Working Paper Series

WORKING PAPER NO. 810

MODELING MONEY-BACK GUARANTEES AS OPTIONS

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Abstract

This paper builds a model to explain the relationship between the price of a product with money-back guarantees and the duration of the return period. Money-back guarantee arrangements are modeled as options and product prices are derived and shown to be a concave function of their duration. The feasibility and optimality of different return options are proven, and the paper demonstrates that these options should not allow consumers to allow arbitrage profits by buying short term options from many retailers. However, different consumers may choose different options based upon their prior knowledge and experience. Some of the main results of the paper are demonstrated with anecdotal evidence for money-back guarantee arrangements for computer peripherals.

MODELING MONEY-BACK GUARANTEES AS OPTIONS

In its November, 1993, issue, *International Business* magazine analyzed the reason for success (and failure) of catalog companies operating in the Japanese market. The three main reasons why 15 U. S. companies have survived in this market while an additional 45 companies failed are due to (1) high quality products (2) unique American features, and (3) the offering of money-back guarantees. Pitta (1992) in *Forbes* connects the success of Dell computers with its low marketing expenses and the fact that Dell offers a 30-day money-back guarantee on its products.

Hutchinson's Communication offered a 14-day money-back guarantee on its cellular phone, declaring that the company (Hutchinson) wanted to give customers who perceived their product and service (including the costs) to be lower than their expectation the opportunity to change their opinions.

Weargard, which advertised in its catalog full money-back guarantees for all its products at any time, for any reason, is not the only example of a no-risk purchasing decision. GAP offers a full money-back guarantee for all their products at any time if a receipt is provided and replacement of a product if there is no receipt.

On the other hand, there are hundreds of stores which offer their merchandise "as is" without money-back guarantees. From the consumers' point of view, it is reasonable to assume that the price of a product is higher when a money-back guarantee is offered than when a product is offered "as is." On average, the market fulfills this expectation. The average price at Nordstrom or GAP is higher than the price of the same products sold in privately owned stores which do not allow full money-back guarantees.

In addition, there are stores that offer duration-contingent money-back guarantees, where, for example, 100 percent of the price is refunded if the product is returned within 14 days, 70 percent is refunded if the product is returned between 15 and 21 days, and no money is refunded if the product is returned after 21 days. For example, the Used Computer Store on Shattuck Avenue in Berkeley, California, offers the following return policy: Five percent price depreciation (stocking and handling fees) for each week, i.e., if the product is returned after four weeks, the consumer gets 80% of his/her money back. Radio Shack, located on the same street, offers a different return policy: 30-day, full money-back guarantee; after 30 days, the product cannot be returned unless it is defective. The return policy of World-Net Microsystems in Milpitas, California, is 15% of the product's price will be deducted if a refund is claimed (within 30 days) and no returns of software and peripherals. Softmate Systems' return policy is a full money-back guarantee within seven days and a 20% restocking fee within 30 days of purchase.

The relationship between the price of the product and the duration of return implies that the market sets the price for the return period which is a function of the return duration; yet, no one has analyzed this relationship and its implications.

Usually the return option is offered to consumers by the retailer. The return policy is an important variable in the sales mix decision of the retailer. It has an influence on the retailer's image and has a major impact on sales and profits.

The price of a product varies among retailers and is a function not only of the return duration and the return terms, but also of the retailer's service level, image (reputation), location, in-store product variety, and other variables. Given that all the above-mentioned variables are kept constant, the relationship between the return duration and the price of the product is not clear. The price of a product may be affected by return option. In addition, price may be an increasing function of return duration. However, it can be a concave or a convex function of the return duration. If the marginal price of the product increases with the duration of the money-back guarantee option, it would be rational to assume that the consumers would be better off if they had purchased short-term contracts (to gain knowledge and pay less for the option) unless there are high transaction costs or the marginal option price is a decreased function of the return option duration.

The objectives of this paper are:

(1) To build a model that explains the relationship between the price of a product with money-back guarantees and the duration of the return periods. Differences in the duration of money-back guarantee periods reflect differences in consumers' ability to learn about product quality and about how the product meets their needs.

(2) To explain the existence of a variety of return option contracts in the market and, in particular, the existence of more than one contract for the same product at the same store.

(3) To prove that with zero consumer transaction cost, these contracts are feasible; that is, the return option is a concave function of the return duration. We model the return option accordingly, assuming that the return costs of the consumers are negligible.

The main result of the paper is that at market equilibrium a range of options with different prices tied to different return periods should be offered. These options should not allow the consumer to enjoy arbitrage profits by buying short-term options from many retailers; however, different consumers may chose different options based upon their prior knowledge and experience.

Literature Survey

Mann and Wissink (1990) argued that replacement options will dominate money-back guarantees when quality is unobservable and the costs of handling the returns are moderate. Mann and Wissink (1988) proved that money-back guarantee contracts are not efficient in the case of very low or very high uncertainty about the product's quality. Heiman, Zilberman, and Purohit (1996) analyzed the situations where demonstrations will dominate money-back guarantees and vice versa.

The process of the sale also influence the expectations of consumers and, therefore, their satisfaction from the product. Retailers who are responsible for the sales process should offer money-back guarantees (see Schmidt and Kernan, 1985; Davis, Gerstner, and Hagerty, 1995). Manufacturers influence the ability of retailers to offer money-back guarantees by determining return policies. Allowing retailers unlimited and unconditional returns increases the willingness of the retailer to sell the product but also causes overstocking and moral hazard problems.

The option to return the product if it fails to match the consumer's needs serves as a sign of quality (see Heal, 1977), reduces the risk of purchasing, increases consumers' expected utility and, therefore, increases their willingness to try new products (Davis, Gerstner, and Hagerty, 1995). As the expected utility of purchasing the product increases, the firm can either increase the product's price or keep it constant and enjoy higher probabilities of purchase. Geistfeld and Key (1991) found that retailers who handled the returns and offered longer terms for the return could increase the price of the products.

Prices with money-back guarantees have been modeled in various ways. Davis, Gerstner, and Hagerty (1995) derived the price with and without money-back guarantees explicitly using constrained linear utility functions. Mann and Wissink (1990) equalized the price to the marginal cost under zero profit constrains. Welling (1989) observed that the price with a refund will be higher than the price without a refund, because it is more costly to the firm to compensate the consumer for the defective unit. With heterogeneous consumers and homogeneous firms, prices and refunds will increase with the quality of the product, and the difference between the selling price and the refund will decrease as a function of the product's reliability. Owen (1993) modeled a situation where there is perpetual selling and the consumer can return the goods, and he concluded that the return option has its own value.

One should recall that, when a product has been sold with a money-back guarantee, the consumer actually purchases two products: the product itself and an option to return the product. The option is a buyer option, and she can use it regardless of the production quality and whether or not the product does or does not match her needs. Like any other option, this has a value which is a function of the asset price (the perceived value of the product) and the redemption conditions.

The Model

The Intuition of the Model

First, we explain the model intuitively. Then we develop the model and find the properties of the product price according to the duration of returns. Next we derive propositions which explain the relationship between the duration time and the price and the relationship between price and the probability of success. Finally, we conclude with suggestions for future research directions and managerial applications.

Imagine the following situation: Your child comes home from school very excited and tells you that next week his class will begin learning how to play musical instruments. He is interested in the saxophone and he asks you to buy him one. The price of a good-quality, second-hand sax exceeds $1,000. Of course, you do not want to purchase the sax until your child has proven consistency in his desire to learn how to play the instrument. The child himself does not know if he has any talent for playing the sax. If he had one, he could try it out for a period of time to determine if he has the ability and/or desire to play the instrument. After some months of trial, you and your child could determine if he selected the right musical instrument. However, if you purchase the musical instrument and, after some time discover your child and the instrument are not a good match, then you are stuck with a useless product. There are numerous homes with pianos that are only being used to display flower vases—a silent evidence to the many cases where a child's interest in the piano waned. On the other hand, if you purchase the sax in a store that allows you to return the product within 30 to 90 days for a full refund, you are in a better situation. The return period allows you to try the product with almost no risk. The 30-90 day trial period may not be long enough to determine some children's ability and/or desire to play an instrument but, for others, it will be sufficient.

You, as a parent and consumer, will be willing to pay more for the sax if you have the option to return it. The situation is different when you have confidence (based on past experience) in your child's ability to play the musical instrument. In this case, you would not be willing to pay for the extra cost of the return option.

This scenario is an example of many purchasing decisions. We now present another example where the learning mechanism is similar but the motivation for the test period is opposite. Here, the consumer wants to screen the product for technical defects or a mismatch. For example, when a consumer buys a printer she looks for defects or for incompatibility with existing hardware and software, in other words, a mismatch. Every day is an opportunity to test more software. The consumer will end her search when the first unmatching evidence is revealed. Again, experienced consumers (experts) will learn faster about matching than consumers without experience (novices). Consumers with diverse software and hardware packages will need more time than consumers who check for compatibility with only a few existing software packages. Finally, consumers who have previous experience with an identical product and identical hardware and software configurations will not need trial time. It is reasonable to assume that the more time is needed for learning, the higher is the price the consumer will be willing to pay for the return option. The same logic holds for the expected loss in the case of unmatched products. The higher the cost, the higher the willingness to pay for this return option.

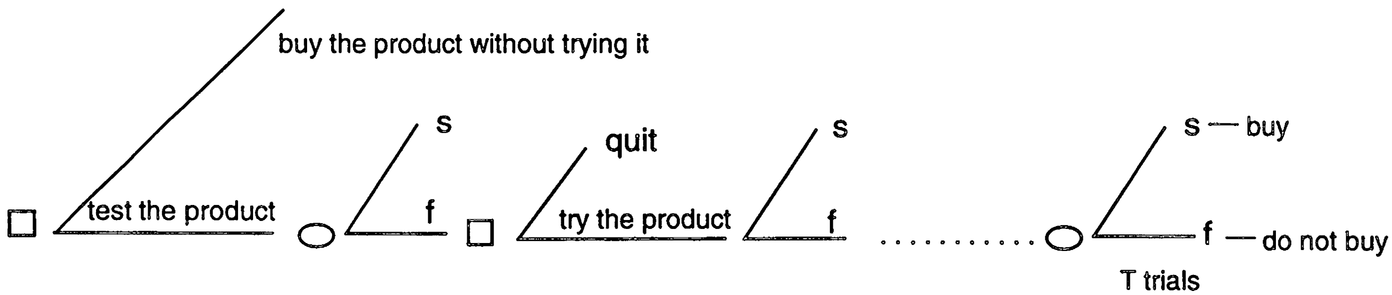
The Consumer Decision Problem

The Model

Consumers: Consumers derive utility from a durable product and from all other products. The utility from the product is a function of how well the product matches the consumer. In order to learn whether the product matches her, the consumer needs to invest learning time. Each unit of time (let's say, a day) will be treated as a test opportunity, where at the end of the test period there are two possible results: (1) product success (the consumer and the product match) or (2) failure (the consumer and the product do not match). If the consumer's trial ends in failure, the consumer tries the product once again and so on for T trials until she reaches the final conclusion (match or no match). The decision process is presented in Figure 1.

FIGURE 1

Trials and the Decision Process



The utility of the consumer if there is a match is defined as:

$$U_s = R + W - P_0.$$

The utility of the consumer of there is no match is defined as

$$U_f = W - P_0.$$

Two-Period Model

For simplicity, we assume that the interest rate is equal to zero ($r = 0$). The implication of a positive interest rate will be discussed in the "Future Research Directions and Managerial Applications" section. The probability of a good match is defined as θ and the probability of an unmatched situation is according to 1 - θ. The expected utility of the consumer without the return option is:

$$E_{wor}(\theta, P) = \theta(R + W - P_0) + (1 - \theta)(W - P_0) = \theta R + W - P_0.$$

Purchasing with return option: The consumer can purchase the product with a return option. The expected utility of the consumer with a money-back guarantee option is:

$$E_{wr}(\theta,P)=\theta(W+R-P_1)+(W-\alpha P_1)(1-\theta).$$

$1-\alpha=$ the percentage of the purchasing price being returned to the consumer $0\leq\alpha\leq1$.

The consumer will use the money-back guarantee option if and only if:

$$(R+W-P_1)\theta+(W-\alpha P_1)(1-\theta)>(R+W-P_0)\theta+(W-P_0)(1-\theta).$$

After using simple arithmetic, we get:

$$(1-\alpha)(1-\theta)P_1>P_1-P_0,$$

that is, the expected gain in the event of failure is higher than the cost of the option.

Multiperiod Model

If the consumer purchases return options for more than one period, then the probability of success for t periods is

$$\theta(t)=\theta(1-\theta)^{t-1}.$$

It is clear that the distribution function is a geometric distribution, and we can calculate $F(t)$ using the following formula:

$$F(t)=\sum_{j=1}^{j=T}\theta(1-\theta)^j=\frac{1-(1-\theta)^{T-1+1}}{1-(1-\theta)}=\left(1-(1-\theta)^T\right).$$

Prices are indexed as P_t ($t=0, ..., T$); t indicates the duration of the money-back guarantee option, $t=0$ indicates there are no return options, and $t=T$ indicates the consumer purchased a return option with a duration of T periods (days). In order to keep the model consistent, we assume that the price of the product increases with the length of the return option.

For a product with duration of return, t, the expected utility is

$$\left(W+R-P_t\right)\left(1-(1-\theta)^{t-1}\right)+\left(W-\alpha P_t\right)(1-\theta)^{t-1}.$$

Equilibrium Conditions

We assume that the market is in perfect competition; therefore, the retailer's profits are zero and equilibrium conditions reflect arbitrage. The equilibrium assumption means that we can divide the market into segments. Each segment is homogeneous in the service level, the reputation, the location, in-store product variety, and all other variables except the return duration which determines the price of the product. Each segment is large enough; that is, there are many retailers and customers. For simplicity, we assume that the retailers' cost of returns are constant over time. This assumption allows us to concentrate on the consumers' side of equilibrium and to model the net effect of learning. Introducing retailers' return costs as functions of the return duration will be described in the future research section of this paper.

Finally, we assume that each retailer at a given market sells one product (or one-product category). Alternatively, we might assume that the retailer creates a synthetic product which is a combination of all the products (combination of the probability of success, reservation price, quality, probability of moral hazard, etc. (This assumption allows us to concentrate on the net effect of duration on prices without considering the differences between products.) The implication of these two assumptions in our findings will be discussed in the "Future Research Directions and Managerial Applications" section.

At equilibrium, which reflects arbitrage, the consumer is indifferent to any two options which differ in their duration. (Note that the consumers' transaction costs are zero.) For example,

$$(R+W+P_{T-1})\left(1-(1-\theta)^{T+1}\right)+(W-\alpha P_{T-1})(1-\theta)^{T-1}=$$
$$(R+W+P_T)\left(1-(1-\theta)^{T}\right)+(W-\alpha P_T)(1-\theta)^{T}.$$

By opening the brackets, using algebraic manipulations,[1] and regrouping, we get the following:

$$(P_T-P_{T-1})-(1-\alpha)(P_T-P_{T-1})(1-\theta)^{T-1}+(1-\alpha)(P_T-P_{T-1})\theta(1-\theta)^{T-1}$$
$$+P_{T-1}(1-\alpha)\,\theta(1-\theta)^{T-1}=R(1-\theta)^{T-1}\theta.$$

Taking (P_T-P_{T-1}) as the common denominator and rearranging, we get:

$$(P_T-P_{T-1})\left[1-(1-\alpha)(1-\theta)^{T-1}+(1-\alpha)\theta(1-\theta)^{T-1}\right]$$
$$=R(1-\theta)^{T-1}\theta-P_{T-1}(1-\alpha)\theta(1-\theta)^{T-1}.$$

Rearranging, we finally get:

$$(P_T-P_{T-1})=\frac{R(1-\theta)^{T-1}\theta}{1-(1-\alpha)(1-\theta)^T}-P_{T-1}\frac{(1-\alpha)\theta(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T}$$
$$=\frac{\theta(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T}\left[R-(1-\alpha)P_{T-1}\right].$$

This is a differential equation with the following solution:

$$\int\frac{P_T-P_{T-1}}{R-(1-\alpha)P_{T-1}}=\int\frac{\theta(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T}$$

$$\frac{P_T-P_{T-1}}{R-(1-\alpha)P_{T-1}}=\frac{P'}{R-(1-\alpha)P}$$

---

1 We replace $-P_T(1-\theta)^T+P_{T-1}(1-\theta)^{T-1}$ with the following:

$$\left[-P_T(1-\theta)+P_{T-1}\right](1-\theta)^{T-1}=-(P_T-P_{T-1})(1-\theta)^{T-1}$$
$$+P_T\theta(1-\theta)^{T-1}-P_{T-1}\theta(1-\theta)^{T-1}+P_{T-1}\theta(1-\theta)^{T-1}.$$

$$\int \frac{P'}{R-(1-\alpha)P} = -\frac{1}{1-\alpha}\ln\left(R-(1-\alpha)P\right)$$

$$\int \frac{\theta(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^{T}} = -\frac{\theta}{(1-\alpha)(1-\theta)\ln(1-\theta)}\ln\left(1-(1-\alpha)(1-\theta)^{T}\right)$$

$$-\frac{1}{1-\alpha}\ln(R-(1-\alpha)P) = -\frac{\theta}{(1-\alpha)(1-\theta)\ln(1-\theta)}\ln\left(1-(1-\alpha)(1-\theta)^{T}\right)$$

$$R-(1-\alpha)\,P = Ke^{\frac{\theta\ln\left(1-(1-\alpha)(1-\theta)^{T}\right)}{(1-\theta)\ln(1-\theta)}}$$

where k is the constant of the integration

$$P = \frac{1}{1-\alpha}R - \frac{1}{1-\alpha}Ke^{\frac{\theta\ln\left(1-(1-\alpha)(1-\theta)^{T}\right)}{(1-\theta)\ln(1-\theta)}}.$$

The expression for the price of the product contains two elements: One is positively related with the reservation price of the product, and the other is a function of the probability of success, θ, the price return percentage and the duration of the money-back guarantee option. In order to explore the relative influence of each variable, we use comparative static and get the following three propositions:

Proposition 1: The price of the product is monotonic increasing with the duration of the money-back guarantee option. (For proof, see Appendix A.)

Proposition 2: The marginal price premium is a decreasing function of the money-back guarantee duration option. (For proof, see Appendix B.)

The implication of Proposition 1 is straightforward. The more time you require for learning, the higher will be the price premium you will have to pay and the higher will be the price of the product. This result is consistent with the consumers' willingness to pay for the money-back guarantee option. The longer the duration of the option, the more knowledge is gained. The lower the probability for a wrong decision, the higher the willingness to pay increases with time. From the firm's side, this result makes sense. For most products, the longer the duration period, the higher the costs of return. Fashion products and high-tech products that are characterized by a short life cycle for a given generation (model) serve as good examples. If the price of the money-back guarantee was fixed (or decreasing), the consumer might return the product after the producer launches a new model (and the old model which is returned is then worthless).

The interpretation of the second proposition is even more important. If the price function according to the length of the return option were a convex function (and not concave as we had found), equilibrium would not exist. The consumers would be better off if they bought short-turn contracts from each retailer and completed the learning duration by purchasing returns options from more than one retailer. The outcome of this scenario is that the market would shrink to one-period contracts.

Proposition 3: The higher the probability of success, the less time is needed to learn about the product and the lower the price premium on this product. (For proof, see Appendix C.)

If we assume correlation between prior experience and success probability in such a way that more experienced consumers have a higher probability of success, then the meaning of Proposition 3 is the following: More experienced customers will be willing to pay less for the learning opportunity of the money-back guarantee than customers with less experience (knowledge).

The managerial implications of Proposition 3 are related to segmentation strategy and price discrimination strategy. The firms have here an opportunity to discriminate between potential customers and offer different return contracts to different customers based on the customers' previous experience.

Anecdotal Evidence

We sampled three stores selling computers and peripherals. The three stores offer identical products and very similar levels of service. We limited ourselves to stores with only one-product category. We chose products that were identical, i.e., we could not compare generic computers because their features were different. One store, Umiracle Microsystems, offers full money-back guarantees within 30 days of purchase. The second store, World-Net Microsystems, offers, for a 1-to-30 day period, a 15% restocking fee. The third shop, Softmate Systems, offers a full seven-day money-back guarantee and a 20% restocking fee for a 8-to-30-day return duration. According to our propositions, we anticipate that the average price will be higher as the return duration increases. This relation is concave and supported, and we present the evidence in Tables 1 and 2.

Next we calculate index prices where the prices in the store that offers a flat 15% restocking fee are the basic prices. Using these indexed prices, ignoring Software Systems' two different return contracts (we refer only to the first contract—seven-day, full money-back guarantee), we estimate the relationship between price and the duration of the return period. Using the following regression, [2]

$$y = a + b \cdot t + c \cdot t^2,$$

[2]Sensitivity check: We collected 27 additional observations from five additional stores (two offering a no-return period, one offering a seven-day return period, and two offering a 30-day return period).

The regression results are:

$$y = \underset{(0.035)}{1.009135} + \underset{(0.00306)}{0.006623t} - \underset{(9.86 \cdot 10^{-5})}{0.00016t^2}$$

$$R^2 = 0.285.$$

We can see that the coefficients of the regressions are not sensitive to additional observations.

TABLE 1

	7-day, full money-back guarantee; 8-30 days, 20% restocking fee	15% restocking fee	30-day full money-back guarantee
Product	Softmate Systems	World-Net Microsystems	Umiracle Microsystems
CD ROM: Toshiba 3601B (SCSI) yx	289	278	290
Monitors: Sony 17 st	839	799	829
Sony 15 st	479	439	487
Viewsonic 17GS	729	699	755
MAG DX-16F	339	338	--
MAG DX-17F	619	599	655
NEC HXV	799	729	--
NEC HXP	1189	1029	--

TABLE 2

Product	1-30 days, 85% return	1-7 days, 100% return; 8-30 days, 80% return	1-30 days, 100% return
Monitors			
Sony 17 st	100	105.0	103.75
Sony 15 st	100	109.1	110.9
Viewsonic 17GS	100	104.3	108.0
MAG DX-17F	100	103.4	105.8
Toshiba 3601B	100	103.96	104.3

where t stands for the return period and y for the indexed prices (a, b, c are the regression coefficients), the results are:

$$
\begin{array}{lcccc}
y = & 0.976\ + & 0.012063t & - & 0.00031t \\
 & (0.035) & (0.003188) & & (0.0001)
\end{array}
$$

$$R^2 = 0.57.$$

The results provide support of our theoretical finding that the price of the product is a concave function of the return duration. The limited number of observations, stores, and products do not allow us to generalize this result, and we think that an important future research study should be a comprehensive empirical investigation.

Future Research Directions and Managerial Applications

In this paper we develop a theory of money-back guarantees as an option. Our theory is based upon the assumption that the market is in equilibrium without specifying the conditions that lead to this equilibrium. The equilibrium assumption means that the market is in a competitive situation and both the consumers and the sellers have perfect information about prices and the return duration. At equilibrium, every consumer can choose a money-back guarantee contract where the contract differs in the price of the product and the duration period. Each additional day covered by the money-back guarantee contract enables the consumers to gain more information about the product and improves their ability to make an educated purchasing decision.

Our findings indicate that the price is a concave function of the duration of the money-back guarantee contract. The concavity assures us that such an equilibrium is possible; otherwise consumers would chose to purchase short-term contracts.

Another interesting finding is that the price (as a function of the duration of the money-back guarantee) increases with the risk of product failure. Note that product failure in this paper does not mean technical failure but, rather, a situation where the product and the consumer do not match. Practically all these results can be interpreted in the following way: If the consumer knows that her probability of failure is smaller (higher) than the average probability, then she will purchase a shorter (longer) duration option.

Consumers can figure out their probabilities using their past experience. For example, consumers who use laser printers at work have more knowledge about the product than consumers who have no experience. Finally, consumers who have perfect knowledge of the product would purchase the product without money-back guarantees.

Managers of retailing firms or manufacturers would be better off to offer a variety of money-back contracts instead of the situation where some offer one type of contract and others offer another. The result of offering only one contract is that consumers with better knowledge prefer to buy in other stores which offer the product for fewer days but at a lower price.

It might be most practical to offer a limited number of contracts rather than a continuum of options because consumers may be confused by too many alternatives. Empirically, we see that stores which offer different money-back contracts indeed offer limited (4 to 5) different contracts. Stores that offer different return contracts in effect reduce the price that the customer receives after the return as a function of the return policy. Empirically, the retailers include the price of the option in the price of the product and do not offer the option separately from the product. The reason for this behavior might be the image of high service that the retailers want to present. Offering a generous return policy positions the retailer high in the service dimension and charging the consumer directly might take the air out of his balloon. On the other hand, the consumers might be better off if they could purchase the contracts separately. It would be interesting to check the consumer's attitude toward such policy. We modeled the return option without taking into account the difference in the return cost between the product and the difference in the probability of a moral-hazard situation. We were able to do this as our model is very general and could be applied to each of the product categories, but it generally does not hold in the cross-product category. We think that there is a place for a model which takes into account the cross-product category's difference in the retailer cost.

Introducing return costs as a function of the return duration changes the rules of the game. We have assumed that in equilibrium consumers are indifferent to the various return options and, therefore, the duration of the return option is determined according to the consumers' decisions. The situation will be different depending on if the costs of handling returns are constant, concave, or convex. We believe that future research incorporating retailers' return cost would highly contribute to this field of research.

In our model, we assume that the consumer's interest rate, r, is equal to zero. A positive interest rate implies that the cost of keeping the product is reduced.

The anecdotal section of this paper supports our theoretical findings but, as it is very limited in its number of observations, number of stores, and variety of products, it cannot be generalized. Further empirical research can contribute to the knowledge in this area.

Finally, our theory has been developed under a scenario where the utility has extreme values, i.e., zero utility in the cases of unmatching products. We think that it would be useful to develop a model where the consumer has some utility even in the case of unmatching products.

APPENDIX A

(Proof of Proposition 1)

$$\frac{dP}{dt} = -\frac{1}{(1-\alpha)} K e^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \cdot \left\{ \frac{-\theta(1-\alpha)\,(1-\theta)^T \ln(1-\theta)}{\left(1-(1-\alpha)(1-\theta)^T\right)(1-\theta)\ln(1-\theta)} \right\}$$

$$\frac{dP}{dt} = K e^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \cdot \left\{ \frac{\theta\,(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T} \right\} > 0.$$

APPENDIX B

(Proof of Proposition 2)

$$\frac{d^2P}{dt^2} = -Ke^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \cdot \frac{\theta\,(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T} \cdot \frac{\theta\,(1-\theta)^{T-1}(1-\alpha)}{1-(1-\alpha)(1-\theta)^T}$$

$$+Ke^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \cdot \frac{\theta\,(1-\theta)^{T-1}\ln(1-\theta)}{\left[1-(1-\alpha)(1-\theta)^T\right]^2}$$

$$\frac{d^2P}{dt^2} = Ke^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \cdot \frac{\theta\,(1-\theta)^{T-1}}{\left[1-(1-\alpha)(1-\theta)^T\right]^2}\left[\ln(1-\theta)-(1-\alpha)\,\theta(1-\theta)^{T-1}\right]$$

$$\frac{d^2P}{dt^2} < 0 \quad \text{iff } \ln(1-\theta) < (1-\alpha)\,\theta\,(1-\theta)^{T-1}, \text{ e.g.,}$$

$$\frac{1}{\theta(1-\theta)^T}\ln(1-\theta) < (1-\alpha)$$

$$(1-\alpha) \geq 0 \forall \alpha$$

$$\frac{1}{\theta(1-\theta)^T} \geq 0 \forall \theta, t$$

$$\ln(1-\theta) < 0.$$

Therefore,

$$\frac{d^2P}{dt^2} < 0$$

for all t, α, and θ.

APPENDIX C

(Proof of Proposition 3)

$$\frac{dP}{d\theta} = -\frac{1}{1-\alpha} K e^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \left\{ \frac{(1-\theta)\ln(1-\theta)}{\left[(1-\theta)\ln(1-\theta)\right]^2} \left[\ln\left(1-(1-\alpha)(1-\theta)^T\right) + \frac{\theta\ (1-\alpha)(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T} \right] \right.$$
$$\left. - \frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{\left[(1-\theta)\ln(1-\theta)\right]^2} \left[-\ln\,(1-\theta) - (1-\theta)\frac{1}{(1-\theta)} \right] \right\}$$

$$\frac{dP}{d\theta} = \frac{-1}{1-\alpha} K l^{\frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{(1-\theta)\ln(1-\theta)}} \left\{ \frac{(1-\theta)\ln(1-\theta)}{\left[(1-\theta)\ln(1-\theta)\right]^2} \left[\ln\left(1-(1-\alpha)(1-\theta)^T\right) + \frac{\theta\,(1-\alpha)(1-\theta)^{T-1}}{1-(1-\alpha)(1-\theta)^T} \right] \right.$$
$$\left. + \frac{\theta \ln\left(1-(1-\alpha)(1-\theta)^T\right)}{\left[(1-\theta)\ln(1-\theta)\right]^2} \left[\ln\,(1-\theta) + 1 \right] \right\} < 0.$$

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