Postponement Strategies for Channel Derivatives

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The value of postponing product differentiation until final distribution for manufacturers who market a family of product derivatives through multiple channels is examined. A model is developed of a supply chain that distributes many short-lived products through different channels. Using the model, we find the postponement is particularly valuable for managing short-life products. Postponement increases distribution service levels while reducing costs and order fulfillment risk. Postponement is particularly valuable when there are many derivative products and forecast error is high. Trade-off curves are presented, that allow managers to evaluate the benefits of investing in postponement strategies.

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Manufacturers in many industries are facing the supply chain challenges of product proliferation [1]. For global firms, specific local requirements such as language, conventions, and government regulations mean that any single product must have multiple product derivatives. In the U.S., market segmentation by business and consumer channels, price, and feature set further increase product variety. For example, consumer electronics and PCs are often customized for each retail channel allowing Wal-Mart to sell a slightly different product than Best Buy or Office Depot. Satisfying the customization needs of each channel creates many supply chain complexities as manufacturing and distribution struggle to manage a wide range of product derivatives [2]. Even forecasting the volume of multiple niche products is ever more difficult. Many supply chains rely on large inventory holdings to reduce the risk of poor product availability. However, this is costly and unsustainable in highly competitive markets.

To further complicate the situation, technology advances have shortened the life cycles for many products, especially in electronics and computers. The short life cycles drastically increase the penalty of holding obsolete finished goods inventory. For example, at Hewlett-Packard, the average life cycle for a DeskJet printer product is approximately 18 months, with some derivatives lasting only a few months. In PCs, six months is more typical, with some products lasting only a few weeks in the channel! The annual cost of holding inventory of printers or PCs may approach 50% of the product cost since products lose value every day and old products must be deeply discounted or sold through alternative channels. Moreover, in computer and peripheral markets, manufacturers face constant price competition and narrowing margins, requiring both low inventories and high service levels to ensure profitability on product development investments.

Manufacturers in such industries have developed many supply chain strategies to address the problems that accompany product proliferation. Delayed product differentiation or postponement is one approach that has proven to reduce inventory needs while ensuring high product availability [3]. In this paper, a model is developed to explore the value of postponement under different operating conditions. This model was developed to better understand when design investments that facilitate postponement are most beneficial. Specifically, using this model we examine design strategies where manufacturers invest in product platforms [4] that can be easily customized into many different product derivatives. The development cost of such platforms and the added material cost to each product can be significant [5]. Thus, we seek to understand when these investments are warranted. Because manufacturers face tradeoff decisions around product postponement and flexible factories, the sensitivity results from the model show how postponement decisions can be effected by different operating conditions - and under which conditions postponement provides the most benefit. The operating conditions focused on are inventory policy, forecast uncertainty, product variety, product mix, and postponement premium. Additionally, the impact of postponement on order fulfillment risk is evaluated. The model and the results provide a management tool for predicting the impact of postponement on future product platform introductions.

Literature Review

The concept of postponing product differentiation beyond manufacturing has been discussed for over 50 years [6], [7]. However, it was only about ten years ago that logistics researchers began to define and study the concept [8]. In the past five years, the demands of managing global product offerings have pushed managers in many industries to seriously consider postponement as a supply chain strategy for mass customization [9]. This has renewed researcher interest in studying the benefits of postponement.

In their landmark paper, Zinn and Bowersox [10] defined and analyzed five different types of postponement (labeling, packaging, assembly, manufacturing, and time). Using simulation models, they examined conditions that favor the different types of postponement. Hewlett-Packard reported one of the early successful applications of postponement in the computer industry involved localizing products for global markets [11]. HP manufactured printers in the U.S. and distributed finished products globally through three distribution centers in Europe, the U.S. and the Far East. Each country had their own local requirements including the appropriate power supply module, power cord terminators, and manuals in the appropriate language. Previously, localization was done in the U.S. factory and finished products were shipped to the three distribution centers (DCs). However, the long transit times to the DCs required them to hold high levels of safety stock. HP began to investigate the benefits of a product and process redesign where a generic printer would be produced at the factory and shipped to the DCs for final customization with the power supply and the manual. The printer itself had to be redesigned so that the power supply model could be added easily at the DC, which required some additional investment at the DC to give them this capability. The results from the DC localization at HP were positive - inventory costs were reduced while a customer service measure like fill rate improved. The value of the pipeline (or in transit) inventory was lower because it was in a generic form and the unlocalized printers were less bulky and therefore less costly to ship. HP also observed that increasing the local content and local manufacturing presence made the product more marketable. This success story strengthened the industrial interest in postponement, motivating further research including the research described in this paper.

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Using an analytical model, Lee [12] examined how product and process redesign for delayed product differentiation (postponement) could be used to improve inventory and service management. Lee examined disc drive manufacturing, which typically required long lead-times due to lengthy testing. He developed two inventory models that could be used to support product and process redesign decisions. Lee found that value of delayed differentiation was greatest when the process was designed so that customization took place after long, non-value-added steps were performed. For example, Lee described how disc drive manufacturers could use a generic coupon board during testing and then insert a customized printed circuit board during final assembly – postponing the final configuration of the disk drive.

Lee and Tang [13] pointed out that before redesign for localization or customization is initiated, the economics must be analyzed because some fixed and variable costs associated with a product/process redesign will change. They analyzed three basic approaches to delayed product differentiation and discussed the conditions that resulted in the greatest benefit. The first was standardization of components, whereby a part was designed to be common to all products. Lee's multi-stage model captured the additional material and processing costs that result from standardization and the costs of holding buffer inventory at intermediate stages in the product process. The model could also be used to evaluate an optimal stage of the process for part standardization. They were able to show that standardization was effective only when the investment and processing costs required for standardization were low. The second approach they evaluated was modular design, where a part was divided into two modules. The first module was common to all products and the assembly of the second module was deferred. Lee and Tang found that with this approach it paid to delay the product differentiation from stage 1 to stage 2 when the lead-time of stage 2 was long, when the additional module was easy to handle or when the modular design was relatively inexpensive. The third approach was process restructuring where the product differentiation results from postponing an operation downstream in the supply chain. They found that this approach was beneficial when the lead-time for the first common stage was long and when stage 2 (postponed step) was a high value-added activity. Lee and Tang [14] also investigated process restructuring through operations reversal whereby the manufacturing process was reengineered and two consecutive stages of the process were reversed. This provided the greatest benefits when high value-added activities were deferred.

Recently, Pagh and Cooper [15] developed a framework for describing different postponement and speculation strategies, while Mason-Jones and Towill [16] considered the role of postponement approaches in decoupling information and material in the supply chain. For an extensive review of the literature on postponement, see "The Benefits of Design for Postponement" [17].

Compared with the earlier research on postponement, this paper concentrates on cases where demand is non-stationary. Most of the previous work concentrated on products, whose demand was uncertain, yet the average demand values were constant. We examine products that experience short life cycles where demand typically surges at product introduction; remains steady for a few months, and then decline at the end of life. Such demand patterns are typical for products in the computer and electronics industry along with other fashion industries like apparel and toys. We also examine additional elements representative of many supply chains including multiple channels, each facing its own demand distribution and complex cost structures including postponement premiums related to material and design costs.

Model Description

To examine the issues around platform design for channel derivatives, we developed a model to evaluate the benefits of postponement under a variety of different operating conditions. The model represents a two-level supply chain where a single manufacturing plant supports multiple demand channels, each facing non-stationary demand from end customers. These different channels could represent similar products sold through multiple consumer channels such as Wal-Mart, Office Depot, and Best Buy or alternative commercial channels such as Ingram Micro. They could also represent direct e-channels like HP.com or pcorder.com. For each case, we compared the inventory and service performance of a traditional supply chain (see Figure 1) where multiple products are produced at the factory to a supply chain where a generic product is produced at the factory and then later differentiated in the distribution channel (see Figure 2).

We used this model to analyze the inventory costs that distribution would incur if those products or channels were manufactured individually (non-postponement), or differentiated from a single platform downstream in the supply chain (postponement). Because manufacturers face many trade-off decisions around product postponement, the objective was to

Figure 1
Traditional Supply Chain Where Manufacturing Produces Final Products

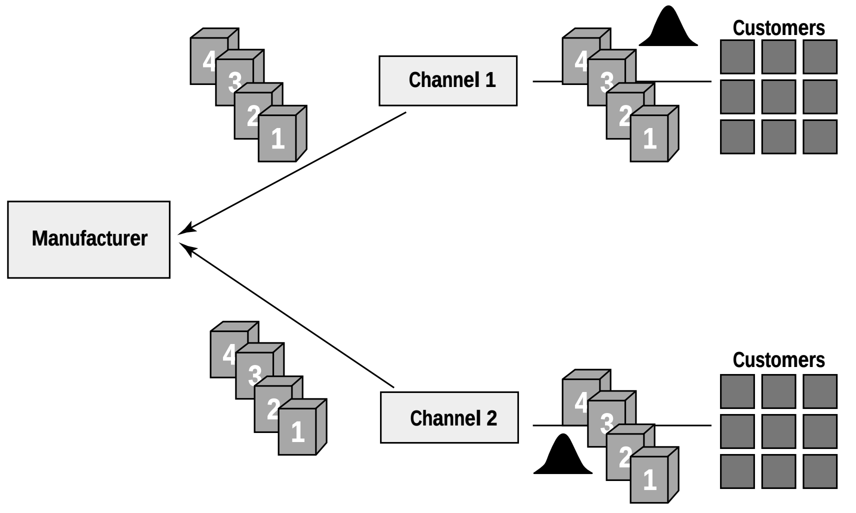
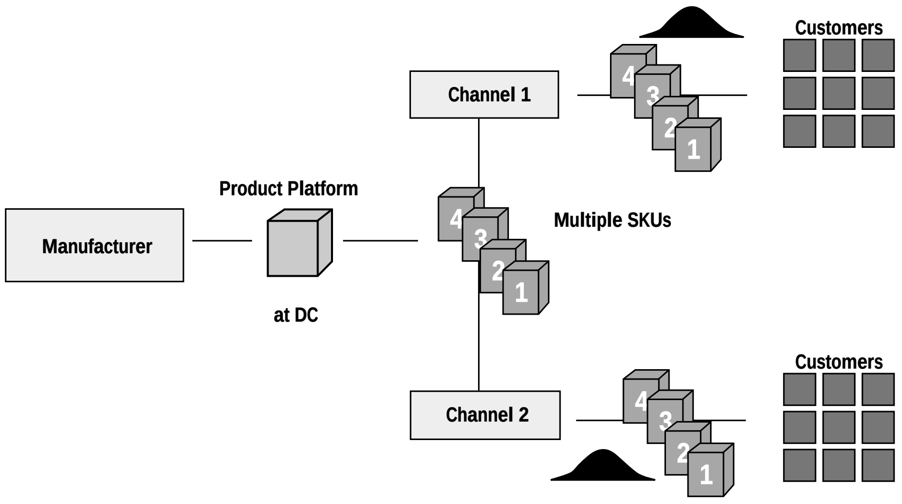


Figure 2
A Supply Chain Where Manufacturing Produces a Generic Product that is Configured by Distribution to a Channel Customized Offering



determine how beneficial postponement would be under a variety of operating conditions. The conditions we focused on were:

- Product variety, or the number of derivatives from a single platform.
- Product mix - symmetry or asymmetry of demand between derivative products.
- Inventory policy decisions.
- Service level goals (fill rate).
- Forecast error.
- Postponement premium cost (material and processing costs).

Model Input

Figure 3 shows a flowchart of the activities that occur each period in our simulation model. The simulation was initiated with the product forecasts and all other system parameters. Product demand for each channel was generated as a normal distribution using the forecast as the mean and the forecast error as the standard deviation. Inventory planning for the non-postponement cases was based on the forecast for each product derivative (individually). For postponement, an aggregate platform forecast was used for planning. After determining the beginning inventory, prior period orders were received and then the demand was filled from the inventory stockpile. If the demand exceeded the inventory stockpile, then demand was either lost or marked as backordered, depending on the backorder parameter (percentage of customers willing to wait). An order quantity was calculated based upon the ending inventory, a foreword look to the forecast, lead-time from the factory, and a desired safety stock policy. Replenishment orders were then recorded as pipeline inventory. Replenishment orders were not taken out of the pipeline until they were received at the distribution center. After the demand was filled in any period, the remaining inventory was assessed a holding cost per unit.

The key performance metrics captured by the model was supply chain costs and service level.

The user input variables to the model were:

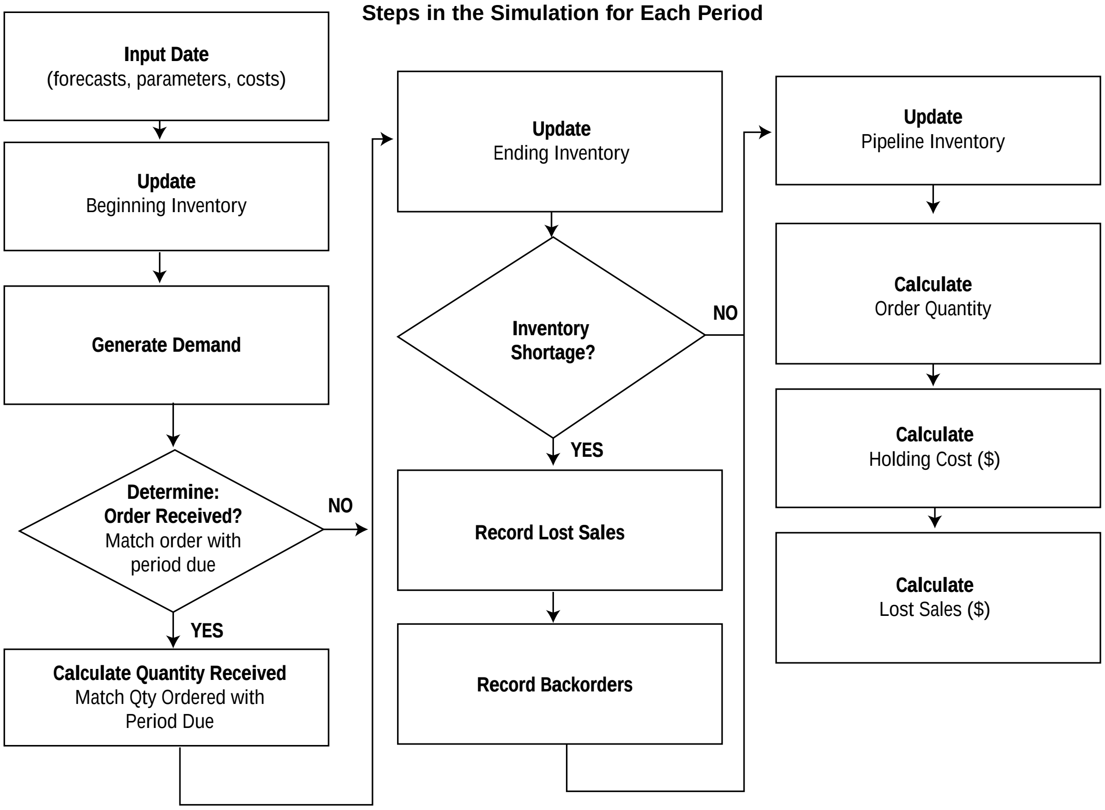
- Number of derivative products on a platform.
- Product forecast and forecast error.
- Lead-time from the factory to the distribution center.
- Desired safety stock policy.
- Platform cost.
- Postponement premium.
- Holding costs.
- Cost of a lost sale (including possible lost sales on future consumables related to the product).

The postponement premium was specified as a percentage of product cost incorporating both the costs of common platform development and postponement production and materials.

Model Output

The key performance metrics captured by the model was supply chain costs and service level [18]. The costs included

Figure 3
Steps in the Simulation for Each Period



inventory-holding costs, lost sales costs and costs related to extra materials required for postponement. We defined holding costs as the annual cost of capital, warehousing, obsolescence, price protection and fire sales. We defined the cost of a lost sale as the contribution margin per unit on unfulfilled demand, plus the margin lost due to future consumables (for example lost sales of printer cartridges). Service level or fill rate was defined as the percentage of items filled from the inventory pool at the distribution center.

Model Verification and Validation

After developing the simulation model, we performed several different verification and validation steps to ensure the model results were reliable [19]. This included verifying the model architecture with other researchers and engineers; comparing the simulation output to analytical models for simple cases; and, showing the results to managers actively working on supply chain issues at the inkjet printer division of HP, who could compare the results to their previous experiences. For steady state cases with no lost sales and stationary demand, we also compared the simulation results for fill rate to those from a well known analytical model [20]. Appendix Table A1 contains the simulation and analytical estimates of fill rate for many different parameter settings (forecast error and safety stock levels). The simulation results include both the average fill rate and associated 95% confidence intervals based on 1000 independent replications of 16 simulated months starting at steady state. As can be seen from the table the simulation results for cases with low forecast error, as defined by the coefficient of variation (CV = standard deviation of forecast error/forecast) less than 0.2, match those of the analytical model (analytical results fall within 95% confidence intervals from the simulation). The analytical model assumes that the forecast error is small enough to ensure nonnegative demand. In the simulation, negative demand was not allowed (truncated at zero). As expected [21] when the forecast error grows (CV > .3), the analytical model slightly underestimates the true fill rate as shown by the simulation results.

As part of the verification and validation process, we also used the simulation to examine earlier findings on benefits of postponement for stationary demand under steady state. We examined a set of scenarios where eight derivative products were either:

- Customized at the factory and then shipped to the distribution centers; or
- Manufactured as a generic product that was later differentiated at the distribution centers.

Table 1 shows the parameter settings for those experiments.

Figure 4 shows that for the same inventory policy, the average fill rate achieved using postponement are substantially higher than differentiating the products at the factory. Figure 5 shows that postponement has the greatest impact when the forecast error is high, however the postponement strategy performs well over a range of forecast errors. These results are consistent with earlier findings. Detailed results from the simulation including confidence intervals for all estimates and comparisons to analytical model results are included in the Appendix Table A2.

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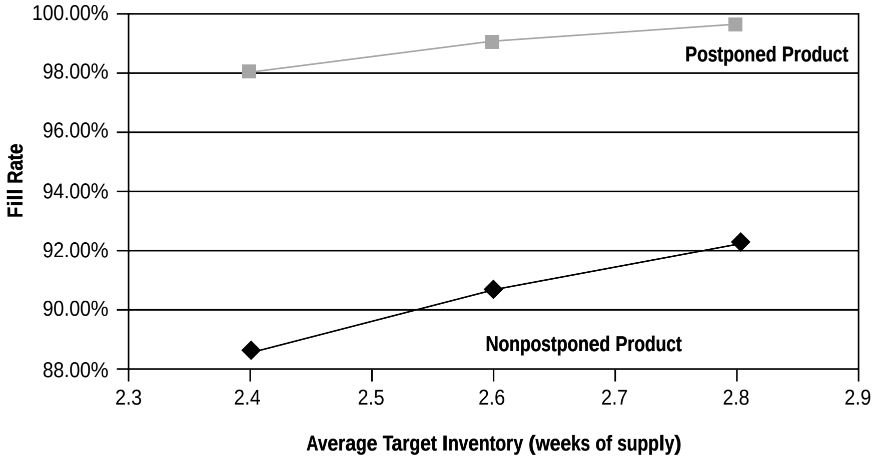
Table 1
Parameter Settings for Experiments
Shown in Figures 4 and 5

Demand Forecast = 10,000/month for all eight skus
Forecast Error CV = .1, .2, .3
Lead-time = 3 months.
Monthly order shipments (and review).
All shortages backordered – no lost sales.
Average inventory target = 2.4, 2.6, 2.8 weeks of supply.

Base Case Model

The focus of this paper is to evaluate the cost and benefits of postponement for more realistic cases where demand is changing and product life is short. These cases never reach steady state and thus analytical models are not readily available. After validating our simulation model for stationary systems, we developed a set of scenarios based on more realistic assumptions. To begin with, we developed a base case to provide a reference point for our analysis. This base case was developed from historical data for printer products at Hewlett-Packard. We examined several different historical printer products to better understand the typical forecast error

Figure 4
Average Fill Rate for Postponed and Nonpostponed Strategy for a Product with Eight Derivative skus. Simulation Results Based on 1000 Independent Replications of 16 Months (forecast error CV = .2)



and product life. An analysis of the forecast and sell-through data showed there were three distinct eight-month periods in an average 24-month product life cycle.

Beginning Period:	Represented by ramping demand.
Middle Period:	Represented by relatively stable demand.
Late Period:	Represented by declining demand.

Figure 6 shows the forecast and actual demand for a typical printer product. After examining the demand trajectory and forecast error for many different printer products, we developed a base case demand pattern shown in Figure 7. The monthly forecast error for a typical product ranged from 50 to 100% as defined by the coefficient of variation (CV), thus we chose 75% for the base case.

The costs used in our analysis were again based on a typical inkjet printer. For such a product, the typical base cost was about $150 (material, labor, capital overhead, transportation, etc). The costs to make

Figure 5
Average Fill Rate for Postponed and Nonpostponed Strategy for a Product with Eight Derivative skus. Simulation Results Based on 1000 Independent Replications of 16 Months (target average inventory set at 2.4 weeks of supply).

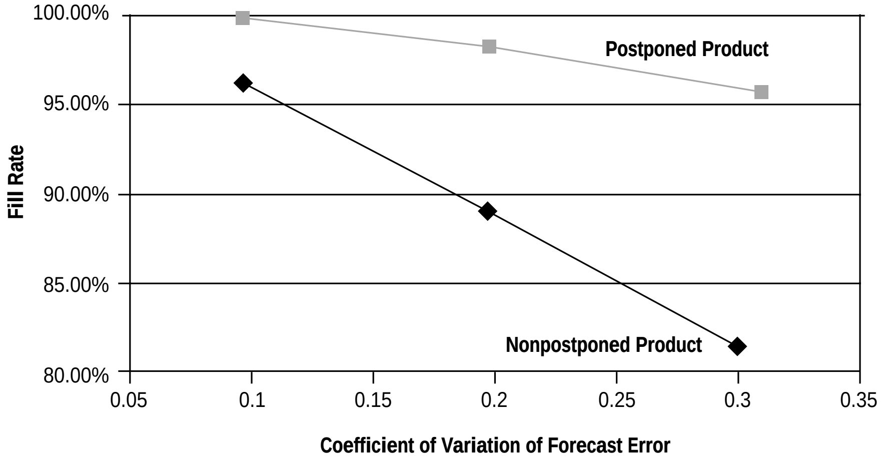
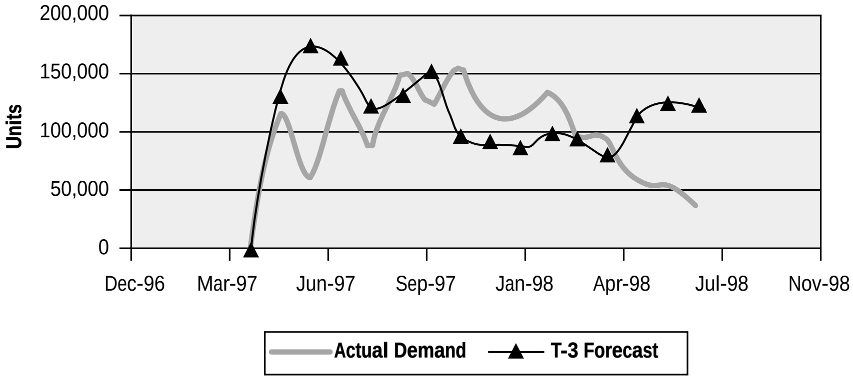


Figure 6
Forecast Performance and Demand for a Typical Printer Product
Typical Product: Actural vs. Forecast



postponement possible included both development cost (spread over the life of the printer) and extra material and processing cost. For example, a power supply that can switch between 110 and 220 is more expensive than a dedicated unit. When shortages occurred, a lost sale resulted in both lost profit margin on the printer (not to mention ill will) and the resulting loss of future cartridge and media sales (assuming the customer buys another brand). For a typical printer, the lost margin on the product was $35 yet the lost future profit on related consumable products over the life of the printer was estimated to be more than the printer ($40). Some customers were willing to wait for the product while others would substitute to another brand. Market research at HP showed that the lost sale rates varied dramatically based on the technology of the product and its competitors. We used 25% as a typical lost sale percentage based on our observations at HP. Since the typical life of a printer product was 12-30 months, printers rarely experienced as much price volatility as a PC and thus the cost of holding inventory was lower than an average PC. Nevertheless, HP documented holding costs ranging for 30-40%.

For nonstationary products, manufacturers rarely use the same inventory holding policy over the life of the product. Rather, they typically try to hold more inventory in the beginning of the product life (to satisfy

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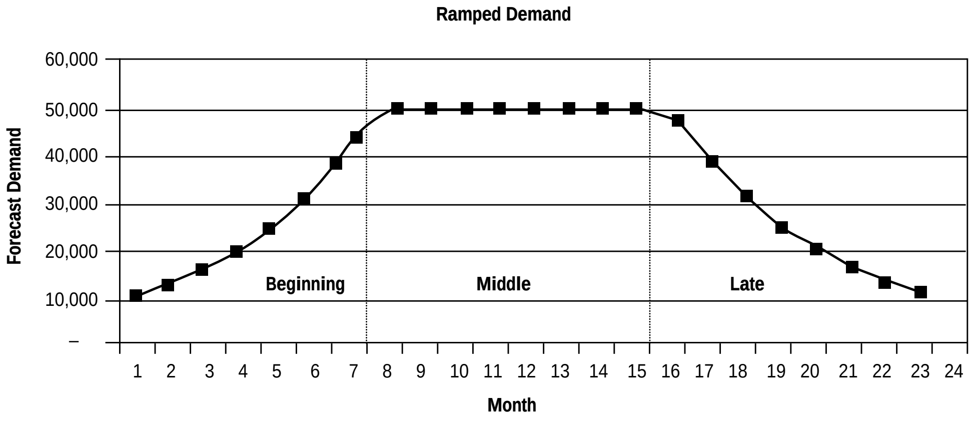
Figure 7
Base Case Demand Trajectory



unexpected early demand) and then reduce the inventory holding as the product ages (to avoid getting stuck with obsolete products). A common approach at HP was to hold 6 weeks of inventory (average based on the forecast) at the beginning portion of the product life (first third), 4 weeks of during the middle portion (second third), and only 2 weeks toward the end of product life (last third). Thus for the base case, we used this (6/4/2) phased inventory policy. The remaining base case parameters are shown in Table 2. In the following sections we will examine the costs and benefits of postponement, varying many of the base case parameters.

Table 2
Base Case Parameters

- Four products/channel (ranging from 1-8).
- Average demand in each channel follows Figure 7.
- Lead-time - 3 months (with shipments reliably delivered within the month).
- Lost demand when back orders – 25%.
- Lost sale cost - $35 in product margin and $40 in future consumable margin (total of $75).
- Product life - 24 months for all products with 8 month ramp-up and ramp-down.
- Base product cost - $150 with annual inventory holding rate of 35%.
- Phased inventory policy (6/4/2) weeks of supply.
- Forecast error - 75%.

Results for Short-Life Products

Starting with the base case, we first examined the impact of the number of product derivatives on the value of postponement. Holding the inventory policy constant (6/4/2) across all cases, Figure 8 shows that postponement does produce higher fill rates in all cases and that the benefit of postponement grows as the number of product derivatives increases (all results mentioned are statistically significant at the 99% level using a modified two-sample-t confidence interval for samples with unequal variances – sometimes called the Welch Confidence Interval [22]). Another more subtle service benefit of postponement is the reduction in order fulfillment risk. Figure 9 (a and b) shows the distributions of fill rate for all 1000 replications of the 24-month product life. Comparing the nonpostponed product derivative to the postponed products, it is clear that postponement creates a far more consistent service level (fill rate). In fact, using a single tailed F test [23], the variance of fill rate for the postponed case is significantly (at the 99% level) smaller than the variance of fill rate in the non-postponed case. This means that not only does postponement provide higher service levels, but also it does so more consistently.

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Another more subtle service benefit of postponement is the reduction in order fulfillment risk.

Figure 10 shows a cost analysis of same set of experiments. As we can see, postponement reduces both inventory holding cost and lost sale cost in all cases and again the relative benefit of postponement grows with the number of product derivatives.

Figure 8
Fill Rate for Base Case with 2, 4, and 8 Product Derivatives Using Postponement (P) and Not Using Postponement (NP)

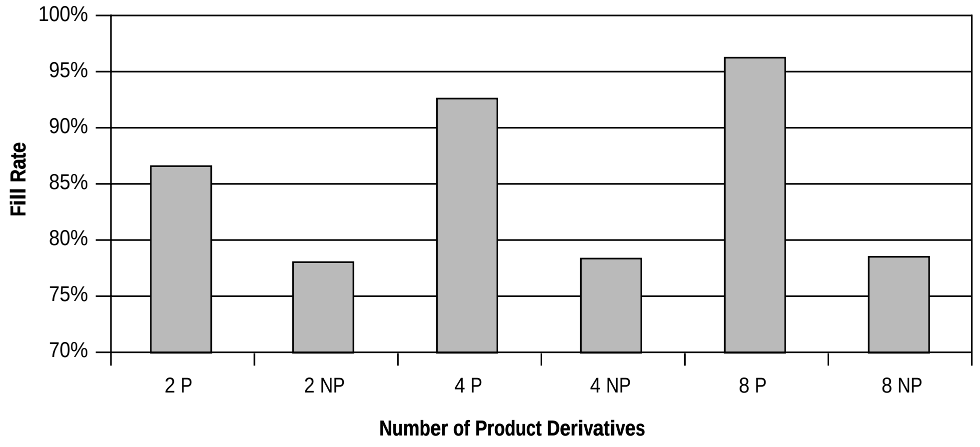


Figure 9 (a&b)
Fill Rate Distribution for Base Case (4 Product Derivatives) Using Postponement (P) and Not Using Postponement (NP)

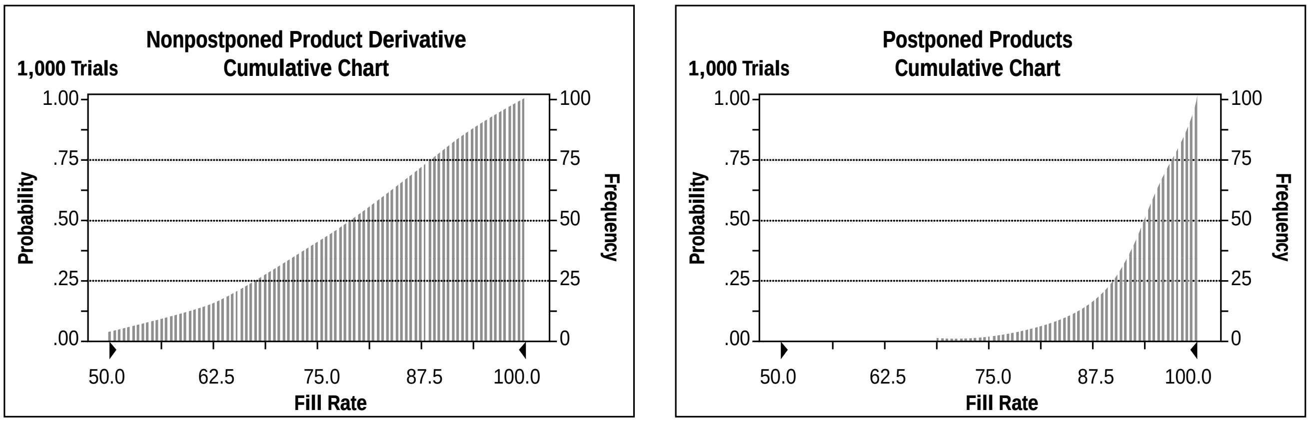
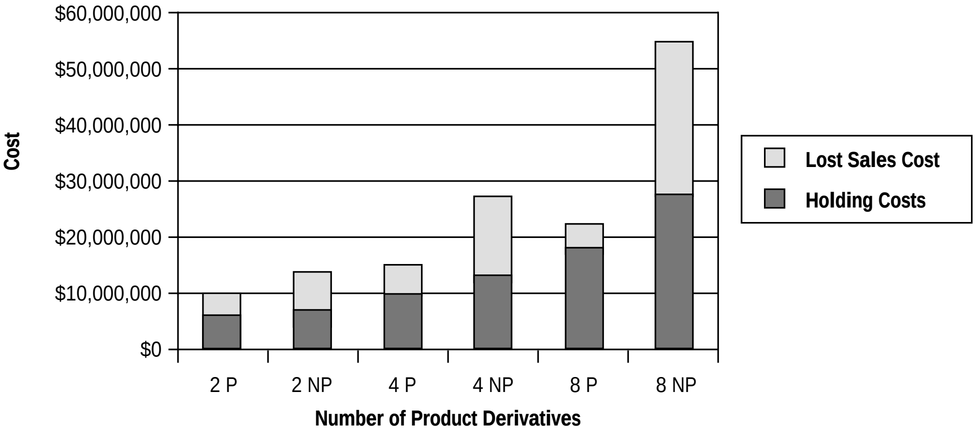


Figure 11 shows that these results hold for lower forecast error scenarios (30% forecast error compared to the base case of 75%), but the value of postponement (both in absolute and relative terms) is not as great. Moreover, we can see the balance of holding costs and lost sale costs shifts (note that the inventory policy was held constant – 6/4/2). With lower forecast errors, both lost sale costs and holding costs decrease and shortage costs become a smaller percentage of overall cost. Of course, we can also shift the balance of holding and shortage costs by increasing the inventory holding policy. Figure 12 shows increasing the inventory targets to 8/6/4 reduces the shortage (lost sale) costs at the expense of holding costs (as compared to the base cases shown in Figure 10). Nevertheless, we see that value of postponement remains compelling.

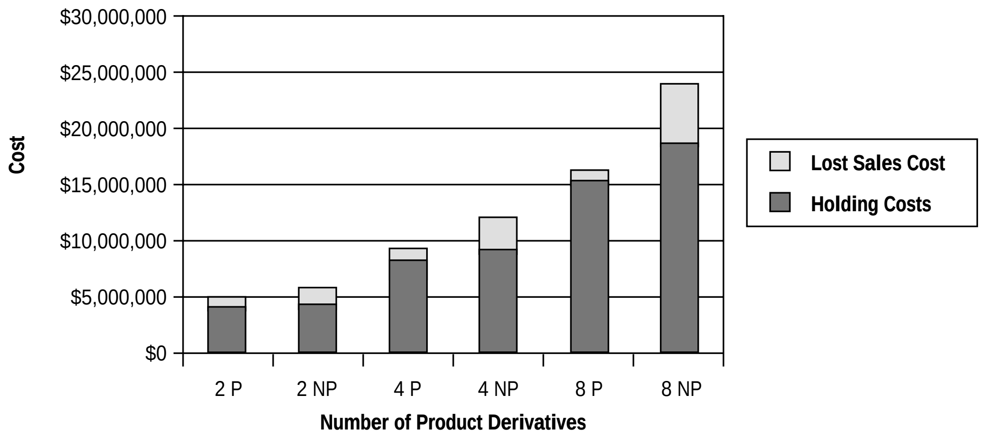
The results shown thus far all consider cases where the demand forecast for each product derivative is the same (even product mix). It is rare in practice to find a group of product derivatives whose demand is the same. More likely, one of the derivatives represents a larger portion of the total demand. To investigate this issue, we examined product mix issues by creating cases with uneven demand. Figure 13 shows

Figure 10
Inventory Holding Cost and Lost Sale Cost for Base Case
With 2, 4, and 8 Product Derivatives



Using Postponement (P) and Not Using Postponement (NP)

Figure 11
Inventory Holding Cost and Lost Sale Cost for Base Case at 30% Forecast Error with 2, 4, and 8 Product Derivatives



Using Postponement (P) and Not Using Postponement (NP)

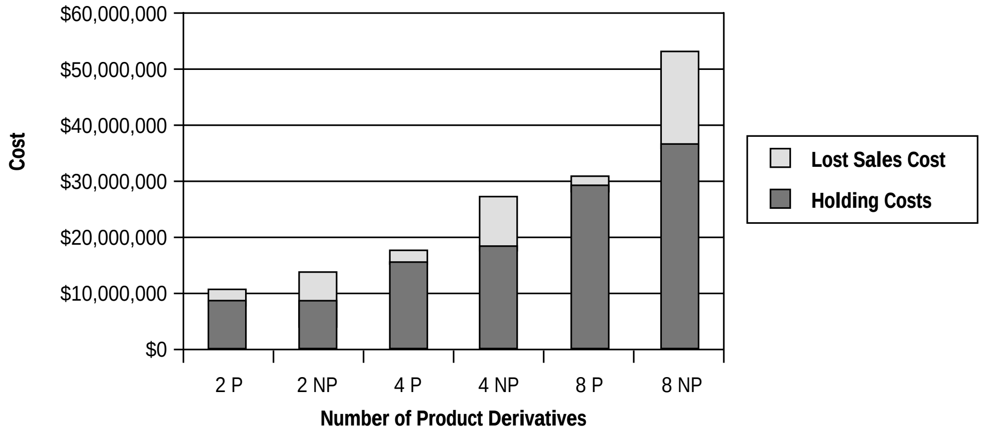
… while postponement is always useful, its value is lower for uneven demand among product derivatives.

the impact of uneven product mix on fill rate. Using the base case with varying numbers of derivatives, we created uneven cases using a version of the popular 80/20 rule – 80% of the demand being driven by 20% of the products. Figure 13 shows that postponement is most valuable when the demand for each product derivative is equal (even). In cases where the demand for a few of the derivatives is far larger than the others, postponement still improves fill rate, but the relative increase is smaller. Figure 14 shows that the same result holds for cost reductions – postponement reduces cost in all cases, but the reduction is smaller when the demand between the product derivatives is not even. Thus, while postponement is always useful, its value is lower for uneven demand among product derivatives.

Understanding When to Invest in Postponement

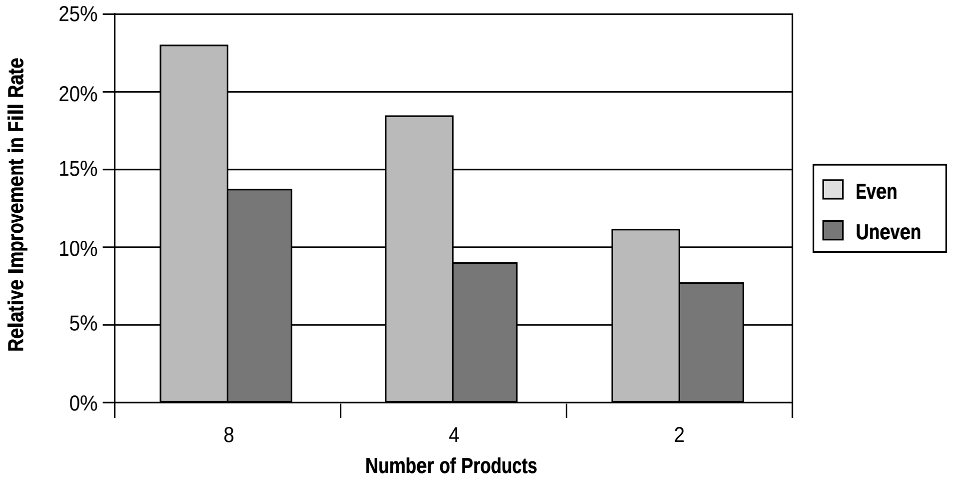
Thus far, we have seen that postponement significantly improves service levels and reduces cost. However enabling postpone often adds both direct material and

Figure 12
Inventory Holding Cost and Lost Sale Cost for Base Case
Using the Increased 8/6/4 Inventory Policy with 2, 4, and 8 Product Derivatives



Using Postponement (P) and Not Using Postponement (NP)

Figure 13
Relative Improvement in Fill Rate When Using Postponement with 2, 4, and 8 Product Derivatives and Even and Uneven Demand



Uneven Demand Split as Follows: (8 products – one derivative each with 60%, 20%, 5% and 5 derivatives with 3%; 4 products – one derivative each with 80%, 10%, and 2 derivatives with 5%; 2 products – one derivative each with 80% and 20%)

labor cost to a product along with development investments in the product and manufacturing process. Key questions facing many managers are: when to invest in postponement strategies? Will postponement investments be recovered in cost savings? To examine these questions, we developed an extensive set of experiments for different levels of forecast error, numbers of product derivatives, target fill rates, and costs. We refer the cost of enabling postponement as the postponement premium, represented as a percentage of the base product cost. The graph in Figure 15 shows the results of our

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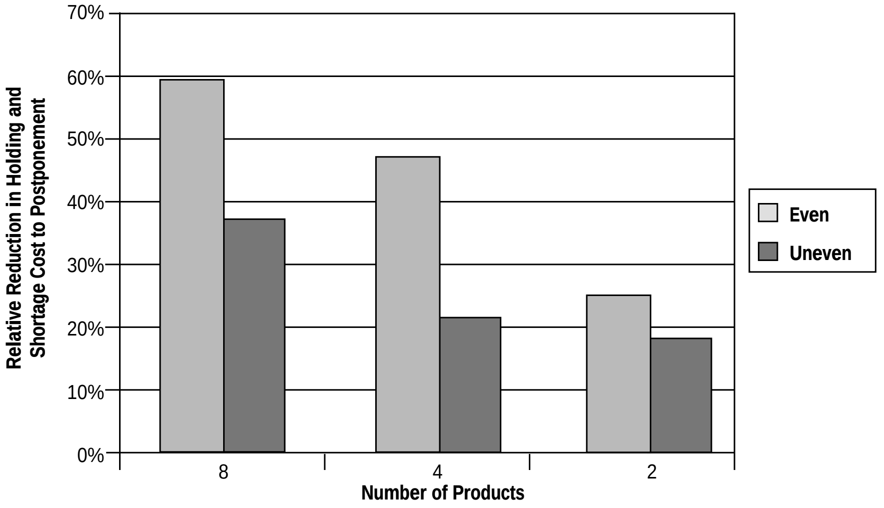
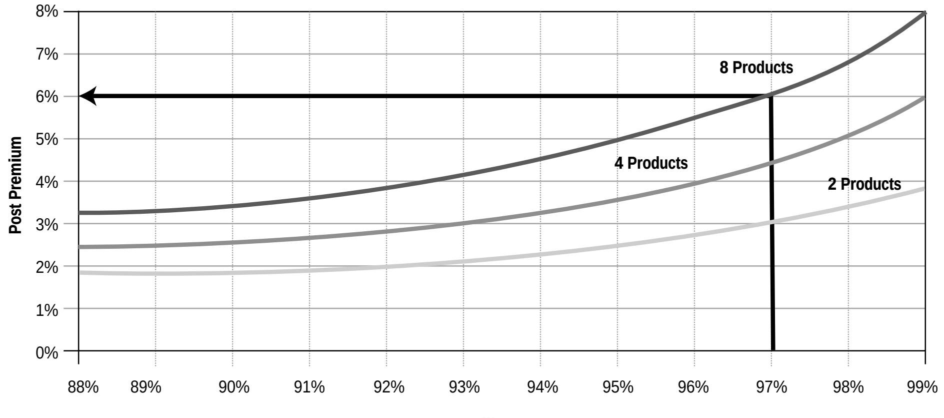
Figure 14
Relative Reduction in Holding and Shortage Cost When Using Postponement with 2, 4, and 8 Product Derivatives and Even and Uneven Demand



Uneven Demand Split as Follows: (8 products – one derivative each with 60%, 20%, 5% and 5 derivatives with 3%; 4 products – one derivative each with 80%, 10%, and 2 derivatives with 5%; 2 products – one derivative each with 80% and 20%)

Figure 15
Postponement Premium Breakeven Curves for
2, 4, and 8 Product Derivatives (base)



Example:
For a desired fill rate of 97%, the maximum postponement premium is 6% for an 8 product platform

experiments. The curve shows the break even postponement premium for different levels of fill rate and different numbers of product derivatives. These curves were created by running hundreds of simulation experiments, using different inventory policies to achieve the targeted fill rate under both postponed and nonpostponed strategies. For each target fill rate level, the breakeven postponement premium was determined as the percentage of product cost for which the total costs (product, inventory holding, and lost sale) were the same for both postponement and nonpostponement. For example, with eight product derivatives and a 97% fill rate target, the curves show that a postponement premium of 6% or less will be recovered in cost savings (holding and shortage costs). While managers may decide that the other benefits of postponement (such as consistent service levels) may warrant larger premiums, the curve shows that the cost would not be fully recovered. Consistent with our earlier findings, Figure 15 shows that more product derivatives on the same platform will warrant larger postponement investments. Figure 16 shows the results of a similar set of experiments with lower forecast error. As one might expect from our earlier results, it shows that with lower forecast error, the breakeven postponement premiums are lower regardless of the number of product derivatives. For example, for the same 97% fill rate target and eight product derivatives the breakeven postponement premium is only 1.75%. Using such curves, managers could quickly evaluate investment decisions related to postponement.

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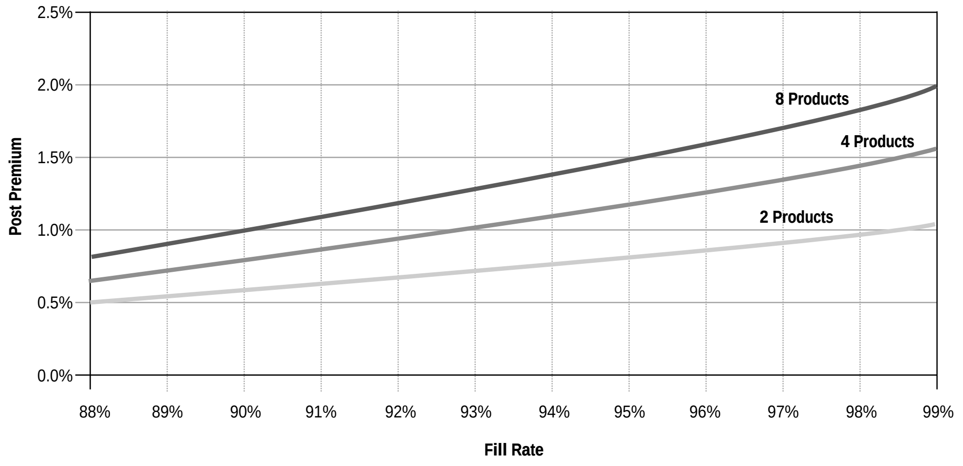
We also have shown that postponement not only improves service while reducing costs, but it reduces the variability of service delivery – thus reducing the risk of providing truly poor service.

Conclusions

From our analysis, we have shown that postponement is indeed a very useful strategy for products with short life cycles. Our results show that the value of a postponement strategy grows with forecast uncertainty and with product proliferation (increased number of product derivatives). Since it has been widely observed that forecasting becomes more difficult as the number of product derivatives grows, postponement represents an effective strategy for managing increased product variety. We also found that postponement is most effective when demand between product derivatives is roughly equal. Thus, we can conclude that postponement would be very useful when managing multiple channel derivatives where the volume in each channel is similar (or not widely different). We also have shown that postponement not only improves service while reducing costs, but it reduces the variability of service delivery – thus reducing the risk of providing truly poor service.

Possibly the most interesting outcome of our model are the postponement premium trade-off curves. Using such curves, managers can quickly evaluate the cost and

Figure 16
Postponement Premium Breakeven Curves for 2, 4, and 8 Derivatives (30% f/c error)



benefits of postponement. Moreover, our approach is very flexible to different operating environments and supply chain challenges. For example, for some products at Hewlett-Packard, managers discovered that they were much better a forecasting the middle portion of the product life than they were at forecasting demand in the product introduction or at the end of product life. In one particular product we examined, the forecast error was 135% during the first 8 months of product life, 15% during the middle eight months, and 90% during the last eight months. This nonstationary forecast error is easily incorporated in the model. Figure 17 shows the trade-off curves for such a product (using the base case parameters, but with the nonstationary forecasting process). Using curves that closely represent the product family, critical postponement strategy investments can be easily analyzed.

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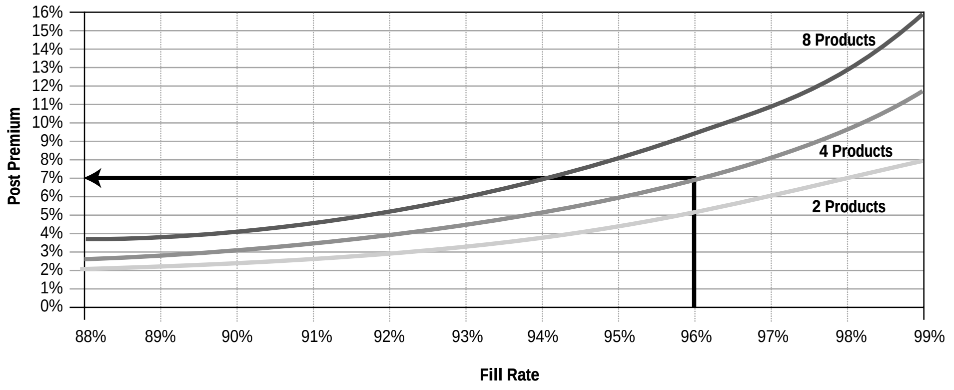
Figure 17
Postponement Premium Breakeven Curves for 2, 4, and 8 Product Derivatives Using a Phased Inventory Polices Where the Forecast Error Varies in Each Stage of the Product Life (135%, 15%, 90%)



Example: For a desired fill rate of 96%, the maximum postponement premium is 7% for a 4 product platform

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Appendix

Table A1

Comparison of simulated fill rate to analytical fill rate model for a single product with: Demand = 10,000/month and Lead-time = 3 months. Simulation results based on 1000 independent replications of 16 months starting from steady state.

Standard Deviation of Forecast Error (units)	Target Order Up To Level (units)	Target Average Inventory (weeks of supply)	Fill Rate Analytical Model	Fill Rate Simulation (average)	Confidence Interval Halfwidth (95%) (simulation)
4000	45000	4.15	87.43%	87.46%	0.72%
3500	45000	4.15	90.37%	90.48%	0.57%
3000	45000	4.15	93.23%	93.60%	0.42%
2500	45000	4.15	95.84%	95.90%	0.31%
2000	45000	4.15	97.98%	98.12%	0.18%
1500	45000	4.15	99.41%	99.38%	0.09%
1000	45000	4.15	99.96%	99.96%	0.01%
500	45000	4.15	100.00%	100.00%	0.00%
4000	44000	4.05	84.75%	85.02%	0.76%
3500	44000	4.05	87.86%	88.57%	0.65%
3000	44000	4.05	90.99%	91.70%	0.52%
2500	44000	4.05	94.00%	94.35%	0.37%
2000	44000	4.05	96.67%	96.76%	0.26%
1500	44000	4.05	98.73%	98.73%	0.13%
1000	44000	4.05	99.83%	99.85%	0.03%
500	44000	4.05	100.00%	100.00%	0.00%
4000	43000	3.95	81.70%	82.86%	0.84%
3500	43000	3.95	84.90%	85.65%	0.74%
3000	43000	3.95	88.24%	88.38%	0.62%
2500	43000	3.95	91.58%	91.94%	0.47%
2000	43000	3.95	94.76%	94.96%	0.34%
1500	43000	3.95	97.50%	97.64%	0.19%
1000	43000	3.95	99.41%	99.47%	0.07%
500	43000	3.95	100.00%	100.00%	0.00%
4000	42000	3.85	78.28%	78.21%	0.99%
3500	42000	3.85	81.49%	81.72%	0.80%
3000	42000	3.85	84.94%	85.56%	0.68%
2500	42000	3.85	88.52%	89.12%	0.56%
2000	42000	3.85	92.09%	92.09%	0.42%
1500	42000	3.85	95.47%	95.75%	0.26%
1000	42000	3.85	98.33%	98.36%	0.13%
500	42000	3.85	99.92%	99.91%	0.02%
4000	41000	3.75	74.51%	74.26%	1.01%
3500	41000	3.75	77.63%	77.33%	0.93%
3000	41000	3.75	81.06%	81.22%	0.79%
2500	41000	3.75	84.73%	84.58%	0.67%
2000	41000	3.75	88.55%	88.21%	0.55%
1500	41000	3.75	92.37%	92.49%	0.36%
1000	41000	3.75	96.04%	96.23%	0.22%
500	41000	3.75	99.17%	99.22%	0.06%

Table A2

Comparison of simulated fill rate to analytical fill rate model for product with eight derivative skus: Demand = 10,000/month and Lead-time = 3 months. Simulation results based on 1000 independent replications of 16 months starting from steady state.

Forecast	Target	No Postponement			Postponement		
Error	Average	Fill Rate			Fill Rate		
Coef. of Var.	Inventory	Analytical	Simulation	Conf. Interval	Analytical	Simulation	Conf. Interval
(st.dev/mean)	(weeks of supply)	Model	Average	Halfwidth (95%)	Model	Average	Halfwidth (95%)
0.1	2.4	96.04%	96.02%	0.08%	99.75%	99.74%	0.03%
0.1	2.6	97.40%	97.41%	0.06%	99.96%	99.96%	0.01%
0.1	2.8	98.33%	98.34%	0.05%	100.00%	100.00%	0.00%
0.2	2.4	88.55%	88.67%	0.18%	98.00%	98.01%	0.13%
0.2	2.6	90.44%	90.61%	0.16%	98.95%	98.95%	0.09%
0.2	2.8	92.09%	92.18%	0.15%	99.50%	99.46%	0.06%
0.3	2.4	81.06%	81.31%	0.27%	95.61%	95.51%	0.23%
0.3	2.6	83.07%	83.46%	0.26%	97.01%	97.01%	0.19%
0.3	2.8	84.94%	85.34%	0.25%	98.03%	98.02%	0.14%

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