# Quantifying the Economic Value of Warranties: A Survey

## Ede LÁZÁR

Sapientia Hungarian University of Transylvania, Faculty of Economic and Human
Sciences, Department of Business Sciences, Miercurea Ciuc
E-mail: lazarede@sapientia.siculorum.ro

**Abstract.** This paper is a review of the most recent literature regarding the econometric modelling of the impact of warranties on demand. The reviewed literature is limited to the papers that apply the random-coefficient logit model based on Berry, Levinsohn and Pakes (1995) to estimate differentiated products demand. An important feature of these demand system models that is a clear advantage to earlier demand functions is to account for the endogeneity of prices. We focus on those model specifications that take into account endogeneity of both prices and warranty. Another goal for modelling the effect of warranties is to explore the economic rationale for warranty provision. Four theories have been proposed in the literature: insurance, sorting, signalling and incentive theories. This paper aims at decomposing the effect of these theories, to account for different underlying assumptions and to separately determine the implications as presented in the recent literature.

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**JEL Classification:** D8, D12, L11

## 1. Introduction

Models of differentiated product demand systems based on empirical data play an important role in practical market research. The literature on empirical analysis of demand and consumer behaviour comprehend at least a hundred years, as Nevo (2011) dates the first statistical estimation to Moore (1914). An important milestone in the literature was the recognition of Stone (1954), who specified a system of demand equation for a set of closely related but not identical products. In each equation, the demand is quantified as a linear function of all prices. However, in such a model when there is a large number of products in a market, the number of parameters to be estimated becomes excessively large. Also, heterogeneity in consumer tastes is not taken into account.

Berry, Levinsohn and Pakes (1995, hereafter BLP) introduced a method for the estimation of demand systems nonlinear in the econometric error using aggregate data on prices, market shares and product characteristics across locations or time. This model parameterizes substitution patterns as functions of observed characteristics of products. The underlying random-coefficients logit model is now widely perceived to be the best for estimating differentiated product demand systems, with an econometric specification that is more flexible than the logit or the nested logit models (Crawford, 2012). This model maintains the advantage of the logit model in handling a large number of products. It has a number of advantages compared to previous models because (1) the model can be estimated using only market-level price and quantity data, (2) it deals with the endogeneity of prices and (3) it produces demand elasticities that are more realistic, for example, cross-price elasticities are larger for products that are closer together in terms of their characteristics.

Applications of these methods include the estimation of the effects of taxes and quotas (e.g. Berry, Levinsohn and Pakes, 1999), estimation of own- and cross-price elasticities to analyse pricing or to simulate the effects of mergers (e.g. Nevo, 2000), measuring the welfare effects of new goods (e.g. Petrin, 2002), quantifying the impact of a product characteristic like warranty duration, product quality, maintenance service quality on the demand (Chu and Chintagunta, 2009, 2011; Choi and Ishii, 2011; Guajardo, Cohen and Netessine, 2012).

The first objective of this paper is to present in detail those warranty model specifications which apply random-coefficient logit models accounting for the endogeneity of price and warranty. The other – inseparable – objective is to explore the economic rationale for warranty provision, to determine those model specification details which allow the decomposition of different theories of economic rationales of warranties.

In the literature, four (recently five) theories have been proposed on economic rationales for warranty, but the relevance of these might depend on the product itself. The automobile industry serves as a preferred setting for empirical study of the warranty effect. Standard & Poor's reports that in this industry "product quality and design are becoming less of an issue in differentiating foreign and domestic manufacturers". The trend is a movement from a "pure manufacturing" paradigm to a business model in which a central role is assigned to the service components. The after-sales services of the products represented 8% of U.S. GDP in 2006 (Guajardo et al., 2012).

Thus, services represent an important differentiating factor for automakers; in particular, we could measure the service dimension of a brand by the length of its warranty. The length of warranty defines the period in which repair services are provided by the manufacturer. Firms have been active in adjusting the length of their warranties in the last decade. They face an important trade-off when

defining their warranty period: while longer warranties may potentially increase demand, they also generate significant costs, e.g. 2–4% of yearly revenue of U.S.-based automakers.

Choi and Ishii (2010) enumerate several examples from the U.S. automobile market how the extended powertrain warranty of a type increased its market share (Hyundai, Dodge) or how the warranty reduction declined the share (Volkswagen). These examples suggest, but do not conclude, the importance of warranty coverage on consumer demand for new automobiles.

In spite of the extensive literature of the economic rationale of warranties, little empirical work has systematically examined the validity of these theories in actual markets. Our paper focuses on the literature of warranty provision that uses structural demand equation based on nested or random coefficient models.

Chu and Chintagunta (2009) apply BLP to quantify the economic value of warranties in the U.S. server market. They find that manufacturers and downstream firms of the indirect channels benefit from warranty provision and from sorting across heterogeneous customers by offering a menu of warranties. Choi and Ishii (2010) seek empirical evidence on the role of warranties as signals of unobservable quality. They adapt the linear random utility model of consumer automobile demand to investigate the extent to which warranties affect consumer choice and the extent to which this estimated warranty effect is due to risk aversion and signalling motives. The objective of Chu and Chintagunta (2011) is to assess empirically whether the economic roles of the warranties are consistent with the different warranty theories. They examine two different markets in the U.S.: the computer server as a business-to-business market and the automobile market as a business-to-consumer type market. They find evidence for insurance and sorting theories, but not for signalling and incentives theories. Guajardo et al. (2012) formulate and estimate a structural model to measure the impact of service attributes on consumer demand in the U.S. automobile industry.

The rest of the paper proceeds as follows. In Section 2, we present the theoretical background of the economic roles of warranties. In Section 3, we itemize the main and detailed research topics of the theme. Section 4 of the paper contains the model specifications and the list of type and sources of the empirical data. Section 5 contains the major results. We conclude with possible further research topics.

## 2. Warranty Theoretical Background

Four theories have been proposed in the literature on economic rationales for warranty provision, while the fifth is mentioned but empirically not tested by one of the literature (Choi and Ishii 2010).

### Insurance Theory

Warranties provide insurance to customers and work as a risk-sharing mechanism because they oblige the manufacturer or seller to compensate the buyer in the event of product failure (Heal, 1977). According to Chu and Chintagunta (2011), the underlying key assumption of the theory is that customers are risk-averse and the probability of product failure is higher than zero. These two assumptions are met because extended automobile warranties (provided by a third party) are popular and the reliability score of new cars indicate non-zero failure rates of automobiles.

An obvious, direct implication of this theory is that the degree of risk aversion and duration of warranty should be positively correlated. A major problem of empirical validation of this hypothesis is how to quantify the risk aversion of the consumer. Chu and Chintagunta (2011) use an indirect way to solve this problem; they base their estimation on known relations of the literature (Dohmen et al., 2005; Jaeger et al., 2007) between demographic attributes and risk attitude, and regress the automobile warranty duration on household demographics. In this manner, they find concave relationship between warranty duration and household income: low-income households are more risk-averse, but they may not be able to afford longer warranties, and the high-income households are less risk-averse, so do not need to buy longer warranties. There is a convex relationship between age and warranty duration, which first decreases and then increases with age.

### Sorting Theory

Warranties work as a means for second-degree price discrimination among customers with different risk preferences. It explores how firms design and price a line of products distinguished by different quality and warranty levels to extract the maximum surplus from each consumer type (Kubo, 1986; Matthews and Moore, 1987; Padmanabhan and Rao, 1993).

The key assumption of this theory by Chu and Chintagunta (2011) is the presence of consumer heterogeneity, a feature that is met by the many patterns of the automobile buyers' attributes.

The sorting theory posits that manufacturers should offer a menu of warranties, which is evident, but in our opinion it is not as widely used as other sorting/price discriminatory tools. There are models and even manufacturers (at least in the period of analysis) who provide only one type of warranty duration (e.g. Audi, BMW, Mercedes-Benz with 6, 23, respectively 12 models in the American automobile market analysed by Chu and Chintagunta, 2011). This seems to contradict the assumption that the product line is primarily differentiated on the basis of warranty coverage and price.

## Signalling Theory

Warranties are used to signal product quality to consumers (Spence, 1977; Gal-Or, 1989), just like they signal quality through advertising (Nelson, 1974). This approach examines the information content of warranties under information asymmetry when some informed agents may try to reduce this disadvantage sending signals to the uninformed agents (Akerlof, 1970; Riley, 1979). This theory has its roots in signalling games and was analysed in perfectly competitive markets (Spence, 1977), in monopoly (Grossman, 1981), and duopoly markets (Gal-Or, 1989).

According to Chu and Chintagunta (2011), the key assumption is information asymmetry in the sense that sellers have better knowledge about the product quality than buyers; thus, sellers need to signal product quality through warranties. In other words, buyers may not be adequately informed about the product performance before purchase, so they try to assess this from its price and/or warranty (Spence, 1977). Warranties can be a signal of product quality and can inform consumers because warranties are costly to the seller, and the costs are systematically related to product reliability.

This theory implies a positive relationship between product quality and warranty duration because only high-quality firms can afford long warranties because of their associated costs. In our opinion, the closeness of this relation is probably reduced by the fact that lower product quality and lower price may also have lower repairing cost. The automobile manufacturers control their warranty cost relating it to income. This assumption is handled by accounting for endogeneity of price and warranty duration in model specification.

Choi and Ishii (2010) mention the assumption that a warranty could be a credible signal of unobservable product quality only if the warranty is (relatively) more costly for firms producing "low quality" products. They empirically test the validity of this theory, analyse the degree to which consumers perceive a manufacturer's warranty as a signal of unobservable product quality and find a stronger role of signalling than risk aversion. Warranties are effective as signals only if manufacturers actually offer different warranty lengths based on their product quality – this assumption could be easily verified by checking the actual market supply. Choi and Ishii considered it important to distinguish only the risk aversion and signalling motives and did not deal with the other two warranty theories. The nature of the analysed powertrain warranties allows them to focus exclusively on these two motives.

## Incentive Theory

Warranties work as an incentive mechanism for firms to reveal and improve product quality. The key assumption is risk endogeneity in the sense that sellers' actions can affect product performance. The probability that a product will break

down is a function of its quality which depends on the producers' quality efforts and also on the consumers' maintenance efforts; thus, producers should take moral hazard into account.

Chu and Chintagunta (2011) empirically examine two implications of this theory in the U.S. server and automobile market, namely that quality is negatively correlated with current warranty and quality is positively correlated with past warranties. They did not find significant evidence for these correlations.

### Profitable Bundling

Profitable bundling, discussed in short by Choi and Ishii (2010), is the fifth possible motive for automobile warranties; it is not considered in the rest of the literature. Firms may be able to procure cheaper repair service than consumers and practically bundle discounted pre-paid repair with the automobile. The extent of a manufacturer capacity to offer repair will vary geographically, depending mostly on its dealership network. This, combined with the fact that powertrain warranties do not vary geographically, suggests that bundling is not an important motive at least for powertrain warranties.

## 3. Research Topics in the Literature

This section reviews the research objectives of four relevant papers. The first objective of Chu and Chintagunta (2009) is to quantify the total value of base warranties in the U.S. server market to manufacturers, channel intermediaries (downstream firms) and customers. Although base warranties are characterized by several attributes, the variation across server models is in the duration of the warranty; thus, they aim to quantify the value of base warranty. The second objective is to decompose the value of a warranty only into its insurance value and its sorting/price discrimination value. This implies that the empirical model needs to incorporate consumer's risk aversion and consumer heterogeneity. They exclude the signalling role of server warranties because different manufacturers offer similar warranty durations for their server products; so, the quality information content of warranties is likely to be limited. In our opinion, the explanation relies on the product itself, the information asymmetry in a consumer choice decision of a server is likely to be smaller than in the case of a car because the buyers of the servers are usually experts who are informed about the performance of the main components. The incentive role of warranties is closely related to the signalling role; however, major manufacturers do not change their server warranty policies over time as their product quality improves. The authors use structural modelling (i.e. BLP) and counterfactual experiments.

The structural model contains a demand model derived from a utility function and a pricing model. The demand model accounts for customer's risk aversion to accommodate the insurance role and it incorporates customer heterogeneity to allow for the sorting motive of the warranty. The pricing model accounts for the specialty of the market: the servers are sold both directly and indirectly, and the intermediaries compete among themselves and with manufacturers.

Choi and Ishii (2010) seek empirical evidence for the role of warranties as signals of unobservable quality. They adapt the linear random utility model of consumer automobile demand to investigate the extent to which warranties affect consumer choice and the extent to which this estimated warranty effect is due to risk aversion and signalling motives. Choi and Ishii derive the marginal effects of both the binary and non-binary explanatory variables in the conditional logit and random coefficient logit models. Their results also demonstrate the strong role of brand loyalty, a finding also found by Train and Winston (2007). They also analyse the relation between warranties and brands, where the question is whether the longer warranty offsets the disadvantage in brand reputation. They compare a newer, lower reputation firm brand (Hyundai) to the category leader (Honda) in the small/medium car category, and the same in the luxury category (Lexus versus BMW). In both comparisons, the newer firm offers a two-year longer powertrain warranty. They model these relations at different levels of information asymmetry, and build up three scenarios:

– both models are unrated by *Consumer Reports (CR)* and there is no past purchase experience; thus, the difference in product quality is strictly the difference in brand reputation, as captured by their brand dummies;

– the category leader type is rated by *CR*; thus, the consumer has additional third-party information on the category leader;

– the category leader type is rated by *CR* and the consumer has previously purchased a car from the category leader; thus, the consumer has additional first- and third-party information on the category leader.

The results of the three models contain the estimated brand dummies and the marginal effect of each additional year of powertrain warranty to the indirect utility of the consumer. Based on these estimations, Choi and Ishii calculate how many extra years of warranty should a manufacturer offer to offset the brand reputation's disadvantage compared to the category leader.

Chu and Chintagunta (2011) examine the conditions under which each of the four competing theories on the economic roles of warranties would apply and derive testable implications from the data. Then, they assess whether these theories have empirical support in the U.S. computer server and automobile market in the context of manufacturer base warranties. The two key assumptions underlying the insurance theory is that buyers are risk-averse and the probability of product failure is non-zero. The insurance theory has the implication that the

degree of risk aversion and the warranty length should be positively correlated. Therefore, the authors expect that the same customers will buy longer warranties when product failure increases and reliability decreases, and given a particular product failure rate, more risk-averse customers will buy longer warranties.

The key assumption of the sorting theory is the presence of consumer heterogeneity; in equilibrium, firms will offer a line of products distinguished by different quality, warranty and price levels. The sorting theory also implies that, in response to the menu of warranties the firm provides, customers with the same observable attributes (i.e. income) but different degrees of risk aversion choose different warranty contracts.

The signalling approach examines the information content of warranties under information asymmetry which is the key assumption in the sense that sellers have better knowledge about product quality than buyers. Two more trivial assumptions are that warranties are costly to the seller and the costs are systematically related to product reliability. The theory implies a positive relationship between product quality and warranty duration because only high-quality firms can afford long warranties because of their associated costs of fulfilment.

The incentive role on the firms' side involves two aspects: signal product quality to consumers through warranties in the presence of consumer moral hazard and motivate the firm to invest in product quality and supply high-quality products, at least to the extent of reducing the chances of its falling below the warranted level. Chu and Chintagunta (2011) expect a positive relationship between quality and previous warranty terms and a positive relationship between warranty terms and new product reliability.

Guajardo et al. (2012) analyse the warranty in a larger context, together with other service attributes, formulate and estimate a structural model to measure the impact of service attributes on consumer demand in the U.S. automobile industry. The authors establish three important differences compared to earlier researches. First, they focus not only on the effect of firms' warranty length, but also on their service quality. Second, they study the effect on the demand of the interaction between service attributes and product quality in order to help firm decision-making regarding both of them. Third, they specify warranty length as endogenous in addition to price in the demand specification. These authors are the first to empirically analyse the value of service attributes as drivers of demand in manufacturing industries and to analyse complementarities between service attributes and product quality in the context of demand models.

# 4. Models, Estimation, Identification, Assumptions

## Specification

The major problem in model identification of the economic value of warranty is that both price and warranty length may depend on all product characteristics observable to the consumer, including those omitted from the indirect utility specification. Without properly taking into account this endogeneity, some or all of the estimated warranty effect may be biased. Choi and Ishii (2010) summarize the possible solutions.

Much of the empirical work in this research topic avoids this problem because it relies on experimental data where price and warranty exogeneity come from the experimental design (Purohit & Srivastava, 2001; Chatterjee, Kang and Mishra, 2005). One possible solution is offered by BLP, who use instrumental variables for estimating a model of consumer demand and firm supply. In BLP, the endogeneity of product characteristics other than price is not modelled; warranty appears as an unobserved characteristic. It is difficult to adapt the BLP approach to account for both price and warranty endogeneity; the explicit modelling of warranty supply depends on clearly observable cost shifters for the warranty supply decision.

Another strategy is based on Goldberg (1995) and Train and Winston (2007), using cross-sectional variation available in household-level data. They include product-specific fixed effects into the indirect utility in order to control for the mean effect of the omitted characteristics; this reduces price and warranty endogeneity due to correlation with omitted variables. This model identification relies on the assumption that unobserved consumer taste heterogeneity is limited to the additive error. The main drawback of this approach is that it requires rich data to allow for the estimation of product-specific fixed effects, in addition to the other included coefficients. Choi and Ishii build on Goldberg's (1995) approach, which they extend from nested logit to random coefficient logit for household-level data.

Guajardo et al. (2012) follow the former strategy; they formulate a structural model of decision-making by both consumers and firms. They estimate the demand model, and present conceptually the supply model, allowing for warranty-length endogeneity. In addition to the main effect model of the warranty length, the authors specify a model involving two-way interactions between warranty lengths, service quality and product quality.

## Estimation of Demand Parameters

In order to estimate their model, Chu and Chintagunta (2009) use a two-step approach by first estimating the demand parameters and then the parameters of the pricing equations. This method is less efficient than a simultaneous estimation

approach, but it provides consistent estimates of the demand parameters even in the presence of misspecified pricing equations. They modify the contraction mapping approach from BLP to handle the nonlinear, customer-specific income effect. Regarding this feature, they decompose the price term of the demand function into a mean price effect and a customer-specific price effect. The estimation of demand parameters contains the following steps:

1. Obtain draws for customer $i$'s income ($y_i$) from the empirical distribution of firm revenue.

2. For each draw of $y_i$, compute the mean price term and a customer specific price term.

3. Choose starting values for $\overline{\beta}$ and for the nonlinear parameters to compute the individual-specific utility and apply the contraction mapping in BLP to obtain the mean utility.

4. Use GMM to compute the parameters in the mean utility.

5. Replace $\overline{\beta}$ in step 3 with the $\overline{\beta}$ estimate from step 4 and iterate until convergence.

Chu and Chintagunta (2009) apply an instrumental variables technique to account for the potential endogeneity of the retail prices of servers using the following cost shifters as instruments:

– product characteristics including dummies for manufacturer, brand, channel, CPU and time trend;

– current and lagged producer price indices for memory and CPU interacted with manufacturer dummies;

– average weekly wage rates for the computer hardware industry.

Together, these instruments explain 63% of the price variation and 74% of log price variation. The potential market for servers is around 14 million calculated with 7.4 million establishments in the United States in 2004 and assuming two servers per establishment. The demand model had 66 linear parameters and 27 nonlinear parameters to be estimated.

Guajardo et al. (2012) consider a random coefficients logit demand model, where the utility that consumer $i$ derives from purchasing vehicle $j$ in calendar year $t$ depends on the vehicle price $p_{jt}$, warranty duration $w_{jt}$, product quality $PQ_{jt}$, service quality $SQ_{jt}$ and a vector of observable vehicle characteristics $x_{jt}$, as follows:

$$u_{ijt} = \alpha_i p_{jt} + x'_{jt}\beta_i + h(w_{jt}, PQ_{jt}, SQ_{jt})\gamma + \zeta_{jt} + \varepsilon_{ijt}.$$

The term $\xi_{jt}$ represents unobserved product attributes common to all consumers and $\epsilon_{ijt}$ is a type I extreme value idiosyncratic shock. The individual level coefficients $\alpha_i$ and $\beta_i$ are decomposed into a mean effect common to all consumers ($\beta$'s) and individual deviations from that mean ($\sigma$'s) as it is common in the BLP literature.

Under the linearity assumption for $w_{jt}$, $PQ_{jt}$, $SQ_{jt}$ variable, the utility function would take the following form:

$$u_{ijt} = \alpha_i p_{jt} + x'_{jt}\beta_i + \gamma^1 w_{jt} + \gamma^2, PQ_{jt} + \gamma^3 SQ_{jt} + \zeta_{jt} + \epsilon_{ijt}.$$

This formulation captures the main effects and it is also consistent with the linearity assumption made for the rest of the covariates, considering PQ and SQ as exogenous in the demand specification. The identification through instrumental variables to account for price and warranty endogeneity is discussed later.

**Estimation of Parameters in the Pricing Equation**

The manufacturers' marginal costs consist of the following: the costs of providing the various attributes of the product, warranty costs and other costs. To estimate the cost of warranties, Chu and Chintagunta (2009) first estimate manufacturer marginal costs on warranty duration and other product attributes using a flexible functional form, a semi-log regression that allows warranty coefficients to vary with quarters to account for potentially changing warranty costs over time.

$$\ln(MC^w_{\omega dt}) = X_{\omega dt}K_{0t} + K_t w_{\omega d}I_{qt} + \zeta_{\omega dt},$$

where $I_{qt}$ is a quarter dummy, $K_{0t}$ is the vector of the effect of product attributes on marginal cost and $K_t$ is the effect of warranty on marginal cost. In the cost equation, 88 linear parameters had to be estimated.

Guajardo's (2012) basic assumption on the supply side is that firms compete in prices and warranties. This assumption is consistent with some prior theoretical models (e.g. Spence, 1977; Gal-Or, 1989), which have modelled competition based on these two variables, taking other factors exogenous. The profit function for firm *f* in period *t* is defined as follows:

$$\pi_f = \sum_{j \in J_f}(p_{jt} - mc_{jt} - wc_{jt})Ms_{jt}(p_t, w_t, PQ_t, SQ_t, x_t, \xi; \theta),$$

where $J_f$ represents the set of vehicles produced by firm *f*, $mc_{jt}$ the marginal costs of production of vehicle *j*, $wc_{jt}$ the expected per-unit warranty costs, *M* is the size of the market and $s_{jt}$ the market share of vehicle *j*. Like BLP, they consider a marginal cost function $g_1$ based on the projection of costs onto observable vehicle characteristics $x^s_{jt}$ and unobservable cost shifters $\varphi_{jt}$:

$$mc_{jt} = g_1(x^s_{jt}, \varphi_{jt}).$$

Considering the heterogeneity of the expected cost per event of failure during warranty length across brands, $xb_{jt}$ denotes other observable characteristics that

capture part of the brand heterogeneity in warranty costs and $\varsigma_{jt}$ unobservable factors. The warranty cost function can be represented as follows:

$$wc_{jt} = g_2\left(w_{jt}, PQ_{jt}, SQ_{jt}, xb_{jt}, \zeta_{jt}\right).$$

Thus, Guajardo et al. (2012) assume that firms compete in both prices and warranties; their supply model provides the fundamentals for the identification strategy for the parameters in the demand model.

## Identification

Guajardo et al. (2012) argue for price and warranty endogeneity as well as product and service quality exogeneity. Price endogeneity is accounted for in BLP through a Bertrand-Nash equilibrium assumption. Their proposed set of instruments are widely used in the literature, but Guajardo et al. (2012) – instead of considering the average characteristics for cars of all other firms – compute the average characteristics of other firms' cars in the same market segment (small, middle, large, luxury), which refines the set of instruments by using cars that are closer to one another in terms of characteristics.

The endogeneity of warranty length is explained by the fact that firms can easily set the length of warranty in response to the unobserved factors in $\xi_{jt}$. A similar observation was made by Menezes and Currim (1992). Conversely, the firms' actions regarding to product and service quality (using better parts/components, redesigning their processes etc.) will be reflected over a term longer than the one-year period of the analysis.

Thus, the exogenous $PQ_{jt}$, $SQ_{jt}$ and the structure of the supply model could be helpful to derive instruments for the warranty length. Guajardo et al. (2012) use the following logic to define instruments. Consider vehicles *j* and *r*, produced by different brands, and the $w_{jt}$ and $w_{rt}$ warranty lengths are correlated because firms compete on price and warranty, and correlate with the drivers of own warranty costs because firms account for the expected warranty cost. Noting that indirect utility $u_{ijt}$ does not depend on the attributes of vehicle *r*, they conclude that $PQ_{rt}$ is a valid source of instruments, and then apply the same argument to generate instruments using the rest of the drivers of the warranty costs, i.e. $SQ_{jt}$ and $xb_{jt}$.

## Robustness Checks for Estimation Results

Chu and Chintagunta (2009) conducted a series of robustness checks, functional form choices and estimation methods. Their findings are as follows:
– Channel-specific price sensitivity not supported by the data.

– The effect of direct channel entry on shares makes customers slightly less price sensitive, but the difference is not significant.

– The potential market size depends on the number of servers each establishment might use. The authors find the estimates are very robust to this number, it only shifts the manufacturer intercept.

– In accordance with recent literature, the authors assume customer preferences for product attributes and price and warranty coefficients follow continuous distributions. As to whether the main results are sensitive to the assumptions on customer heterogeneity distributions, the authors estimate a two-segment and a three-segment logit model, assuming the main explanatory variables follow discrete distributions. They obtain price and warranty elasticities similar to those from the current model.

## Empirical Data Used

According to Choi and Ishii (2010), one reason for the few empirical paper examining warranties is the difficulty in obtaining the necessary data set that combines the appropriate product, manufacturer and consumer information. In *Table 1*, we summarize the variables introduced in the automobile demand models with their definitions and the data sources.

**Table 1.** *Summary of the variables in various automobile demand models with their definitions and the data sources*

| | Definition | Used by | Data source |
|---|---|---|---|
| Manufacturer basic warranty | repairs vehicles for a specific time and mileage | Chu and Chintagunta (2011) | consumerreports.org, manufacturer web sites |
| Manufacturer powertrain warranty | offers protection beyond the basic warranty | Chu and Chintagunta (2011) | consumerreports.org, manufacturer web sites |
| | | Guajardo et al. (2012) | |
| | extended warranties | Choi and Ishii (2010) | Warranty Direct.com |
| Overall quality scores | a 100-point scale based on CR's tests, subscriber survey data and other tests | Chu and Chintagunta (2011) | consumerreports.org, manufacturer web sites |
| | product quality – nr. of problems per 100 vehicles in the first 90 days, examines 217 vehicles attributes | Guajardo et al. (2012) | J.D. Power's Initial Quality Study (IQS) |

|                                    | Definition                                                                                                                                                                                              | Used by                                                    | Data source                                            |
|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|--------------------------------------------------------|
| Overall quality scores             | Service Quality satisfaction level of the owners in 3 years measured in a 1,000-point scale based on six metrics                                                                                          | Guajardo et al. (2012)                                     | J.D. Power's Customer Satisfaction Index (CSI)         |
|                                    | car ratings                                                                                                                                                                                              | Choi and Ishii (2010)                                     | consumerreports.org,                                   |
| Accident avoidance                 | a 5-point composite score based on CR's tests results for braking performance, emergency handling, acceleration, driving position, visibility and seat comfort. Braking and emergency handling carry the most weight. | Chu and Chintagunta (2011)                                | consumerreports.org, manufacturer web sites            |
| Predicted reliability for new cars | CR's forecast                                                                                                                                                                                            | Chu and Chintagunta (2011)                                | consumerreports.org, manufacturer web sites            |
| Sales data                         | monthly data at the make-model level                                                                                                                                                                     | Chu and Chintagunta (2011)                                | J.D. Power, Ward's automotive                          |
|                                    | household purchases: 1998–2002                                                                                                                                                                           | Choi and Ishii (2010)                                     | Consumer Expenditure Surveys                           |
| Price                              | real transactional prices after rebates                                                                                                                                                                  | Guajardo et al. (2012)                                     | J.D. Power                                             |
|                                    |                                                                                                                                                                                                         | Choi and Ishii (2010) Train and Winston, (2007)           | Automotive News Ward's Automotive Yearbook             |
| Car attributes                     | e.g. type, make, horsepower, MPG etc.                                                                                                                                                                    | Chu and Chintagunta (2011)                                | Consumer Expenditure Surveys                           |
|                                    | category dummies, engine size, length / trim-level data                                                                                                                                                  | Choi and Ishii (2010)                                     | Automotive News                                        |
|                                    | brand dummies                                                                                                                                                                                            | Choi and Ishii (2010)                                     |                                                        |
| Consumers' characteristics         | income                                                                                                                                                                                                   | Choi and Ishii (2010)                                     | Consumer Expenditure Surveys                           |
|                                    | risk aversion – vehicle insurance expenditures in the model used warranty * risk aversion quartiles                                                                                                       | Choi and Ishii (2010)                                     | Consumer Expenditure Surveys                           |

# 5. Major Results

Chu and Chintagunta (2009) find several important results applicable by managers. First of all, the validity of their estimates is considered to be confirmed by comparing to benchmark data. For example, the estimated gross markup of the downstream firms ranges with market data and the customer preference order of the four major manufacturers is also consistent with the market shares. Manufacturers and channel intermediaries benefit greatly from warranty provision and from price discrimination by offering non-uniform warranties, and they quantify exactly these benefits. If all manufacturers offered three-month warranties (the shortest in the market), the total manufacturer and retail profits in 1999–2004 would be 82.8% and 81.1%, respectively, of the current levels. Sun benefits the most from offering warranties followed by Dell, while IBM benefits the least.

Consistent with the theoretical predictions (Tirole, 1988), the firms also benefit from price discrimination by offering a menu of warranties instead of one. If all manufacturers offered two-year uniform warranties for all their products, their profits would be 86.3% and 87.1% respectively. This price discrimination value of the warranties varies substantially across manufacturers: IBM gains the most, followed by Sun, HP and Dell. The counterfactual experiments allow the authors to evaluate the profit, maximizing the best warranty scheme for each manufacturer. The turning point in profit is one year for HP and Sun, six months for IBM and two years for Dell, although the differences in Dell's profits under one-year and two-year uniform warranties are small.

Customers also benefit from manufacturers offering a menu of bundled warranties. The total customer welfare is quantified $5,972 billion or $498 per server if all manufacturers offered uniform three-month warranties, and it would require $136 per server in the case of two-year uniform warranties. The authors also compute warranty elasticities across manufacturers and channels. Given the current warranty scheme, they find that a 1% increase in warranty duration will increase manufacturer shares by about 0.35%.

They find that server customers are heterogeneous in their preferences for manufacturers, CPU and channel, warranty preference and price sensitivity. This indicates the sorting role of warranties.

The methodology used has the limitation that only a subset of product attributes that are observed influence a customer's choice. If customers valued the unobserved product attributes and if warranties were positively correlated with these unobserved attributes, the estimated value of warranties would be overstated. This is a general problem of modelling the warranty value. Another strong limitation of their research theme is avoiding extended warranty; they only quantify the value of base warranties.

Choi and Ishii (2010) find that the conditional logit results from the simple model are mostly consistent with the results for the random coefficient logit model from the corresponding specification, except for the coefficient of the after-purchase income variable for the low- and middle-income groups. These estimation results show statistical significance, suggesting that consumers indeed have a heterogeneous preference for after-purchase income. These authors find some differences in the impact of warranties across car classes in the random coefficient logit model without brand-fixed effects; the warranty effect on different car classes decreases after including brand-fixed effects. In this full model, warranties seem to have bigger effect in the "small" and "luxury" categories, which, in the opinion of the authors, is a result consistent with the signalling theory. Another result that supports the importance of signalling motive is that the interaction between warranty and brand experience is strongly and statistically negative, indicating that consumers value warranties much less for experienced brands. In accordance with these findings, consumers heavily discount cars that have no *Consumer Reports* rating, but less so for those that come with longer warranty. This result of warranty lengths mattering more for cars with no rating further supports the signalling motive, as these cars are among those with the greatest asymmetric information between consumers and manufacturers.

The importance of insurance theory is not proved by the results. If risk aversion is a strong motive of warranty demand, the coefficients for the interaction between warranty and risk aversion proxies should be positive and increasing with quartiles. Nevertheless, none of the four models show statistical significance for any quartile of risk aversion and the signs of risk aversion coefficients are contrary to expectations. The authors tried other proxies for risk aversion, using other non-warranty insurance expenditures, but obtained no different results.

Choi and Ishii (2010) calculate the marginal effect of explanatory variables, which reflect how the probability of a consumer's observed choice changes with shifts in the values of a single explanatory variable. They use the average of each studied individual's marginal effects rather than the marginal effects of a "representative individual" with the average value for each explanatory variable. For non-binary explanatory variables, the marginal effect is the average across each individual probability derivative, and for binary explanatory variables it is the average of the difference between the actual estimated probability for the observed choice and the counterfactual estimated probability for the observed choice, assuming that the value of the binary explanatory variable of focus is zero. The analysis of marginal effects shows the strong role of brand loyalty, a result also found by Train and Winston (2007). The excluded brand of the brand dummies was Suzuki; a positive value of marginal effect indicates preference over this brand.

An interesting and novel topic in Choi and Ishii (2010) is the examination of possible trade-offs between warranty length and brand reputation, the degree to

which longer warranties seem to offset differences in the estimated brand dummy. They compared a newer, lower reputation firm brand (Hyundai) to the category leader (Honda) in the small/medium car category, and the same in the luxury category (Lexus versus BMW). In both comparisons, the newer firm offers a 2 year longer powertrain warranty. The results of the three models with different levels of information asymmetry are the estimated brand dummies and the marginal effect of each additional year of powertrain warranty to the indirect utility of the consumer. Choi and Ishii quantify how many extra years of warranty a manufacturer should offer to offset the brand reputation disadvantage to the category leader. This suggests that Hyundai's two year longer warranty in 1998 was inadequate to compensate for Honda's greater reputation, and in the luxury category the longer warranty does not sufficiently address perceived quality difference for first-time luxury car buyers.

Chu and Chintagunta (2011) assess the four competing theories on the economic roles of warranties in the U.S. computer server and automobile market. Here we discuss the results in the automobile market. In the case of insurance theory, they verified the two underlying assumptions. Similar to the server market, they found indirect evidence of consumers' risk aversion through their purchases of extended automobile warranties. This, together with the *Customer Report* data regarding product reliability, indicates non-zero failure rates of automobiles.

The insurance theory predicts that the degree of consumer's risk aversion is positively correlated with the duration of the warranties purchased. The authors use proxies for household risk attitudes, relying on results by Dohmen et al. (2005). These authors find a concave relationship between age and risk attitude, which implies a convex relationship between age and warranty duration, and, similarly, a concave relationship between income and warranty duration. The results are consistent with their expectations.

The sorting theory posits that manufacturers should offer a menu of warranties, which is a fact for most manufacturers. This theory also predicts that in market equilibrium households with the same observable characteristics will buy different automobile warranties; the authors use income to illustrate this. Consistent with insurance theory, higher-income households tend to buy shorter warranties because of their lower level of risk aversion; however, households of the same income levels also buy different warranties. The authors formulate that manufacturers cannot price-discriminate their warranty policies solely on the basis of household income. To extract more consumer surplus, they choose to offer a menu of warranties and let households self-select into different warranty contracts in accordance with their risk preference.

The information asymmetry assumption of the signalling theory is verified by running two sets of regressions of automobile quality indicators (overall quality score and accident avoidance score) on warranty duration, product price and major product attributes. One set of regressions includes manufacturer dummies

as regressors, while the other set does not. The powertrain warranty years are positively correlated with the quality score only when the manufacturer dummies are not included in the model. This implies that when other quality signals, that is manufacturer reputation and brand, are present, warranty length is no more a signal of product quality.

According to the authors, the insignificant warranty coefficient in these regression models also implies that automobile warranties do not play an incentive role for manufacturers to reveal product quality to consumers. The incentive theory posits a positive correlation between new product reliability and warranty duration. The results show that powertrain warranty has a significant effect on the predicted reliability of new vehicles only if the manufacturers' fixed effect is not included in the model. Therefore, the authors conclude that there is no evidence to support the incentive theory of warranties in the automobile market.

# 6. Further Research Topics

Chu and Chintagunta (2009) suggest as a further research topic the question how base and extended warranties interact with each other. The market for extended warranties is growing rapidly, and it would be profitable for the firms to know what type of customers are more likely to buy extended warranties and why. Other further research topics refer to the indirect channels; to the interactions between manufacturer and retailer warranty provisions whether they are complements or substitutes; whether warranties are overprovided and consumers are overprotected, and whether these two are mutually profit-enhancing. In addition, future research could try to use firm-level warranty data instead of aggregate data and firm characteristics, and examine their relationship.

Choi and Ishii's (2010) main finding is that signalling should be a more important motive for warranties in the automobile industry than risk aversion. In terms of future research, specifications with more direct measures of risk aversion and product information need to be developed to understand the consumer perception of warranties as signals. The analysis should be extended from the consumer behaviour to the supply side. According to these authors' hypothesis, automobile manufacturers may view exceptionally long warranties only as a transitional strategy until their brand reputation "catches up" with the category leaders.

As a direction for further research, Chu and Chintagunta (2011) determine decomposing the four warranty theories in markets different from the U.S. automobile market. Markets differ in their degree of information asymmetry – as we have observed in the case of server market in Chu and Chintagunta (2009) –, availability of other quality cues, consumer risk aversion and moral hazard. It is likely that warranties assume different roles in different markets.

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