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Exploratory analysis of free shipping policies of online retailers

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ABSTRACT

Online retailers (or Internet divisions of brick and mortar retailers) often offer shipping discounts (for example "free shipping on orders above $150") to entice customers. The premise is that the retailer will attract more customers and these customers will likely buy more per order to avail the shipping discount, increasing total revenues and profits. In parallel, the retailer must also plan the replenishment of items sold during the free shipping promotion. This paper provides an exploratory model that analyzes (a) what form a retailer should use the free shipping promotion, and in parallel, (b) how the retailer should plan for replenishment from their suppliers.

1. Introduction

Online retailers (or the Internet divisions of brick and mortar retailers) often offer free shipping promotions to attract and retain customers. Saks Fifth Avenue, an upscale department store on its saksfifthavenue.com web site has a "FREE SHIPPING on orders of $150 or more with code: AUGSHIP10".[1] Vitaminshoppe.com, a purveyor of vitamins and supplements, has a "FREE SHIPPING on $99+ orders"[2] promotion.

Many studies have shown (see PayPal, 2008) that one of the biggest issues facing online retailers is the "abandonment" of online shopping carts. Abandonment refers to customers who "add" products to the shopping cart but when it comes time to pay and checkout, they simply leave the web site. Surveys estimate (PayPal, 2008; Mulpuru et al., 2010) that the top reasons customers abandon their shopping carts are due to high shipping costs (about 25% of all those who abandon do it due to shipping costs). Free shipping promotions are primarily designed to capture those customers who are sensitive to shipping costs.

However, there does not seem to be any consensus on *how* these shipping promotions should be run. Some retailers have free shipping irrespective of what or how much is ordered. Some ship free to members of their loyalty club (Amazon's Prime service or Overstock.com's Club O). By far, the most common form of promotion is free shipping if the order value exceeds a certain threshold amount (Barry, 2010), just like Saks Fifth avenue of Vitaminshoppe mentioned earlier. However, a quick survey of net retailers indicates that this threshold is wildly variable—anywhere from $25 to over $250 (see Istobe.com, 2010).

1.1. Model context

The context of this paper is a retailer who is offering free shipping if the customer spends more than a predetermined threshold value. The premise of the promotion is that it will give an incentive to those customers who would otherwise abandon their shopping carts to proceed and compete the checkout process. Additionally, if this retailer has the same prices on similar products as its competitors, it may attract some customers who may otherwise shop elsewhere. In other words, the promotion will likely produce more orders (Lewis, 2006; Tedeschi, 2007). The promotion will also provide incentives to customers to buy more so they can avail the free promotion, increasing the average value of a customer order (Lewis et al., 2006). The conventional wisdom is that increased customer order combined with the increased value per order will increase the overall revenue for the retailer during the promotional period.

The benefits of increased revenue are countered by multiple costs. One, the retailer now has to bear the cost of shipping to those customers who meet the threshold value. Second, retailers typically sign procurement contracts with suppliers that also outline frequency of shipments. These procurement contracts are signed prior to running promotions. If retailers do not sufficiently plan for the increased revenue from free shipping promotions, they run the risk of stocking-out, not fully taking advantage of the promotion. On the other hand, if they order too much, they run the risk of holding too much inventory. So planning inventory for the promotion may entail higher procurement levels, ordering more often from suppliers, and holding more in inventory. Third, if the profit margins are low, the retailer may never make up the cost of the free shipping promotion.

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[1] Website accessed August 19, 2010.
[2] Website accessed August 19, 2010.

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The model in this paper explores the relevant costs and benefits of running a successful free shipping promotion. Specifically, we model the number of orders and the average customer order value as a function of the threshold value—as the threshold decreases, the number of orders and the average order value increase as does the total revenue. On the other hand, decreasing the threshold increases the cost of shipping and the cost of maintaining the inventory policy needed to support the promotion. This model is unique since it encompasses total logistics costs on both the supplier and the customer side. On the customer side, the increased revenues compete with the increased cost of transportation and holding inventory. On the supply side, the cost of ordering competes with the cost of holding inventory. We construct an optimization model that gives the retailer insights on how to set threshold values for the free shipping promotion, and simultaneously, how to set order size with suppliers in planning inventory.

A second contribution of the paper comes from the fact that we model customer order value as a random variable—so when the promotion is run there is uncertainty on the total revenues. The paper constructs a simulation model based on the optimization model to provide insights into how a retailer can assess the risks of a free shipping promotion.

The remainder of the paper is organized as follows: Section 2 introduces the notation; develops the optimization model that computes the optimal threshold and inventory policy; and makes observations on model assumptions and structure. Section 3 presents a numerical illustration, introduces the simulation model, and provides insights into risks involved in running a free shipping promotion. Finally in Section 4, we present a summary and some thoughts on further research.

2. Model development

2.1. Notation

Decision variables:

- Q = order size from supplier (in $'s).
- T = threshold value. If the value of the order is above this threshold value, then shipping of the order is free.

Variables and constants:

- A = value of order, normally distributed with mean μ_T and standard deviation σ. The mean value of the order, μ_T is a function of T. For the purposes of this paper, we assume that $\mu_T = \mu_o + \alpha T^{-\beta}$, where μ_o, α, and β are positive constants.
- N_T = number of orders during the promotion period. For the purposes of this paper, we assume that $N_T = N_o + \gamma T^{-\delta}$, where N_o, γ, and δ are positive constants.
- S = ordering cost.
- h = inventory cost per dollar of inventory.
- m = profit margin on procurement cost. The procurement cost includes the product cost and the cost of transportation from the supplier to the retailer.
- p = proportion of orders that qualify for free shipping.
- r = transportation cost to the customer.
- k = safety factor for computing safety stocks.

2.2. Model

The expected profit over the course of the "free shipping" promotion as a function of the supplier order size (Q) and the Threshold value (T) can be represented as

$$E(P) = \mu_T N_T m - Q/2h - \mu_T N_T (1-m)/QS - k\sigma N_T (1-m)h - pN_T r \qquad (1)$$

The first term in the equation is the total profits less ordering cost to suppliers, holding costs of inventory, and shipping costs to the customer. The total revenue over the course of the promotion is $\mu_T N_T$. This multiplied by m gives the profits made on procurement. The second term in the profit function is the cost of holding inventory. The average inventory, $Q/2$, multiplied by the cost of inventory h gives the cost of inventory holding during the promotion. The third term is the cost of ordering replenishments from the suppliers. The total number of orders during the promotional period is $\mu_T N_T (1-m)/Q$. Therefore multiplying the number of orders by the cost per order S is the total ordering costs. The fourth term in the expected profit is the cost of holding safety inventory. The standard deviation of revenue at cost (this is a surrogate for demand) is $\sigma N_T (1-m)$. The retailer chooses k so that a desired level of uncertain demand can be satisfied (see Silver et al., 1998). For example, $k=1.96$ would cover 95% of demand. The final term in the profit function is the cost of shipping to the customer. The proportion of orders that qualify for free shipping, $p = P(A = a > T)$. Since r is the cost of shipping per shipment, the total shipping cost to customers is $pN_T r$.

As the threshold value T decreases, it increases both μ_T and N_T and therefore the profits (the first term in (1)). A decrease in T also increases the number of orders, the cycle and safety inventory, and the cost of customer shipping. The optimal T will balance the increases in profits with the increases in the cost of maintaining inventory and the customer shipping costs. Numerical techniques can be used to compute the Q and T that maximize $E(P)$. In this paper, we focus on the optimization of the expected profit. Since the average value of the order is normally distributed the profits will also be distributed around $E(P)$. The explicit assessment of risk of the free shipment promotion is outside the scope of this paper. However, the numerical illustration in Section 4 provides insights on how the retailer can assess the risk of the promotion.

2.3. Observations on how T impacts revenue and shipping costs

The following three observations explore the impact of threshold price on the customer-side economics. These observations are based on the assumed functional forms of μ_T and N_T.[3]

A1. The average value of an order is a decreasing function of T, with a minimum at μ_o.
A2. The number of orders during the promotion period is a decreasing function of T, with a minimum at N_o.
A3. The proportion of orders that qualify for free shipping is a decreasing function of T.

2.4. Proof

A1. Since $\lim_{T\to\infty} \mu_T = \mu_o$, μ_o represents the average value of the order without the promotion. The "free shipping" promotion increases the average value of the order to a value above μ_o. The parameters α and β control, for a given T how much the average value of the order increases beyond μ_o. Since $\partial\mu_T/\partial T < 0$, (a) follows. The point elasticity (wrt T) of the average order value for a given T is $-\alpha\beta T^{-\beta}/\mu_T$. This elasticity increases with T but is

[3] As one referee pointed out, this paper does not formally validate the functional form of μ_T and N_T by empirical data or case-based data. It is based on the authors' experience with multiple retailers – that μ_T and N_T are decreasing functions with a lower bound.

always <1, suggesting a relatively inelastic relationship between the threshold price and the average order value.

A2. The number of orders during the promotion, while deterministic, follows a function similar to the average order value. $\lim_{T\to\infty} N_T = N_o$, N_o represents the number of orders without the promotion. The premise is that free shipping will induce more orders, increasing the number of orders during the promotion to a value above N_T. The parameters γ and δ control, for a given T how much the number of orders increase beyond N_o. Since $\partial N_T/\partial T < 0$, (b) follows. The point elasticity (wrt T) of the number of orders for a given T is $-\gamma\delta T^{-\delta}/N_T$. This elasticity increases with T but is always <1, suggesting a relatively inelastic relationship between the threshold price and the number of orders.

A3. The proportion of orders that qualify for free shipping $p = P(A = a > T) = 1 - \int_{-\infty}^{T} \phi(z)\partial z$, where ϕ is the pdf of the Standard Normal distribution and $z = (a-\mu_T)/\sigma$. Note that $\partial p/\partial T = -e^{(\mu_T - T)^2/2v^2}(1+\alpha\beta T^{-1-\beta})/\sqrt{2\pi}\sigma < 0$.

Therefore with increasing T, p decreases from 1 to 0 and has a sigmoid form (the mirror image of the Normal cdf function).

2.5. Observations on how T interacts with Order Size Q to the suppliers

B1. The optimal order quantity Q^* takes the form $\sqrt{2S(1-m)\mu_T N_T/h}$

B2. The optimal number of orders is given by $\sqrt{(1-m)\mu_T N_T h/2S}$.

B3. The optimal inventory on hand is $\sqrt{(1-m)\mu_T N_T S/2h} + k\sigma N_T(1-m)h$.

2.6. Proof

B1. $\partial E(P)/\partial Q = -h/2 + (1-m)S\mu_T N_T/Q^2$.

Solving for $\partial E(P)/\partial Q = 0$ yields the result in B1. This is the familiar *EOQ* form. For a given T, as Q increases (decreases), the number of orders to the suppliers decreases (increases) but the inventory holding costs increases (decreases). The optimal Q balances these two costs. Since the demand changes with T, the optimal Q^* depends on T.

B2. The number of orders is $\mu_T N_T(1-m)/Q$. The result is got by substituting for Q^* from B1.

B3. The optimal inventory is the sum of cycle and the safety stock: $Q^*/2 + k\sigma N_T(1-m)h$. Substituting for Q^* proves B3.

The above observations provide insights into the trade-offs involved with adjusting the threshold level and the order size. For lower levels of T, μ_T and N_T are higher, producing a higher revenue. However, as B3 shows, so will be the proportion of orders that are shipped free. Lower T also means that more inventory is needed on hand to maintain the desired level of service that could warrant more frequent orders from the suppliers. The optimal T will balance the benefits of increased revenue with the cost of running the promotion—shipping and inventory. The optimal Q will balance the supply-side cost economics—ordering from suppliers with the cost of cycle inventory.

3. Numerical illustration and discussion

Consider a retailer whose average order value is normally distributed with mean $\mu_o = \$100$ and a standard deviation $\sigma = \$2$. The number of orders $N_o = 75$ over a period of time a typical free shipping promotion is run. All relevant parameters are available in Table 1.

For illustrative purposes, we will call this the "base case" and will use this as a benchmark to compare it to the retailers' promotion strategy. The base case is a special case of the free shipping promotion when $T\to\infty$, i.e., the customer always pays for the shipping. The expected profit under the base case scenario is simply the mean procurement profit less the cost of ordering, holding both cycle and safety stock. If Q_b is the order size under the base case, the expected profit can be represented as

$$E(P) = \mu_o N_o m - Q_b/2h - \mu_o N_o(1-m)/Q_b S - k\sigma N_o(1-m)h. \quad (2)$$

As Table 1 shows, the optimal value of Q_b is 1299.04 and the expected profit is \$361.19.

The retailer plans a free shipping promotion where the customer gets free shipping if the order value is above a threshold value T. The premise is that the threshold will entice more customers to shop increasing the number of orders and a portion of customers will likely spend at least T increasing the average order value from its current levels (μ_o).

Fig. 1 shows how the average order value and the number of order change with T (the functional parameters are in Table 1). The Figure illustrates observations B1 and B2—the average order value and the number of orders increase exponentially but with diminishing returns with decreasing T.

Fig. 2 illustrates the sigmoid form of how the proportion of orders shipped free changes with T. As T decreases, the proportion shipped free increases, cutting into the benefits of increased revenue from lower thresholds.

Based on model assumptions, the retailer also predetermines the order size and the frequency of shipments prior to the promotion. While a lower value of T may provide the customer an incentive to buy more, the retailer will lose this opportunity if

Table 1
Input parameters and optimal solution.

Inputs		Derived values	Base case	Promotion
m	0.10	μ_T	100.00	102.76
h	0.20	N_T	75.00	77.87
S	25.00	p	0.00000	0.00012
k	2.00	Number of orders	5.20	5.37
r	15.00	Cycle stock	649.52	670.91
α	150.00	**Costs**		
β	0.85	Procurement	\$6,750.00	\$7,201.86
σ	2.00	Ship to customer	\$0.00	\$0.15
μ_o	100.00	Safety inventory	\$54.00	\$56.07
γ	250.00	Cycle inventory	\$129.90	\$134.18
δ	0.95	Ordering	\$129.90	\$134.18
N_o	75.00			
		Decisions		
		Order from suppliers (Q_b)	1299.04	
		Order from suppliers (Q)		1341.81
		Threshold (T)		\$110.08
		Profit ($E(P)$)	**\$361.19**	**\$395.61**

Fig. 1. How μ_T and N_T change with T.

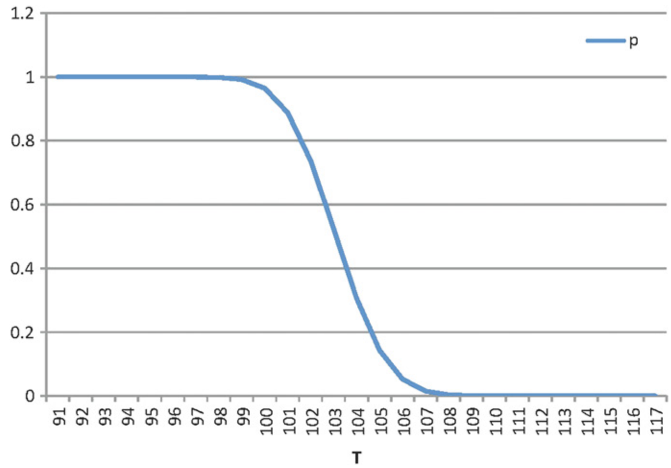

Fig. 2. How p changes with T.

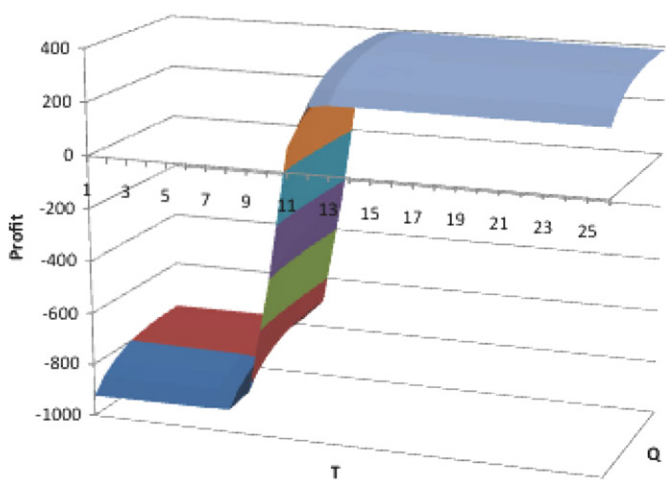

Fig. 3. How $E(p)$ changes with Q and T.

inventory policy is poorly planned. For example, if the total procurement amount over the period of the promotion is smaller than the demand, there will be lost sales. On the other hand excess amounts procured will incur the cost of holding inventory.

The form of the expected profit makes analytical computation intractable. So numerical techniques like the Newton or Conjugate Gradient methods are used to compute the optimal solution. Table 1 gives the optimal solution—an order size $Q=1341.81$ and a threshold value of \$110.08. This policy means that the retailer expects on average the order value to be \$102.76 and the number of orders to be 77.87. Therefore the retailer will procure at cost $\$102.76*77.87*90\% = \$7201.86$ from the supplier. Since the order size is 1341.81, 5.37 orders will be procured from the supplier over the course of the promotion.

Fig. 3 shows the surface graph of the expected profit function, with its peak denoting the optimal decision parameters. The optimal value is \$395.61. Based on the model parameters, at least on average the promotion seems to have worked with an average profit increase of 14.88%. Noteworthy observations when compared to the base include that fact that the promotion has forced the retailer to hold more cycle and safety inventory, order more frequently, and incur a shipping cost to the customer. However, the increases in average order value and the number of orders increased revenues significantly enough to make more profits than the base case.

3.1. Insights into assessing risk of the promotion

Since the order value is a random variable, there is uncertainty associated with the actual order value. It impacts profits in an important way. If the average order value is higher than expected, so is the potential revenue from the promotion. Safety stock will protect the retailer to a desired service level—but a higher than expected order value can lead to significant lost sales. If on the other hand, the average order value is smaller than expected, the retailer will be forced to carry inventory on hand on the unsold value that has been procured from the supplier.

Ultimately, the retailer is interested in the range of profits for both the base case and the promotion to better evaluate the success of the promotion. To provide a better insight, a simulation model was constructed to evaluate profit for both the base case and the promotion.

For the base case, we use $Q_b = 1299.04$ as the inventory policy. So the retailer orders 1299.04 units 5.2 times during the course of the promotion. The average order value is sampled from a Normal distribution with mean $\mu_o = 100$ and standard deviation $\sigma = 2$. The random sample multiplied by the number of orders (at cost) is the demand during the promotion. If the demand is greater than the sum of the cycle and safety inventory, then the retailer will sell out. If the demand is less than the on-hand inventory, than inventory will be left over with the obvious cost of carrying it. The simulation ran 10,000 replications for the base case and the histogram for the profits is shown in Fig. 4(a). Profits range from \$313.52 to \$366.59 with a mean of \$358.21. The standard deviation is 9.6. The distribution as expected is skewed—this represents cases where the order value was less than what was planned for (the model planned for selling more than expected by including safety stock), selling less with inventory left over making lower profits.

To simulate the promotion, the optimal order size of 1341.81 is used for planning inventory. Since the optimal threshold is \$110.08, the corresponding values of μ_T and N_T are 102.75 and 77.87 respectively. The expected revenue is $102.75*77.87 = 7201.86$ which translates to 5.36 from the suppliers. The order value is sampled from a normal distribution with mean $\mu_T = 102.76$ and standard deviation $\sigma = 2$. Just as in the base case, the actual demand is computed from the sample, and if it is greater than 7257.93 (the value of expected demand + safety stock), then the retailer has run out. On the other hand, if demand is less than 7257.93, there is inventory left over. Based on the random same, the proportion of orders that qualify for free shipment is computed and therefore the cost to ship them can also be calculated.

Fig. 4(b) shows the results of the simulation. The profits range from -158.61 to 400.71 with a mean of 381.76. The standard deviation of the profit under the promotion is 21.96.

The two empirical distributions in Fig. 4(a) and (b) provide a way to evaluate the promotion. Given the parameters in this illustration, the promotion has worked very well. For example, based on the simulated profits, there is only a 5.27% chance that the promotion will provide a profit of less than \$366.59, the maximum observed value in the base case.

In a typical situation, the retailer will have to estimate the functional parameters α, β, γ, and δ from historical data. These data will include past promotions and how the order value and the number of orders change with T. It is also common for retailers to change the product assortment from promotion to promotion – so to get a better insight into the efficacy of the promotion, the retailer also needs to access the impact of the sensitivity of the profit to a range of estimated values of α, β, γ, and δ.

Table 2 gives the expected profit and the standard deviation for different values of α and β. The values of all other parameters

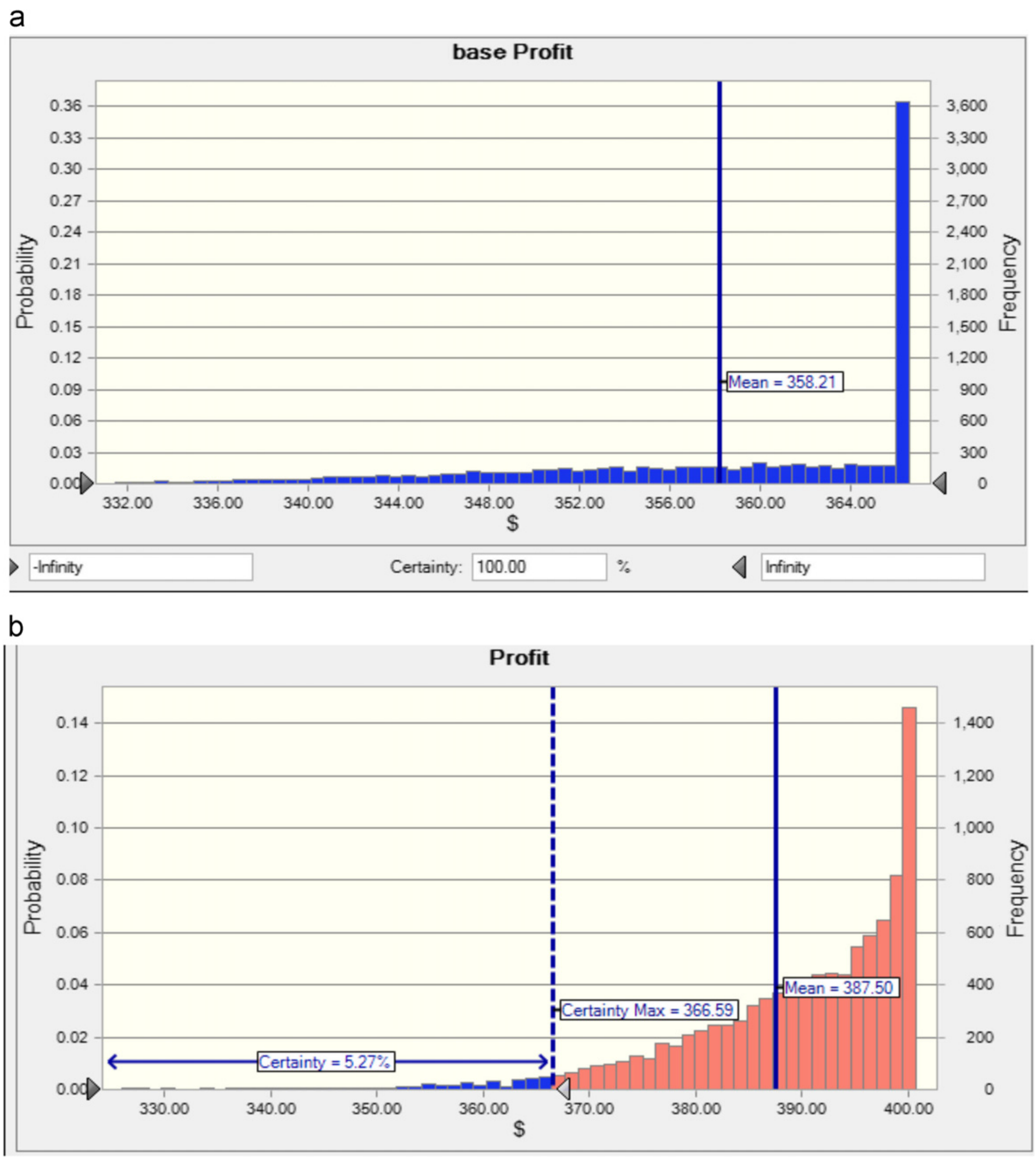

Fig. 4. (a) Base case profit distribution. (b) Profits under free-shipping promotion.

Table 2
Expected profit and standard deviation for different α and β values.

β/α	130	140	150	160
0.65	413.62, 17.66	416.09, 26.99	418.56, 28.50	421.01, 21.14
0.75	401.37, 27.56	402.94, 12.87	404.51, 26.14	406.08, 32.51
0.85	393.61, 21.14	394.61, 17.63	395.61, 23.90	396.60, 16.76
0.95	388.71, 25.42	389.34, 23.13	389.97, 18.15	390.60, 13.57
1.05	385.61, 20.68	386.0, 18.73	386.41, 26.03	386.81, 28.90

Table 3
Expected profit and standard deviation for different γ and δ values.

δ/γ	230	240	250	260
0.75	422.20, 23.85	424.22, 45.89	426.24, 35.67	428.26, 27.81
0.85	404.85, 27.74	406.10, 20.17	407.36, 32.96	408.62, 20.27
0.95	394.05, 19.81	394.83, 27.83	395.61, 23.90	396.39, 24.49
1.05	387.31, 24.09	387.80, 36.67	388.29, 26.32	388.77, 25.26
1.15	383.11, 19.17	383.42, 19.58	383.72, 30.25	384.03, 25.67

are the same as in Table 1. The expected profit is the solution to the optimization problem in Eq. (1). The standard deviation is computed by simulating the model as described earlier. From Table 2, increasing α for a given β increases profits. Additionally, increasing β for a given α decreases expected profits. Both these observations are a result of the functional form of μ_T. Increasing α and decreasing β increase the average order value and eventually the profits. The standard deviation gives a way to compare the profits for different α and β values to the base case. For example, when $\alpha = 130$ and $\beta = 0.65$, the probability that the promotion will succeed is much higher than when $\alpha = 160$ and $\beta = 1.05$.

Similarly, Table 3 gives the expected profits and the standard deviation for different values of γ and δ. All other parameters are in Table 1. As we would expect, increasing γ and decreasing δ increases the expected profit. As before the standard deviation gives a way to compare the performance of the promotion to the base case.

The above range of parameters for α, β, γ, and δ are chosen for illustrative purposes. A practical approach would be for a retailer to run the optimization for any combination of these parameters to determine if the expected profit is higher than the base case. If yes, a simulation can be run to access the risk of the promotion. The retailer has to ultimately trade-off between the potential of increased profits and that of increased risk.

4. Summary and conclusion

The primary intent in this paper was to explore how free shipping promotional strategies can be structured; and simultaneously how inventory policies can be designed to maximize profits. Specifically our model considered the case of a retailer running a conditional free shipping promotion – that is a customer gets free shipping if the order size is higher than a threshold value. To plan for the increased revenue potentially generated by the promotion, the retailer also needs to plan order size and the frequency of orders from the supplier. Based on an optimization model that encompasses costs of procurement, ordering and holding inventory, and shipping to customers, our model presents the optimal threshold value and order size that maximize profits.

Additionally we also present a simulation based on the optimization model that assesses the risk of running the promotion.

Our model has many implications. First, it gives a way for a retailer to implement a data-driven model to compute optimal threshold levels. It is common for retailers to run free shipping promotions multiple times in a year. The data collected from those promotions can be used to estimate how A and N_T change with the threshold value. Most of the other data requirements—profit margin, cost of ordering and holding can be estimated from financial reporting documents (see for example, Ganeshan et al., 2004). Second, when running promotions, the model will also force the retailer to carefully plan supply contracts – often overlooked in our experience. Third, retailers can design promotion parameters to achieve a certain level of profit – this could mean aggressive threshold levels to increase revenues; and finding ways to minimize the costs associated with ordering, inventory holding, and shipping. For example, rewriting contracts with suppliers to get a lower prices with longer commitments or working with freight consolidators to save on shipping to customers.

Our model is exploratory – we see immediate potential for further research in the following areas:

- We have assumed shipping cost to be a constant. It is actually a function of weight, volume, and the distance traveled. For bulkier items traveling longer distances, the cost of transportation will be higher. So the free shipping promotion may not work in the same way for these items as it would for smaller items traveling shorter distances. Effective shipping promotion strategies are needed that incorporate weight, volume, and distance into the model.
- We have assumed exponential models for N_T and μ_T. More empirical research is needed to accurately estimate the functional form and the associated parameters of these functions.
- We have assumed that the retailer cannot change their supply contracts during the course of the promotion. A more dynamic procurement strategy will make for more richer model.

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