of the other product. At the end of the day, the number of units stocked out, if any, is recorded for both products. This number is added to any previously stocked out units, if any, during the same replenishment time period. Also, at the end of every day, the current inventory status is checked with the reorder level, and if the existing inventory is less than or equal to the reorder point, an order is placed with the product's supplier. At the start of the next day, the same cycle is repeated. At the start of the day, if any incoming supplier shipments are received, that marks the end of that particular replenishment cycle. At the end of every replenishment cycle, all the data statistics such as the number of products stocked out for either product are recorded, and the statistics are cleared to start the recording for the next cycle. We repeat this for forty replenishment cycles for every simulation replication.

In case of stock out of either product, the demand that would be satisfied by the other product would depend upon the probability of substitution. If this probability is a fraction, that means not all units stocked out could be satisfied by the other product, even if the other product is available. Thus, though a portion of unmet demand would be satisfied owing to substitution, still there would be a stock out. Thus, if we use some other measure of customer service such as probability of stock outs, it is quite possible that we would be doing much better in terms of customer service, as we are satisfying more customers, thanks to substitution, still we will have same probability of stock out. For this reason, we use fill rate as our measure of customer service.

The simulation parameters and their values are shown in Table 1. The values shown are for both, Product A and Product B. We make forty replications for every parameter combination. As shown in the table, we have four variables at five levels each, and two variables at three levels each. Thus, we have a total of 5,625 parameter combinations. We replicate each combination for forty times, thus we have a total of 225,000 replications in the simulation.

Table 1. Simulation parameters and their values

Parameter	**Values**
Probability of substitution	0.0, 0.25, 0.50, 0.75, 1.00
Desired fill rates	0.80, 0.85, 0.90, 0.95, 0.99
Order quantity factor	1, 2, 3
Daily demand distribution	Normal (Mean = 100, SD = 20)
Lead time distribution	Normal (Mean = 10, SD = 1.634)

RESULTS

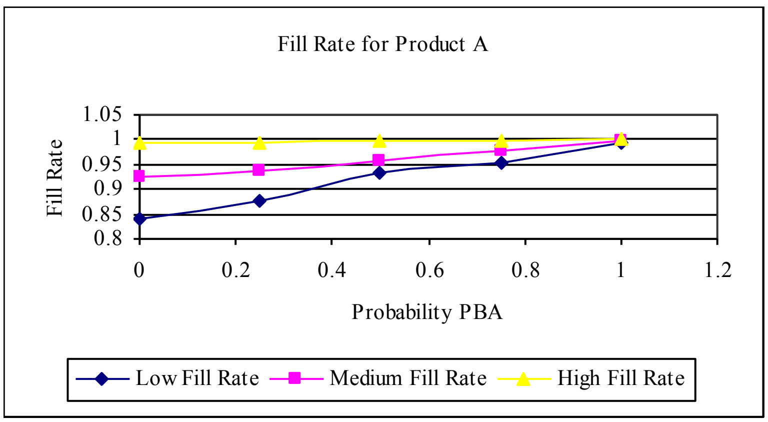
We first investigate whether there is any benefit of product substitution in terms of customer service. It is very intuitive, given the nature of product substitution and the existing literature, that product substitution should result in improved customer service.

As shown in Table 1, we have five levels of fill rates. We present our analysis at three of these levels; low (0.8) medium (0.9) and high (0.99) fill rates. We use the following notations for further analysis and presentation of findings

PAB = Probability of Product A substituting for Product B
PBA = Probability of Product B substituting for Product A

Figure 2 presents the fill rates for Product A at different probabilities of substitution of PBA, with PAB being held constant at 0. Figure 2 is in the expected direction. However, there is an interesting observation to be made. The improvement in customer service seems to be dramatic when the initial desired fill rate is low. When the expected fill rate itself is set at a higher level, though there is improvement in customer service owing to product substitution, the improvement seems only marginal.

Figure 2. Fill Rate for Produce A



So, does the importance of customer service improvements due to product substitution depend upon the existing level of customer service? Tables 2, 3 and 4 present statistical treatments to answer this and other interesting questions that we subsequently raise in this section. The tables are a series of t-tests on differences of means. The base case for the mean differences is both the probabilities of substitution being zero (PAB = PBA = 0). We present the confidence intervals for the mean differences. By the design of the tests, if we do not have a zero in the confidence interval, this implies that the particular test is significant. On the other hand, if there is a zero in the confidence interval, it implies that the particular test is not significant.

To analyze whether the importance of customer service improvements due to product substitution depends upon the existing level of customer service, the relevant t-test of mean difference is the second row of the three tables. The test is significant at 0.1 and 0.01 level at low fill rate, at 0.1 level for medium fill rate, and is not significant at high fill rate. Thus, this trend shows that the importance of customer service improvements due to product substitution indeed depends upon the existing level of customer service. The benefit of substitution seems to be statistically significant only when the existing customer service is low. Though it does seem that substitution helps at all levels, it seems to make a meaningful difference only when the existing customer service level is low.

Thus, whether significant or not, product substitution seems to improve the customer service for a product which is being stocked out. However, one might argue, for example, when you substitute Product B to meet the demand for Product A, would it hurt the customer service of Product B? In other words, as one might argue, are the customer service improvements worth the increased stakeouts that might result for the other product?

Figures 3, 4 and 5 give an initial evidence for this question. These figures show the change in fill rate of product A, both when PAB is fixed and when PBA is fixed. All the figures show that the improvement in fill rate of A with increasing PBA is more striking than the deterioration in product A's fill rate as a result of increasing PAB. Thus, this gives us preliminary evidence that the benefits of product substitution might outweigh the loss.

Figure 3. Low Fill Rate

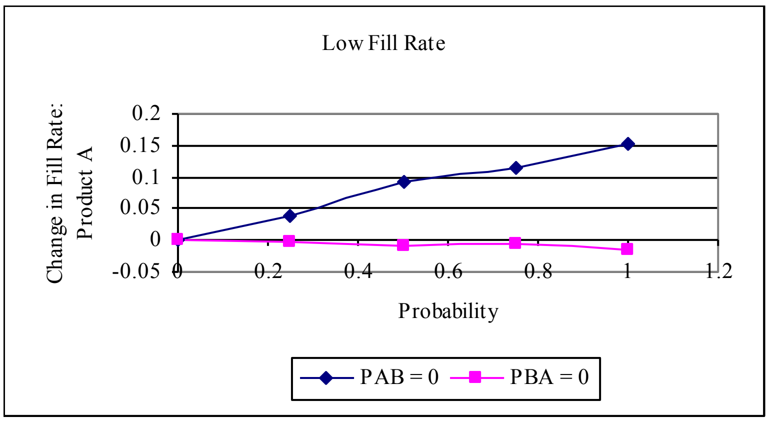


Figure 4. Medium Fill Rate

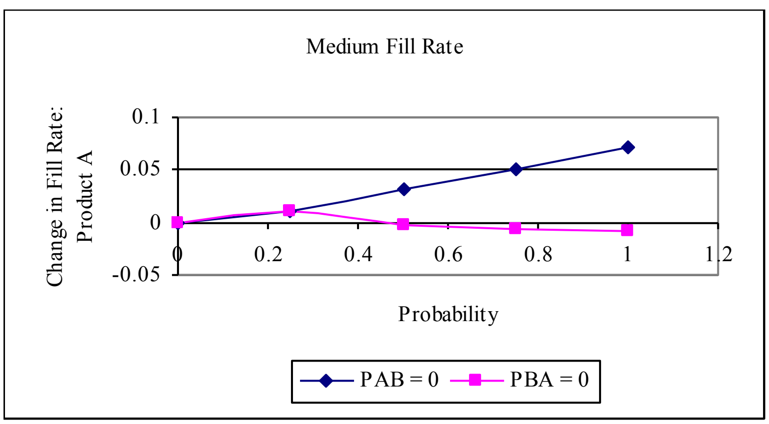
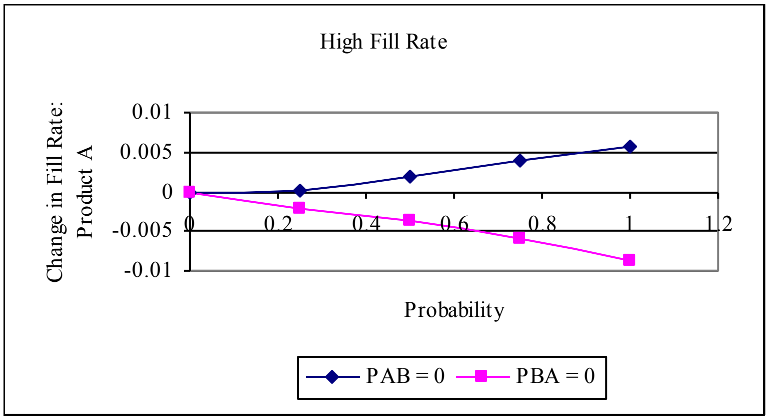


Figure 5. High Fill Rate



To rigorously examine whether indeed this is the case, we present the t-test of differences. The relevant test statistics are presented in Table 2, 3 and 4 in rows 3. As is evident, the statistical significance is not much affected, and the test for low level of fill rates remains statistically significant, indicating that the benefits of substitution indeed outweigh the losses.

Table 2. Low Fill Rate: Paired T-Comparisons with the base case; PAB = 0, PBA = 0

Probabilities	**Confidence Interval (0.1)**	**Confidence Interval (0.01)**
PAB = 1, PBA = 0	(0.036, -0.067)	(0.052, -0.083)
PAB = 0, PBA = 1	(0.181, 0.124)	(0.189, 0.115)
PAB = 1, PBA = 1	(0.193, 0.104)	(0.206, 0.091)

Table 3. Medium Fill Rate: Paired T-Comparisons with the base case; PAB = 0, PBA = 0

Probabilities	**Confidence Interval (0.1)**	**Confidence Interval (0.01)**
PAB = 1, PBA = 0	(0.114, -0.131)	(0.151, -0.168)
PAB = 0, PBA = 1	(0.142, 0.002)	(0.163, -0.019)
PAB = 1, PBA = 1	(0.135, -0.003)	(0.156, -0.024)

Table 4. High Fill Rate: Paired T-Comparisons with the base case; PAB = 0, PBA = 0

Probabilities	**Confidence Interval (0.1)**	**Confidence Interval (0.01)**
PAB = 1, PBA = 0	(0.018, -0.036)	(0.026, -0.044)
PAB = 0, PBA = 1	(0.012, -0.001)	(0.014, -0.003)
PAB = 1, PBA = 1	(0.012, -0.005)	(0.015, -0.008)

One interesting question to examine might be, whether product substitution does at all hurt the customer service of the product being substituted? In other words, are we ever worse off with product substitution? Row 1 of Tables 2, 3 and 4 present the relevant statistical test. The t-test of mean differences show that there is no significant difference in the customer service levels with or without substitution. That is, if product A is substituted for product B, without the benefit of product B substituting for product A, the customer service of product A is not statistically different from the case when neither products substitute for each other. This gives a convincing evidence to assert that we are never worse off with product substitution.

One can explain this result as follows. When a product substitutes for another product, it might be doing so from either cycle stock or from safety stock. When it substitutes for another product from cycle stock, there is no reason for its customer service to get affected. On the other hand, when it substitutes from safety stock, there again are two possible scenarios. The product could be either in a high demand phase or a low demand phase. Again, when the product is in a low demand phase, substituting it for another product might not cause any undue problems for its own customer service. Its only when the product substitutes for another product out of the safety stock and being in the high demand phase, that there is some reasonable chance of its customer service being affected. However, the probability of this happening seems to be very low, and that might explain our result.

MANAGERIAL IMPLICATIONS

The results in this research have some useful managerial implications. We have shown that product substitution improves customer service. This implies that in the presence of substitutable products, it's possible to achieve higher fill rates with less safety stocks. Thus, managers can achieve desired customer service levels with lesser safety stocks than that mandated by the traditional inventory management models, which does not take product substitution into account.

However, as our results indicate, this improvement is dependent upon the existing level of customer service. Specifically, the customer service improvements seem to be meaningful only when the existing levels are low. Thus, those products that have low customer service levels, for reasons such as limited product availability, saving on inventory cost, etc., would benefit the most.

Managers might be concerned when allowing products to substitute for the demand of other products out of the fear that it might adversely impact the customer service of the product being substituted. However, our results show that one is never worse off with product substitution. Thus, our results imply that managers should encourage product substitution wherever possible, without any second thoughts, as this could only improve customer service.

LIMITATIONS AND FURTHER RESEARCH AVENUES

We have analyzed the benefits and losses of product substitution solely on the basis of customer service as measured by fill rates. However, though it might be beneficial to substitute in terms of fill rate, things might be different when consideration is given to issues such as the price of the product etc. There is an opportunity to include such considerations in our modeling.

Various parties such as customers or suppliers, etc. can initialize product substitution. For example, Gateway computer can substitute an 8 GB hard-disk for a customer order of a computer, when a customer has requested a hard-disk of only 4 GB. When does it make sense for Gateway to adopt such a policy? One would suspect that it would be based on the price differential between the two products. It might make sense only when price differential is not large. There exists an opportunity to investigate such issues in our modeling context.

In the presence of product substitution, individual product customer service levels tend to understate the true customer service being achieved. Thus, measuring customer service by the traditional measures might be misleading. There is a need for some composite measure of customer service, which would present a better assessment of the true customer service being attained, taking into consideration product substitution.

In this paper, we have assumed individual ordering of the products. However, firms might have a policy of joint ordering of products, to save on ordering costs. It would be reasonable to believe that in case of joint ordering, the impacts of product substitution might be different from that observed in this study. For instance, in the case of joint ordering, one may not get the benefit of lead-time pooling, and that might lessen the benefits of product substitution from that observed in this study. It might be interesting to extend this study to investigate such issues arising out of joint ordering of products.

To the best of our knowledge, there isn't any study in the literature that presents analytical models to predict customer service levels based on different levels of product substitution. There is an opportunity to do analytical modeling to address this issue, based on similar lines on the inventory pooling literature.

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APPENDIX A

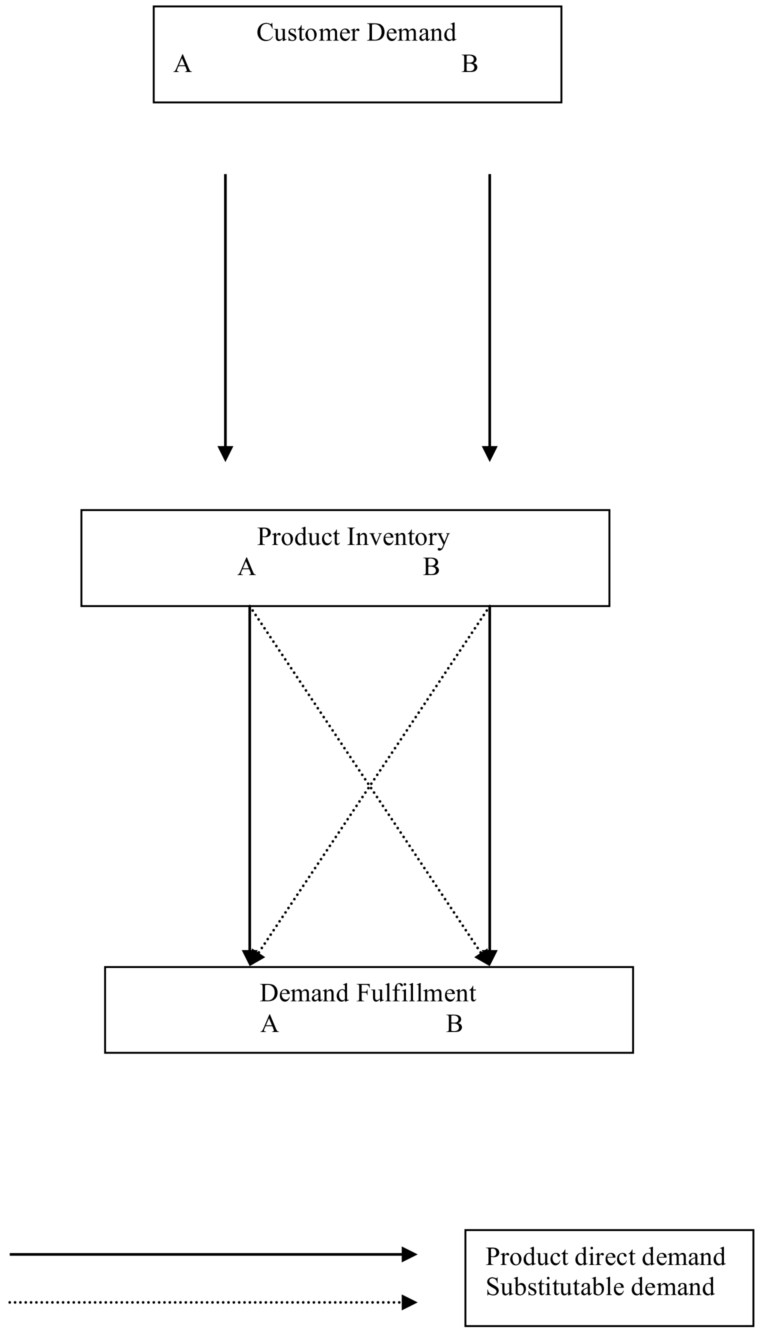

Figure 1

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