Warranty Designs and Brand Reputation Analysis in a Duopoly

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When product quality is unobservable to consumers, a manufacturer can convey the quality information using signals such as warranty and brand reputation. This paper develops a non-cooperative duopoly model to study the interaction between warranty, brand reputation and product quality. Two competing manufacturers offer warranties on their respective product with different qualities, which is unobservable to consumers. Consumers make purchase decisions based on quality beliefs derived from the warranties offered and the brand reputations of the manufacturers. Factors that influence the optimal decisions of warranty and profit are analyzed.

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I. INTRODUCTION

Quality is unobservable for most goods and services before purchase. This includes virtually all services and consumer durables, as well as some quality attributes of frequently purchased items, like taste of restaurant's meals and shrinkage of clothing (Shapiro, 1982). When product quality is unobservable to consumers, a manufacturer can convey the quality information using signals such as warranty and brand reputation.

A product warranty is offered by the manufacturer to assure consumers that a product is of good quality and against defects or failures. If the product fails during the specified warranty period, the manufacturer is responsible for repairing or replacing failed parts and correcting any related problems. Due to the warranty costs in the event of product failure, the manufacturer

will need to ensure high product quality if an extensive warranty coverage is offered. On the other hand, a poor quality product with high failure rate will not be able to afford extensive warranty coverage. Thus, warranties can be used as signals of product quality, especially when the knowledge of product quality is difficult to obtain by consumers. Sahin and Polatogu (1998) demonstrate that both warranty length and warranty contents could be used as signals of product quality. Boulding and Kirmani (1993) as well as Spence (1977) also have similar findings.

Brand reputation is another important signal of product quality under information asymmetry. Brand reputation is regarded as a perception of product quality associated with a brand name. A branded manufacturer is expected to claim the true value of the unobservable product quality. A false statement would lead to unattractive future profits, according to the

signaling theory in economics. Hence, a rational consumer will associate reputable brand with good quality. Shapiro (1982) has shown that brand reputation can be modeled as an expectation of quality when consumers have imperfect information about product quality.

Empirical research has demonstrated that consumers often rely on information of warranty and brand reputation to infer unobservable product quality. Blair and Innis (1996) have shown this phenomenon by analyzing consumer data concerning two brands: Schwinn, a well-known brand in bikes and fitness equipment, and Monarch, a fictitious brand name. Consumers' responses are measured on a scale of 1 – 7 and 7 as being high. On the responses to question of how much to rely on brand information about product quality, the mean for Schwinn is 3.1 and the mean for Monarch is 1.5. On the responses to question of what level of product quality can be inferred from warranty information, using Schwinn as an example, the following means were obtained: 2-year warranties (4.63), and 20-year warranties (5.79). The data collected and studied by Soo et al. (2001) on personal computer and PIP color television sets also reports similar findings.

The empirical results demonstrate the importance of brand reputation and warranty in the study of product quality. However, theoretical work on interactions among warranties, brand reputation, and product quality is limited. Most of the theoretical work studies the quality relationship either with warranties (Lutz and Padmanabhan, 1998; Balachandran and Radhakrishnan, 2005; Padmanabhan, 1995) or with brand reputation (Shapiro, 1982), but not with both. Inspired by the empirical studies, this paper models brand reputation and warranty as quality perceptions of consumers and studies the interactions between warranty, brand reputation and product quality in a duopoly setting.

From the manufacturer's perspective, we explore the joint effects of brand reputation and warranty in signaling new product quality under competition. Many interesting research questions

are investigated. What are the optimal warranties to offer for the two competing manufacturers? How do brand reputation, warranty costs, and product quality affect the optimal warranty decisions? Is extensive warranty coverage always optimal for a high quality product? How do brand reputation and warranty influence the optimal profits? We develop a non-cooperative duopoly model in this paper to answer these questions.

We consider two competing manufacturers who produce and sell a high quality product and a low quality product respectively. Product warranty, modeled as a length of coverage, is offered together with the product. Product demand depends on prices and product qualities from both competing manufacturers. Product quality is exogenously given and is unobservable by consumers before purchase. Consumers form quality perception based on the warranty offered and the brand reputation of the manufacturer. We model the warranty cost in terms of repair cost, warranty length and product quality. Under this setting, we develop a duopoly model to analyze optimal warranty designs and product pricing. Brand reputation and warranty factors that influence the optimal profits are also studied.

The remainder of this paper is organized as follows. We review the literature in the next section. Model setups are described in Section III. We present the model and analyze the results in Section IV. In the last section, we summarize the paper and remark on future directions. All proofs are deferred to the Appendix for clarity of presentation.

II. LITERATURE REVIEW

Our paper is mostly related to the warranty design literature, particularly from a theoretical perspective. Theoretical modeling on the relationship between warranty and quality can mostly be found in the economics and operations management literature. Lutz and Padmanabhan (1998) model a situation where

consumers infer unobservable quality from warranties. Their paper focuses on the effect of extended warranties on a manufacturer's warranty policy. Balachandran and Radhakrishnan (2005) study quality implications of warranties in a supply chain setting. However, most of the literature typically treats warranties as cash compensation in case of a product failure. Examples of such work are Padmanabhan (1995) and Lutz and Padmanabhan (1998). In practice, warranty contracts are usually specified by coverage duration instead of monetary compensation. Our model captures this feature of warranties and distinguishes our paper from the monetary warranty literature.

Another stream of the literature, which focuses on *empirically* examining the relationship between warranty, quality and brand reputation, is closely related to our paper. Soo et al. (2001) conduct an experiment to investigate the use of warranty coverage and warrantor reputation in signaling product quality. Price and Dawar (2002) empirically study the interaction of brand information and warranty information in determining quality perception. They find that warranties can enhance brand signal credibility, and the joint signaling effects of brands and warranties depend on both inherent information content and relative credibility. The empirical study of Blair and Innis (1996) analyzes the effect of consumers' product knowledge on the evaluation of product quality through brands and warranties. The empirical literature shows the importance in studying the interactions among warranties, brand reputation, and product quality. Our model develops a theoretical approach to examine the interactions of the three elements and obtains important managerial insights. To the best of our knowledge, we are the first to study these interactions in a duopoly.

III. MODEL SETUPS

In this section, we first describe product and consumer configurations. We then present demand functions, the duopoly warranty model and its results.

Products

Consider a market consisting of two competing manufacturers. They manufacture and sell a high quality product and a low quality product respectively. Correspondingly, we call them h-manufacturer and l-manufacturer. Quality in our model is predetermined and exogenously given, and we denote it by q. The value of quality q is normalized to be within the range of [0, 1]. We assume the probability of product failure is only dependent upon quality q and is decreasing in q. We further assume the probability of product failure to be $1-q$. Similar assumptions can be found in Cooper and Ross (1985).

The respective qualities offered by the two competing manufacturers are denoted by q_h and q_l, and their relationship is $q_h > q_l$. The costs of manufacturing the products are constant since qualities are exogenously determined. Without loss of generality, the manufacturing costs are normalized to zero.

The two competing products are also offered with warranties. Consistent with observations in practice, we model the warranties as a duration of time. The warranties for the high quality product and the low quality product are denoted by w_h and w_l, respectively. If the product fails during the warranty period, the manufacturer provides the consumer with free repairs or replacement. We assume that the number of product failures increases quadratically with time. The literature (Anderson, 1977 and Menke, 1969) often assumes that the number of failures increase exponentially with time. Our quadratic failure assumption captures the increasing rate of product failure with time, while retaining the analytical tractability. Let c_h and c_l denote the average repair cost per failure for the high quality product and low quality product, respectively. The value of the average repair cost can normally be estimated by examining the past data of repairs on products

with similar quality. Recall that the probability of product failure is *1- q*. Thus, the cost of providing the warranty for the high quality product is $c_h(1-q_h)w_h^2$, which decreases in product quality and increases in warranty length. Similarly, $c_l(1-q_l)w_l^2$ is the warranty cost of the low quality product.

We further assume the product is a durable product. Durable goods provide a significant service period to consumers and are often considered a one-time buy. Thus, a consumer will leave the market forever, once she has bought a unit of the product, regardless of quality. In other words, we do not consider repeat purchases.

Consumers

The actual quality of product is observable to the manufacturers, but not to consumers prior to purchase. Consumers must rely on their quality belief, which is derived from product warranty and brand reputation, when making purchase decisions.

First, consumers believe that the more warranty coverage the manufacturer offers, the higher the product quality will be. This belief is rational when we consider the expected warranty cost for the manufacturer is $c_i(1-q_i)w_i^2$, where *i = h or l*. A high quality product has a low probability of failure, therefore, the manufacturer can afford to offer a better warranty coverage.

Second, consumers believe more a reputable manufacturer offers a higher quality product. Brand reputation is an equity investment, which is often increased by investing in advertising, product design, quality control, etc. (Kirmani and Rao, 2000). The investment is expected to be recouped from future sales. If a low quality product is offered by a reputable manufacturer, then the investment will be lost after the low quality is revealed. Therefore, brand reputation is capable of raising credibility of unobservable product quality.

Based upon the above discussions, we assume the quality beliefs of consumers are positively associated with brand reputation and

product warranty. We use a simple expression r_iw_i for the quality beliefs of consumers, where r_i is the brand reputation of manufacturer *i*, w_i is the warranty coverage offered by the manufacturer *i*, and where *i = h or l*. In other words, consumers perceive the unobservable product quality *q* as a function of brand reputation and product warranty *rw*. Please note that r_h is not necessarily greater than r_l, and w_h is not necessarily greater than w_l. In other words, the manufacturer for the high quality product may have a low brand reputation and may offer a low warranty coverage.

Demand Functions

If the product quality is observable to consumers, the demand function in a duopoly can be expressed as follows.

$$d_i = 1 - p_i + ap_j + q_i - bq_j \qquad (1)$$

Where *p* is the product price, *q* is the product quality, positive parameters *a* and *b* represent the substitutability between the two competing products, and where *i, j = h, l* and *i ≠ j*. Please note that the values of parameters *a* and *b* are less than 1, since the demand of a product is more related to its own price, and is relatively less affected by the price of its competitor. Also, the higher the values of *a* and *b*, the more the degree of substitutability is between the two competing products. The deterministic demand defined in (1) is similar as that of McGuire and Staelin (1983).

Consumers make purchase decisions based on quality beliefs, when the product quality is unobservable. Consequently, the qualities in function (1) will be replaced by consumers' quality beliefs. The demand function becomes:

$$d_i = 1 - p_i + ap_j + r_iw_i - br_jw_j \qquad (2)$$

The Model

The objectives of the two competing manufacturers are to maximize their respective profits (the product price minus warranty cost and multiplied by the corresponding demand). Each manufacturer simultaneously chooses

warranty length/coverage and product price by taking into consideration the rational decisions of the other. The decision-making process of the two manufacturers is modeled as a non-cooperative game.

$$\max_{p_h, w_h} \pi_h = [p_h - c_h(1-q_h)w_h^2] \cdot (1 - p_h + ap_l + r_h w_h - br_l w_l) \tag{3}$$

Similarly, the profit maximization problem for the low quality product manufacturer l is as follows.

$$\max_{p_l, w_l} \pi_l = [p_l - c_l(1-q_l)w_l^2] \cdot (1 - p_l + ap_h + r_l w_l - br_h w_h) \tag{4}$$

From (3) and (4), we obtain the first-order conditions and solve for the optimal solutions of the four decision variables simultaneously. We present the results in the following proposition:

The high quality product manufacturer h maximizes his profit by optimally choosing the product price p_h and the warranty length w_h.

Proposition 1:

(a) It is optimal for the high quality product manufacturer to charge a price for the product of
$p_h^* = \frac{2c_l r_h^2(3-ab)(1-q_l)+c_h(1-q_h)[4c_l(2+a)(1-q_l)+(3a-4b)r_l^2]}{4c_h c_l(4-a^2)(1-q_h)(1-q_l)}$ *and to offer a warranty with length of*
$w_h^* = \frac{r_h}{2c_h(1-q_h)}.$
The optimal profit is $\pi_h^* = \{\frac{c_l r_h^2(2-2ab+a^2)(1-q_l)+c_h(1-q_h)[4c_l(2+a)(1-q_l)+(3a-4b)r_l^2]}{4c_h c_l(4-a^2)(1-q_h)(1-q_l)}\}^2.$

(b) It is optimal for the low quality product manufacturer to charge a price for the product of
$p_l^* = \frac{c_l r_h^2(3a-4b)(1-q_l)+2c_h(1-q_h)[2c_l(2+a)(1-q_l)+(3-ab)r_l^2]}{4c_h c_l(4-a^2)(1-q_h)(1-q_l)}$ *and to offer a warranty with length of*
$w_l^* = \frac{r_l}{2c_l(1-q_l)}.$
The optimal profit is $\pi_l^* = \{\frac{c_l r_h^2(3a-4b)(1-q_l)+c_h(1-q_h)[4c_l(2+a)(1-q_l)+(2-2ab+a^2)r_l^2]}{4c_h c_l(4-a^2)(1-q_h)(1-q_l)}\}^2.$

IV. RESULTS ANALYSIS

In this section, we present detailed result analysis and managerial implications. Specifically, we discuss the characteristics and the optimal design of the warranties, and analyze the optimal profits of the two competing manufacturers.

Warranty Analysis

First, we obtain the following proposition by investigating sensitivities of the optimal warranties.

Proposition 2: *The optimal warranty is decreasing in the repair cost c_i, where $i = h$ or l; and increasing in the product quality q_i and the brand reputation r_i.*

Our model assumes a quadratic cost of warranty. Therefore, for a given price, as the repair cost increases (decreases), the manufacturer reduces (increases) the length of the warranty. According to *The Wall Street Journal*, DaimlerChrysler reduced the extended warranty on its vehicles from year 2006 due to

higher repair costs resulting from more expensive labor and more complicated technologies (Saranow, 2005). Our finding explains this business action.

As product quality increases, the probability of product failure decreases. Consequently, the expected warranty repair cost decreases. Spencer (2002) mentions that the overall cost of providing warranties is actually declining for many carmakers because of improvements in vehicle quality. According to estimates by J&L Warranty Pros, in the case of GM and Ford, the average warranty cost per vehicle is roughly $1,000, down from $1,600 in the early 1990s. These examples support the notion that better product quality is associated with lower warranty costs. Consequently, it becomes more affordable to offer a longer warranty, which in turn attracts more demand.

The effect of brand reputation on warranty is similar to that of product quality. Brand reputation is a perception of product quality by consumers. Better brand reputation is a reflection of higher product quality. For a reputable manufacturer, it is optimal to offer a longer warranty to justify the higher quality it signals.

We next compare the optimal warranties between the two competing manufacturers. We intend to investigate whether extensive warranty coverage is always optimal for a high quality product. The following proposition summarizes our findings.

Proposition 3:

(a) *It is optimal for the low quality product to have a longer warranty than the high quality product if and only if its repair cost satisfies condition* $c_l < \frac{c_h r_l (1 - q_h)}{r_h (1 - q_l)}$.

(b) *When the repair costs of the two competing manufacturers are equal, it is optimal for the low quality product to have a longer warranty if the manufacturer's brand reputation satisfies condition* $r_l > \frac{r_h (1 - q_l)}{(1 - q_h)}$.

Proposition 3(a) indicates that a longer warranty is only optimal to the low quality

product if its unit repair cost is small enough. Warranty cost depends upon both the unit repair cost and the product failure rate. Low quality increases the possibility of product failure and the corresponding warranty cost. However, if the unit repair cost of the low quality product is sufficiently small, then its overall warranty cost could be lower than that of the high quality product. Consequently, the manufacturer of the low quality product would be able to afford a longer warranty.

Brand reputation plays a crucial role in warranty determination when the unit repair costs of the two competing manufacturers are equal. Proposition 3(b) shows that, it is optimal for the low quality product manufacturer to offer a longer warranty, only if his brand reputation is higher than that of the high quality product manufacturer (note that $\frac{1-q_l}{1-q_h} > 1$). If the low quality product is accompanied by a longer warranty, the resulting high warranty cost would lower the marginal profit. However, the longer warranty and a high enough brand reputation also increase product demand, due to higher quality beliefs from consumers. The increased demand could be large enough to compensate for the decreased marginal profit, and lead to a better profit for the low quality product manufacturer.

Profit Analysis

In the following, we investigate how brand reputation and warranty influence the optimal profit by conducting various sensitivity analyses. The warranty effect is detailed by the unit repair cost and the failure rate factor, i.e. the product quality. We summarize our findings in the following proposition.

Proposition 4: *The signs of the first derivative that the optimal profits have with respect to various parameters are summarized in the table below.*

Signs of the first derivatives	Optimal profit of the high quality product (π_h^*)	Optimal profit of the low quality product (π_l^*)

c_h	-	+
c_l	+	-
q_h	+	-
q_l	-	+
r_h	+	-
r_l	-	+

We use the parameters of the high quality product to illustrate their influence towards the optimal profits. The explanation for the low quality product parameters is similar.

First, we consider the influence of unit repair cost towards the optimal profit. As c_h increases, the optimal profit of the high quality product deceases and the one of the low quality product increases. According to Proposition 2, an increased repair cost will shorten the corresponding warranty length. Many consumers will find the high quality product becomes less attractive and switch to the low quality product. Consequently, the profit of the high quality product decreases and the profit of the low quality product increases.

Next, we explain the relationship between the product quality and the optimal profits. The optimal profit of the high quality product increases in its quality q_h. However, an increasing q_h will decrease the optimal profit of the low quality product. As shown in Proposition 2, an increased value of quality q_h accompanies a longer warranty w_h, which increases the product demand of the h-manufacturer, and decreases the product demand of his competitor. In addition, the failure rate decreases in the high quality product and remains unchanged in the low quality product. The changes in the product demands and the failure rates explain the quality relationship with the optimal profits.

Last, we look at the profit sensitivity with respect to brand reputation. The optimal profits are influenced by brand reputation through product demands. If brand reputation r_h increases, the demand of the high quality product increases, and the demand of the low quality product decreases. The demands affect the profits of the two products accordingly.

V. SUMMARY

In this paper, we developed a non-cooperative game model to study warranty designs in a duopoly setting. Two competing manufacturers, with different brand reputation, sell products of a high quality and a low quality respectively. Warranty is offered together with the product and is modeled as a duration of coverage. Warranty cost incorporates the probability of product failure, the number of product failures, and the corresponding repair cost. The product quality is not observable by consumers, who form quality beliefs based on information of product warranty and brand reputation of the manufacturers. The two competing manufacturers maximize their respective profit by simultaneously choosing product price and warranty length. We focused on the sensitivity analysis of the optimal warranty and showed the influence of repair cost, brand reputation and product quality on warranty design. We also identified the optimal conditions of offering a longer warranty for the two competing companies. Sensitivity analysis of the optimal profits revealed the influence of warranty elements and brand reputation.

This paper can be extended in several directions. First, we assumed the probability of product failure only depends upon product quality. An important and more realistic extension would be to include product care effort from consumers and explore the double moral hazard issues in warranty design. Second, we exogenously assumed the product quality in our model. More valuable insights might be obtained by examining the quality as a decision variable. Finally, for simplicity, we did not consider repeated purchase in our model. The warranty

decision might be different if repeated purchases are allowed.

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