Reverse logistics in e-business
Optimal price and return policy

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Abstract *In an Internet direct sales supply chain, the customers buy direct from the manufacturer sacrificing the benefit of physical inspection of the product. This increases the likelihood that customers will have some dissatisfaction with the product and would like to return it. A clearly explained and generous return policy, then, will be welcome by the customers and therefore will enhance demand. From the manufacturer's point of view, this will increase revenue, but will also increase cost due to increased likelihood of return. This paper develops a profit-maximization model to obtain optimal policies for price and the return policy in terms of certain market reaction parameters. It obtains jointly a number of managerial guidelines for using marketing and operational strategy variables to influence the reaction parameters so as to obtain the maximum benefit from the market. The paper mentions several future research possibilities.*

1. Introduction

A traditional supply chain involves the distribution of manufactured goods through distribution warehouses, wholesalers, and a series of retailers. From the manufacturer's point of view, this indirect channel of sales is beneficial due to the retailer's economies of scale, reputations, and knowledge of local markets (Emmons and Gilbert, 1998). From the customers' point of view, they like the advantage of actually seeing and inspecting and sometimes trying the product physically before making the buying decision. But one of the biggest advantages for the customer is the ease of returning the item in case it does not meet the customers' expectation. In a recent survey, more than 70 percent of shoppers say that they are very likely to consider the return policy before deciding to shop (Pinkerton, 1997; Trager, 2000). Return policy, then, is seen as an important competitive weapon in the marketplace and can substantially influence product sales.

The e-business revolution in recent time has brought an alternative model for the part of the supply chain from the manufacturer to the customer. More and more manufacturers are now attempting to sell directly to the customers bypassing the traditional distributor-wholesaler-retailer chain. The motivation for this is to reduce the distribution cost and be more responsive to customers' requirement. The size of the market is also promising. According to ActivMedia research, 74 percent of the current 90 million Internet users in USA and Canada made at least one purchase over the Internet. They forecast that online revenues would reach $1.3 trillion in 2003 and $2.8 trillion in 2004

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(Wilson and Abel, 2002). From the customers' point of view the Internet purchase is advantageous because it drastically reduces the search cost, and is convenient due to the fact that the store is open 24 hours per day seven days a week. However, a common customer's concern is the lack of a proper return policy for internet purchase and the complicated logistics for returning an item. In a recent survey, Davis (2001) found that although more and more e-tailers are offering return options, brick and mortar retailers still lead the way. In their survey, Rogers and Tibben-Lemke (1999) find that 63 percent respondents felt that clear and attractive return policy is one of the most important tools to stay competitive. In this paper, we will study the topic of this reverse logistics in the area of e-business and specifically look at the optimal return policy for an Internet seller in conjunction with an optimal pricing policy. Note that the Internet seller could be the manufacturer itself or a retailer. For the lack of an appropriate term, we will call the seller "e-tailer" in this paper.

The return policy practice in e-business varies across industry and stores, and may range from unconditional money back guarantee to store credit only to no refund whatsoever. Restrictions imposed by an e-tailer for returning include, but are not limited to, short time limits for returning the product, unused product, returned in original packaging, and special instruction on labeling. See Davis *et al.* (1998) and Rogers and Tibben-Lemke (1999) for a survey of existing return policy.

From the e-tailer's point of view, return policy constitutes a tradeoff. On the one hand, a generous return policy, a proven tool to increase customers' confidence, would increase sales revenue by inducing more customers to buy. On the other hand, it would increase the cost of business substantially. Last year the Spiegel Group shipped $1.5 billion of merchandise from its Spiegel, Eddie Bauer, and Newport News catalogs and Web sites and saw $300 million in returns (Trebilcock, 2002). The cost increase is due to the higher quantity of returned merchandise. Returned merchandise has always been a problem for all parties in the supply chain due to the disruption in operations and headache in processing returned merchandises that could take range from 2 percent to 50 percent of total sales (Rogers and Tibben-Lemke, 1999). In addition to that, many of these returned merchandises are resold with significant discount if not sold at scrap value. According to Gartner Group, by 2002, online store will take back merchandise worth $11 billion that will result in a loss of about $1.8-2.5 billion (Richardson, 2001).

In this paper, we will study the issue of the trade-off mentioned above. A generous return policy would increase sales revenue and at the same time would increase cost, thereby affecting both sides in the profit equation. We can therefore expect that an optimum policy would exist where the resultant profit would be maximum. We also recognize the fact that price is a decision variable for the firm and the pricing policy is related to the return policy. The specific question we will address in this paper would include the definition of a generous return policy, optimal return policy, and optimum pricing policy for a profit maximizing firm.

The rest of this paper is organized as follows. In the next section, we will review the existing literature in the area of return policy. In section 3, we will introduce our profit maximizing model and show the interactions among the variables such as price, return policy, and profit in the presence of various market reaction parameters. We also present the optimality conditions for our model. In section 4, we present our main results on optimal policies and sensitivity analyses. In section 5, we present the results of our numerical analysis to provide some further insights for the e-tailer. Section 6 concludes the paper with a summary of managerial implications and suggestions for future research.

2. Literature review

In this section, we review the literature relevant to our paper namely in the areas of pricing and return policy decisions in both direct and indirect channels of distribution and in the areas of reverse logistics of supply chain. First category in these areas examines the effect of discounting of price on ordering decision and inventory level. Parlar and Wang (1994) study discounting and ordering decisions of seller and buyer in a single period game theoretical framework. They show that both seller and buyer can gain significantly from quantity discount scheme by ordering more. Lal and Staelin (1984) examine a quantity discount pricing scheme to alter ordering behavior of their customers. Another body of research focuses on retailer's response to marketing effort.

There are several works that focus on retailer's response to manufacturer's return policy directly. These studies examine the effect of manufacturer's return policy on retailer's ordering behavior and inventory level. Pasternack (1985) models a pricing policy and return policy using a single period newsboy setting with the retail price determined exogenously. Emmons and Gilbert (1998) examine the behavior of a retailer in the presence of return policy and uncertainty of demand. Webster and Weng (2000) considered a system when manufacturer offers a rebate to retailers for unsold inventory at the end of season for a short life cycle product. They investigated the risk and return of return policy in the presence of demand uncertainty. Marvel and Peck (1995) examines pricing policy, return policy and inventory by incorporating two types of uncertainties, customers' arrival and customers' valuation.

Padmanabhan and Png (1995, 1997) demonstrate the strategic role of an unlimited full return policy. They use a single period game theoretic model where the manufacturer behaves like a Stackelberg leader to illustrate that a return policy can increase a manufacturer's profit by increasing the intensity of retail competition. They limit their analysis to a comparison between two extreme policies i.e. no return policy and full return policy. Tsay and Agrawal (2000) investigated the effect of price and service competition to a supply chainperformance with two competing retailers and one manufacturer but did not consider the effect of return policy on the quantity of merchandises being returned. Lee (2001) studies the role of inventory, price discount, and return policy in supply chain coordination with a two period newsboy problem. All of these works study return policy from the manufacturer's point of view. Their setting is manufacturer-retailer system that is different from the direct channel setting used in our work. Also, they only examine return policy at extreme points i.e. full return policy and no return policy.

There are only a few studies that examine customer's response to retailer's return policy. One study used statistical model to demonstrate the relationship between return quantity, price, and time factor in apparel industry and show that there is a positive relationship between return quantity and retail price. Wood (2001) uses experimental design study to examine the effect of return policy on customer's purchasing decision in remote purchase setting. She observes that a remote retailer has greater variance in terms of return generosity compared to brick and mortar stores and finds that more generous return policy results an increase in probability of order.

The following works analytically examine customer's response to retailer's return policy. Davis *et al.* (1998) examine return policy at retailer level. Sarvary and Padmanabhan (2001) view return policy as an efficient demand-learning tool for manufacturer and retailer rather than a simple insurance against unsold inventory. They show that the return policy is an efficient way to reduce uncertainty about product demand in the case where accurate estimate of demand is not available. These works too only consider two extreme policies i.e. no return and full return policy and do not examine the effect of return policy on retail price.

Our work differs from the existing research in the areas of pricing and return policies in three distinct ways. First, we examine the return policy in the context of the e-business setting where the manufacturer or a retailer is selling directly to customer via Internet. This situation is unique in the sense that customers are wary of the difficulty of returning an item in case it is defective or is different from what they envisioned it to be (especially important because in this case they lack the opportunity to examine the product physically as is possible in a brick and mortar store). Second, we study the interaction of two important decision variables, namely price and the return policy. We do not consider price as an exogenous variable but a decision variable jointly being optimized along with the return policy. The advantage with this approach is that we may get an insight into the case where the firm can possibly charge higher price for a more generous return policy. Third, we are not just considering the two extreme return policies namely no return and full return. Our decision variable is the returned amount given by the firm to the customer and is continuously variable. Furthermore, we do not place any restrictions on the quantity of return. We present our model, incorporating all the above, in the next section.

3. Model formulation

We consider a simple supply chain system consisting of two parties: the e-tailer who sells a product and customers who buy the product. We formulate the flow of payment as follows. A customer buys a product from e-tailer and pays p dollars. After receiving and trying the product, the customer may decide that it does not match his/her expectations, and then decide to return the product. The e-tailer will give r dollars back to the customer as the refund amount ($0 \leq r \leq p$). We can interpret that e-tailer offers no return if $r = 0$ and full refund if $r = p$. In addition, higher r means that the e-tailer is practicing more generous return policy. Mathai (2002) gives a list of retailers resorting to varying their return policy.

3.1. Formulating the demand function

We assume that a generous return policy offered by the e-tailer will generate higher demand. Reda (1998) cites Best Buy tightening their return policy (decreasing r) and found that demand also decreases. Davis (2001) believes that minor adjustments to e-tailer's business strategy such as a simple return policy can increase sales. At the same time, higher price is assumed to have a negative impact on the demand. The demand for the product D is a function of both p and r.

$$D = f(p, r) \tag{1}$$

$$\text{with } \frac{\partial D}{\partial p} < 0 \text{ and } \frac{\partial D}{\partial r} > 0. \tag{2}$$

Without any loss of generality, we assume a linear demand function as used by many researchers in this area (Tsay and Agrawal, 2000; Padmanabhan and Png, 1997; Parlar and Wang, 1994; Zhao and Weng, 2002) and assume that the demand of the product will take the following form:

$$D = \alpha - \beta p + \gamma r. \tag{3}$$

The parameter α, β, and γ are explained as follows. $\alpha > 0$ represents the primary demand which does not depend on the price or the return policy. This base demand depends on factors such as product quality, brand image, and general economic factors manipulations of which are outside the scope of this paper. $\beta > 0$ is the sensitivity of the demand with respect to price. Specifically, as p increases, demand is reduced from its base value at the rate of β units. $\gamma > 0$ on the other hand, is the sensitivity of demand with respect to the return policy and represents the rate of demand increase from the base value as return policy become more generous (increasing r).

3.2. Modeling the return function

In our model, the e-tailer is allowing the customer to return the item for a refund of r dollars. While this policy will motivate more demand (see equation (3)), this will also generate more quantity returned by the customer. We model this by the following linear equation:

$$R = \phi + \psi r \tag{4}$$

where R is the returned quantity. Parameter $\psi > 0$ is the rate of return with respect to the refund amount r motivating more people to return because returning the item becomes more and more worthwhile. $\phi > 0$ is a base return quantity which depends on factors other than the refund amount. As seen in equation (4), we assume $\frac{\partial R}{\partial r} > 0$.

3.3. Profit function

The profit to the e-tailer can be written as:

$$\pi = Dp - Rr \tag{5}$$

where Dp is the total revenue obtained by selling D units at a price p per unit and Rr is the total amount refunded to customers who returned the items. Note that Revenue should be net of production cost and the returned amount should be net of any salvage value obtained from the returned goods. We eliminate these from our equation to simplify the treatise without losing any generality because optimal policies will not be affected by them as they are not decision variables in our model. Plugging in equations (3) and (4) into equation (5), we get:

$$\pi = (\alpha - \beta p + \gamma r)p - (\phi + \psi r)r. \tag{6}$$

As can be seem from equation (6), the effect of an increasing r is not obvious because it increases one element of the profit function but reduces the other. The objective of the firm would, therefore, be to decide on the optimal pricing and return policies to maximize profit. In what follows next, we will establish the optimality conditions and then obtain insights regarding the form of the optimal policies. Proofs of all results are not included in the Appendix.

P1. Under the condition of $4\beta\psi - \gamma^2 > 0$, the profit function given in equation (6) is concave and has a unique maxima.

To verify the behavior of the profit function as the values of decision variables varies, we resort to a numerical solution method. The values of the various exogenous parameters used in the numerical solution are given In Table I.

In Figure 1, we show how the profit function varies as the price p is increased for a given r. The plot confirms *P1* that the profit function is concave. We also see that as r is increased as a percentage of price, profit also increases for a given p, so does profit. Figure 2 shows the variation of maximum profit when r (as a percent percentage of the price) increases for a given price. Again the function is concave. Also, when p increased, we see that maximum profit also increases. One interesting observation from Figure 2 is that when price is

Table I.

Parameter	α	β	γ	ϕ	ψ
Value	1,000	7	5	10	3

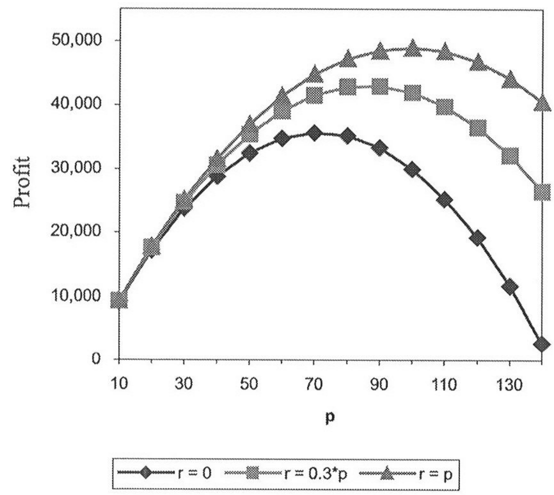

Figure 1.
Variation of profit with price for a fixed of return policy

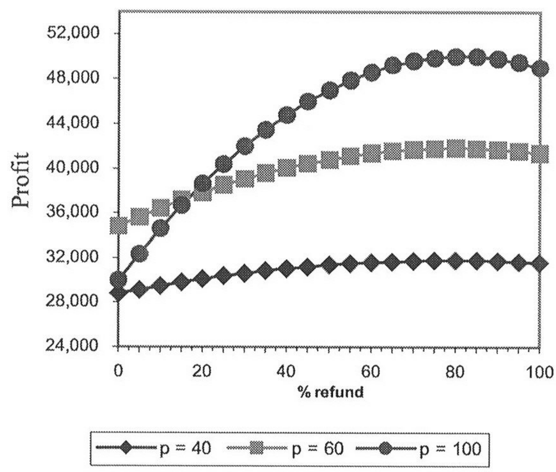

Figure 2.
Variation of profit with return policy for a fixed price

very high with no return policy, the profitability suffers and is quite low. It improves as more generous return policy is offered.

Given *P1*, we know that the concave profit function will have unique maxima for p and r in terms of the sensitivity parameter. In the next proposition, we obtain the closed form solutions for our decision variables p and r, in terms of the market parameters.

P2. Under the condition of *P1*, the optimal policies are given as follows:

1. The optimal price is given by the equation: $p^* = \dfrac{2\alpha\psi - \gamma\phi}{4\beta\psi - \gamma^2}$

2. The optimal return policy is given by the equation: $r^* = \dfrac{\alpha\gamma - 2\beta\phi}{4\beta\psi - \gamma^2}$.

By substituting p^* and r^* from *P2* into equations (3) and (4), we obtain the demand of the product and return quantity functions as:

$$D^* = \beta\left(\frac{2\alpha\psi - \gamma\phi}{4\beta\psi - \gamma^2}\right) \tag{7}$$

$$R^* = \frac{\alpha\gamma\psi + 2\beta\phi\psi - \gamma^2\phi}{4\beta\psi - \gamma^2}. \tag{8}$$

Above, we found analytical expressions for optimum policies regarding price and the return policy and the resultant product demand and the return quantity, all in terms of the five sensitivity parameters. Given the basic demand and return functions, the optimal policies can, thus, be calculated using the parameters which basically are market reactions to the firm's decision.

Observation 1. In a rational market, price and demand are positive. We, therefore, will assume that $2\alpha\psi > \gamma\phi$. Similarly, since return policy cannot also be negative then $\alpha\gamma \geq 2\beta\phi$. In the next section, we will present the result of sensitivity analyses, where we will obtain managerial insights into the ways the optimal policies change if these market reactions parameters are influenced to change.

4. Sensitivity analysis

In this section, we will analyze the effect of any change in the sensitivity parameters to the decision variables. The objective of this study is to generate a number of managerial guidelines that can be used for making decisions regarding return policies. First, we analyze the effect of changes in the market sensitivity parameters β, γ, and ψ.

P3. In a market where customers are less price sensitive (decreasing β), the firm should offer a more generous return policy and at the same time will be able to charge higher price.

Corollary 1. In a market described above, where the price sensitivity (β) is decreasing, optimum pricing and return policies will generate higher demand for the product but the firm will also see higher return quantity.

The results in *P3* and Corollary 1 are not obvious. In a market where customers are less price sensitive, marketers find it quite difficult to formulate an appropriate marketing strategy. It would seem that a price increase in such a market may not have significant impact and thus should not be resorted to. *P3* and Corollary 1 establish important managerial guidelines. If the firm can use strategy variables such as advertising and/or product quality and influence $\beta$to decrease, then it would be able to charge a higher price and offer more generous return policy leading to increased demand and profit even though the return quantity would increase.

In the next proposition, we will study the optimum policy in a market where customers like to see generous return policy. In general, internet marketing falls in this category. Here customers are not able to physically inspect the product and therefore welcome a more generous return policy. This behavior is modeled by increasing the value of the parameter γ.

> *P4.* In a market where the demand is increasingly more sensitive to the return policy (increasing γ), the optimum price will increase and the firm should offer more generous return policy.

Corollary 2. In a market as characterized above (increasing γ), demand and return quantity would both increase.

P4 and Corollary 2 give an interesting managerial guideline. A higher γ is desirable because it increases both demand and price and also increases profitability. It is, therefore, worthwhile for the manager to employ any possible means to influence the market to increase γ. For example, the firm can use advertising and/or other promotional means to make customers aware of its generous return policy and therefore can see an increase in γ. This point is also mentioned by Padmanabhan and Png (1995) that "a manufacturer that accepts return will invest in advertising and promotion." Here we get analytical confirmation for that statement.

Next, we will study the behavior of the optimal policy *vis-à-vis* a change in the parameter ψ, which represents the rate at which the customer will return the product for a given return policy:

> *P5.* If the firm can decrease the rate at which the customer returns the item for a given return policy (decreasing ψ), then it will be able to charge a higher price and offer a more generous return policy.

Corollary 3. With decreasing ψ as in *P5*, demand and return quantity would both increase.This proposition too gives an interesting managerial guideline. As we see, a decrease in the value of the parameters ψ is desirable, just like an increase in the parameter γ in *P4*. The question is how can a manager influence the value of ψ. Note that ψ is the rate at which the customer returns the item for a given return policy. Now, for example, if the manager increases the quality of the product or increases the attractiveness of the product by some other means, then for the same refund amount more people will be inclined to keep the product rather than returning it. This will mean a reduction in the rate of return. This example is also consistent with signaling theory (see Chu, 1992; Kirmani and Rao, 2000). When a seller or manufacturer believes that the likelihood of customer returning the product is low i.e. low ψ, a seller will invest more on return policy i.e. offering more generous return policy. Another example of effective way to decrease ψ can be found in Cruz (2001) which cites Tech Data and Ingram Micro cases. Their representatives help customers to select the right product in the first place, which effectively reduces the need for returns.

The next proposition compares the optimal price when optimal return policy, $0 < r^* < p$, is followed with that of no return policy:

P6. When a firm offers its optimal return policy (i.e. $r = r^*$), it will be optimal to charge a higher price compared to when it offers no return policy (i.e. $r = 0$).

This proposition establishes a guideline that is not intuitively obvious. It shows that following the optimal return policy ($r > 0$) will have a ripple effect where demand will increase while the firm will also be able to charge higher price. These results are consistent with previous research in the area. Padmanabhan and Png (1997) found that price with return policy will be higher since it should incorporate some kinds of insurance premium. Tsay and Agrawal (2000) also found that the level of price affect the level of service. Marvel and Peck (1995) show that high return allowance encourages retailers to gamble on customer's demand by stocking more and hence induce higher retail price. Pasternack (1985) shows that an increase in return allowances should be balanced with increase in the price.

In the next proposition, we will show that the literature which confines itself to two extreme return policies i.e. no refund and full refund (e.g. Padmanabhan and Png, 1997; Sarvary and Padmanabhan, 2001), are missing the completeness of the optimal policies. Specifically, we show that an optimum policy obtained using our model will be profitable than either of the two extreme policies.

P7. When a firm offers its optimal return policy (i.e. $r = r^*$), it will earn more profit compared to either of the two extreme policies, that is no refund (i.e. $r = 0$) and full refund (i.e. $r = p$).

5. Numerical experimentation

In this section, we report various results obtained from our extensive numerical experiments to illustrate the effect of changes in market parameters on the optimal strategy and to illustrate the effect of price and return policy level to e-tailer's profit. The other objective to numerical experimentation is to verify the analytical results we obtained in Section 4. Graphical representation resulting from this experimentation would help explain and understand the dynamics of the system.

First, we studied the effect of changing a sensitivity of the demand with respect to price on the optimal price and return policy. Figure 3 shows that when customer is less price sensitive then e-tailer can charge higher price and increase the profit. Also, as price increase, return policy becomes more generous. Figure 4 shows some interesting observations. When customer is less

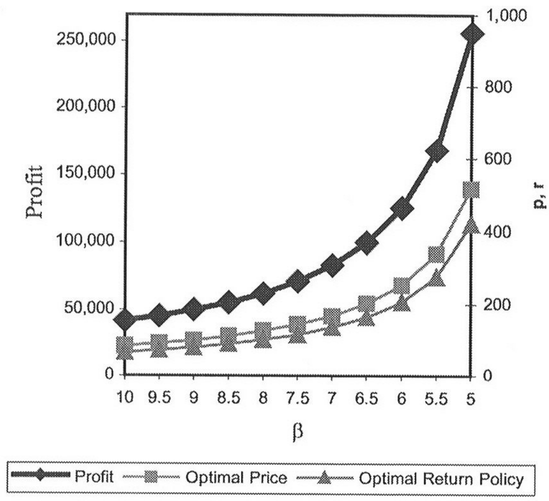

Figure 3.
Effects of varying β on profit, price, and return policy

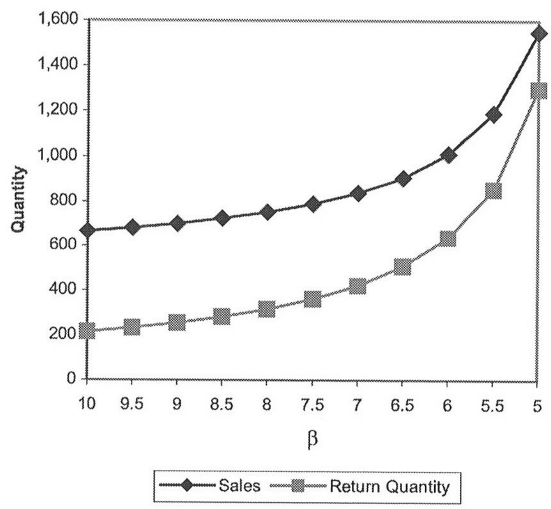

Figure 4.
Effects of varying β on sales and return quantity

sensitive to price, e-tailer can enjoy high sales volume while at the same time charging them with high price. Return quantity also increases at the same time. But overall, the profit can be maintained at a higher level because the extra revenue from charging higher price and from increased sales outweighed the increase in cost due to increase in return quantity. This is exactly what we analytically found in *P3* and Corollary 1.

Next, we study the effect of changing the sensitivity of demand with respect to the return policy (i.e. γ) on the optimal price and return policy. The results are shown in Figures 5 and 6. We see that when customer's demand is more and more sensitive to return policy (increasing γ), offering more generous return

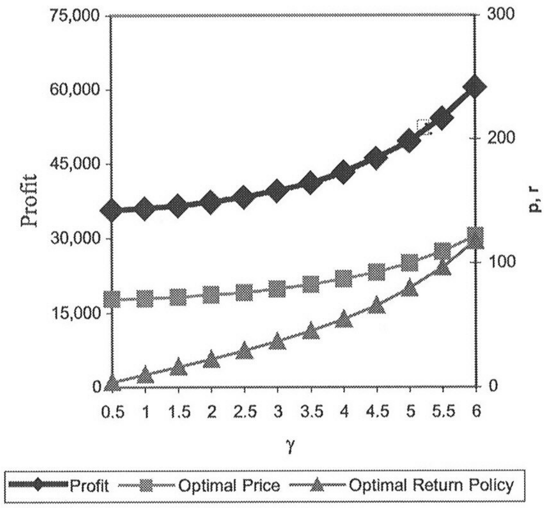

Figure 5.
Effects of varying γ on profit, price, and return policy

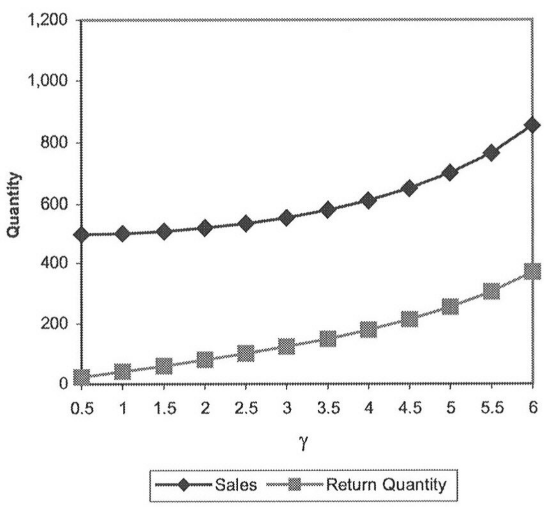

Figure 6.
Effects of varying γ on sales and return quantity

policy will increase sales. Although it is true that offering more generous return policy will also increase return quantity, it will not decrease e-tailer's profit. When customer is more sensitive to return policy, e-tailer can charge higher price to offset the cost increase due to offering more generous return policy. This confirms our analytical observation obtained in *P4* and Corollary 2. Interestingly, as γ increases, we see that the optimum refund amount approaches 100 percent of price.

Next, we study the effect of varying ψ, the rate of return with respect to the refund amount on the optimal price and return policy. Figures 7 and 8 at first

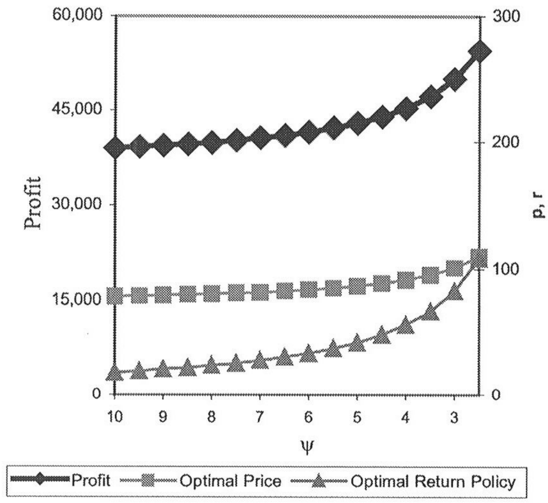

Figure 7.
Effects of varying ψ on profit, price, and return policy

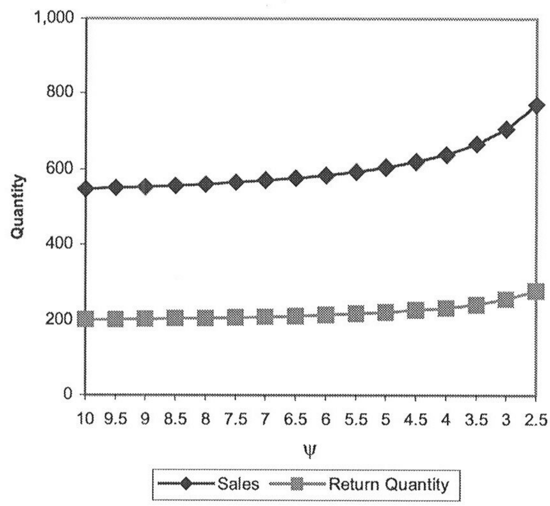

Figure 8.
Effects of varying ψ on sales and return quantity

seem counterintuitive. It shows that e-tailer offers more generous return policy when customer is less sensitive to the rate of return with respect to return policy and still enjoys high profit. This behavior can be explained as follows. When the customer is less sensitive to the rate of return parameter, offering generous or restrictive return policy will not make much difference. Offering more generous return policy means showing good faith in customer, as Padmanabhan and Png (1997) put it "Returns policies: make money by making good." The e-tailer, then, will offer more generous return policy without affecting profit level. On the other hand, when customer is sensitive to the rate of return parameter, e-tailer tends to offer more restrictive return policy because e-tailer is afraid that customer might abuse their return policy. To compensate less attractive return policy, e-tailer lowers the price to attract customers. This strategy at least helps to prevent excessive decrease in profit. Again, our *P5* and Corollary 3 predicted this behavior. Figures 7 and 8 are also consistent with what happens in practice. In electronic and apparel industry where the customers are widely known as sensitive to the rate of return parameter, we often see that sellers impose less generous return policy on their customer. On the other hand, in arts industry where the customers are less sensitive to the rate of return parameter, generally sellers offer more generous return policy.

6. Conclusions and further research

Effect of return policy on customer's buying pattern and the product's sales and seller's profit are not widely studied, especially for Internet sales. It is assumed that a generous a generous return policy is good for the firm because it will induce customers wary from "buying blind" to go ahead and buy. We modeled the buying behavior by assuming a demand function which is positively influenced by the generosity of the return policy operationalized by increasing the refund amount in case of return by the customer. At the same time, our model incorporates a return function wherein the amount returned also increased with generous return policy. The trade-off in our model then, is between increased revenue due to increasing demand and increased cost due to increased return quantity.

We obtained closed form optimal solutions for our two decision variables: price and refund amount. Our results are stated in terms of three main market parameters: price sensitivity of the customer demand (β), sensitivity of demand to the return policy (γ), and the return rate for a given return policy (ψ). From our results, we derived a number of insights into how a manager can influence these parameters using marketing and operational strategy variables to obtain the desired optimum values for the firms decision variables, price and refund amount, and get the benefit of a ripple effect to increase the optimum profit. For example, we found that if the firm uses advertising or product quality to reduce the price sensitivity of demand, it can experience higher profit while at the same time charging a higher price and offering more generous return policy.

While our model increases the threshold of existing literature in this topic, we recognize a number of ways our research could be embellished. Future research in this topic can be done in a number of areas. First, uncertainty can be incorporated in both the demand function and the return function. Stochastic demand function, for example, has been used by Krishan *et al.* (1999). We can also use a probabilistic return function because customers may decide not to return an item even if they could. Second, we can use a dynamic model where the demand for a product changes over time (following the product life cycle, for example) and we will then need to determine the values of the decision variables to determine the values of the decision variables not just as a static value as in this paper, but as a time trajectory. Third, competition can be explicitly incorporated in the model where the demand will depend not only on our price and return policy, but also on the decisions of the competitors. Finally, we can investigate the role of a third party logistics handler to whom the firm contracts out handling of the return items and their disposal.

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Appendix

Proof for P1

Hessian matrix for our profit function as stated in equation (6) is $\begin{bmatrix} -2\beta & \gamma \\ \gamma & -2\psi \end{bmatrix}$. The associated H_1 is -2β and H_2 is $4\beta\psi-\gamma^2$ where H_1 and H_2 are principal minors. The profit function is strictly concave function if and only if all nonzero principal minors have the same sign as $(-1)^k$ where k is leading principal minor. (See Winston (1997, p. 657) for more discussion on Hessian matrix.) This means that we need $H_1 < 0$ and $H_2 > 0$. $H_1 = -2\beta < 0$ as $\beta > 0$. So if $H_2 = 4\beta\psi - \gamma^2 > 0$ then the equation (6) is strictly concave. □

Proof for P2

By taking the first derivative of profit with respect to price and return policy and setting each equal to zero, we have:

$$\frac{\partial \pi}{\partial p} = \alpha - 2\beta p + \gamma r = 0 \tag{A1}$$

$$\frac{\partial \pi}{\partial r} = \gamma p - \phi - 2\psi r = 0. \tag{A2}$$

After some algebraic manipulations, one can obtain optimal price and optimal return policy in terms of market sensitivity parameters by using equations (A1) and (A2). The final equations for optimal policies are given below:

$$p^* = \frac{2\alpha\psi - \gamma\phi}{4\beta\psi - \gamma^2}$$

$$r^* = \frac{\alpha\gamma - 2\beta\phi}{4\beta\psi - \gamma^2}. \;\square$$

Proof for P3 *and Corollary 1*

Differentiating p^* and r^* given in *P2*, each with respect to the price sensitivity (β), we obtain $\frac{\partial p^*}{\partial \beta} = -\frac{4\psi(2\alpha\psi - \gamma\phi)}{(4\beta\psi - \gamma^2)^2}$ and $\frac{\partial r^*}{\partial \beta} = \frac{2\gamma(\gamma\phi - 2\alpha\psi)}{(4\beta\psi - \gamma^2)^2}$. Since the denominator is positive and the numerator is negative given Observation 1, we have both $\frac{\partial p^*}{\partial \beta} < 0$ and $\frac{\partial r^*}{\partial \beta} < 0$. Similarly, to prove Corollary 1, we can differentiate equation (7) and (8) with respect to β, will result $\frac{\partial D^*}{\partial \beta} = \frac{\gamma^2(\gamma\phi - 2\alpha\psi)}{(4\beta\psi - \gamma^2)^2}$ and $\frac{\partial R^*}{\partial \beta} = \frac{2\gamma\psi(\gamma\phi - 2\alpha\psi)}{(4\beta\psi - \gamma^2)^2}$. Since the denominator is positive and the numerator is negative, we have $\frac{\partial D^*}{\partial \beta} < 0$ and $\frac{\partial R^*}{\partial \beta} < 0$ $\square$.

Proof for P4 *and Corollary 2*

Taking derivative of p^* (given in *P2*) with respect to γ, we have $\frac{\partial p^*}{\partial \gamma} = \frac{4\alpha\gamma\psi - 4\beta\phi\psi - \gamma^2\phi}{(4\beta\psi - \gamma^2)^2}$. Next, rewrite observation 1 to:

$$\begin{aligned}
&\alpha\gamma \geq 2\beta\phi \\
&\Rightarrow 4\alpha\gamma\psi \geq 8\beta\phi\psi && \text{(Multiplying by } 4\psi\text{)} \\
&\Rightarrow 4\alpha\gamma\psi - 4\beta\phi\psi \geq 4\beta\phi\psi \\
&\Rightarrow 4\alpha\gamma\psi - 4\beta\phi\psi \geq \gamma^2\phi && \text{(Because } 4\beta\psi > \gamma^2 \text{ from } P1\text{).}
\end{aligned}$$

Therefore, we get $\frac{\partial p^*}{\partial \gamma} \geq 0$. Similarly, differentiating r^* with respect to γ, we obtain $\frac{\partial r^*}{\partial \gamma} = \frac{4\alpha\beta\psi + \alpha\gamma^2 - 4\beta\gamma\phi}{(4\beta\psi - \gamma^2)^2}$. Next, rewrite observation 1 to:

$$\begin{aligned}
&\alpha\gamma \geq 2\beta\phi \\
&\Rightarrow 2\alpha\gamma^2 \geq 4\beta\gamma\phi && \text{(Multiplying by } 2\gamma\text{)} \\
&\Rightarrow \alpha\gamma^2 \geq 4\beta\gamma\phi - \alpha\gamma^2 \\
&\Rightarrow 4\alpha\beta\psi \geq 4\beta\gamma\phi - \alpha\gamma^2 && \text{(Because } 4\beta\psi > \gamma^2 \text{ from } P1\text{).}
\end{aligned}$$

Since the denominator is positive and the numerator is positive from the above expression, we have $\frac{\partial r^*}{\partial \gamma} > 0$. To prove Corollary 2, taking derivative of equations (7) and (8) with respect to γ, we get $\frac{\partial D^*}{\partial \gamma} = \frac{\beta(4\alpha\gamma\psi - \gamma^2\phi - 4\beta\phi\psi)}{(4\beta\psi - \gamma^2)^2}$ and $\frac{\partial R^*}{\partial \gamma} = \frac{\psi(4\alpha\beta\psi - 4\beta\gamma\phi + \alpha\gamma^2)}{(4\beta\psi - \gamma^2)^2}$. Notice that the expression inside the parenthesis of the numerator of $\frac{\partial D^*}{\partial \gamma}$ and $\frac{\partial R^*}{\partial \gamma}$ are already shown to be positive. Therefore $\frac{\partial D^*}{\partial \gamma} > 0$ and $\frac{\partial R^*}{\partial \gamma} > 0$. $\square$

Proof for P5 *and Corollary 3*

Differentiating p^* and r^* given in *P2* with respect to ψ respectively will yield $\frac{\partial p^*}{\partial \psi} = \frac{2\gamma(2\beta\phi - \alpha\gamma)}{(4\beta\psi - \gamma^2)^2}$ and $\frac{\partial r^*}{\partial \psi} = \frac{4\beta(2\beta\phi - \alpha\gamma)}{(4\beta\psi - \gamma^2)^2}$. Since the denominator is positive and the numerator is negative given Observation 1, then $\frac{\partial p^*}{\partial \psi} < 0$ and $\frac{\partial r^*}{\partial \psi} < 0$. Similarly, to prove Corollary 3, we differentiate D^* and R^* given in equations (7) and (8) with respect to ψ respectively will yield $\frac{\partial D^*}{\partial \psi} = \frac{2\beta\gamma(2\beta\phi - \alpha\gamma)}{(4\beta\psi - \gamma^2)^2}$ and $\frac{\partial R^*}{\partial \psi} = \frac{\gamma^2(2\beta\phi - \alpha\gamma)}{(4\beta\psi - \gamma^2)^2}$. Since the denominator is positive and the numerator is negative, we have $\frac{\partial D^*}{\partial \psi} < 0$ and $\frac{\partial R^*}{\partial \psi} < 0$. □

Proof for P6

Setting $r = 0$ in equation (6) will yield $\pi_{r=0} = (\alpha - \beta p)p$. Taking the first derivative with respect to price and set it equal to zero will yield the optimal price when offers no return policy, $p^*_{r=0} = \frac{\alpha}{2\beta}$. Note that optimal price when offering optimal return policy is $p^* = \frac{2\alpha\psi - \gamma\phi}{4\beta\psi - \gamma^2}$ (from *P2*). Next, rewrite Observation 1 into:

$$\begin{aligned}
&\alpha\gamma \geq 2\beta\phi \\
&\Rightarrow \alpha\gamma^2 \geq 2\beta\gamma\phi \qquad \text{(Multiply by } \gamma) \\
&\Rightarrow 4\alpha\beta\psi - 2\beta\gamma\phi \geq 4\alpha\beta\psi - \alpha\gamma^2 \\
&\Rightarrow 2\beta(2\alpha\psi - \gamma\phi) \geq \alpha(4\beta\psi - \gamma^2) \\
&\Rightarrow \frac{2\alpha\psi - \gamma\phi}{4\beta\psi - \gamma^2} \geq \frac{\alpha}{2\beta}.
\end{aligned}$$

Therefore $p^* \geq p^*_{r=0}$. □

Proof for P7

First, we need to derive the expression for $\pi_{r=r^*}$, $\pi_{r=0}$, and $\pi_{r=p}$. After some algebraic manipulations, we can have the following expressions:

- From equations (5), (7), (8), and *P2*:

$$\pi_{r=r^*} = \frac{\alpha^2\psi + \beta\phi^2 - \alpha\gamma\phi}{4\beta\psi - \gamma^2}.$$

- From equation (5) and *P6*:

$$\pi_{r=0} = \frac{\alpha^2}{4\beta}.$$

- Setting $r = p$ in equation (6) will yield $\pi_{r=p} = (\alpha - \beta p - \gamma p)p - (\phi + \psi p)p$. Taking the first derivative with respect to price and set it equal to zero will yield the optimal price when offers full return policy, $p^*_{r=p} = \frac{\alpha - \phi}{2(\beta - \gamma + \psi)}$. Substituting $p^*_{r=p}$ back to the profit function will yield:

$$\pi_{r=p} = \frac{(\alpha - \phi)^2}{4(\beta - \gamma + \psi)}.$$

In order to prove that $\pi_{r=r^*} > \pi_{r=0}$, we rewrite Observation 1 into:

$$\begin{aligned}
&(\alpha\gamma - 2\beta\phi)^2 \geq 0 \\
&\Rightarrow 4\alpha^2\beta\psi + 4\beta^2\phi^2 - 4\alpha\beta\phi\gamma \geq 4\alpha^2\beta\psi - \alpha^2\gamma^2 \\
&\Rightarrow 4\beta(\alpha^2\psi + \beta\phi^2 - \alpha\phi\psi) \geq \alpha^2(4\beta\psi - \gamma^2) \\
&\Rightarrow \frac{\alpha^2\psi + \beta\phi^2 - \alpha\gamma\phi}{4\beta\psi - \gamma^2} \geq \frac{\alpha^2}{4\beta}.
\end{aligned}$$

Therefore $\pi_{r=r^*} \geq \pi_{r=0}$. Next, to prove that $\pi_{r=r^*} > \pi_{r=p}$, we can also use Observation 1 by rewriting it into:

$$\begin{aligned}
&[(\alpha\gamma - 2\beta\phi) - (2\alpha\psi - \gamma\phi)]^2 > 0 \\
&\Rightarrow (\alpha\gamma - 2\beta\phi)^2 - 2(\alpha\gamma - 2\beta\phi)(2\alpha\psi - \gamma\phi) + (2\alpha\psi - \gamma\phi)^2 > 0 \\
&\Rightarrow \alpha^2\gamma^2 - 4\alpha\beta\gamma\phi + 4\beta^2\phi^2 - 4\alpha^2\gamma\psi + 8\alpha\beta\phi\psi + 2\alpha\gamma^2\phi - 4\beta\gamma\phi^2 4\alpha^2\psi^2 - 4\alpha\gamma\phi\psi + \gamma^2\phi^2 > 0 \\
&\Rightarrow 4\alpha^2\beta\psi + 4\beta^2\phi^2 - 4\alpha\beta\gamma\phi - 4\alpha^2\gamma\psi - 4\beta\gamma\phi^2 + 4\alpha\gamma^2\phi + 4\alpha^2\psi^2 + 4\beta\phi^2\psi - 4\alpha\gamma\phi\psi \\
&\quad > 4\alpha^2\beta\psi - 8\alpha\beta\phi\psi + 4\beta\phi^2\psi - \alpha^2\gamma^2 + 2\alpha\gamma^2\phi + \gamma^2\phi^2 \\
&\Rightarrow 4(\beta - \gamma + \psi)(\alpha^2\psi + \beta\phi^2 - \alpha\gamma\phi) > (4\beta\psi - \gamma^2)(\alpha - \phi)^2 \\
&\Rightarrow \frac{\alpha^2\psi + \beta\phi^2 - \alpha\gamma\phi}{4\beta\psi - \gamma^2} > \frac{(\alpha - \phi)^2}{4(\beta - \gamma + \psi)}.
\end{aligned}$$

Therefore $\pi_{r=r^*} \geq \pi_{r=p}$. □