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Abstract
We formulate a structural econometric model to analyze the impact of service attributes (warranty length, after-sales service quality) on consumer demand in the U.S. automobile industry. Our results indicate that service attributes play a compensatory role with respect to product quality, i.e., the impact of warranty length and service quality on demand increases when product quality decreases. Conversely, both service metrics are complementary with respect to demand, i.e., the better the service quality, the higher the marginal effect of longer warranties. Our results estimate a median willingness to pay for one year of warranty of about $850, which is equivalent to 2.5% of the average vehicle price in our sample. We find that, for an average car in our sample, the effect on demand of a 1% price decrease is equivalent to increasing product quality by 3%, which is in turn equivalent to increasing the warranty length by 9%.

Keywords: Services in Manufacturing; Competition; Differentiated Products; Pricing; Product Quality; Service Quality; Warranty; Automobiles; Econometrics
1. Motivation

A fundamental trend in manufacturing industries is the movement from a “pure manufacturing” paradigm to a business model in which a central role is assigned to the service component of products based on the value they provide to consumers (Cohen et al. 2006). The movement towards a service-based economy has coincided with this change and has encouraged many manufacturing firms to put more emphasis on the delivery of services associated with their product offerings (Shankar et al. 2009). It has been reported that the sales of after-sales services and spare parts represent 8% of the annual gross domestic product in the U.S. (Cohen et al. 2006). In the automotive sector, in particular, recent industry reports indicate that for manufacturers in this industry, service and parts operations are on average 54% more profitable than the main business of producing and selling vehicles, and account for an average of 36% of revenues (Koudal 2008). In the technology sector, companies like IBM that traditionally sold manufactured goods, today derive more than 50% of their revenue from services (Suarez et al. 2008). In short, services have become an important part of an OEM’s competitive strategy in traditional manufacturing industries. While existing models of product differentiation in manufacturing industries have provided some insights in explaining the consequences of pricing and other product characteristics on demand, they have mostly ignored the impact of services. This paper takes a step in addressing this issue, by formulating an empirical model to analyze the role of services as part of a firm’s competitive strategy in the U.S. automobile industry, and the joint effect that service attributes and product quality have on consumer demand.

The automobile industry has served as a preferred setting for empirical studies on product differentiation (e.g. Berry et al. 1995 and 2004, Sudhir 2001, Train and Winston 2007, among many others), and constitutes a natural choice for our research. Indeed, Standard & Poor’s (2011) reports that in this industry “product quality and design are becoming less of an issue in differentiating foreign and domestic manufacturers,” as a result of the actions taken by Detroit automakers to improve their designs and to streamline their manufacturing processes in recent decades. Services, on the other hand, represent an important differentiating factor for automakers, especially given the high level of competition and low concentration in the U.S. automobile market (Koudal 2008). The fact that auto OEM’s have been adjusting their service strategies in recent years, as we describe shortly, provides some support for this notion.

We focus on services during the in-warranty period. In particular, we measure the service dimension of a brand by the length of its warranty, along with a metric of the after-sales service quality delivered during the in-warranty period. The warranty period covered by
OEM’s has steadily increased over time, from about three months in the 1930’s, to as much as ten years in recent years (Murthy and Blischke 2006). The length of the warranty defines the period in which repair services are provided by the OEM as part of the value that consumers obtain with the purchase of the car, and therefore is a managerial decision that partially reflects the service intensity provided by OEM’s. Firms have been active on adjusting the length of their warranties in the last decade: Ford, Chevrolet, Acura, Mazda, Mitsubishi, Audi and Kia are just some examples of brands that have increased the length of their warranties in that period. For example, Ford increased their powertrain warranty from 3 years/36,000 miles to 5 years/60,000 miles in 2007. In the words of a spokesperson from Ford when asked about the reasons behind the warranty length increase: “We think that some people weren’t considering Ford products because we didn’t have an extended powertrain warranty versus some of our competition. We hope that it will increase our competitiveness... We think that customers do want it, and do care about it” (Warranty Week 2006). On the other hand, Chrysler and Volkswagen both decreased their warranty length at least once during the same period. Indeed, company sources have suggested that the increase in warranty length by Chrysler for the 2008 model year “wasn’t as valuable to consumers as we might have hoped” (Automotive News 2009), and as a result the company cut it back in 2009.

Firms face an important trade-off when defining their warranty period: while longer warranties may potentially increase product demand, they also generate significant costs. For U.S.-based automakers, these costs have typically been in the range of $10 billion per year, which represents roughly 2-4% of their yearly revenue (Warranty Week 2011). These data, along with the aforementioned managerial actions and the attention of the trade press to them, reflect the importance of improving our understanding of the role of warranties and service attributes as drivers of demand, the conditions under which they influence demand, and the magnitude of these effects.

In this paper we formulate and estimate a structural model to measure the impact of service attributes on consumer demand in the U.S. automobile industry. Combining data from multiple sources, we propose an empirical model using market-level data for new light cars sold in the U.S. between 2001 and 2007, a period in which firms actively adjusted their service and warranty strategies. Our analysis is based on a random coefficients logit demand model that allows for customer heterogeneity in tastes for different car attributes and, unlike most existing models, incorporates the two aforementioned variables to characterize firm service strategies, i.e. warranty length and the quality of after-sales service. Our results provide new evidence to explain the influence of warranty length and service quality on the demand for a given model, relative to the influence of other characteristics such as price and
product quality. Most existing empirical models of competition in this and other industries deal with the endogeneity of prices while assuming that all other characteristics in the demand specification are exogenous. Our model is different in that we not only endogenize pricing but also the warranty length decision. We do so by generating instruments based on the factors driving firm decision-making for the warranty length. Our findings indicate that, when the endogeneity of warranties is ignored, service attributes do not have a significant impact on demand. Once the endogeneity of warranties is considered, however, there is a significant effect of warranty length on demand, while service quality does not have a significant effect when this variable is considered in isolation. Our estimates imply a median willingness to pay for one year of warranty of about $850, and that for a vehicle with average characteristics in our sample, a 1% price decrease has the same effect on consumer demand as an improvement in warranty length of 9% or as a 3% improvement in the vehicle’s product quality.

We also investigate complementarities and substitution effects between warranty length, service quality and product quality. Indeed, the following example from a survey by CNW Marketing Research\(^1\) illustrates that there may be important differences in warranty effects across firms. The company conducted a survey (September-November 2006) with shoppers of GM, Hyundai, and Toyota, asking them how important the length of the warranty was in their shopping decision. The results of the survey revealed that 45.1% of all intenders considered the warranty length to be “extremely or very important” in order to have these companies on their shopping list. Breaking down the results at the company level, however, showed important differences, i.e., the percentage of intenders that considered the length of the warranty extremely or very important was 54.6% for Hyundai intenders, 53.4% for GM intenders, and only 28.4% for Toyota intenders. To our knowledge, the existing literature has not offered an explanation consistent with these data. While multiple hypotheses can be proposed to explain the difference in these specific cases, our research conducts a systematic analysis to understand the joint influence of service attributes and product quality on consumer demand. We propose that warranty length, service quality and product quality, interact in a non-trivial way in the consumer’s value function, and we investigate the nature of these interactions. In particular, we test whether the effect of service attributes on consumer demand is independent of, or is a complement or substitute for product quality. The theory of compensatory effects on consumer decision-making (e.g. Dieckmann et al. 2009) support the hypothesis that both dimensions act as substitutes, i.e., good service serves the main purpose of compensating consumers for poor product quality. Alternatively, service attributes could be complements with product quality if consumers see both dimensions as reinforcing their brand preference, i.e., if the primary effect of offering good product quality

\(^1\)Available at http://www.cnwbyweb.net (subscription required to access data)
and good service is to create better brand image. Our results indicate that the value that consumers derive from warranty length and service quality in the U.S. automobile industry increases when product quality decreases, i.e. service attributes have a bigger impact on demand when product quality is low, providing evidence for a compensatory rather than a complementary role of services relative to product quality. Similarly, we test whether both service attributes have independent, complementary or substitution effects on demand, and find evidence for a complementary relationship in this case, which is contrary to our findings for the case of product quality. This suggests that a firm that increases its warranty length would make the most out of this investment (in terms of its impact on demand) by simultaneously investing in providing better service quality. The results of our analysis thus indicate that the joint consideration of product and service is essential for the development of an effective competitive strategy.

2. Related Literature

Service competition is a major topic of interest in operations management (OM). In traditional service industries, theoretical models have examined competition when consumer demand depends on price and service levels (So 2000, Cachon and Harker 2002, Allon and Federgruen 2007 and 2009, Bernstein and Federgruen 2007), and in empirical OM research several studies have tested some of these and related theories in, e.g., the fast food industry (Allon et al. 2011) and the banking industry (Buell et al. 2011). In manufacturing industries, in contrast, service competition has been the subject of theoretical models in OM, e.g., service competition between a manufacturer and a retailer (Cohen and Whang 1997), between retailers that interact strategically with a manufacturer (Tsay and Agrawal 2000), and between manufacturers (Lu et al. 2011). The empirical evidence in the case of manufacturing industries, however, is scarce, and indeed we are not aware of any OM papers that analyze the impact of service competition on consumer demand in manufacturing industries empirically. In the economics literature, on the other hand, theoretical models of product differentiation (e.g. Shaked and Sutton 1982, Caplin and Nalebuff 1991), have prompted numerous empirical studies, especially in the automobile industry where researchers have studied different aspects of firm competition and consumer demand (e.g. Berry et al. 1995 and 2004, Train and Winston 2007, among many others). Similar to the OM literature, these economic models of demand have omitted the role of supporting services by automakers. Our paper thus attempts to fill this gap by analyzing the role of service attributes as drivers of consumer demand in the U.S. automobile industry. Moreover, as our results illustrate, considering the interaction between service attributes and product quality is essential in order
to disentangle the effects of service attributes on demand in this industry, and thus analyzing service competition in a manufacturing industry offers new evidence that goes beyond what has been done in service industries.

One of the service variables we focus on is length of warranty. Four main rationales regarding the economic role of warranties have been proposed in the literature (see e.g. Emons 1989 for a comprehensive discussion): protection against product failures (insurance role), provision of product quality information to consumers (signaling role), a mechanism to discriminate consumer risk preferences if customer heterogeneity is not fully observable by the seller (sorting role), and to incentivize the seller to improve product quality (incentives role). These theories would thus be consistent with consumer preferences for longer warranties, all else being equal. Regarding the insurance role (e.g. Heal 1977), warranties provide consumers with some security against poor product quality and are often used by manufacturers as a value-added feature to promote their products (Thomas 2006). The signaling argument, on the other hand, predicts that higher quality products will have longer warranties, and is perhaps the one that has received the most attention. Since Spence’s model of perfect competition in which warranties serve as signals of reliability (Spence 1977), several theoretical models have qualified this finding in alternative settings (e.g. Cooper and Ross 1985, Gal-Or 1989). Empirical tests of the signaling role of warranties are also numerous. While early papers like Wiener (1985) showed a positive association between warranty length and product quality providing support for the signaling argument, others like Douglas et al. (1993) showed that the opposite is possible. More recently -and more broadly- Chu and Chintagunta (2011) empirically tested for the different roles of warranties in the U.S. automobile and PC server industries, finding support for the insurance and sorting role of warranties, but not for the signaling and incentives roles. Given the numerous papers studying the economic role of warranties, we do not address this question and rather build our model upon some of the findings in this literature, to study how service attributes such as warranty length and service quality, along with product quality, jointly influence consumer demand.

Empirical models of demand related to ours that include consumer response to warranties include Menezes and Currim (1992) and Chu and Chintagunta (2009). Menezes and Currim (1992) formulate a theoretical model to define the appropriate warranty length for firms, and they also perform some empirical testing in the automobile industry. Their empirical analysis is based on a sales response model (aggregate demand function), for which OLS analysis is performed, and in which several attributes (including aggregate functions of other firms’ actions) are used to explain total sales for a given model. They do not deal with the endogeneity of either the price or the warranty length in the demand specification. In a paper more closely related to our study, Chu and Chintagunta (2009) empirically analyze the
value of warranties in the U.S. server market. Their research in this B2B setting quantifies the value of warranties for manufacturers, intermediaries and customers, and finds a positive value for warranties in all cases. As in our case, their demand model is based on a random coefficients logit model that allows for customer heterogeneity and that is based on market data, but they only account for the endogeneity of the pricing decision.

While past empirical studies are certainly relevant for our analysis, we establish at least three important differences. First, these papers focus on warranties exclusively, while our interest is in services more broadly defined, which includes not only the firm’s warranty length but also its service quality in the demand specification. Second, our focus is on understanding the effect on demand of the interaction between service attributes and product quality, in order to enlighten firm decision-making regarding both of them. To our knowledge, our findings in this regard have not been established in previous empirical literature. Third, from a methodological perspective, unlike past papers, note that we explicitly deal with the endogeneity of both pricing and warranties, and our identification strategy for warranty effects could be used in other settings. With respect to the third aspect, most existing models of product differentiation have accounted for the endogeneity of prices in the demand specification, under the assumption of exogeneity of all other product characteristics. This assumption has been recognized as an important shortcoming in this literature (Berry 1994). As a response, a recent and growing stream of research on endogenous product choice has considered models in which some product characteristics other than price are treated as endogenous (see Crawford 2012 for a recent review of this research stream; good examples include Draganska et al. 2009 and Fan 2011). Our research thus also relates to the endogenous product choice literature, as we deal with the endogeneity of both pricing and the warranty length decision by firms. Finally, our research is also related to the numerous empirical studies in OM that examine the automobile industry, including Fisher et al. (1999), Ramdas and Randall (2008), Olivares and Cachon (2009), and Gallino et al. (2012), among many others, that as ours attempt to examine some aspect that contribute to an understanding of factors influencing the matching between what firms supply and what consumers demand in this industry.

In short, this paper contributes to the aforementioned streams of research by being one of the first to empirically analyze the value of service attributes as drivers of demand in manufacturing industries, and by being (to our knowledge) the first study to empirically analyze complementarities between service attributes and product quality in the context of demand models in a competitive manufacturing setting. Product quality, service quality

\footnote{See section 4.3 for a discussion of the required assumptions under which our identification strategy is valid.}
and warranty length are variables of longstanding importance in OM research. The new empirical evidence of their impact on demand in a competitive setting provided in this paper, contributes to a better understanding of the strategic implications of the joint management of these variables by firms.

3. Data and Industry Background

Market-level data was collected from different sources for our analysis. We obtained data on sales and product characteristics from Ward’s Automotive, for all new light cars sold in the U.S. in the period 2001-2007. Vehicle specifications include miles-per-gallon, length, width, height, horsepower and weight, among other features. Data about warranty length were obtained from Automotive News for the period 2003-2007; we completed and validated the data for the period 2001-2007 from the manufacturers’ websites and the 2009 Official Warranty Guide (J&L Warranty Pros). Data on product quality and service quality at the brand level were obtained from J.D. Power’s press releases. Aggregate yearly data on transactional prices were obtained from a secondary source, based on J.D. Power data. Below, we discuss some characteristics of these data sources in more detail, along with aspects of the industry that help to clarify our analysis.

Warranty data: Automakers include manufacturer warranties bundled with the purchase of every new car, to protect consumers against defects for a certain period of time/usage. There are three main types of warranties bundled with a new car: basic, powertrain, and corrosion. The basic warranty (a.k.a. bumper-to-bumper) is the most comprehensive and covers most parts of a vehicle. The powertrain warranty (a.k.a drivetrain) covers the major cost components of the car such as the engine, transmission, etc., usually for an extended period of time (for some brands in some years, the coverage period is the same for basic and powertrain warranties). The corrosion warranty covers the vehicle against rust. For example, the Acura 2007 model year vehicles had basic, powertrain, and corrosion warranties of 4/50,000, 6/70,000, and 5/unlimited [years/miles], respectively. For a given brand, there is a high correlation between the warranty terms for these three types of warranties, and also between the years/miles metrics. Most of the existing studies on warranties have focused on the duration of the powertrain warranty for several reasons. First, the powertrain warranty covers the most expensive parts of the vehicle. Second, most of the changes in warranty strategies by OEM’s refer to powertrain warranty duration and therefore is the richer source of longitudinal variation, e.g., Acura from 4/50,000 to 5/70,000 in 2006, Chevrolet from 3/36,000 to 5/100,000 in 2007, Kia from 5/60,000 to 10/100,000 in 2001, Mazda from 3/50,000 to 4/50,000 in 2003, Mitsubishi from 5/60,000 to 10/100,000 in 2004, among many
others. Finally, the powertrain warranty is the warranty that automakers advertise the most. Consistent with these arguments, we use the length of the powertrain warranty in years as our warranty variable.

**Quality data:** J.D. Power publishes yearly reports on product quality and service satisfaction at the brand level. Here we provide a brief description of the data used in our analysis, further details can be obtained via http://www.jdpower.com/.

Our product quality metric is based on J.D. Power’s Initial Quality Study (IQS), which determines the number of problems per 100 vehicles in the first 90 days of ownership. The study examines 217 vehicle attributes, and reports on a broad range of problems reported by owners, including defects/malfunctions (complete breakdown or malfunction of any component, feature, or item) and design problems (components or features that may be functioning as designed, but are perceived to be difficult to use or understand, or are in a poor location). Every year this information is summarized in a brand-level metric. For example, in 2004 the best brand was Lexus with 87 problems per 100 vehicles, the worst was Hummer with 173 problems per 100 vehicles, and the industry average was 119 problems per 100 vehicles. In 2007, the best brand was Porsche with 91 problems per 100 vehicles, the worst was Land Rover with 170 problems per 100 vehicles, and the industry average was 125 problems per 100 vehicles. We take the negative of the number of problems per vehicle as our product quality metric $PQ_{jt}$, such that a higher value for $PQ_{jt}$ (smaller number of problems per vehicle) denotes higher product quality.

Similarly, J.D. Power’s Customer Service Index (CSI) measures the satisfaction of vehicle owners who visited the dealer service department for maintenance or repair work during the first three years of ownership. According to the J.D. Power’s description, the CSI study “provides an overall customer satisfaction index score based on six measures: service initiation, service advisor, in-dealership experience, service delivery, service quality, and user-friendly service.” The score is based on a 1000 point scale. For example, in 2004 the best brand was Lincoln with a score of 912, the worst was Daewoo with a score of 754, and the industry average was 862. Similarly, in 2007 the best brand was Jaguar with a score of 925, the worst was Isuzu with a score of 780, and the industry average was 876. We note that this metric refers to after-sales service at dealers during the first three years of ownership, which is coincident with the minimum warranty period observed in the industry. This metric thus reflects services that occurred during the in-warranty period, and in conjunction with the warranty length, defines the variables that we use to characterize the service dimension of a brand. Specifically, our service quality variable $SQ_{jt}$ is a scaled version of the customer service index (CSI score/1000).

Figure 1 displays the relationship between the IQS and CSI metrics for 2004 and 2007, for
the brands in our sample. Figures 2 and 3 do the same for the relationship between warranty length and IQS and CSI, respectively. We note several interesting observations. Pooling the data for our period of analysis at the brand level (2001-2007), we obtain a correlation of -0.64 between IQS and CSI, denoting a positive relationship between product quality and service quality (recall that the IQS index reflects negative product quality). As illustrated in Figure 1, most brands are located on the diagonal of the graph. The graph from 2004 suggests some exceptions, like Saturn (low product quality, high service quality), and Hyundai and Toyota (high product quality, low service quality). Similarly, we obtain correlations of 0.13 between warranty and IQS, and -0.29 between warranty and CSI. These statistics reflect a negative correlation between warranty length and both product quality and service quality. Note that the negative correlation between warranty and product quality counters the signaling role of warranties.

Finally, we note that, while the service experience at dealers is not fully determined by OEM’s, they can and do influence the service process in several ways (see e.g. Cohen et al. 2000). First, OEM’s impose guidelines and service standards on their dealers. Second, they can facilitate the quality of service delivered by dealers through a wide range of managerial interventions, e.g., by setting up parts pooling mechanisms, sharing information, using vendor-managed inventory and implementing a generous parts return policy for dealers. Third, OEM’s usually set up incentive programs, whereby a dealer’s compensation is, in part, based on service performance. Finally, the design of the service network, for example, the definition of the number of dealers, is ultimately defined by the OEM.

**Sales, prices and product characteristics:** We obtained data on sales and product characteristics from Ward’s Automotive for all new light cars sold in the U.S. between 2001 and 2007. This includes cars belonging to the segments small, middle, large and luxury, as categorized by Ward’s. Sales data is available at the make-model level (e.g. Toyota Corolla) monthly. Data on product characteristics (e.g. miles-per-gallon, length) is available for each model year and for each of the versions of a given make-model. As noted in existing studies (e.g. Berry et al. 1995, Sudhir 2001), a certain level of aggregation is required to match sales data with the respective product characteristics. For a given product characteristic, e.g. length, we consider the average length of the options of a given model year as the length associated with that model year (an approach also taken by Balachander et al. 2009).
Figure 1: CSI vs. IQS (2004: left, 2007: right)

Figure 2: IQS vs. warranty length (2004: left, 2007: right)

Figure 3: CSI vs. warranty length (2004: left, 2007: right)
In addition, we obtained yearly data on transactional prices at the make-model by model year level from a secondary source based on J.D. Power data\(^3\). These data are collected at the daily level by J.D. Power from a sample of dealers in the U.S. covering about 70% of the geographical areas and 15-20% of total U.S. sales. These data reflect transactional prices paid by consumers after rebates and as such, are more informative of actual consumer expenses than the manufacturer suggested retail price which is usually used in research papers due to the unavailability of information about transactional prices. We only have access to these data at the aggregate yearly level, more precisely, the average across time of the transactional prices paid by consumers for a given make-model by model year in the period September-August of each year, which is the definition used for calendar year in our analysis. Note that sales data from Ward’s do not distinguish between different model years of a given make-model sold in the same calendar year. In practice, however, in a given calendar year different model years of the same make-model are sold simultaneously. The pricing data set contains sales at the model year level for each calendar year for the sample of dealers described above. We use the distribution of sales in this data set and apply it to the market level sales data from Ward’s to obtain sales at the make-model by model year level. A similar approach to matching both data sets was taken by Copeland et al. (2011).

**Sample:** We match all data sources as described above. Our final sample consists of 2122 yearly observations for all new light cars sold in the U.S. in calendar years 2001-2007, which includes model years from 2000 to 2008. Our unit of analysis is a make-model by model year and calendar year, e.g. 2005 Toyota Corolla in calendar year 2005.

4. **Model**

In this section we describe the structural model formulated to study the role of service attributes as drivers of demand in the automobile industry. It considers decision-making by both consumers (demand model) and firms (supply model). In what follows, we describe the demand model in detail, and provide a high level discussion of the underlying supply model. As will be shown, while we do not estimate supply side parameters in our analysis, our empirical formulation does make extensive use of the underlying supply model to derive identification conditions for demand parameters. Thus, the formulation of this supply model and its assumptions allow us to deal with the endogeneity of the warranty length decision by firms in the demand specification. We do discuss the identification strategy in detail, and finalize the section with a brief outline of the estimation procedure.

\(^3\)We thank Adam Copeland for making these data available to us.
4.1 Demand

We consider a random coefficients logit demand model, where the utility that consumer \( i \) derives from purchasing vehicle \( j \) \((j = 1, \ldots, J)\) in calendar year \( t \) \((t = 1, \ldots, T)\) 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 (size, horsepower to weight ratio, etc.) \( x_{jt} \), as follows:

\[
  u_{ijt} = \alpha_i p_{jt} + x_{jt}' \beta_i + h(w_{jt}, PQ_{jt}, SQ_{jt}) \gamma + \xi_{jt} + \epsilon_{ijt} \tag{1}
\]

The term \( \xi_{jt} \) represents unobserved product attributes common to all consumers, and \( \epsilon_{ijt} \) is a type I extreme value idiosyncratic shock. Consumers maximize utility, and purchase vehicle \( j \) in calendar year \( t \) if and only if \( u_{ijt} \geq u_{irt} \) for all \( r = 0, 1, \ldots, J \). Here, \( r = 0 \) defines the outside good, i.e. the option of not purchasing a new light car in year \( t \), where \( u_{i0t} = \epsilon_{i0t} \).

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 is common in the literature (e.g. Berry et al. 1995, Sudhir 2001). The total effect of attribute \( x_{jt}^k \) on the utility of consumer \( i \) is thus modeled as \((\beta_k + \sigma_k \nu_{ik}) x_{jt}^k\), where \( \beta_k \) and \( \sigma_k \) are parameters to be estimated, and \( \nu_{ik} \) is a shock from a standard normal distribution; the same holds for \( \alpha_i \).

It is useful to note that \( u_{ijt} \) can be thus expressed more compactly as a function of the mean utility \( \delta_{jt} \) common across all consumers, and the heterogeneity terms \( \mu_{ijt} \) and \( \epsilon_{ijt} \) as:

\[
  u_{ijt} = \delta_{jt}(p_{jt}, x_{jt}, w_{jt}, PQ_{jt}, SQ_{jt}; \theta_1) + \mu_{ijt}(p_{jt}, x_{jt}, w_{jt}, PQ_{jt}, SQ_{jt}, \nu_i; \theta_2) + \epsilon_{ijt} \tag{2}
\]

Here, \( \theta_1 \) is a vector containing all parameters of the mean utility \((\alpha, \beta, \text{and } \gamma)\), and \( \theta_2 \) all the heterogeneity parameters \((\sigma)\). Let \( d_{jt} \) contain all \( M \) vehicle characteristics. \( \delta_{jt} \) and \( \mu_{ijt} \) are thus defined as:

\[
  \delta_{jt} = \alpha p_{jt} + x_{jt}' \beta + h(w_{jt}, PQ_{jt}, SQ_{jt}) \gamma + \xi_{jt} \tag{3}
\]

\[
  \mu_{ijt} = \sum_{m=1,\ldots,M} \sigma_m d_{jt}^m \nu_{im} \tag{4}
\]

The function \( h(w_{jt}, PQ_{jt}, SQ_{jt}) \) defines the way in which warranty length, product quality and service quality enter into the utility function. Under the linearity assumption for these variables, the utility function would take the following form:

\[
  u_{ijt} = \alpha_i p_{jt} + x_{jt}' \beta_i + \gamma^1 w_{jt} + \gamma^2 PQ_{jt} + \gamma^3 SQ_{jt} + \xi_{jt} + \epsilon_{ijt} \tag{5}
\]
This formulation is useful to capture the main effects of the variables of interest, and is also consistent with the linearity assumption made for the rest of the covariates. We refer to the model derived from the utility function in Eq. 5 as the main effects model.

We are also interested in testing, however, whether service attributes and product quality act as complements, substitutes or independently in the demand function. For this purpose, we consider an enhanced formulation in which the function \( h(w_{jt}, PQ_{jt}, SQ_{jt}) \) not only includes the main effects for these three variables -as described in Eq. 5- but also their two-way interaction terms \( w_{jt} \times PQ_{jt} \), \( w_{jt} \times SQ_{jt} \), and \( PQ_{jt} \times SQ_{jt} \). These interactions reflect the non-linearities of interest, i.e., the complementarity/substitution effects between service attributes and product quality. A recent study by Guajardo and Cohen (2012) has shown that service quality and product quality act as complements in terms of how they determine the likelihood to recommend the brand in an application in the consumer electronics industry, i.e., the better the perceptions of product quality of a person, the higher the impact of better perception about service quality on the person’s likelihood to recommend the brand.

In the context of our demand model, we would expect service attributes and product quality also to be complements if the dominating mechanism by which they affect consumer demand is through their impact on brand image. On the other hand, service attributes could act as substitutes for product quality if the main mechanism by which they affect consumer demand is by compensating consumers for poor product quality, i.e., if the car purchase process can be described as a compensatory process with respect to these attributes. In a compensatory decision process (e.g. Dieckmann et al. 2009), strengths along one or more dimensions of product or service quality can compensate for weaknesses along others. This is in contrast to the case of non-compensatory processes, in which no compensation is possible if certain attributes of a product or service are weak, even if it possesses strengths along other dimensions. The role of compensatory effects on consumer decision-making would thus provide a basis for characterizing our service attributes as substitutes for product quality. Similar arguments can be hypothesized for the interaction between warranty and service quality, i.e., a negative interaction under the hypothesis of compensatory attributes, or a complementary (positive) relationship not only if they both contribute to better brand image, but also if the main mechanism by which they affect consumer demand is by providing complementary functionality (longer and better service support). In the case of warranties and product quality, their insurance role (Heal 1977, Emons 1989) implies that warranties should be more important for consumers when the product is expected to fail more often, i.e. when product quality is lower, which would provide additional support for the hypothesis of a negative coefficient for the term \( w_{jt} \times PQ_{jt} \). Alternatively, all three attributes may exhibit independent effects on consumer decision-making, in which case no significance would be obtained for
the interaction terms. In this scenario of competing theories, whether service attributes act as complements, substitutes, or independently of product quality in the demand function is ultimately an empirical question, which we test in our analysis.

4.2 Supply

We assume that firms compete on prices and warranties. This assumption is consistent with some prior theoretical models (e.g. Spence 1977, Gal-Or 1989), which have modeled competition based on these two variables, taking other factors such as product quality as given. As noted, by offering warranties, firms incur important warranty costs. We incorporate these costs in our formulation, and define the profit function for firm $f$ in period $t$ as follows:

$$\pi_f = \sum_{j \in J_f} (p_{jt} - mc_{jt} - wc_{jt}) M s_{jt}(p_t, w_t, PQ_t, SQ_t, x_t, \xi_t; \theta)$$ (6)

In Eq. 6, $J_f$ 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 $j$ (market-level variables are in bold). As in most existing models, (e.g. Berry et al. 1995, Sudhir 2001), we consider a marginal cost function $g_1$ based on the projection of costs onto observable vehicle characteristics $x_{jt}^S$ (e.g., horsepower, size) and unobservable cost shifters $\varphi_{jt}$, i.e.,

$$mc_{jt} = g_1(x_{jt}^S, \varphi_{jt})$$ (7)

Next, we consider the warranty cost function. Generically, let $N(t)$ be the stochastic process for the number of failures of a vehicle by time $t$, and $Y_n(t)$ the cost of failure $n$ at time $t$, independent of $N(t)$. A standard formulation for expected warranty costs (e.g. Thomas 2006 pp. 67) if the warranty length is set to $W$ is thus $wc(W) = E[\sum_{n=1,...,N(W)} Y_n(t)]$. If the time between failures is iid, the expected warranty costs are given by $wc(W) = E[N(W)] E[Y_n(t)]$. The term $E[N(W)]$ represents the expected number of failures during the warranty period, which depends on the warranty length and the failure process. For example, if $N(t)$ is assumed to be a homogeneous Poisson process and $\lambda$ is the failure rate per time unit, then $E[N(W)]=\lambda W$; if the failure process is more complex, in general $N(t)$ will not necessarily have a tractable closed-form solution. For our purposes (and using our notation), however, it

$^4$Naturally, firms choose not only prices and warranties, but also vehicle characteristics and positioning with respect to product quality and service quality. The main argument behind our formulation is based on the nature of the model and the timing of firm decisions. While firms can easily adjust prices and warranties, decisions on vehicle characteristics as well as actions influencing product quality and service quality occur over a longer time horizon than the one we consider here. We discuss this issue more extensively in subsequent sections.
suffices to note that \( E[N(W)] \) is a function of product quality \( PQ_{jt} \) and the warranty length \( w_{jt} \). With respect to the expected cost per event, \( E[Y_n(t)] \), we must consider heterogeneity across brands. In particular, and in line with the previous literature (e.g. Cohen and Whang 1997), providing a certain level of service quality is costly, and thus the cost per event will depend on the quality of service provided when servicing the vehicle, for which our \( SQ_{jt} \) variable can serve as a proxy. Let \( xb_{jt} \) denote other observable characteristics that capture part of the brand heterogeneity in warranty costs, and \( \varsigma_{jt} \) unobservable factors. The warranty costs function \( g_2 \) can be thus represented conceptually as:

\[
w_{c_{jt}} = g_2(w_{jt}, PQ_{jt}, SQ_{jt}, xb_{jt}, \varsigma_{jt})
\]

Finally, we turn to firm behavior. The vast majority of studies on product differentiation focus exclusively on firms’ pricing behavior. In our case, we assume that firms compete on both prices and warranties, and make their decisions in order to maximize profits in each period, according to the profit function (6). While we do not estimate supply side parameters, the supply model presented here, and the drivers of marginal costs and warranty costs in particular, provide the fundamentals for our identification strategy for the parameters in the demand model.

### 4.3 Identification and instruments

In practice, all the observed variables in our demand specification \((p_{jt}, x_{jt}, w_{jt}, PQ_{jt}, SQ_{jt})\) are determined or influenced by firm decisions. On the other hand, \( \xi_{jt} \) reflects characteristics or shocks not observed in the data, such as style, prestige, and reputation, that affect the demand for different products. An endogeneity problem for the demand parameters emerges if some of the observed variables are set by firms upon observing the demand shocks \( \xi_{jt} \).

As noted, most existing studies have accounted for the endogeneity of prices in the demand specification under the assumption of exogeneity for all other product characteristics. While this assumption has been widely acknowledged as a shortcoming since Berry (1994), the underlying argument for it relies on the fact that, while the prices are easily adjustable by firms according to the market conditions and therefore \( p_{jt} \) is likely to be correlated with \( \xi_{jt} \) (i.e. price endogeneity), other product characteristics captured by \( x_{jt} \) (e.g. horsepower, size) are defined by firms well in advance of the time when a model is sold in the market, and thus are assumed to be uncorrelated with \( \xi_{jt} \). To account for the endogeneity of prices, instrumental variables can be used in the estimation. A well-known example is Berry et al. (1995)’s model for the auto industry involving prices \( p_{jt} \) and product characteristics \( x_{jt} \) in the demand specification. Their supply model considers firms competing on prices, and makes
a Bertrand-Nash equilibrium assumption. Under these assumptions, they propose a set of instruments to deal with price endogeneity: the sum (or average) of product characteristics $x_{jt}$ for (i) other cars of the same firm, and (ii) cars of other firms. Product characteristics $x_{jt}$ are exogenous by assumption, and are thus also used as instruments. This set of instruments has been widely used to deal with price endogeneity since then (e.g., Sudhir et al. 2001, Train and Winston 2007, Balachander et al. 2009). We use this set of instruments to deal with price endogeneity; as in Sudhir (2001), instead of considering the average characteristics for cars of all other firms, we 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 each other in terms of characteristics.

Our specification of the demand model involves not only prices and vehicle characteristics, but also brand level attributes $w_{jt}$, $PQ_{jt}$, and $SQ_{jt}$. As in the case of prices, firms can easily set the length of the warranty $w_{jt}$ in response to the unobserved factors in $\xi_{jt}$. A similar observation was made by Menezes and Currim (1992), who noted that in contrast to changes in product quality, changes in warranty length and price could be carried out almost instantaneously. Thus, warranties are expected to be endogenous in the demand specification in the same way (in terms of timing) as prices. Conversely, let us consider firm actions to influence $PQ_{jt}$ and $SQ_{jt}$. Note that firms can affect product quality by introducing changes in product design, using better parts/components (Ramdas and Randall 2008), redesigning their processes, etc. All of these factors will be reflected over a term longer than our yearly period of analysis. The time-to-market of a vehicle, for example, can take several years from the beginning of the design stage to product launch. Similarly, factors influencing service quality such as the implementation of optimization-based technologies for the management of parts inventories, more investment in spare parts inventory, the design of a more efficient service network, and a higher focus on services more generally, will usually involve long-term efforts and cultural changes by firms (see e.g. Cohen et al. 2000). We thus argue that the observed $PQ_{jt}$ and $SQ_{jt}$ are not easily adjustable contemporaneously by firms upon observing the shocks $\xi_{jt}$, and therefore will consider $PQ_{jt}$ and $SQ_{jt}$ to be exogenous in the demand specification. We derive instruments for the warranty length based on the exogeneity assumption for $PQ_{jt}$ and $SQ_{jt}$ and the structure of our supply model as follows. Consider vehicles $j$ and $r$, produced by different brands. Note that given our model in which firms compete on prices and warranties, $w_{jt}$ and $w_{rt}$ are the result of the strategic interaction of firms and are therefore correlated. If firms set their warranties optimally (or at least, take into account the expected warranty costs), $w_{jt}$ will be correlated with the drivers of warranty costs, e.g. $PQ_{jt}$ (see Eq.8). Similarly, $w_{rt}$ will be correlated with $PQ_{rt}$. Noting that $u_{ijt}$ does not depend on the attributes of vehicle $r$, then $PQ_{rt}$ is a valid (source of) instruments
for $w_{jt}$. We thus consider the average of product quality of other brands as an instrument for the warranty of a given brand.

We apply this same argument to generate instruments using the rest of the drivers of warranty costs, i.e. $SQ_{jt}$ and $xb_{jt}$ (Eq.8). In $xb_{jt}$ we include dummies for the region of the manufacturer (coded into three categories: USA, Europe, Asia) to partially capture heterogeneity across brands. Thus, our set of instruments for warranties includes the average product quality of other brands, the average service quality of other brands, and the proportion of brands belonging to the different geographical regions. Note that heterogeneity at the vehicle model level is already captured through the $x_{jt}$-based instruments. Finally, since 2003 it has been mandatory for firms traded in the U.S. to disclose warranty costs in their financial statements, which was private information before that. This modifies the information set under which firms make their warranty decisions and, being unrelated to the demand side, may thus serve as an additional source of exogenous variation to instrument for warranties. We thus construct an indicator function (pre vs. post 2004 calendar year) and include it as an additional instrument.

Finally, note that we observe cross-sectional and longitudinal price variation for all models and years, as well as for product quality and service quality for all brands and years. Although the variation in warranties is more limited (e.g. it does not allow us to include brand fixed effects in the demand specification), we do observe cross-sectional variation across brands in our warranty variable each year and longitudinal variation for several brands at some point in our observation period. For some of these brands with longitudinal changes we also observe variation in warranty length for different model years of the same make-model being sold in the same calendar year. Finally, there is variation in the observed warranties in the market (as well as in the rest of the variables) due to changes in the choice set of vehicles available in the market each year. Also note that, along with the warranty length, we include other brand-level variables in the demand specification (product quality, service quality, and manufacturer geographical region), which alleviates concerns about brand fixed effects as potential confounders.
4.4 Estimation

The estimation of random coefficients demand models is discussed in detail in Berry (1994), Berry et al. (1995), and elsewhere. Here we briefly review the key aspects of the estimation procedure.

Under the Type I extreme value distribution assumption for $\epsilon_{ijt}$, the market share for product $j$ in calendar year $t$ obtained from Eq.(2) is given by:

$$s_{jt} = \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J} \exp(\delta_{kt} + \mu_{ikt})} = \int_{v} \frac{\exp(\delta_{jt} + \mu_{ijt}(v_{i}, \ldots, \theta_2))}{1 + \sum_{k=1}^{J} \exp(\delta_{kt} + \mu_{ikt}(v_{i}, \ldots, \theta_2))} P(v)dv, \quad (9)$$

where $P(v)$ is the joint distribution over all elements of $v_{i}$, which in our case is the product of standard normals. The integral in Eq.(9) does not have a closed form, and is evaluated using simulation, drawing values from the distribution of $v$ for a sample of individuals. The estimation of the model proceeds as follows. For a given draw of $\theta_2$, the actual and predicted (Eq.9) market shares are equated by means of a contraction mapping that allows us to obtain a unique solution for $\delta_{jt}$, which is in turn used to compute the value of $\xi_{jt}$, or more precisely, $\xi_{jt}(\theta)$ (inner loop). Let $Z$ denote the available instruments, which includes the exogenous characteristics in the demand specification. The sample analogs to the moment conditions $E[\xi Z] = 0$ can thus be constructed by using $\xi(\theta)$. An outer loop searching for the parameters $\hat{\theta}$ that solve the minimization of the GMM objective function completes the estimation routine (i.e., $\hat{\theta} = arg \min_\theta Z \Phi^{-1}Z'\xi(\theta)$). Here, the weighting matrix $\Phi$ is a consistent estimate of $E[Z'\xi(\theta)\xi(\theta)'Z]$, and is obtained employing the usual two-stage procedure (see Nevo 2000 for more details). Finally, as noted by Knittel and Metaxoglou (2012), the estimation procedure is subject to variability depending on the optimization algorithms and initial values considered. Similarly, Dube et al. (2011) note the dangers of using loose tolerance levels in the estimation procedure. Consistent with best practices recommended in both cases, we use multiple optimization algorithms, 50 different starting values, and best-practice tolerance levels in our implementation.

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5 For additional details, we refer the interested reader to Knittel and Metaxoglou (2012) and Nevo (2000). Our implementation largely follow theirs.

6 Market shares are obtained by dividing actual sales by the market size. As in most previous studies, we define the market size as being the number of households in the U.S. for a given year. Data on the number of households was obtained from the U.S. Census Bureau (available at http://www.census.gov)

7 We use five optimization methods in our experiments (available in the implementation by Knittel and Metaxoglou 2012): quasi-newton 1 and 2, nelder-mead simplex, solvopt and conjugate gradient. Also, we use tolerance levels of $e^{-14}$ for the inner loop and $e^{-6}$ for the outer loop.
5. Empirical analysis

5.1 Main effects model

Our specification for $x_{jt}$ builds upon existing literature, using variables similar to those used by Berry et al. (1995), Sudhir (2001) and Balachander et al. (2009). We include the size of the car measured as the product between the length and the width (SIZE), the ratio of horsepower to weight (HPWT), and the miles per dollar (MPD) of the vehicle as product characteristics in $x_{jt}$. The MPD variable is obtained by dividing the miles-per-gallon by the dollars-per-gallon in a given year. We obtained monthly average prices for gasoline from the U.S. Department of Energy (http://www.eia.doe.gov), which are aggregated at the calendar year level to calculate the MPD variable. Fuel prices are expressed in 2007 dollars using the CPI index for the respective year, and the same is done for the vehicle price $p_{jt}$ (PRICE), i.e., all monetary variables in our analysis are expressed in 2007 dollars (data on CPI’s were obtained from the U.S. Department of Labor, Bureau of Labor Statistics, available at http://www.bls.gov/cpi/cpirsdc.htm). We also include in $x_{jt}$ dummy variables to indicate whether a model year is from the previous year (PREVY MY) or the next year (NEXTY MY), dummy variables for manufacturer region (MANUF EUR, MANUF ASIA), dummy variables to indicate whether the model was launched in the last 2 years (INTRO2Y) or is soon (2 years) to be out of the market (EXIT2Y), and a time trend (TREND). Table 1 displays descriptive statistics for the relevant variables in our sample of 2122 observations, including statistics for the warranty length (WARR), product quality (PQ), and service quality (SQ). Table 2 displays the correlation matrix for these variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRICE ($1,000)</td>
<td>34.938</td>
<td>22.161</td>
<td>10.286</td>
<td>170.689</td>
</tr>
<tr>
<td>WARR (years)</td>
<td>4.7</td>
<td>1.9</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>PQ (-1 x problems per vehicle)</td>
<td>-1.289</td>
<td>0.235</td>
<td>-2.670</td>
<td>-0.760</td>
</tr>
<tr>
<td>SQ (CSI score/1000)</td>
<td>0.863</td>
<td>0.032</td>
<td>0.781</td>
<td>0.925</td>
</tr>
<tr>
<td>MPD ([miles/$]/10)</td>
<td>1.028</td>
<td>0.336</td>
<td>0.439</td>
<td>3.770</td>
</tr>
<tr>
<td>HPWT (100 x hp/lb)</td>
<td>0.643</td>
<td>0.171</td>
<td>0.203</td>
<td>1.578</td>
</tr>
<tr>
<td>SIZE (sq. inches/10,000)</td>
<td>1.314</td>
<td>0.145</td>
<td>0.792</td>
<td>1.708</td>
</tr>
</tbody>
</table>

We start our discussion of the results with the estimation of the main effects model (Eq. 5). The random coefficients model - which allows for customer heterogeneity and accounts for the endogeneity of prices and warranties - is obtained by performing the estimation procedure described in section (4.4).\(^8\) If customer heterogeneity is ignored (i.e. $\mu_{ijt} = 0$), the model

\(^8\text{In our implementation, we include random coefficients for variables for which we observe most substantial}\)
Table 2: Correlation Matrix

<table>
<thead>
<tr>
<th>Variable</th>
<th>PRICE</th>
<th>WARR</th>
<th>PQ</th>
<th>SQ</th>
<th>MPD</th>
<th>HPWT</th>
<th>SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>WARR</td>
<td>-0.19***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PQ</td>
<td>0.29***</td>
<td>-0.10***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SQ</td>
<td>0.26***</td>
<td>-0.24***</td>
<td>0.66***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPD</td>
<td>-0.39***</td>
<td>0.02</td>
<td>-0.18***</td>
<td>-0.41***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPWT</td>
<td>0.76***</td>
<td>-0.18***</td>
<td>0.24***</td>
<td>0.30***</td>
<td>-0.56***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIZE</td>
<td>0.28***</td>
<td>-0.22***</td>
<td>0.21***</td>
<td>0.32***</td>
<td>-0.44***</td>
<td>0.24***</td>
<td></td>
</tr>
</tbody>
</table>

Note: *, **, ***, Significant at the 0.1, 0.05, 0.01, confidence levels, respectively.

(Eq. 3) can be estimated by OLS regression (if the endogeneity of prices and warranties is not accounted for) or by using instrumental variable techniques (e.g. 2SLS). We refer to the latter case as IV LOGIT. Table 3 displays the results obtained in each of the aforementioned cases.

The results in Table 3 show that the coefficient for the price moves in the expected direction, i.e., demand becomes most sensitive to price as the price endogeneity is accounted for. Indeed, sensitivity to price more than doubles, similar to the findings in Berry et al. (1995) and Petrin (2002). Similarly, the coefficient of the warranty variable has a negative sign in the OLS regression (-0.034). However, once the endogeneity of the warranty length is accounted for using the instrumental variables described in the discussion of our identification strategy (IV LOGIT and Random coefficients model), we obtained a positive and significant effect of warranty length on demand.\(^9\) Note that the fact that a positive coefficient for warranty (0.082 in the random coefficients model, 0.132 in the IV LOGIT) is only obtained after correcting for the endogeneity of the warranty variable and that a negative coefficient is obtained otherwise, is consistent with a scenario in which brand reputation (which is part of the unobservable) is negatively correlated with the warranty length, which in turn explains the bias in the warranty coefficient if we do not employ our strategy for endogeneity correction. Other variables with a significant effect on demand are PQ, HPWT, SIZE, and dummy control variables for vehicle model year, manufacturer region (significant effect for European automakers only), model exit, and the time trend. The results displayed for the random coefficients model also include the magnitude of the estimates for the heterogeneity parameters, which indeed reveals significant heterogeneity effects for price, the horsepower to weight ratio, and the vehicle size.

\(^9\)We also estimated the model accounting only for the endogeneity of price, ignoring the endogeneity of warranty length (not reported in the text). We obtained a negative coefficient of warranty length in that case.
Table 3: Estimation of the main effects model

<table>
<thead>
<tr>
<th>Variable</th>
<th>OLS</th>
<th>IV LOGIT</th>
<th>RANDOM COEFFICIENTS MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRICE</td>
<td>-0.035***</td>
<td>0.003</td>
<td>-0.083***</td>
</tr>
<tr>
<td>WARR</td>
<td>-0.034*</td>
<td>0.018</td>
<td>0.132***</td>
</tr>
<tr>
<td>PQ</td>
<td>0.670***</td>
<td>0.168</td>
<td>0.755***</td>
</tr>
<tr>
<td>SQ</td>
<td>-7.038***</td>
<td>1.449</td>
<td>1.193</td>
</tr>
<tr>
<td>HPWT</td>
<td>0.059</td>
<td>0.298</td>
<td>4.369***</td>
</tr>
<tr>
<td>SIZE</td>
<td>1.625***</td>
<td>0.257</td>
<td>3.245***</td>
</tr>
<tr>
<td>MPD</td>
<td>-0.169</td>
<td>0.138</td>
<td>0.302*</td>
</tr>
<tr>
<td>NEXTY_MY</td>
<td>-2.64***</td>
<td>0.075</td>
<td>-2.652***</td>
</tr>
<tr>
<td>PREVY_MY</td>
<td>-1.885***</td>
<td>0.063</td>
<td>-1.928***</td>
</tr>
<tr>
<td>INTRO2Y</td>
<td>0.089</td>
<td>0.090</td>
<td>0.115</td>
</tr>
<tr>
<td>EXIT2Y</td>
<td>-0.891***</td>
<td>0.123</td>
<td>-0.943***</td>
</tr>
<tr>
<td>TREND</td>
<td>-0.042**</td>
<td>0.019</td>
<td>-0.152***</td>
</tr>
<tr>
<td>MANUF_EUR</td>
<td>0.057</td>
<td>0.106</td>
<td>1.209***</td>
</tr>
<tr>
<td>MANUF_ASIA</td>
<td>-0.101</td>
<td>0.077</td>
<td>-0.049</td>
</tr>
<tr>
<td>CONSTANT</td>
<td>-1.844</td>
<td>1.533</td>
<td>-13.135***</td>
</tr>
</tbody>
</table>

Note: *, **, ***, Significant at the 0.1, 0.05, 0.01, confidence levels, respectively.

With respect to the estimation of the random coefficients model, as noted in section 4.4, we use different optimization algorithms and starting values. The reported solution in Table 3 is the one for which the value of the GMM objective function is minimized (equal to 169.1 in this case), and satisfies both first and second order conditions of optimality (i.e. zero gradient and positive-definite Hessian)\(^{10}\). Most important, the results of the main effects model illustrate the effect of the instruments used in estimation, which act to adjust the price and warranty coefficients in the expected direction. In the first stage of the 2SLS procedure, the test for excluded instruments leads to rejection of the null hypotheses of excluded instruments having no explanatory power both in the case of PRICE and WARR (p-value<0.0001 in both cases), with \(R^2\) and \(F\) statistic of 0.78 and 222.7 in the case of PRICE, and 0.44 and 50.5 in the case of WARR, respectively. The underidentification test also leads to rejecting the null of underidentification (p-value<0.0001, Anderson LM statistic=146.7). Overall, the model has desirable statistical properties and the tests performed indicate that our proposed instruments are appropriate for our application.

\(^{10}\)The estimation procedure arrives at the same optimal solution in 52% of the runs, which is in the order of magnitude of recent reports, e.g. Knittel and Metaxoglou (2012) and Dube et al. (2011), and is aligned with their findings about the need to use multiple starting values, optimization algorithms, and tight tolerance levels.
5.2 Model with complementarities

The model in the previous section is useful to study the main effects of our variables of interest and to illustrate the way in which our instrumentation strategy works. As noted earlier, however, we are also interested in investigating complementarities/substitution effects between service attributes and product quality. We now turn to the discussion of the results of the model involving two-way interactions between warranty length, service quality and product quality. We “mean center” the variables involved in interaction terms (WARR, PQ and SQ), i.e., we subtract the mean from each individual observation, such that the individual coefficients for the single terms of these variables reflect the effect when the other two variables are set to their average values. The results of the random coefficients model are displayed in Table 4. The GMM function in the optimal solution is 128.6 in this case, the solution satisfies both first and second order conditions for optimality, and the estimation procedure led to the reported optimal solution in 52% of the runs. Similarly to the main effects model, the model has the desirable statistical properties and the tests performed indicate that our proposed instruments are appropriate. In the first stage of the 2SLS procedure, the test for excluded instruments leads to rejection of the null hypotheses of excluded instruments having no explanatory power in all cases of PRICE, WARR, WARRxPQ, WARRxSQ (p-value<0.0001 in all cases), with $R^2$ and $F$ statistic of 0.78 and 217.8 in the case of PRICE, 0.45 and 50.1 for WARR, 0.27 and 22.6 for WARRxPQ, and 0.21 and 16.7 for WARRxSQ, respectively. The underidentification test leads to rejecting the null of underidentification (p-value<0.0001, Anderson LM statistic=113.9). Again, the instruments exhibit reasonable statistical properties.

Next, we concentrate on the results obtained for our variables of interest, i.e., the joint effect of WARR, PQ, and SQ. The negative and significant coefficient for the interaction term WARRxPQ indicates that the marginal effect of an additional year of warranty coverage on demand decreases with product quality, or, conversely, is higher when product quality is lower. A longer warranty acts as a partial substitute for product quality, which is consistent with the insurance role of warranties. Similarly, we obtain a negative and significant coefficient for the term PQxSQ. Noting that the effect of service quality is not significant when treated in isolation in the main effects model (Table 3), this result suggests that service quality is of value for consumers only when the product quality is low. Jointly, these results provide support for the compensatory role of service attributes with respect to product quality, ruling out potential complementarities between product and service attributes in the demand function. In contrast, we obtain a positive and significant coefficient for the term WARRxSQ, indicating that the marginal effect on demand of an additional year of warranty coverage increases with service quality, i.e., there is a complementary relationship between
Table 4: Estimation of the model with complementarities (Random coefficients model)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Main effect ($\beta$)</th>
<th>Heterogeneity ($\sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRICE</td>
<td>-0.101***</td>
<td>0.011</td>
</tr>
<tr>
<td>WARR</td>
<td>0.142*</td>
<td>0.079</td>
</tr>
<tr>
<td>PQ</td>
<td>1.369***</td>
<td>0.326</td>
</tr>
<tr>
<td>SQ</td>
<td>-2.123</td>
<td>3.089</td>
</tr>
<tr>
<td>WARR x PQ</td>
<td>-1.217***</td>
<td>0.331</td>
</tr>
<tr>
<td>WARR x SQ</td>
<td>7.465***</td>
<td>2.871</td>
</tr>
<tr>
<td>PQ x SQ</td>
<td>-29.236***</td>
<td>6.943</td>
</tr>
<tr>
<td>HPWT</td>
<td>1.021</td>
<td>1.071</td>
</tr>
<tr>
<td>SIZE</td>
<td>2.204***</td>
<td>0.527</td>
</tr>
<tr>
<td>MPD</td>
<td>-0.562*</td>
<td>0.330</td>
</tr>
<tr>
<td>NEXTY_MY</td>
<td>-2.728***</td>
<td>0.093</td>
</tr>
<tr>
<td>PREVY_MY</td>
<td>-1.889***</td>
<td>0.064</td>
</tr>
<tr>
<td>INTRO2Y</td>
<td>0.058</td>
<td>0.098</td>
</tr>
<tr>
<td>EXIT2Y</td>
<td>-0.982***</td>
<td>0.147</td>
</tr>
<tr>
<td>TREND</td>
<td>-0.341***</td>
<td>0.045</td>
</tr>
<tr>
<td>MANUF_EUR</td>
<td>0.708***</td>
<td>0.310</td>
</tr>
<tr>
<td>MANUF_ASIA</td>
<td>-0.048</td>
<td>0.107</td>
</tr>
<tr>
<td>CONSTANT</td>
<td>-7.281***</td>
<td>1.314</td>
</tr>
</tbody>
</table>

Note: *, **, ***, Significant at the 0.1, 0.05, 0.01, confidence levels, respectively.

the length of the warranty and service quality.

5.3 Discussion

Our results indicate that warranties have a significant effect on consumer demand, and that the marginal value of an additional year of warranty decreases with product quality and increases with service quality. Further analysis of our main effects model reveals that the median implied willingness to pay for an additional year of warranty, obtained as the ratio of the marginal utility of warranty length to the marginal disutility of price, is approximately $850 which is equivalent to about 2.5% of the average vehicle price in our sample. In other words, and all else being equal, for an average vehicle in our sample, increasing the length of the warranty by one year is equivalent to decreasing the vehicle price by about $850, in terms of their effect on consumer demand. This estimate seems reasonable by industry standards. Indeed, a similar number was quoted in a recent industry report which mentioned that “consumers pay about 2 percent of the vehicle price per year of extended service” (Consumer Reports 2008).

Also, if we focus on the mean utility implied by the main effects model, we note that, for
Figure 5: Marginal effect of warranty on utility function

A car with average characteristics in our sample, the effect on demand of a 1% price decrease is equivalent to increasing product quality by 3%, and is in turn equivalent to increasing the warranty length by 9%. These benchmarks are useful for understanding the relative impact of different managerial interventions with respect to consumer demand. Indeed, these demand estimates can inform managerial decision-making by allowing managers to anticipate the effect of alternative interventions on consumer demand, which together with their usually good knowledge about the costs involved for each of these interventions, could be used to quantify trade-offs involved in managerial decision-making regarding these variables.

Further analysis of our model with complementarities also reveals that the value of one year of warranty is on average about two times more important for U.S. manufacturers than for foreign firms during our period of analysis. Our analysis provides an explanation for this observation, i.e., that U.S.-based brands had on average lower product quality and higher service quality than their foreign counterparts in that period. According to the results of our model, both of these factors imply a higher marginal effect of warranty length on consumer demand. Figure 5 illustrates the relationship obtained for the marginal effect of warranty length on consumer utility as a function of PQ and SQ (the grid surface), and also displays some of the brands in our sample.

As an illustration of the implications of our results, we return to the example in section 1 (survey data Sept-Nov 2006) in which remarkable differences were observed for the importance of the warranty length for customers of Hyundai, GM and Toyota. Our results
provide an explanation for these differences which is consistent with the data observed in that case. While the main brands of GM and Toyota both had a 5 year powertrain warranty in the survey period, GM had worse product quality and better service quality than Toyota. The results of our model suggest that both lower product quality and higher service quality increase the effect of warranty length on demand, consistent with the observation from the survey that the warranty length was considered extremely or very important for 53% of GM customers, in contrast to only 28% of Toyota customers, even though the warranty length was 5 years in both cases. Similarly, while Hyundai had slightly better product quality and worse service quality than GM, the fact that Hyundai’s warranty was 10 years makes the overall impact of its warranty length on consumer utility higher than in the case of GM and Toyota according to our model, consistent with the observation from the survey that Hyundai customers are those for whom warranty length was of higher importance when considering the brand in the shopping list, among the three brands considered in the survey. Overall, these observations offer face validity of our estimates.

Finally, another interesting implication of our results concerns the complementarity between service attributes. Consider, for example, the case of Kia, a brand that was characterized as having both low product quality and low service quality during our period of analysis. Kia increased the length of their powertrain warranty from 5 years/60,000 miles to 10 years/100,000 miles in 2001, i.e., the brand offered “America’s No. 1 warranty” in conjunction with Hyundai. Our results imply that Kia would have benefited the most out of this great warranty coverage (in terms of the effect of this policy on consumer demand), if it had contemporaneously invested in providing better service quality, along with the warranty length increase. In short, being good at one service dimension (service quality), amplifies the effect of being good at another service dimension (warranty length).

5.4 Robustness

We briefly discuss some of the relevant modeling choices and examine the robustness of our main findings with respect to variations in some model constructs.

First, in section 3, we discussed a number of reasons why we use the length of the powertrain warranty in years as our warranty variable. We performed experiments using alternative definitions, and our main findings remain robust if, for example, we consider miles instead of years, or if we consider a weighted average between powertrain and basic warranty as our warranty variable. Perhaps a more sensitive issue is the definition of our product quality variable. Arguably, there is no perfect way to measure quality. We believe, however, that the metric of problems per vehicle based on the initial quality study by J.D. Power is a reasonable choice. Indeed this metric captures a relatively objective metric of product quality,
that has been widely available in the past, and that has had lots of visibility for consumers historically. J.D. Power also publishes data on vehicle dependability, which measures quality problems after 3 years of ownership. We collected some of these data and found a high correlation (0.75) between the vehicle dependability metric and our initial quality variable, which suggest some consistency in both product quality metrics. Furthermore, we think that quality problems in the first three months of ownership may be much more disruptive than quality problems after three years, which is one reason to prefer the initial quality variable used in our study (in addition, considering initial quality instead of vehicle dependability allows us to perform the analysis with a larger sample size). Nevertheless, we estimated the model using the vehicle’s 3-year dependability metric to construct the product quality variable, and found results that are largely consistent with our main results (with the exception of the coefficient for the WARRxSQ variable that became marginally non-significant).

Another concern is related to the potential role of brand fixed effects as confounders. As noted in section 4.3, the level of variation in our warranty variable does not allow us to control for brand fixed effects in the model specification, and thus the role of omitted brand fixed effects is certainly a valid concern. We noted, however, that the warranty is not the only brand-level variable in our model, and indeed, we are including product quality, service quality and an indicator of the manufacturer region as brand level variables. We make the following two observations in this regard. First, note that omitted brand-level factors are part of the unobservable term, and accordingly this is part of the reason behind our identification strategy for warranties, i.e. in our formulation we are implicitly accounting for them in the estimation of warranty effects. Second, we collected some additional brand-level variables, like the number of dealers of each brand (obtained from Automotive News’s market data books) and the brand age, and estimated our models including these variables in the model specification as a way to partially control for some brand effects not captured in the main formulation, and our main findings remained robust to these variations.

Finally, one could postulate a three-way interaction effect between product quality, service quality and warranty, meaning that the two-way interaction effects postulated by our model could in turn be moderated by the remaining variable as a third factor. We extended our model specification by adding the three-way interaction term WARRxPQxSQ and our main findings remain robust to this variation.

Table 5 displays the results obtained for some of the robustness checks discussed in this section. For ease of display, we only show results for the mean utility estimates in each case.
Table 5: Selected Robustness checks

<table>
<thead>
<tr>
<th>Variable</th>
<th>(1)</th>
<th></th>
<th>(2)</th>
<th></th>
<th>(3)</th>
<th></th>
<th>(4)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PRICE</td>
<td>-0.101***</td>
<td>0.012</td>
<td>-0.084***</td>
<td>0.011</td>
<td>-0.077***</td>
<td>0.013</td>
<td>-0.102***</td>
<td>0.012</td>
</tr>
<tr>
<td>WARR</td>
<td>0.125*</td>
<td>0.066</td>
<td>0.135*</td>
<td>0.080</td>
<td>0.116</td>
<td>0.073</td>
<td>0.154*</td>
<td>0.083</td>
</tr>
<tr>
<td>PQ</td>
<td>1.805***</td>
<td>0.369</td>
<td>0.477***</td>
<td>0.146</td>
<td>0.971***</td>
<td>0.327</td>
<td>1.415***</td>
<td>0.346</td>
</tr>
<tr>
<td>SQ</td>
<td>-4.416</td>
<td>3.048</td>
<td>-0.507</td>
<td>3.120</td>
<td>-0.585</td>
<td>2.811</td>
<td>-1.373</td>
<td>3.242</td>
</tr>
<tr>
<td>WARR x PQ</td>
<td>-1.856***</td>
<td>0.415</td>
<td>-0.572***</td>
<td>0.171</td>
<td>-0.956***</td>
<td>0.308</td>
<td>-2.052***</td>
<td>0.437</td>
</tr>
<tr>
<td>WARR x SQ</td>
<td>9.788***</td>
<td>2.368</td>
<td>6.467</td>
<td>4.098</td>
<td>4.875*</td>
<td>2.701</td>
<td>6.597**</td>
<td>2.916</td>
</tr>
<tr>
<td>NDEALERS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.201***</td>
<td>0.057</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WARRxPQxSQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-18.446**</td>
<td>7.197</td>
</tr>
</tbody>
</table>

Notes: All columns display results for the mean utility estimates of the random coefficients model, for the most relevant variables (All models include the same control variables as in Table 4, estimates not reported). (1): Powertrain warranty in (10,000's) miles instead of years; (2): PQ in demand specification measured using the problems per vehicle metric of J.D. Power’s dependability study instead of the initial quality study; (3): Including NDEALERS (number of franchised dealers, measured in 1000's) in the model specification; (4): Including the 3-way interaction WARRxPQxSQ.

*, **, *** Significant at the 0.1, 0.05, 0.01, confidence levels, respectively.

6. Conclusion

In this paper we formulate and estimate a model to study the impact of service attributes on demand, and the moderating role of product quality in that relationship. We focus on services for the in-warranty period, and characterize the service strategy of a firm by both its warranty length and its after-sales service quality. Our results indicate that both service metrics are complementary, i.e., the better the service quality of a brand, the higher the marginal effect of offering longer warranties on demand, and vice versa. Thus, these two service attributes reinforce each other. In contrast, no complementarities are observed for service attributes and product quality, and services play, rather, a compensatory role with respect to product quality, i.e., the impact of both service variables on demand increases when product quality decreases. Collectively, our results suggest that competing on services is more effective (in terms of its effect on demand) for firms that have lower product quality, and that a firm that increases its warranty length would benefit most by simultaneously investing in improving its service quality. These findings illustrate that firms would benefit by defining their product and service strategies jointly rather than independently, i.e., they show that the joint consideration of product and service is essential for the development of an effective competitive strategy. In particular, the positioning of a firm with respect to product/service quality dimensions directly influences the marginal effect of its warranty length on consumer demand (Figure 5). Our model thus also provides a tool for managers to evaluate the impact of offering different warranty lengths on consumer demand (for a given positioning in
product quality and service quality), which if complemented with actual warranty cost data (which are internally available), would help companies to define optimal warranty levels. More generally, we illustrated how our model can inform decision-making regarding how alternative managerial interventions (e.g. price decrease, quality increase, warranty increase) impact consumer demand, e.g. for an average vehicle our model suggests that reducing the price by 1% is equivalent (in terms of its impact on consumer demand) to improving product quality by 3%, which is in turn equivalent to increasing the length of the warranty by 9%. We believe that the demand-side estimates derived from our analysis constitute a critical missing component for managerial decision-making in practice, as managers are usually very good at estimating the implied costs of different managerial interventions, while demand effects are much more difficult to isolate.

Our analysis of the service strategy of firms focused exclusively on the in-warranty period. In practice, firm service strategies also include the out-of-warranty period, and thus the definition of the warranty length could have implications in terms of the profits that firms derive from selling extended warranties. If appropriate data becomes available, modeling the interaction between in-warranty and out-of-warranty policies offers a promising avenue for future research. Also, our identification strategy requires the exogeneity of product quality and service quality in the demand specification, which, as noted, is justified by the timing of our model, in which firms and consumers make decisions within a one-year horizon. While appropriate to capture short-term effects, our model does not capture longer-term dynamic aspects involved in firm decision-making and consumer demand. The formulation of a dynamic model that endogenizes long-term effects of firm investment in product quality and service quality is thus a natural -and much more complex- extension of our analysis. Finally, as noted throughout the document, to our knowledge this is the first paper to empirically study how firm service strategies interact with product quality in a demand model of firm competition. The formulation of similar studies in other manufacturing industries would allow for a broader understanding of the value of services as part of firms’ competitive strategies. We hope to conduct further research in these areas.

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