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Service Competition and Product Quality in the U.S. Automobile Industry

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We study the impact of service attributes (warranty length, after-sales service quality) on consumer demand in the U.S. automobile industry, examining the presence of complementarities/substitution between service attributes and product quality. Our results estimate a median willingness to pay for one year of a warranty of approximately $850, which is equivalent to 3.1% of the median vehicle price in our sample. We find that, for a car with median characteristics, the effect on consumer utility of a 1% price decrease is equivalent, all else being equal, to increasing product quality by 2.2%, and is in turn equivalent to increasing the warranty length by 8%. Our results also 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 thus imply that, in our period of analysis, warranties played a more important role for American firms than for foreign firms, consistent with the fact that American manufacturers exhibited lower product quality and higher service quality than non-American firms.

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 toward 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 United States (Cohen et al. 2006). In short, services have become an important part of an OEM's competitive strategy in traditional manufacturing industries. Although 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, Sudhir 2001, and Train and Winston 2007, among many others), and constitutes a natural choice for our research. 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 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 it is a managerial decision that partially reflects the service intensity provided by the OEM.[1] Firms have been

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[1] We refer to the warranty length as a service attribute because it directly determines the length of the period over which services are delivered and paid for by the manufacturer. It can also be seen as a product attribute that is related to insurance.

active in 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 power train warranty from 3 years/36,000 miles to 5 years/60,000 miles in 2007. When asked about the reasons behind the warranty length increase, a spokesperson from Ford said: "We think that some people weren't considering Ford products because we didn't have an extended power train 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" (Wernie 2009); as a result, the company cut it back in 2009.

Firms face an important trade-off when defining their warranty period: although 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 approximately 2%–4% of their yearly revenue (*Warranty Week* 2011). This discussion reflects the importance of improving our understanding of the conditions under which warranties and service attributes influence demand.

In this paper we formulate and estimate a model to measure the impact of service attributes on consumer demand in the United States 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. Our analysis is based on demand formulation that 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 considered, there is a significant effect of warranty length on demand, whereas service quality does not have a significant effect when this variable is considered in isolation.

We also investigate complementarities and substitution effects among warranty length, service quality, and product quality by conducting 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 nontrivial 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 to or substitute for product quality. The theory of compensatory effects in consumer decision making (e.g., Dieckmann et al. 2009) supports the hypothesis that both dimensions act as substitutes; i.e., good service serves the 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 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. 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, 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. 2015). 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; 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, 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 particular advantage that is gained by incorporating product and service dimensions into a single analysis is that it allows us to examine the existence of complementarities and substitution effects. As we discuss in the paper, we are not aware of other papers that have looked at studying such interaction effects in a competitive market. We believe that this novel feature of our model also connects operations variables related to quality to the competitive strategy of the firm, which includes product/service bundle positioning. Further, some survey-based studies in the automobile industry have suggested that service quality plays a role in determining customer satisfaction and brand loyalty (e.g., Mittal et al. 1999, Devaraj et al. 2001), but we are not aware of research that focuses on the impact of service attributes on consumer demand in manufacturing industries and in a competitive context, and how that effect of service attributes on demand depends on characteristics of the product.

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 incentives for 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 it 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. Although 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 but 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 ordinary least squares (OLS) analysis is performed and in which several attributes 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 business-to-business setting quantifies the value of warranties for manufacturers, intermediaries, and customers, and finds a positive value for warranties in all cases. As in our analysis, 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.

Although past empirical studies are certainly relevant for our analysis, we establish at least three important differences. First, these papers focus on warranties exclusively, whereas our interest is in services more broadly defined, including 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. 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.[2]

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 review of this research stream, or Fan 2013 for a recent example). 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 related to the numerous empirical studies in OM that examine the automobile industry, including Fisher et al. (1999), Ramdas and Randall (2008), Cachon and Olivares (2010), and Cachon et al. (2013), among many others, that attempt (as ours does) to examine some aspects 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 the complementarity and substitution between service attributes and product quality in the context of demand models in a competitive manufacturing setting. Product quality, service quality, and warranty length are variables of long-standing 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 were 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 United States 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 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 Initial Quality Study (IQS; 2001–2007) and U.S. Customer Service Index Study (2001–2007). 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.

3.1. 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. The most relevant warranties bundled with a new car are the basic warranty (which covers most parts of a vehicle) and the power train warranty (which covers the major cost components of the car such as the engine, transmission, etc., usually for an extended period of time). For example, the Acura 2007 model year vehicles had basic and power train warranties of 4/50,000 and 6/70,000 years/miles, respectively. For a given brand, there is a high correlation between the warranty terms for these two types of warranties (indeed, for several brands the coverage period is often the same for basic and power train warranties), and also between the years/miles metrics.

Most of the existing studies on warranties have focused on the duration of the power train warranty for several reasons. First, the power train warranty covers the most expensive parts of the vehicle. Second, most of the changes in warranty strategies by

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[2] See §4.2 for a discussion of the required assumptions under which our identification strategy is valid, and §§5.4 and 6 for discussion of the limitations of our strategy.

OEMs refer to power train warranty duration; therefore, it is the richer source of longitudinal variation. There were 25 longitudinal changes for the power train warranty during our observation periods, but only 7 if we look at basic warranties. Examples of changes in power train warranties include 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, Acura from 4/50,000 to 5/70,000 in 2006, and Chevrolet from 3/36,000 to 5/100,000 in 2007, among several others. Finally, the power train warranty is the warranty that automakers advertise the most. Consistent with these arguments, we use the length of the power train warranty in years as our warranty variable.

3.2. 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 at 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. We take the negative of the number of problems per vehicle as our product quality metric PQ_{bt}, such that a higher value for PQ_{bt} (smaller number of problems per vehicle) denotes higher product quality.

Similarly, J.D. Power's Customer Service Index (CSI) Study 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 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 1,000-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.

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_{bt} is a scaled version of the customer service index (CSI score/1,000).

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 PQ_{bt} and SQ_{bt}, meaning a positive relationship between product quality and service 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 product quality (PQ), and -0.29 between warranty and service quality (SQ). These statistics reflect a negative correlation between warranty length and both product quality and service quality. Note that the fact that we do not find a positive correlation between warranty and product quality provides some descriptive evidence that counters the signaling role of warranties. Figure 1 displays the relationship between our warranty (WARR), product quality (PQ), and service quality (SQ) metrics for 2004 for the brands in our sample.

Finally, we note that, although the service experience at dealers is not fully determined by OEMs, they can and do influence the service process in several ways. First, OEMs 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, OEMs usually set up incentive programs, whereby a dealer's compensation is, in part, based on service performance. Finally, the design of the service network (e.g., the definition of the number of dealers) is ultimately defined by the OEM. As an illustration, consider, e.g., the evidence discussed in Cohen et al. (2000), where persistent brand-level differences in after-sales services are documented with respect to parts availability for repair services by different brands, as well as with respect to mechanisms for information sharing and distributed service systems

Figure 1 (Color online) Visualization of Warranty, Service Quality, and Product Quality (2004)
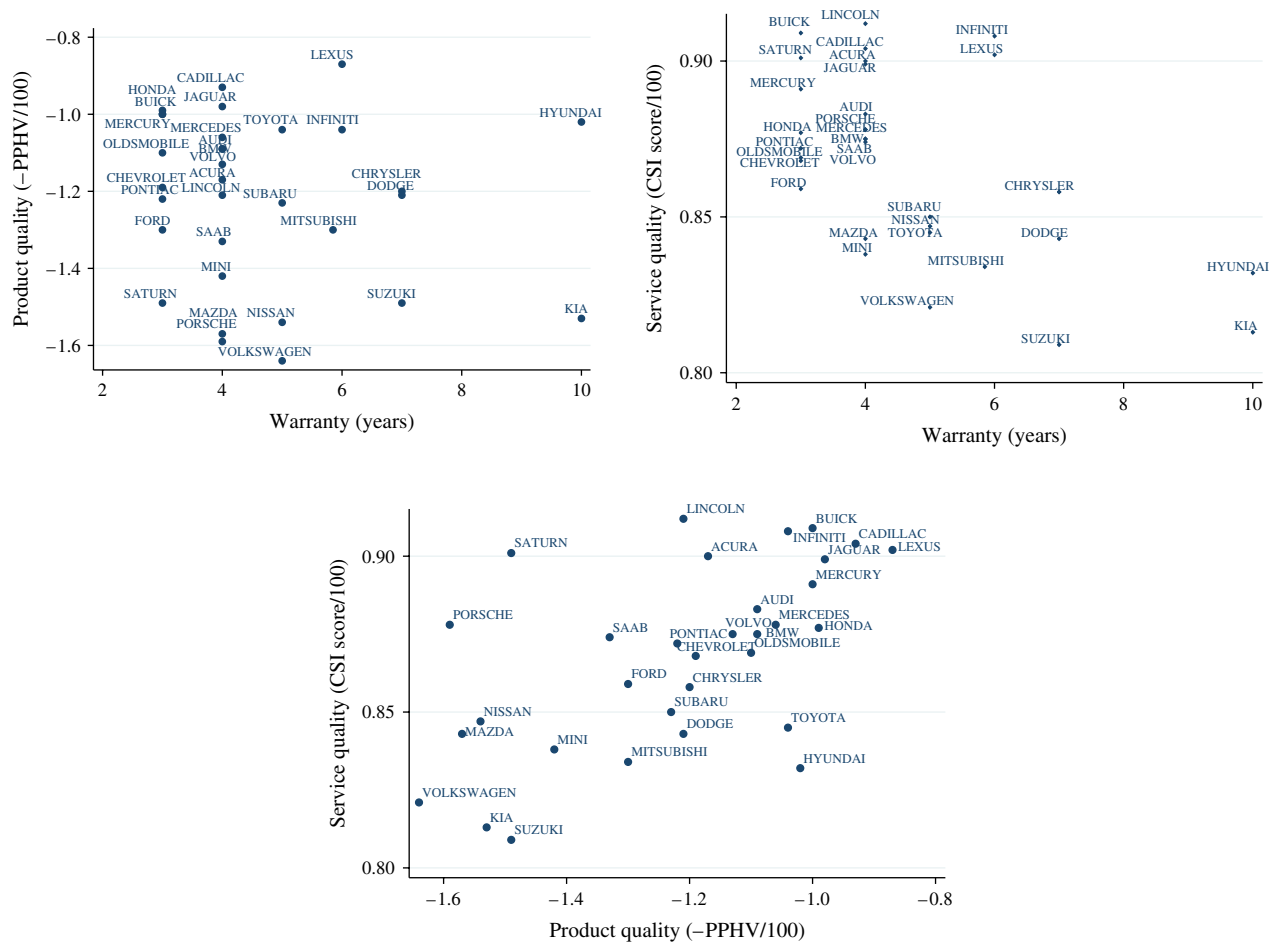
employed in Saturn's service supply chain, in contrast to industry standards at the time.[3]

3.3. 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 United States between 2001 and 2007. This includes cars belonging to the segments small, middle, large, and luxury, as categorized by Ward's. Sales data are available at the make-model level (e.g., Toyota Corolla) monthly. Data on product characteristics are available for each model year and for each of the versions of a given make-model. Several vehicle-level variables are of interest. First, the size of the

[3] Naturally, when it comes to after-sales services, it is clear that in practice some important variation would occur at the dealer level, not only at the brand level. Dealer-level metrics would potentially provide richer variation, in contrast to the low level of variation we observe in our brand-level metrics (Table 1). However, as we argue, there are a number of decisions that are taken at the OEM level, which supports the perspective we adopt in our study. For further details about dealer/OEM interactions, we refer the reader to Cohen et al. (2000) for service aspects and to Cachon and Olivares (2010) for more general aspects.

car (SIZE) was measured as the product of the length and the width. The ratio of horsepower to weight (HPWT) is self-descriptive. We also constructed the variable miles per dollar (MPD), 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 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 CPIs were obtained from the U.S. Department of Labor, Bureau of Labor Statistics, available at http://www.bls.gov/cpi/cpirsdc.htm). 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., size, we consider the average size of the options of a given model year as the size associated with that model year (an approach also taken by Balachander et al. 2009).

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. These data are collected at the daily level by J.D. Power from a sample of dealers in the United States covering approximately 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 because of the unavailability of information about transactional prices. We only have access to these data at the aggregate yearly level or, 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).

3.4. Sample

We match all data sources as described above. Our final sample consists of 2,122 yearly observations for all new light cars sold in the United States 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. Table 1 displays descriptive statistics for the relevant variables in our sample of 2,122 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 1   Descriptive Statistics

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

Table 2   Correlation Matrix

Variable	PRICE	WARR	PQ	SQ	MPD	HPWT	SIZE
WARR	-0.19***						
PQ	0.29***	-0.10***					
SQ	0.26***	-0.24***	0.66***				
MPD	-0.39***	0.02	-0.18***	-0.41***			
HPWT	0.76***	-0.18***	0.24***	0.30***	-0.56***		
SIZE	0.28***	-0.22***	0.21***	0.32***	-0.44***	0.24***	

***Indicates significance at the 0.01 confidence level.

4.   Model

4.1.   Demand Model Formulation

We consider a random coefficients logit demand model, where the utility that consumer i derives from purchasing vehicle model j ($j = 1, \ldots, J$) of brand b ($b = 1, \ldots, B$) in calendar year t ($t = 1, \ldots, T$) depends on the vehicle price p_{jt}, a vector of observable vehicle characteristics (size, horsepower to weight ratio, etc.) x_{jt}, warranty duration w_{bt}, product quality PQ_{bt}, service quality SQ_{bt}, other brand-level variables x_{bt}, as follows:

$$u_{ijt} = \alpha_i p_{jt} + x'_{jt}\beta_i + h(w_{bt}, PQ_{bt}, SQ_{bt})\gamma + x'_{bt}\eta + \xi_{jt} + \epsilon_{ijt}. \quad (1)$$

The term ξ_{jt} represents unobserved product attributes common to all consumers, and ϵ_{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 α_i and β_i are decomposed into a mean effect common to all consumers ($\beta's$) and individual deviations from that mean ($\sigma's$). The total effect of attribute x_{jt}^k on the utility of consumer i is thus modeled as $(\beta_k + \sigma_k v_{ik})x_{jt}^k$, where β_k and σ_k are parameters to be estimated, and v_{ik} is an individual-level shock obtained from a standard normal distribution; the same holds for α_i. It is useful to note that u_{ijt} can be thus expressed more compactly as a function of the mean utility δ_{jt} common across all consumers, and the heterogeneity terms μ_{ijt} and ϵ_{ijt} can be expressed as follows:

$$u_{ijt} = \delta_{jt}(p_{jt}, x_{jt}, w_{bt}, PQ_{bt}, SQ_{bt}, x_{bt}; \theta_1) + \mu_{ijt}(p_{jt}, x_{jt}, v_i; \theta_2) + \epsilon_{ijt}. \quad (2)$$

Here, θ_1 is a vector containing all parameters of the mean utility (α, β, and γ), and θ_2 contains the heterogeneity parameters (σ). Let d_{jt} contain all M vehicle characteristics involved in the heterogeneity estimates. Thus δ_{jt} and μ_{ijt} are defined as

$$\delta_{jt} = \alpha p_{jt} + x'_{jt}\beta + h(w_{bt}, PQ_{bt}, SQ_{bt})\gamma + x'_{bt}\eta + \xi_{jt}, \quad (3)$$

$$\mu_{ijt} = \sum_{m=1,\ldots,M} \sigma_m d_{jt}^m v_{im}. \tag{4}$$

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 takes the following form:

$$u_{ijt} = \alpha_i p_{jt} + x'_{jt}\beta_i + \gamma_1 w_{bt} + \gamma_2 PQ_{bt}$$
$$+ \gamma_3 SQ_{bt} + x'_{bt}\eta + \xi_{jt} + \epsilon_{ijt}. \tag{5}$$

This formulation is useful in capturing 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 Equation (5) as the main effects model.

We are also interested in testing whether service attributes and product quality act as complements, as substitutes, or independently in the demand function. For this purpose, we consider an enhanced formulation in which the function $h(w_{bt}, PQ_{bt}, SQ_{bt})$ not only includes the main effects for these three variables—as described in Equation (5)—but also their interaction terms $w_{bt} * PQ_{bt}$, $w_{bt} * SQ_{bt}$, and $PQ_{bt} * SQ_{bt}$. These interactions reflect the nonlinearities of interest, i.e., the complementarity/substitution effects between service attributes and product quality.

In this regard, a recent study by Guajardo and Cohen (2015) has shown that service quality and product quality perceptions act as complements in terms of how they determine the likelihood of recommending the brand in an application in the consumer electronics industry. In their study, they focus on brand loyalty by customers and they find that 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 of recommending the brand. Their results are based on a sample of existing customers of one major brand, in contrast to this paper, in which we focus on the whole market and cover all brands under competition. 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. A related argument can be proposed in support of the complementarity hypothesis. If higher product quality creates higher utility and enjoyment for drivers, receiving good service (e.g., cars repaired more quickly and smoothly) could be more valuable for cars with higher product quality (if they serve the basic need of transport with value added in terms of driving experience), relative to a lower quality car (if it only satisfies the basic need of transport).

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 noncompensatory 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 in 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 $w_{bt} * PQ_{bt}$.

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, as substitutes, or independently of product quality in the demand function is ultimately an empirical question, which we attempt to answer in this study.

4.2. Identification and Instruments
In practice, most of the observed variables in our demand specification are determined or influenced by firm's decisions. On the other hand, ξ_{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 ξ_{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. More precisely, the mean independence condition $E[\xi \mid x] = 0$ is assumed for all exogenous x. Although the exogeneity assumption for nonprice characteristics has been widely acknowledged as a shortcoming since Berry (1994), the underlying argument for it

relies on the fact that, although the prices are easily adjustable by firms according to the market conditions and therefore p_{jt} is likely to be correlated with ξ_{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 ξ_{jt}.

To account for the endogeneity of prices, instrumental variables (IVs) can be used in the estimation. A well-known example is the model of Berry et al. (1995) 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 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_{bt}, PQ_{bt}, and SQ_{bt}. In principle, firms can easily set the length of the warranty w_{bt} in response to the unobserved factors in ξ_{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.[4] Thus, warranties are expected to be endogenous in the demand specification.

Conversely, let us consider firm actions to influence PQ_{bt} and SQ_{bt}. 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 the product launch. Similarly, factors influencing service quality, such as the implementation of optimization-based technologies for the management of parts inventories, 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 assume that the observed PQ_{bt} and SQ_{bt} are not easily adjustable contemporaneously by firms upon observing the shocks ξ_{jt}, and therefore will consider PQ_{bt} and SQ_{bt} to be exogenous in the demand specification. This is our main identification assumption.

We assume therefore 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 wc_{jt}. In order to illustrate our instruments, it is useful to expand on the drivers of the warranty costs for firms.

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, p. 67) if the warranty length is set to W is thus $wc(W) = E[\sum_{n=1,\dots,N(W)} Y_n(t)]$. If the time between failures is independent and identically distributed (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 λ 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 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 s_{jt} unobservable factors. The warranty costs function g can be thus represented conceptually as

$$wc_{jt} = g(w_{bt}, PQ_{bt}, SQ_{bt}, xb_{jt}, x_{jt}, s_{jt}). \qquad (6)$$

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[4] Of course, consistent with the observed data, in practice there are factors that could prevent firms from adjusting warranties too frequently. For example, firms that want to decrease warranty length as a response to a negative warranty cost shock may opt to not do so because of potential detrimental impact on brand image.

Figure 2   Instruments
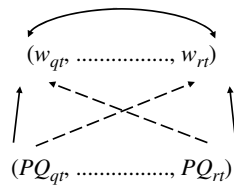
We derive instruments for the warranty length based on the exogeneity assumption for PQ_{bt}, SQ_{bt}, and for product characteristics other than price and warranty more generally, and our supply side assumption (with competition on prices and warranties only) as follows. Consider vehicles i and j, produced by brands q and r respectively ($q \neq r$). Note that, given our assumption that firms compete on prices and warranties, w_{qt} 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_{qt} will be correlated with the drivers of warranty costs, e.g., PQ_{qt} (see Equation (6) and Figure 2). Similarly, w_{rt} will be correlated with PQ_{rt}. If u_{ijt} depends only on vehicle $i's$ attributes, then PQ_{rt} (attribute of vehicle j) is a valid instrument (source of instruments) for w_{qt} (attribute of vehicle i). We thus consider the average of product qualities 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_{bt} and x_{bt} (Equation (6)). In x_{bt} we include dummies for the region of the manufacturer (coded into three categories: USA, Europe, and 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. To further explain the logic behind these instruments, warranty definitions by a brand should consider the brand's product quality and service quality. Since in our model the warranty length is the result of strategic interaction among firms, product quality and service quality of competing brands thus indirectly influence the warranty choice for a brand. This mechanism justifies the relevance of our proposed IVs of average product quality and average service quality by other brands.

Exogeneity of these IVs follows from the assumption of the exogeneity of product quality and service quality and from the fact that the utility obtained from a given product does not depend on other products' characteristics (recall that we require the mean independence assumption $E[\xi \mid x] = 0$ for all exogenous variables x). 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 United States 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- versus 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 partially alleviates concerns about brand fixed effects as potential confounders.[5]

4.3. 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 only some key aspects.

Under the type I extreme value distribution assumption for ϵ_{ijt}, the market share for product j in calendar year t obtained from Equation (2) is given by

$$s_{jt} = \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J} \exp(\delta_{kt} + \mu_{ikt})}$$

$$= \int_{v} \frac{\exp(\delta_{jt} + \mu_{ijt}(v_i, \ldots, ; \theta_2))}{1 + \sum_{k=1}^{J} \exp(\delta_{kt} + \mu_{ikt}(v_i, \ldots, ; \theta_2))} P(v) \, dv, \quad (7)$$

where $P(v)$ is the joint distribution over all elements of v_i, i.e., the product of standard normals. The integral in Equation (7) does not have a closed form

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[5] Note, however, that omitted brand effects may still be playing an important role. Not being able to fully account for this aspect is a limitation of our data. We provide a number of robustness checks along with an in-depth discussion of the role of brand in §5.4.

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 θ_2, actual[6] and predicted (Equation (7)) market shares are equated by means of a contraction mapping that allows us to obtain a unique solution for δ_{jt}, which is in turn used to compute the value of ξ_{jt}, or more precisely, $\xi_{jt}(\theta)$ (inner loop). Let Z denote the available instruments. 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 generalized method of moments (GMM) objective function completes the estimation routine (i.e., $\hat{\theta} = \arg_\theta \min \xi(\theta)'Z\Phi^{-1}Z'\xi(\theta)$). Here, the weighting matrix Φ 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 (2014), the estimation procedure is subject to variability depending on the optimization algorithms and initial values considered. Similarly, Dube et al. (2012) 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.[7]

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 variables SIZE, HPWT, and MPD as product characteristics in x_{jt}. 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 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). In terms of the additional brand-level variables x_{bt}, we include dummy variables for manufacturer region (MANUF_EUR and MANUF_ASIA; MANUF_USA is the excluded category).

We start our discussion of the results with the estimation of the main effects model (Equation (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 §4.3.[8] If customer heterogeneity is ignored (i.e., $\mu_{ijt} = 0$), the model (Equation (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., two-stage least squares (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 (IVs) 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] 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; note that this fact is consistent with a scenario in which brand reputation (which is part of the unobservable factors) 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 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.

With respect to the estimation of the random coefficients model, as noted in §4.3, we use different optimization algorithms and starting values. The reported

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[6] Market shares are obtained by dividing actual sales by the market size. As in most previous studies, we define the market size as the number of households in the United States 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: two quasi-Newton methods, 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.

[8] In our implementation, we include random coefficients for variables for which we observe the most substantial variation at the make-model level, i.e., PRICE, HPWT, SIZE, and MPD.

[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

| | OLS | | IV LOGIT | | Random coefficients model | | | |
| | | | | | Main effects | | Heterogeneity | |
Variable	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
PRICE	−0.035***	0.003	−0.083***	0.010	−0.096***	0.010	0.028***	0.006
WARR	−0.034*	0.018	0.132***	0.049	0.082*	0.048		
PQ	0.670***	0.168	0.755***	0.186	0.950***	0.183		
SQ	−7.038***	1.449	1.193	2.257	0.069	2.126		
HPWT	0.059	0.298	4.369***	0.905	2.319**	0.941	0.729***	0.249
SIZE	1.625***	0.257	3.245***	0.422	2.497***	0.440	0.436***	0.118
MPD	−0.169	0.138	0.302*	0.180	−0.110	0.227	0.131	0.194
NEXTY_MY	−2.64***	0.075	−2.652***	0.083	−2.654***	0.089		
PREVY_MY	−1.885***	0.063	−1.928***	0.071	−1.916***	0.060		
INTRO2Y	0.089	0.090	0.115	0.100	0.103	0.094		
EXIT2Y	−0.891***	0.123	−0.943***	0.136	−1.015***	0.132		
TREND	−0.042**	0.019	−0.152***	0.030	−0.265***	0.037		
MANUF_EUR	0.057	0.106	1.209***	0.260	0.907***	0.252		
MANUF_ASIA	−0.101	0.077	−0.049	0.110	−0.034	0.103		
Constant	−1.844	1.533	−13.135***	2.765	−8.626***	2.839		

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively.

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 importantly, 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 in either the case of PRICE or 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 hypothesis of underidentification (p-value < 0.0001, Anderson Lagrange multiplier (LM) statistic $= 146.7$). Overall, the model has desirable statistical properties, and the tests performed support the use of our instruments.

5.2.   Model with Interactions
The model in the previous section is useful for studying the main effects of our variables of interest and for illustrating 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 among 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 leads to the reported optimal solution in 52% of the runs. Similarly to the main effects case, the model and the instruments have desirable statistical properties. 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, WARR $\times$ PQ, WARR $\times$ SQ (p-value < 0.0001 in all cases), with R^2 and F statistic of 0.78 and 217.8 for PRICE, 0.45 and 50.1 for WARR, 0.27 and 22.6 for WARR $\times$ PQ, and 0.21 and 16.7 for WARR $\times$ SQ, respectively. The underidentification test leads to rejecting the null hypothesis of underidentification (p-value < 0.0001, Anderson LM statistic $= 113.9$).

The negative and significant coefficient for the interaction term WARR $\times$ PQ 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

[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 (2014) and Dube et al. (2012), and is aligned with their findings about the need to use multiple starting values, optimization algorithms, and tight tolerance levels.

Table 4   Estimation of the Model with Interactions (Random Coefficients Model)

Variable	Main effect		Heterogeneity	
	Estimate	SE	Estimate	SE
PRICE	−0.101***	0.011	0.035***	0.006
WARR	0.142*	0.079		
PQ	1.369***	0.326		
SQ	−2.123	3.089		
WARR × PQ	−1.217***	0.331		
WARR × SQ	7.465***	2.871		
PQ × SQ	−29.236***	6.943		
HPWT	1.021	1.071	1.119***	0.291
SIZE	2.204***	0.527	0.353***	0.106
MPD	−0.562*	0.330	0.318	0.233
NEXTY_MY	−2.728***	0.093		
PREVY_MY	−1.889***	0.064		
INTRO2Y	0.058	0.098		
EXIT2Y	−0.982***	0.147		
TREND	−0.341***	0.045		
MANUF_EUR	0.708**	0.310		
MANUF_ASIA	−0.048	0.107		
Constant	−7.281***	1.314		

*, **, and *** indicate significance at the 0.1, 0.05, and 0.01, confidence levels, respectively.

product quality, which is consistent with the insurance role of warranties. Similarly, we obtain a negative and significant coefficient for the term PQ × SQ. 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 mainly 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 WARR × SQ, 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 the length of the warranty and the 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. Our estimates reveal 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 approximately 3.1% of the median vehicle price in our sample. This estimate seems reasonable by industry standards. Indeed, a comparable number was quoted

in a recent industry report that 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 consumer utility, we note that, for a car with median product characteristics in our sample, the effect on consumer utility of a 1% price decrease is equivalent, all else being equal, to increasing product quality by 2.2%, and is in turn equivalent to increasing the warranty length by 8%. 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 also reveals that median elasticities across manufacturers are −2.3 and 0.6 for price and warranty, respectively (for product quality and service quality, medians are 2.2 and 0.5, respectively). Moreover, our estimates indicate that warranties play a more important role for U.S. manufacturers than for foreign firms during our period of analysis. Indeed, median implied warranty elasticity is approximately 50% higher for U.S. than for non-U.S. manufacturers, and similarly willingness to pay for warranties is larger for American brands. Our analysis provides an explanation for the higher relevance of warranties for American cars; i.e., U.S.-based manufacturers 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.

To summarize, warranties act as a substitute for product quality and as a complement to service quality. As an illustration, if we split our sample into high (upper 50%) and low (bottom 50%) product quality and service quality, we observe that the highest demand response to warranty is obtained in the low product quality/high service quality region, where demand is actually elastic with respect to warranties, whereas the impact is lower when product quality is high and service quality is low. Indeed, warranty elasticity is approximately 10 times higher in the low product quality region than in the high product quality region, and approximately twice as large in the high service quality region than in the low service quality region.

As further illustration of the implications of these results, let us 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. Having low product quality, and consistent with our result of warranties acting as substitutes for product quality, Kia increased the length of their power train 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." Our results imply that Kia would have benefited the most from 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), and the demand effect of both service attributes is higher when product quality is lower.

5.4. Robustness

We now discuss some of the relevant modeling choices and examine the robustness of our main findings with respect to variations in some model constructs. Tables 5 and 6 display the results obtained for some selected robustness checks discussed in this section; several others are discussed but not displayed due to space limitations. For ease of display, we only show results for the mean utility estimates and for a subset of covariates; all models referenced in this section refer to the ones in Tables 5 and 6 unless otherwise noted.

First, in §3, we discussed a number of reasons that we use the length of the power train warranty in years as our warranty variable. Using alternative definitions, we found our main findings to be robust if, for example, we consider miles instead of years (model 1), or if we consider a weighted average between power train and basic warranty as our warranty variable (model 2; the interaction WARR × SQ becomes insignificant with a p-value 0.13); the basic warranty has very low variation and partially dampens significance.

Another relevant issue is the definition of the 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 (2001–2007) is a reasonable choice. Indeed, this definition 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 measure quality problems after three 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 suggests 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 three-year dependability metric to construct the product quality variable (model 3) and found results that are largely consistent with our main results, with the exception of the significance of the coefficient for the WARR × SQ variable with a p-value of 0.11.

As an additional test in this regard, we collected data from Consumer Reports that measure product quality (reliability ratings on a relative five-point scale) at the model level, as opposed to the brand-level product quality variable from J.D. Power. We report results for this test in model 4, which also considers the quality variables lagged by one period.[11] As can be seen, directionally we obtain results somewhat similar to our main models, with the exception of the interaction between product and service quality becoming nonsignificant. There is an important caveat regarding the models that use Consumer Reports data, though, which is that these data are available for only 60% of our sample (equivalent to 78% in terms of sales), which could introduce some undesirable selection bias in those estimates, in particular dismissing some of the variation in our data necessary for identification (even at a brand level, the limited sample dismisses almost 20% of the brand years). In addition, Consumer Reports data are a relative measure of product quality on a 1–5 scale, in contrast to the J.D. Power metric, which measures product quality on an absolute scale, a factor also influencing these results.

Another concern with the model specification is that the results could be driven by extreme data points. In particular, Saturn can be seen as the only clear example of a brand consistently having good service quality and low product quality. We run our models excluding observations from Saturn, obtaining similar results to our main specification (not reported). Similarly, one could postulate a three-way

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[11] We use contemporaneous quality metrics in our main models. One reasonable alternative could be to use lagged variables if consumers consider looking at that information in their decision-making process (something perhaps more likely in the case of Consumer Reports scores). The ideas behind our choice of contemporaneous metrics are that the quality metrics reflect the actual quality experienced by consumers and that this information is a good summary of the quality information for consumers in a given year. We do not postulate that consumers would look exactly at that information before making a purchase, but rather that in general terms they reflect reality for consumers reasonably well in a given period.

Table 5   Selected Various Robustness Checks: Estimates of Mean Utility Coefficients

	(1)		(2)		(3)		(4)	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
PRICE	−0.101***	0.012	−0.099***	0.012	−0.084***	0.011	−0.113***	0.024
WARR	0.125*	0.066	0.119	0.112	0.135*	0.080	0.083	0.082
PQ	1.805***	0.369	1.363***	0.300	0.477***	0.146	0.038	0.062
SQ	−4.416	3.048	−3.331	2.889	−0.507	3.120	0.210	0.292
WARR × PQ	−1.856***	0.415	−1.207***	0.408	−0.572***	0.171	−0.311***	0.105
WARR × SQ	9.788***	2.368	5.978	3.901	6.467	4.098	1.030***	0.316
PQ × SQ	−35.018***	8.100	−23.785***	6.261	−20.725***	4.203	−0.081	0.136

Notes. (1) Power train warranty in (10,000s) miles instead of years; (2) combined power train/basic warranty variable; (3) PQ in demand specification measured using the problems per vehicle metric of J.D. Power and Associates 2003–2011 Vehicle Dependability Study; (4) PQ measured by the model-level reliability rating from Consumer Reports (2001–2007, Consumers Union), with quality metrics lagged by one period.

   * and *** indicate significance at the 0.1 and 0.01 confidence levels, respectively.

interaction effect among 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 WARR × PQ × SQ, and our main findings remain robust to this variation (not reported).

Next, based on the exogeneity assumption for product quality and service quality, our identification strategy makes use of a competitor's product quality and service quality as instruments, among several other instruments. We have argued extensively that in our static model of price and warranty competition these instruments are well justified. However, as a way to partially relax the impact of that assumption, we tested a model that does not include a competitor's product quality and service quality as additional instruments, obtaining very similar results (not reported); in particular, all our key coefficients remain significant.

Perhaps a more sensitive issue is the potential role of brand fixed effects as confounding factors. As noted in §4.2, the level of variation in our warranty

variable does not allow us to control for brand fixed effects in the usual way in the model specification. This is certainly a limitation of our data and a matter of concern in our analysis and in our identification strategy. We note, however, that the warranty is not the only brand-level variable in our model: 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 factors, 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 2002–2008 Market Data Books, Crain Communications) and the brand age, and we 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. Our main findings remained only partially robust to these variations (models 5 and

Table 6   Selected Brand-Robustness Checks: Estimates of Mean Utility Coefficients

	(5)		(6)		(7)		(8)	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
PRICE	−0.077***	0.013	−0.077***	0.014	−0.091***	0.012	−0.094***	0.013
WARR	0.116	0.073	0.073	0.074	0.155**	0.078	0.219**	0.093
PQ	0.971***	0.327	1.009***	0.295	0.862***	0.281	1.054***	0.355
SQ	−0.585	2.811	−1.478	2.854	1.297	2.527	0.095	2.424
WARR × PQ	−0.956***	0.308	−0.909***	0.284	−0.742**	0.298	−0.908**	0.357
WARR × SQ	4.875*	2.701	3.663	2.612	5.402*	2.895	6.942*	3.691
PQ × SQ	−26.718***	6.593	−23.327***	7.057	−20.770***	7.074	−24.522***	7.776
NDEALERS	0.201***	0.057	0.249***	0.064				

Notes. (5) Including NDEALERS (number of franchised dealers, measured in 1,000s) in the model specification; (6) including both NDEALERS and brand age dummies; (7) including brand dummies for all top-10 seller brands that have longitudinal variation in warranties; (8) including brand dummies for all brands that have longitudinal variation in warranties.

   *, **, and *** indicate significance at the 0.1, 0.05, and 0.01 confidence levels, respectively.

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6). In particular, the complementarity and substitution patterns remain qualitatively mostly robust (with the exception of the interaction WARR * SQ in model 6), although some effects are quantitatively less strong in terms of effect size than in our main model. We also tested some logit models with instrumental variables (IVs) including brand-level random effects, and the results were largely robust to this variation, with the exception of the nonsignificance of the interaction between warranty and service quality (not reported).

Finally, as a perhaps more definitive test of the brand issue, and considering the impossibility of including brand fixed effects and our brand-level variables at the same time for all brands, we adopted a modified approach that partially addresses this issue. The approach is to include brand fixed effects (dummies) but only for brands for which we observe longitudinal variation in warranties (i.e., brands with at least one warranty change in the observation period). We tested two versions of this approach: including brand fixed effects for the subset of brands with longitudinal variation in warranties that were in the top 10 brands with most sales (model 7), and including brand fixed effects for all brands with longitudinal variation in warranties (model 8). As can be seen in Table 6, our main results remain remarkably robust; in particular, the significance of the interactions remains quite strong (with the exception of WARR * SQ, which in this case is significant only at the 10% level).

Overall, we believe that these robustness checks are useful in supporting our main results to the extent possible with our data. In the case of the role of brand in particular, if more granular data become available (e.g., at the dealer level), future research may further examine our findings in more detail (e.g., if variation in services across different dealers can be exploited as a richer source of identification). More generally, our analysis is subject to the usual limitations encountered when dealing with observational data and identification strategies based on instrumental variables (IVs). Although it may be unrealistic to conduct controlled field experiments in multifirm and multiyear settings under competition like the one we consider, perhaps future research could explore single-firm field experiments to test effects similar to ours without the need to rely on instruments-based identification.

6. Conclusion

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 after-sales services 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 after-sales 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 after-sales 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 if existing service quality is low.

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. 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. We believe that the demand-side estimates derived from our analysis constitute a critical missing component for managerial decision making in practice, because managers are usually very good at estimating the implied costs of different managerial interventions, whereas 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 the definition of the warranty length could have implications for the profits that firms derive from selling extended warranties. Modeling the interactions between in-warranty and out-of-warranty policies offers an 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 given our static model in which firms compete on prices and warranties only. Although 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. Future research could also explore refinements to our model specifications. For example, the incorporation of data on demographics would allow the inclusion of nonlinear income effects in the model. Finally, 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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