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An Empirical Test of Warranty Theories in the U.S. Computer Server and Automobile Markets

Four theories on the economic rationale for warranty provision have been proposed in the literature: (1) Warranties provide insurance to customers and work as a risk-sharing mechanism, (2) warranties are a sorting mechanism and work as a means for second-degree price discrimination among customers with different risk preferences, (3) warranties work as a signal of product quality to consumers under information asymmetry, and (4) warranties work as an incentive mechanism for firms to reveal and improve product quality. The authors examine the conditions under which each theory would apply and derive testable implications from the data. They then assess whether these theories have empirical support in the U.S. computer server and automobile markets in the context of manufacturer base warranties. The results indicate that in both markets, warranties primarily provide customers with insurance against product failure, and warranties of different durations work as a sorting mechanism across customers with different levels of risk aversion. Warranties are not used to signal product quality or to provide an incentive for manufacturers to reveal or improve product quality.

Keywords: warranties, insurance, sorting, signaling, incentives, second-degree price discrimination, server market, automobile market

A warranty is a promise by the seller to assume specific responsibilities in case the quality or the performance of the purchased item does not conform to its specifications or to the buyer's legitimate contractual expectations (Parisi 2004). Durable goods are often sold in combination with warranties. Laboratory experiments have shown the value of warranties in decision making under risk and uncertainty (Shimp and Bearden 1982). A survey by the U.S. Department of Commerce (1992) reveals that one of every two consumers interviewed used warranties to judge product quality when making a purchase decision.

These examples indicate that buyers value product warranties. However, what are the mechanisms by which a warranty provides value to different parties involved in the warranty contract? Four theories on the economic rationale for warranty provision have been proposed in the literature (for a review, see Emons 1989). First, warranties provide insurance to customers and work as a risk-sharing mechanism between customers and firms (Heal 1976, 1977). Second, warranties are offered as a sorting mechanism across heterogeneous consumers and work as a means for second-degree price discrimination with consumers who self-select into an appropriate warranty plan (Kubo 1986; Matthews and Moore 1987). Third, warranties are used to signal product quality to consumers under information asymmetry (Balachander 2001; Courville and Hausman 1979; Gal-Or 1989; Grossman 1981; Lutz 1989; Spence 1977). Fourth, warranties work as an incentive mechanism for manufacturers to reveal product quality to consumers, improve product quality, or at least not cheat on product quality. This is because a commitment to a long warranty would result in larger warranty costs if the product's true quality were lower than the warranted level (Cooper and Ross 1985; Lutz 1989; Priest 1981).

These theories make different assumptions about firm and consumer behavior and have different predictions on the economic roles of warranties. However, little empirical work has systematically examined the validity of these theories in actual markets. Lutz (1989, p. 252) notes that "more empirical work will be necessary to determine whether warranties serve as signals or as incentives for the production of quality products.… The role of warranties will have to be addressed on a market by market basis." The objective of this article is to assess empirically whether the economic roles of warranties in the U.S. computer server and automobile markets are consistent with the different warranty theories. The server market is a business-to-business market with firms and various institutions as main users, and the automobile market is a business-to-consumer market with individuals and households as main buyers. Thus, an empirical assessment of warranty theories in these two markets can help us better understand warranty theories across different types of markets.

There are two types of warranties: base/basic warranties and extended warranties. The key difference between them

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is that base/basic warranties are bundled with the product and cannot be purchased separately; thus, their prices are not observable. Conversely, extended warranties are optional and can be purchased separately at an additional cost to the buyer. Base warranties are usually provided by manufacturers, while extended warranties can be provided by manufacturers, retailers/dealers, or independent third parties. Automobile and computer server manufacturers offer both types of warranties for their products.[1] Studies have shown that manufacturers and retailers/dealers provide extended warranties primarily for risk sharing and sorting purposes (Kelley and Conant 1991), while for manufacturer base warranties, the four economic rationales may apply in principle. Therefore, in this article, we consider only manufacturer base warranties. We want to determine whether manufacturers use base warranties as insurance, screening, signaling, or incentive mechanisms. Base warranties are characterized by several attributes, such as service response time and warranty duration, but the variation across product models is primarily in warranty duration. Thus, assessing the various theories on warranties is equivalent to examining the relationships between a product's warranty duration and its other attributes (e.g., price, reliability).[2]

A major reason for the scant empirical research on warranties is the lack of appropriate data. To investigate these theories, we need data on product warranty duration, quality, price, and other attributes. Thus, we collect data on manufacturer base/basic warranties of major server and automobile models sold in the U.S. market, together with price, product reliability, and key product attributes. We find that the major roles of warranties in these markets are to (1) provide customers with insurance against product failure and (2) work as a sorting mechanism for second-degree price discrimination among heterogeneous customers. They are not used to signal product quality to customers or to provide an incentive for firms to reveal product quality to customers or improve product quality.

The rest of the article proceeds as follows: We first review the theoretical literature on the economic roles of warranties and the limited empirical research. Then, we describe the data and the observed warranty patterns in the two markets. Next, we assess the various economic theories of warranties in each market. We conclude with managerial implications.

[1]Selling of extended warranties for durable goods, such as consumer electronics, is typically dominated by retailers/dealers because they are an important source of profits (Paulson 2007). However, durable goods manufacturers have stepped up the provision of extended warranties. In the automobile market and product markets (e.g., servers and personal computers) in which manufacturer direct selling is common, extended warranties are a profitable enterprise for manufacturers. For example, Ford and Dell each bring in more than $1 billion a year through the sale of extended warranties (*Warranty Week* 2005a). Dell's extended warranty revenue as a percentage of operating income sales rose from 24% in 2003 to 38% in 2005 (*Warranty Week* 2005b).

[2]Researchers typically use warranty duration as the appropriate metric when testing the signaling role of warranties (e.g., Boulding and Kirmani 1993; Priest 1981; Shimp and Bearden 1982; Soberman 2003).

The Economics of Warranties

Rationales for Warranty Provision

There is a large body of literature on the economic rationales for warranty provision. Four theories have been proposed for their use: insurance, sorting, signaling, and incentive. We summarize these theories in Table 1 and describe them subsequently. The insurance, signaling, and incentive motives are based on the premise that warranties lower the risk associated with a purchase; the sorting notion is driven by firms' desire to extract consumer surplus.

Insurance theory. By definition, warranties obligate a manufacturer or seller to compensate the buyer in the event of product failure. They are a form of insurance and work as a risk-sharing mechanism between buyers and the seller (Heal 1976, 1977). The key assumption underlying the insurance theory is that buyers are risk averse. In the absence of risk aversion, insurance does not play a role, because risk-neutral or risk-loving buyers can simply bear all the risks. Whatever the other roles of warranties, the insurance role exists as long as there is a nonzero probability of product failure and buyers are risk averse. Therefore, providing insurance to buyers seems to be the most fundamental function of warranties.

A direct implication of the insurance rationale for warranty provision is that the degree of risk aversion and the duration of warranty should be positively correlated. Therefore, we expect that (1) the same customers will buy longer warranties when product failure increases and reliability decreases, and (2) given a particular product failure rate, more risk-averse customers will buy longer warranties than less risk-averse customers.

Sorting theory. The sorting theory of warranties examines the use of warranties as a screening mechanism in markets characterized by consumer heterogeneity in quality evaluation and risk attitude (Kubo 1986; Matthews and Moore 1987; Padmanabhan and Rao 1993). This stream of research focuses on mechanism design that can better screen consumers into different warranty contracts according to their "type." It explores how firms design and price a line of products distinguished by different quality (fully observable) and warranty levels to extract the maximum surplus from each consumer type. In other words, firms should design a profit-maximizing set of contracts that specify price, quality, and warranty. Screening in the context of manufacturer base warranties can occur through a product line that is primarily differentiated on the basis of warranty coverage and price (i.e., buyers can self-select into a more expensive product that offers more insurance). Retailers/dealers screen customers through the sale of retailer-backed extended warranties (Kelley and Conant 1991); however, an open question remains, Do manufacturers screen customers on the basis of risk aversion through the design of their product lines? Doing so may be an effective strategy for manufacturers to capture some of the profits from extended warranty sales.

The key assumption underlying the sorting theory of warranties is the presence of consumer heterogeneity. Con-

TABLE 1
Summary of Warranty Theories and Empirical Implications in the Computer Server and Automobile Markets

				Empirical Verification			
				Server Market		Automobile Market	
Theory	Studies	Key Assumptions	Implications	Assumptions Met?	Supported?	Assumptions Met?	Supported?
Insurance/ risk sharing	Heal 1977	Consumers are risk averse	Degree of risk aversion and warranty duration are positively correlated: (1) The same customers buy longer warranties when product reliability decreases, and (2) more risk-averse customers buy longer warranties.	Yes	Yes (Table 7)	Yes	Yes (Table 11)
Sorting/price discrimination	Kubo 1986; Matthews and Moore 1987	Consumers are heterogeneous in quality evaluation/ risk aversion	1. Menu of warranties for similar or differentiated products. 2. Firms of same size buy different warranties. 3. Households of same demographics buy different warranties.	Yes	Yes, all major manufacturers offer nonuniform warranties (Tables 4 and 8)	Yes	Yes, some automakers offer menu of warranties (Tables 5 and 12)
Signaling	Spence 1977	Information asymmetry	Quality and warranties are positively correlated.	Unclear	No, warranty and quality are not correlated (Table 9)	Unclear	No, warranty and quality are not correlated (Table 13)
Incentive	Heal 1977; Lutz 1989; Priest 1981	Risk endogeneity	1. Quality is negatively correlated with current warranty. 2. Quality is positively correlated with past warranties.	Unclear	No, quality is not correlated with current or lagged warranty durations (Tables 9 and 10)	Unclear	No, new car reliability is not correlated with warranty duration (Table 13)

sumers differ in their evaluation of a product's quality, in their levels of risk aversion, or along other important dimensions that are private and not observable to the firm. Because it is often impossible for firms to design a contract for each individual consumer, they design a contract for each *type* of consumers and let consumers self-select into different contracts. In equilibrium, firms will offer a line of products distinguished by different quality, warranty, and price levels. For the sorting theory of warranties to have a presence in a given market, different combinations of these three attributes must be observed in the data. The sorting theory also implies that, in equilibrium, in response to the menu of warranties the firm provides, customers with the same observable attributes but different degrees of risk aversion will exhibit different choice behaviors for warranty contracts in accordance with their risk profiles.

Signaling theory. The signaling approach examines the information content of warranties under information asymmetry (Akerlof 1970; Riley 1979). The key assumption of signaling theory is information asymmetry in the sense that sellers have better knowledge about the product quality than buyers. Thus, buyers may not be accurately informed about the product performance before purchase because of the random nature of product quality, and sellers need to signal product quality through warranties, similar to how they signal quality through advertising (Nelson 1974).

Several researchers have studied the signaling role of warranties in different contexts (e.g., Balachander 2001; Grossman 1981; Lutz 1989).[3] In Spence's (1977) influential work in this area, consumers try to infer product quality from product price or warranty. Warranties can be a signal of product quality and consumers can be well informed in equilibrium because (1) warranties are costly to the seller and (2) the costs are systematically related to product reliability. Quality signaling of warranties implies a *positive* relationship between product quality and warranty duration because only high-quality firms can afford long warranties because of their associated costs of fulfillment. However, for a low-quality seller, signaling works only if the provision of a good warranty raises the seller's cost to a level higher than that of the high-quality seller. If the low-quality seller can offer a good warranty and fully absorb the higher cost of warranty fulfillment by charging a higher price, warranties will not be a successful quality signal (Kirmani and Rao 2000).

Incentive theory. Incentive theory examines firms' and consumers' incentive problems resulting from the provision of warranties (Cooper and Ross 1985; Lutz 1989; Lutz and Padmanabhan 1995; Priest 1981). The key assumption is risk endogeneity in the sense that buyers' and sellers' actions can affect product performance. The probability that a product will break down is a function of its intrinsic quality, which depends on firms' product efforts and consumers' maintenance efforts. The maintenance effort is costly to consumers and unobservable to sellers, so warranties cannot be made conditional on the amount of effort expended. When choosing warranties, firms must take the moral hazard into account. That is, they must consider the effect of warranties on consumers' incentive to take care of the product.

The incentive issue on the firm side involves two aspects. The first is firms' incentive to signal product quality to consumers through warranties in the presence of consumer moral hazard, and the second is firms' incentive to invest in product quality and supply high-quality products. According to Lutz (1989), the seller's incentive to signal product quality is strongly affected by the interaction between consumers' perceived quality and maintenance effort. Maintenance effort can be either positively or negatively correlated with perceived product quality. Lutz shows that in both cases, a *negative* relationship between perceived quality and warranty is possible.

Warranties may also affect a firm's incentive to improve the quality of its product and supply a high-quality product, at least to the extent of reducing the chances of its falling below the warranted level (Heal 1977; Priest 1981). This is because quality improvement reduces a firm's future warranty compensation and increases its profits. Therefore, we expect a positive relationship between quality and *previous* warranty terms and a positive relationship between warranty terms and *new* product reliability.

Empirical Research on the Economic Roles of Warranties

Little empirical work examines all competing theories of warranty provisions in actual markets, though some research tests the signaling role of warranties with market data. The findings are mixed; positive, negative, weak, and no relationships are all reported in the literature.

Kelley (1988) and Wiener (1985) use *Consumer Reports* (*CR*) data to examine the relationship between warranty coverage and reliability for consumer durables, appliances, and automobiles and find a significant, positive association between warranty coverage and product reliability for the majority of products examined. Douglas, Glennon, and Lane (1993) examine the relationship between warranties and reliability for automobiles and find a significant, negative correlation. However, higher warranty terms reflect higher levels of reliability when dealer costs are taken into account. Gerner and Bryant (1981) investigate warranties of five products and find that warranty scope tends to converge to standard basic coverage within and across appliances, indicating a weak relationship between warranty and reliability. Priest (1981) compares the duration of warranty coverage with expected service life for automobiles and various appliances and finds no support for signaling theory. Agrawal, Richardson, and Grimm (1996) use *CR* data to examine the relationship between warranty terms and reliability for a sample of household appliances and electronic products and find that warranty terms are poor predictors of brand reliability for the sample under study. In the Canadian used-car market, Soberman (2003) finds indirect evidence of sellers using the length of base warranties and both

[3]Grossman (1981) studies the quality signaling of warranties when the quality or quality characteristics of the product are *ex post* verifiable, Lutz (1989) studies quality signaling under consumer and firm moral hazard, and Balachander (2001) studies quality signaling in markets characterized by new entrants competing with established brands.

prices and a menu of extended warranties to signal and screen simultaneously. Our study differs from these in that we examine all four theories on the roles of manufacturer base warranties in the server and automobile markets.

Wiener (1985), Kelley (1988), and Agrawal, Richardson, and Grimm (1996) all use *CR* data, but they reach different conclusions, even for the same product categories. A key challenge with empirical work is obtaining the data that will help understand the various relationships of interest, while controlling for other factors that could influence the key factors, such as quality and warranty duration.

In summary, empirical work has not kept pace with theoretical developments, particularly in the areas of insurance, sorting, and incentive roles. Indeed, little work has simultaneously assessed the four economic rationales for warranty provisions and determined which rationales are consistent with the data. Our objective is to make some progress in this area.

Data Summary

We use data from the U.S. computer server and automobile markets to assess the four theories on the economic rationales of warranty provision. For the computer server market, we focus on x86-based servers; for the automobile market, we focus on new cars.

x86 Server Data

The U.S. x86 server market includes both large players (e.g., Hewlett-Packard [HP]/Compaq, Dell, IBM, Sun) and small players (e.g., Acer, Fujitsu Siemens, Toshiba). In 1999–2004, 6.2 million servers were sold to various institutions with total revenues of $36.5 billion (according to Gartner Research data). During this period, sales of x86 servers more than tripled, and their revenues nearly doubled. Dell's shares increased from 23.4% to 29.7%; HP came in second place, though its shares dropped from 48.5% to 26.0%. IBM primarily sold mainframe servers and came in third place in the x86 server market. Sun entered the market in the late 1990s but had a relatively low presence.

We collected manufacturer warranty duration data (in months) for major server models sold in the U.S. market, together with their wholesale and retail prices and main product attributes, such as processor number, speed and type, RAM size and type, hard drive size, number of hard drives, total slots, and bays. We collected these data by visiting manufacturers' and resellers' Web sites and other relevant Web sites, searching copies of *PC Magazine* and other related publications, and directly contacting manufacturers and resellers. Multiple sources enabled us to validate and cross-check information from the various sources.

We obtained quarterly data on corporate customers' quality evaluations of servers in the U.S. market for 2002–2004 from Technology Business Research Inc (TBRI). This firm conducts a quarterly survey of corporate information technology buying behavior and customer satisfaction of x86 servers. The firm screens respondents, and only those who are personally involved in evaluating or recommending x86 servers for their organizations are eligible to answer the questionnaire. Survey questions include firm demographics, server purchases and vendor switching, hardware quality evaluation, overall value of the purchase, ease of doing business with the vendor, delivery time/product availability, replacement parts availability, telephone support, on-site support, and overall satisfaction. The evaluation questions are administered on a seven-point Likert scale, where 1 is "totally dissatisfied" and 7 is "totally satisfied or excellent." All firms receive high evaluation, indicating high overall server quality. Dell has the highest mean score of 6.21 (SD = .07), though it is only slightly higher than HP (M = 6.18, SD = .09), and IBM's score is the lowest but still above 6.0 (SD = .07). The TBRI surveys are highly accredited in the industry; all major server makers subscribe to TBRI research and publicize the research results when they outrank their competitors.[4]

We obtained data on server manufacturers' quarterly advertising expenditures for 1999–2004 from Competitive Media Report. We obtained quarterly wholesale and retail prices of major x86 server models in the U.S. market from Gartner. These data also contain information on major server attributes, by which we match price data with warranty duration and quality evaluation. Buyer segments include education, governments, and firms of various sizes, including small offices (1–9 employees), small firms (10–99 employees), midsize firms (100–499 employees), large firms (500–999 employees), and very large firms (≥1000 employees). We summarize the various variables and their definitions, operationalization, and data sources in Table 2.

Automobile Data

Automobiles represent a large market in the United States, with 7.6 million cars sold in 2007 and 6.8 million cars sold in 2008. Large automakers include General Motors (21.93%), Toyota (16.47%), Ford (14.73%), Chrysler (10.77%), Honda (10.59%), and Nissan (7.06%). Small automakers include Hyundai, Volkswagen, Kia Motors, BMW, Mazda, Subaru, Mitsubishi, and Suzuki, among others (see www.wardsauto.com). There are two types of manufacturer base warranties in the automobile market. One is a basic car warranty, or "bumper-to-bumper" warranty, and the other is a powertrain warranty. A basic car warranty typically repairs vehicles for a specific time and mileage (e.g., 3 years/36K miles), whichever occurs first. All factory-installed parts and some dealer-installed accessories are covered for defects and workmanship. Items such as tires, wiper blades, and batteries are generally not covered under the basic warranty, though some of these parts may have their own warranty. A powertrain warranty offers protection beyond the basic warranty and is applicable for major components, such as the engine, transmission, and drive shafts.

We collected manufacturer basic and powertrain warranty data for 424 car models available in 2009 in the United States from *CR* (see www.consumerreports.org). The models are made by 23 manufacturers from six coun-

[4]For examples, see www.lenovo.com/news/us//en/2006/09/tbr06.html.

TABLE 2
Variable Definition and Data Sources

Variables	Definition/Operationalization	Data Sources
Server Market		
Manufacturer server warranty duration, server wholesale and retail prices, and attributes		Manufacturer and reseller Web sites, various copies of *PC Magazine*, and directly from manufacturers and resellers
Corporate customers' quality evaluation of servers	Seven-point Likert scale, where 1 = "totally dissatisfied" and 7 = "totally satisfied or excellent"	TBRI quarterly surveys
Manufacturer quarterly advertising expenditures		Competitive Media Report quarterly data
Quarterly sales and revenues of server models		Gartner quarterly data
Satisfaction with actual server reliability	Ten-point Likert scale	1999–2004 *PC Magazine* surveys
Automobile Market		
Manufacturer basic warranty	Typically repairs vehicles for a specific time and mileage and covers all factory-installed parts and some dealer-installed accessories for defects and workmanship.	www.consumerreports.org, manufacturer Web sites
Manufacturer powertrain warranty	Offers protection beyond the basic warranty and is applicable for major components, such as engine, transmission, and drive shafts.	www.consumerreports.org, manufacturer Web sites
Overall quality score	A 100-point scale, based on *CR*'s tests, *CR*'s subscriber survey data, and government and/or insurance industry crash tests or rollover tests.	www.consumerreports.org
Accident avoidance	A five-point composite score of *CR*'s test results for braking performance, emergency handling, acceleration, driving position, visibility, and seat comfort. Braking and emergency handling carry the most weight.	www.consumerreports.org
Predicted reliability for new vehicles	*CR*'s forecast of how well a model is likely to hold up derived from *CR*'s annual Car Reliability Survey. It averages a model's used car verdict for the newest three years, provided the model did not change significantly during that time.	www.consumerreports.org
Car attributes (e.g., type, make, manufacturer, horsepower, engine size, MPG)		www.consumerreports.org
Household demographics and automobile purchase data		Consumer expenditure surveys (www.bls.gov)

tries (United States, Japan, Germany, United Kingdom, Sweden, and Korea). We verified the warranty data by checking each manufacturer's Web site. For each model, we collected data on its type (e.g., sport-utility vehicle, sedan, wagon), manufacturer, make, low and high manufacturer suggested retail prices, test car price, interior and exterior specifications, safety features, crash tests results, performance, horsepower, engine size, overall miles per gallon (MPG), overall quality score, accident avoidance, and predicted reliability for new vehicles.[5] We used the last three variables as quality measures. We also obtained household automobile purchase data from the 2008 consumer expenditure survey (see www.bls.gov), together with household demographics. We matched these data with automobile warranty and characteristics. Manufacturer warranty policies, particularly basic car warranties, tend to be stable over time. The most recent warranty policy change occurred in 2006 when Ford lengthened its powertrain warranty for Ford and Mercury models to 5 years/60K miles and for Lincoln models to 6 years/70K miles.[6]

[5]*Consumer Reports* gives an overall quality score on a 100-point scale to the model and trim line it tests. The score is based on *CR*'s tests, *CR*'s subscriber survey data, and government and/or insurance industry crash tests or rollover tests. Accidence avoidance is a five-point composite score of *CR*'s test results for braking performance, emergency handling, acceleration, driving position, visibility, and seat comfort. Braking and emergency handling carry the most weight. Predicted reliability is *CR*'s forecast of how well a model is likely to hold up and is derived from *CR*'s annual Car Reliability Survey. It averages a model's used-car verdict for the newest three years, provided the model did not change significantly during that time.

[6]Other warranty policy changes exist in the automobile industry. Most changes occurred around the turn of the century and are not covered in the data. Mitsubishi lengthened its basic warranty from 3 years/36K miles to 5 years/60K miles and its powertrain warranty from 5 years/60K to 10 years/100K miles in 2004. Hyundai lengthened its basic warranties from 3/36 to 5/60 and its powertrain warranties from 5/60 to 10/100 at the beginning of 1999. Chrysler lengthened its powertrain warranties from 3/36 to 7/100 in 2001, and Suzuki had the same change in 2002. Volkswagen lengthened its basic warranty from 2/24 to 4/50 and shortened its powertrain warranty from 10/100 to 5/60 in 2002.

Table 3 reports summary statistics of product attributes, warranty duration, and quality levels across all car models. The mean test car price is $32,454, the mean MPG is 22.78, the mean engine size is 3.10 liters, and the mean horsepower is 236.66. The mean basic warranty is 3.51 years and 42.63K miles, and the mean powertrain warranty is 5.58 years and 73.76K miles. The mean quality score is 69.90 (on a scale of 100), the mean accident avoidance score is 3.63 (on a scale of 5), and the mean predicted reliability for new vehicles is 3.00 (on a scale of 5).

Warranty Patterns in the Computer Server and Automobile Markets

In the computer server market, manufacturers primarily provide base warranties, though they may contract out warranty fulfillment services to third parties. All manufacturers offer base warranties for all servers, ranging from three months to three years, with one year and three years the most commonly offered. Warranties vary across manufacturers, across the same manufacturers' different models, and across the same server models' different variants. For a given model or model variant, however, warranties do not change over time. Table 4 summarizes base warranty patterns in the x86 server market. For example, HP offers one- or three-year warranties for each model but varies warranty durations across models; the more advanced the model, the longer is the warranty. IBM varies warranty durations primarily across models and offers longer warranties for more advanced models. For some models, such as the IBM xSeries 226, however, the warranty varies even within a model, though the higher-priced model variants still have longer warranties. Dell offers shorter warranties for base models and enhanced models but longer warranties for advanced models. Sun offers longer warranties for low-priced and high-priced servers but has shorter warranties for medium-priced servers. All other manufacturers either offer uniform warranties for all machines or vary warranty durations across models. In summary, although server warranties vary across manufacturers and models, in general the more advanced and the higher priced the model, the longer is the warranty duration.

Table 5 reports sales-weighted wholesale price, warranty duration, and perceived product reliability of x86 servers for 2002–2004 for HP, IBM, and Dell. Perceived product reliability across these firms is fairly similar. Warranty duration and perceived product reliability do not seem to be correlated. The raw data seem to support the insurance and the sorting roles of warranties but not the signaling and incentive roles.

Table 6 shows warranty patterns and mean quality indicators for major automakers. Basic car warranty duration ranges from two to five years, and mileage coverage ranges from 24K to 60K miles. The most common basic warranty is "3/36" (62.97% of the car models), followed by "4/50" (20.05%) and "5/60" (15.09%). The powertrain warranty is often longer than the basic warranty, ranging from two to ten years and from 24K to 100K miles. The most common powertrain warranty is "5/60" (45.05%), followed by "5/100" (22.41%), "10/100" (12.74%), and "4/50" (11.56%). The most common basic and powertrain warranty combination is "3/36–5/60" (41.98%), followed by "3/36–5/100" (19.10%) and "5/60–10/100" (12.74%).

TABLE 3
Summary of Product Attributes and Warranty Durations for Automobiles

	M	SD	Minimum	Maximum	Mdn	Mode
MSRP: low	26,621	15,748	9,970	98,500	21,647	15,455
MSRP: high	38,555	28,745	13,915	296,250	31,499	27,000
Test car price	32,454	16,300	12,745	105,855	28,355	25,170
Overall MPG	22.78	5.56	11	44	22	18
Engine liter	3.10	1.39	1	8.4	2.5	2
Horsepower	236.66	100.78	70	600	228.5	110
Warranty years	3.51	.75	2	5	3	3
Warranty miles	42.63	9.50	24	60	36	36
Powertrain years	5.58	1.78	2	10	5	5
Power train miles	73.76	20.72	24	100	60	60
Overall score	69.90	13.86	17	99	71.5	64
Accident avoidance	3.63	1.10	1	5	4	4
Predicted reliability	3.00	1.22	1	5	3	3
Likelihood to buy again	3.00	1.08	1	5	3	4

Notes: MSRP = manufacturer suggested retail prices.

TABLE 4
Summary of Warranty Patterns for x86-Based Server

Manufacturer	Warranty Duration	Warranty Pattern
HP	1 year, 3 years	Vary across models
IBM	1 year , 3 years	Vary across and within models
Dell	1 year, 3 years	Vary across models
Sun	3 months, 1 year, 3 years	Vary across models
Other manufacturers	3 months, 1 year, 3 years	Either uniform warranty or vary across models

TABLE 5
Sales-Weighted Wholesale Price, Warranty Duration, and Perceived Product Quality for x86-Based Servers

	2002			2003			2004		
	Wholesale Price	Warranty Duration	Perceived Quality	Wholesale Price	Warranty Duration	Perceived Quality	Wholesale Price	Warranty Duration	Perceived Quality
HP	$4,784	30.59	6.11	$5,134	30.59	6.28	$4,688	30.76	6.14
IBM	$5,340	31.41	6.05	$4,837	31.19	6.11	$4,934	31.80	6.03
Dell	$3,921	29.11	6.22	$3,741	28.35	6.26	$3,502	29.41	6.13
Total	$4,506	30.09	6.15	$4,483	29.31	6.24	$4,201	30.66	6.12

Notes: Quality ratings are on a seven-point scale, where 7 = "highest quality."
Source: TBRI.

Manufacturers offer one, two, or three warranty policies for their car models. Honda, Nissan, Toyota, and General Motors offer two warranty policies, and Ford offers three warranty policies for different car makes (e.g., Lincoln, Ford, Mercury), but warranties are the same for all car models of the same make (e.g., Mercury Mariner V6, Mercury Mountaineer V6, Mercury Grand Marquis, Mercury Sable). Of the two or three warranty policies, "3/36–5/60" is offered by Honda, Nissan, Toyota, and Ford for 126 of their 160 car models. General Motors offers "3/36–5/100" warranty for 55 models and "4/50–5/100" for 11 models. All other manufacturers offer uniform warranties for all car models.

Given that many automakers offer similar warranty terms, the information content of warranties is limited. Furthermore, there does not seem to be a consistent correlation between warranty duration and product quality indicators, even for the same manufacturers that offer different warranty policies. For example, the overall quality score for Toyota "3/36–5/60" is 69.23 and for Toyota "4/50–6/70" is 81.00; for Ford, the overall quality score for these two warranty conditions is 69.31 and 66.40, respectively.

Test of Warranty Theories in the Computer Server and Automobile Markets

Test in the Computer Server Market

Insurance theory. We first examine whether the two assumptions underlying the insurance theory hold in the server market. The first assumption is that consumers are risk averse. Although this is a common assumption in the literature, it is difficult to observe measures of risk aversion directly. An indirect evidence of consumer risk aversion is extended warranties, which consumers buy primarily for the purpose of risk sharing. The sales of extended warranty contracts have increased over time (Stafford 2006), implying that consumers buy more warranties to protect against product failure. This makes sense only if consumers are risk averse. The second assumption is that the probability of product failure is greater than zero. According to *PC Magazine*'s various annual surveys, this seems to be the case. The 2002 *PC Magazine* survey shows that 34% units needed repair in the past 12 months, and the 2004 survey gives 28% for all servers and 16% for servers less than one year old. Note that survey respondents are not randomly chosen, and thus these percentages might be biased. Nevertheless, the percentages imply a nontrivial probability of product failure. The nontrivial failure rate justifies the prevalence of warranties as an insurance device in the server market.

We can derive two predictions from the insurance theory: First, the same consumers will buy longer warranties when actual product failure increases and product reliability decreases, and second, more risk-averse consumers will buy longer warranties than less risk-averse ones. To check the first prediction, we need to show that warranty durations and actual product failure rates are positively correlated or that warranty durations and actual product reliability are negatively correlated. To do so, we need information on product failure or reliability rates for each period, which we do not have. From various *PC Magazine* surveys, we obtain annual figures on satisfaction with actual server reliability (a ten-point scale) for 1999–2004. We compute sales-weighted warranty duration for each year and then compute the Pearson correlation coefficient between satisfaction scores of server reliability and warranty duration. The correlation coefficient is –.721 (p = .106). The correlation is in the expected direction and large in magnitude, but it is only marginally significant. Although we only have six data points (for the six years), the result is still noteworthy. Our finding provides some evidence for the insurance role of warranties in the server market.

To verify the second prediction, we need to know the degree of risk aversion for each type of customer. Although we do not have a direct measure of risk aversion, we can reasonably assume that smaller firms are more risk averse than larger ones, an assumption consistent with previous research in other contexts (e.g., Misra, Coughlan, and Narasimhan 2005). For example, small firms are more risk averse because they are more likely not to have a backup for their server system. If we can show that smaller firms buy longer warranties than larger firms after controlling for other factors, this will be consistent with the insurance theory. To this end, we regress the logarithm of warranty duration on product attributes, price, and firm size; the results appear in Table 7. We tried three model specifications. In Model 1, we use the mean number of employees for firm size (e.g., 5 for small offices, 55 for small firms, and so on). In Model 2, we use the logarithm of firm size in the regression. In Model 3, we treat firm size as a categorical variable. In all models, firm size is negatively correlated

TABLE 6
Manufacturer Warranty Patterns and Mean Quality Indicators for Automobiles

Country of Origin	Manufacturer	Brand	Basic–Powertrain Warranty (Years/1K Miles)	Number of Models	Model Share (%)	Market Share(%)	Overall Score	Accident Avoidance	Predicted New Car Reliability
Germany	Audi	Audi	4/50–4/50	6	1.42	.01	77.50	3.83	3.67
	BMW	BWM, Mini, Mini Cooper	4/50–4/50	23	5.42	2.25	79.00	4.26	2.65
	Mercedes-Benz	Mercedes-Benz	4/50–4/50	12	2.83	.00	78.75	3.33	3.25
	Porsche	Porsche	4/50–4/50	5	1.18	.19	87.40	2.80	3.00
	Smart	Smart	2/24–2/24	3	.71	.00	28.00	3.00	2.00
	Volkswagen	Volkswagen	3/36–5/60	14	3.30	2.30	80.21	4.07	3.64
Japan	Honda	Honda	3/36–5/60	28	6.60	10.59	73.93	3.86	4.04
		Acura	4/50–6/70	5	1.18		80.20	3.60	3.00
	Mazda	Mazda	3/36–5/60	21	4.95	1.96	77.05	3.86	3.44
	Mitsubishi	Mitsubishi	5/60–10/100	15	3.54	.72	65.73	3.60	3.40
	Nissan	Nissan	3/36–5/60	26	6.13	7.06	72.00	3.62	3.00
		Infiniti	4/60–6/70	5	1.18		87.20	3.60	2.81
	Subaru	Subaru	3/36–5/60	17	4.01	1.39	81.53	4.06	3.06
	Suzuki	Suzuki	3/36–7/100	6	1.42	.63	63.83	3.17	3.80
	Toyota	Toyota, Scion	3/36–5/60	40	9.43	16.47	69.23	3.70	4.00
		Lexus	4/50–6/70	9	2.12		81.00	3.67	3.22
Korea	Hyundai	Hyundai	5/60–10/100	22	5.19	2.98	71.23	3.91	4.00
	Kia	Kia	5/60–10/100	17	4.01	2.03	65.59	3.53	3.17
Sweden	Saab	Saab	4/50–5/100	3	.71	.16	70.33	4.00	2.67
United Kingdom	Jaguar	Jaguar	4/50–4/50	3	.71	.11	73.33	3.33	1.00
	Land Rover	Land Rover	4/50–5/60	3	.71	.22	58.00	2.67	5.00
	Lotus	Lotus	3/36–3/36	2	.47	.01	55.00	3.00	—
United States	Chrysler	Chrysler, Dodge, Jeep	3/36–5/100	26	6.13	10.77	51.08	3.23	3.04
	Ford	Ford, Mercury	3/36–5/60	32	7.55	14.19	69.31	3.53	3.47
		Lincoln	4/50–6/70	5	1.18		66.40	3.40	4.00
		Volvo	5/60–5/60	10	2.36	.54	68.80	3.30	3.38
	General Motors	Chevrolet, GMC, Pontiac, Saturn	3/36–5/100	55	12.97	21.93	62.53	3.40	3.02
		Buick, Cadillac, Hummer	4/50–5/100	11	2.59		64.91	3.55	2.57

TABLE 7
Regression of Log Warranty on Firm Size

	Model 1			Model 2			Model 3		
	Estimate	SE	t-Statistic	Estimate	SE	t-Statistic	Estimate	SE	t-Statistic
Acer	.896	.145	6.180	1.005	.145	6.918	.922	.145	6.370
Compaq	.526	.146	3.611	.635	.146	4.350	.553	.145	3.803
Cray	–.126	.212	–.596	–.021	.212	–.099	–.104	.212	–.494
Data General	.284	.173	1.643	.390	.173	2.254	.307	.172	1.781
Dell	.962	.147	6.555	1.070	.147	7.284	.988	.147	6.743
Fujitsu/ Fujitsu Siemens	.775	.152	5.088	.885	.152	5.809	.802	.152	5.281
Gateway	.879	.146	6.015	.990	.146	6.771	.907	.146	6.219
HP	.433	.149	2.918	.543	.149	3.648	.461	.148	3.106
Hitachi	.629	.159	3.963	.750	.159	4.717	.664	.159	4.185
IBM	.893	.148	6.022	1.001	.148	6.745	.919	.148	6.207
Intergraph	.541	.165	3.276	.648	.165	3.924	.566	.165	3.437
MPC	.628	.153	4.096	.737	.153	4.802	.654	.153	4.273
NCR	.132	.188	.703	.242	.188	1.288	.157	.187	.836
NEC	.623	.152	4.106	.731	.152	4.812	.649	.151	4.283
RLX Technologies	.740	.145	5.109	.854	.145	5.892	.769	.145	5.316
Rackable Systems	.219	.145	1.507	.328	.146	2.251	.245	.145	1.690
SGI	.191	.156	1.225	.298	.156	1.910	.216	.156	1.389
Sequent	–.006	.186	–.033	.099	.186	.530	.016	.186	.087
Stratus	.607	.170	3.561	.713	.170	4.184	.630	.170	3.705
Sun	.292	.146	1.995	.401	.147	2.734	.318	.146	2.178
Toshiba	1.337	.147	9.064	1.447	.148	9.802	1.362	.147	9.249
Unisys	.390	.160	2.436	.497	.160	3.105	.415	.160	2.596
VA Linux	.362	.151	2.401	.470	.151	3.115	.388	.150	2.580
CPU1	–.090	.243	–.370	–.089	.243	–.368	–.090	.242	–.372
CPU2	–.187	.023	–8.114	–.187	.023	–8.105	–.187	.023	–8.154
CPU3	–.062	.129	–.479	–.062	.129	–.480	–.062	.129	–.482
CPU4	–.302	.049	–6.167	–.303	.049	–6.194	–.303	.049	–6.191
CPU5	–.416	.043	–9.707	–.416	.043	–9.725	–.416	.043	–9.731
CPU6	.030	.042	.722	.030	.042	.713	.029	.041	.711
CPU7	–.271	.018	–14.685	–.271	.018	–14.683	–.271	.018	–14.707
CPU8	–.144	.024	–5.992	–.145	.024	–6.021	–.145	.024	–6.026
CPU9	–.386	.133	–2.901	–.392	.133	–2.948	–.394	.133	–2.966
ln(price)	.222	.013	17.674	.223	.013	17.756	.223	.013	17.808
ln(CPU speed)	.084	.014	6.085	.084	.014	6.092	.084	.014	6.114
Firm size (1000 employees)	–.142	.010	–13.931						
ln(firm size)				–.038	.003	–14.449			
Small firms							–.049	.017	–2.828
Midsize firms							–.110	.017	–6.380
Large firms							–.213	.017	–12.375
Very large firms							–.214	.018	–12.176
N	7913			7913			7913		
R^2	.340			.341			.345		

Notes: Coefficient estimates of specific brands (e.g., ProLiant, Integrity) are not reported for space reasons.

with warranty duration, and the correlation is significant, even though the difference between large and very large firms in Model 3 is not statistically significant. In general, the larger a firm, the shorter is the warranty it purchases. After we control for price and other product attributes, small firms have 4.8% shorter warranty durations than small offices, midsize firms have 10.4% shorter warranty durations, and large and very large firms have approximately 20% shorter warranty durations than small offices. Large firms may have in-house information technology departments to handle breakdown issues and thus do not require warranties as much as small firms do. Although we cannot rule out this possibility because of our lack of data on this aspect, our finding is nevertheless consistent with the predictions of the insurance theory. Given these results, we conclude that there is evidence in support of the insurance theory for server warranties.

Sorting theory. Do warranties play a sorting role and work as a mechanism for second-degree price discrimination in the server market? First, we check whether the key assumption for the sorting role—that is, that consumers are heterogeneous—is met in the server market. Matthews and Moore (1987) assume consumer heterogeneity in risk aversion and quality evaluation. Consumer heterogeneity definitely exists in the server market because buyers of servers are various institutions. In 1999–2004, 5.41% of x86 servers

in the United States were sold to educational institutions, 12.10% to governments, 10.92% to small offices, 15.62% to small firms, 21.78% to midsize firms, 15.28% to large firms, and 18.78% to very large firms. These institutions differ substantially in size, revenue, income, technical capability, and usage intensity. Revenue and income are directly related to risk aversion and willingness to pay for quality and warranties.

The sorting theory predicts that nonuniform or a menu of warranties is offered to consumers by the same firms. Table 4 lists such a menu. The same manufacturer offers three-month, one-year, or three-year warranties for its products. For example, IBM offers either one-year or three-year warranties for different variants within its xSeries 226 model. These variants are of similar quality and different prices. A regression of warranty durations of all 52 variants of this model on product attributes and prices (not shown) indicates that coefficients of all variables, except for price, are not significant, implying some randomness in the assignment of warranty duration. However, the price coefficient is positive and significant. This is consistent with the sorting theory prediction, whereby manufacturers use warranties as a mechanism for second-degree price discrimination by offering different warranty durations at different prices (after controlling for product attributes) and allowing consumers to self-select into their preferred price/warranty level (Matthews and Moore 1987). Customers are heterogeneous in their risk preferences; some customers are more risk averse and prefer to pay a premium for longer warranties. Because manufacturers cannot distinguish customers by their risk aversion, the best they can do is to offer different warranties and let customers self-select into different contracts. Given the service nature of warranties and the difficulty of arbitrage, this second-degree price discrimination might be more effective.

If the sorting role of warranties is effective, in equilibrium, we should observe different consumers choosing different warranty contracts in accordance with their risk profiles. Table 8 shows this behavior. On average, smaller firms tend to buy longer warranties, but firms of the same size tend to buy different warranty contracts. For example, small firms bought 24.67% IBM servers with 12-month warranties and 75.33% with 36-month warranties; very large firms bought 46.68% IBM servers with 12-month warranties and 53.32% servers with 36-month warranties. Firms of the same size apparently have different degrees of risk aversion, which is not observable to sellers. Firm size is a proxy for risk preference but not a perfect measure. This means that manufacturers cannot price discriminate their warranty contracts on the basis of firm size (third-degree price discrimination). To screen among these buyers more efficiently and extract more consumer surplus, manufacturers offer products that are differentiated along warranty duration and price and let buyers self-select into different contracts. This is the essence of second-degree price discrimination in warranty provision.

Signaling theory. We now examine the quality-signaling role of warranties in the server market. In the theoretical literature, signaling occurs at the firm level because the unit of analysis is the individual firm. It is not economically rational for manufacturers to use different warranty terms to signal different product qualities because, in the server market, corporate brands (e.g., HP, Dell) dominate brand evaluations. Poor quality of any specific brand (e.g., HP ProLiant) may tarnish the corporate brand and hurt overall sales. Given that different manufacturers offer similar warranty durations in this market, the signaling role of warranties should be limited. Moreover, because some manufacturers offer different warranty durations for the same model, signaling the product's quality does not seem to be the main consideration.

Furthermore, signaling is often used by firms whose product quality is not known to consumers (i.e., in markets with information asymmetry). Given that major players in the server market are all well-established firms whose product quality and reputation are well known to buyers through word of mouth, repeat purchase, or public or private information sources, the signaling role of warranties would be further limited. Nevertheless, we formally validate the predictions of the signaling role for warranties in the server market.

The signaling literature defines quality as reliability, durability, or nonbreakdown performance. Although we do not have direct measures of actual reliability information for each server model, we are able to obtain corporate buyers' perceived hardware quality of x86 servers, which are similar to desktops in technology. According to *CR* (www.consumerreports.org), perceived reliability and actual reliability of desktops are highly correlated; therefore, we assume that they are also highly correlated for x86 servers. Thus, manufacturers' use of perceived product quality should produce similar results to those using actual quality.

TABLE 8
Server Sales Distribution (%) by Server Warranty Duration and Buyer Size

	IBM		HP		Dell	
	12-Month Warranty	36-Month Warranty	12-Month Warranty	36-Month Warranty	12-Month Warranty	36-Month Warranty
Small offices	22.89	77.11	10.30	89.70	31.72	68.28
Small firms	24.67	75.33	15.88	84.12	33.95	66.05
Midsize firms	29.51	70.49	16.20	83.80	40.01	59.99
Large firms	37.50	62.50	17.13	82.87	43.19	56.81
Very large firms	46.68	53.32	20.51	79.49	46.05	53.95
Total	35.80	64.20	17.19	82.81	40.21	59.79

To check whether warranties have any information content about product quality, we regress corporate customers' perceived hardware quality on warranty, advertising, wholesale price, product attributes, and time dummies for HP, IBM, and Dell (see Table 9). The coefficient on warranty is not statistically different from zero. A statement will be false if its contrapositive is false; therefore, we conclude that in the server market, warranties do not signal quality.

Researchers have proposed several theories on quality signaling, including the signaling value of price (Desai and Srinivasan 1995; Srinivasan 1991), brand name (Png and Reitman 1995; Wernerfelt 1988), and money-back guarantee (Moorthy and Srinivasan 1995). We show that warranties in the server market do not play a signaling role. There are two possible reasons for this. First, consumers may have better quality signals than warranties and do not need warranties to signal quality. Laboratory experiments have shown that in the presence of multiple cues of product quality, the diagnosticity of some cue types depends on the valence of other cue types in the environment (Purohit and Srivastava 2001). The regression shows that price, manufacturer reputation, and brand names are good signals of quality, which is consistent with Png and Reitman's (1995), Srinivasan's (1991), and Wernerfelt's (1988) theoretical predictions.

Second, the precondition for signaling is information asymmetry and buyers being unaware of product quality. This precondition may not exist in the server market, in which buyers can obtain quality information from various sources, including repeat purchase, word of mouth, and private information providers. Server buyers are various institutions that frequently upgrade their machines and therefore can learn a firm's product quality through repeat purchase. Private information providers often publish their research results, and many institutions subscribe to their services and therefore are well informed of product quality. This means that server customers may not need to infer quality from warranties.

TABLE 9
Regression of Perceived Server Quality on Warranty and Product Attributes

	Estimate	SE	t-Statistic
Warranty	–.000	.000	–.853
Price (millions of dollars)	.233	.096	2.420
Advertising (millions of dollars)	4.290	.537	7.988
HP	6.167	.009	704.790
IBM	6.022	.014	418.800
Dell	6.230	.008	817.627
CPU1	–.004	.004	–1.043
CPU2	.001	.004	.220
CPU3	–.003	.010	–.266
CPU4	–.007	.006	–1.180
2Q2002	–.037	.006	–5.777
3Q2002	–.048	.006	–7.660
4Q2002	–.052	.007	–7.736
1Q2003	–.012	.007	–1.744
2Q2003	.105	.007	15.034
3Q2003	.067	.007	9.361
4Q2003	.037	.007	4.961
1Q2004	.004	.007	.603
2Q2004	–.104	.007	–14.084
3Q2004	–.056	.007	–7.828
4Q2004	–.126	.007	–17.041
Number of observations	2110		
R^2	.807		

Notes: Coefficient estimates of specific brands are dropped for space reasons.

According to Balachander (2001), new firms may use warranties to signal product quality. We checked whether manufacturers changed their warranty policies over time. Because IBM and HP are well established in the server market (and did not change their server warranty policies during the data period), we focus on Dell. Dell entered the server market in 1996 and was a relatively newer player than IBM and HP. The theory predicts that Dell would offer longer warranties in the beginning and shorten its warranties over time when its products improved. However, Dell offered one- and three-year base warranties for its servers on entry, the same warranty policy that is in effect today. Dell did not change its warranties as its product quality improved. This lends further support to our conclusion that warranties are not used to signal product quality in the server market. Our finding is consistent with the findings of Agrawal, Richardson, and Grimm (1996), Chu and Chintagunta (2009), Gerner and Bryant (1981), and Priest (1981).

Incentive theory. We focus on the manufacturer's incentive problem. We investigate how warranties affect manufacturers' incentives to reveal product quality to consumers and improve product quality. Regardless of whether the intrinsic product quality and consumers' maintenance effort are positively or negatively correlated, if the incentive motivation exists, the perceived product quality and warranties will be negatively correlated (Lutz 1989), which clearly is not the case (see Table 9). Furthermore, we would expect firms with longer warranties to invest more in product quality improvement, which would reduce future warranty compensation and increases profits, which in turn would result in more reliable products in the future (Heal 1977; Priest 1981). Therefore, product reliability should be positively correlated with *past* warranties.

To check whether these relationships hold, we first compute sales-weighted warranties for HP, IBM, and Dell and then compute the correlations between perceived product quality and current and lagged warranty durations (see Table 10). Product quality does not seem to be correlated with warranties, either current or past. A statement will be false if its contrapositive is false; therefore, we conclude that in the server market, warranties do not play an incentive role. This is not surprising, because server reliability is primarily determined by the reliability of its components, over which manufacturers have little control. Different manufacturers may source components from the same suppliers. IBM, HP, and Dell all buy chips from Intel or Advanced Micro Devices. In addition, competition in the server market may force manufacturers to offer the most reliable products that current technology allows. In summary, we find empirical support for the insurance and sort-

TABLE 10
Correlations Between Server Quality and Current and Past Warranties

	IBM		HP		Dell	
	Coefficient	Prob > |r|	Coefficient	Prob > |r|	Coefficient	Prob > |r|
Current warranty	–.096	.767	.102	.752	–.423	.171
1 Quarter lag	.068	.834	–.306	.333	–.357	.255
2 Quarter lag	.343	.275	–.411	.184	–.027	.934
3 Quarter lag	.361	.249	–.073	.821	.468	.125
4 Quarter lag	.290	.360	–.193	.549	.763	.084
5 Quarter lag	–.122	.705	–.148	.646	.523	.181
6 Quarter lag	–.195	.544	.224	.483	.304	.337
7 Quarter lag	–.597	.041	.405	.191	.289	.362

Notes: Warranty durations are sales-weighted averages, which vary over time because of changes in product mix.

ing roles of warranties in the server market but not for the signaling and incentive roles of warranties.

Test in the Automobile Market

Insurance theory. We first check whether the two assumptions for the insurance theory are met in the automobile market. First, similar to the server market, we find indirect evidence of consumers' risk aversion through their purchases of extended automobile warranties. Automobile extended warranties are a lucrative business. According to *Warranty Week* (2005a), the market for extended warranties topped $15 billion in 2004 with automobiles and personal computers, accounting for the largest proportion of revenue. Top companies of automobile extended warranties include Mogi, Warranty Direct, CARCHEX, StopRepairBills.com, U.S. Fidelis, U.S. Direct, Auto Protection, Fidelity Automotive, Endurance Protection, and Auto Service Warranty. Second, *CR* shows that the mean predicted reliability of new cars is 3 on a five-point scale, indicating that product quality is far from perfect. The popularity of automobile extended warranties and the reliability score of new cars indicate the nonzero failure rates of automobiles.

The insurance theory predicts that the degree of consumer risk aversion is positively correlated with the duration of warranties purchased. We use household demographics, such as age, income, gender, marital status, and number of children, as proxies for household risk attitudes. Dohmen et al. (2005) find a concave relationship between age and risk attitude and a convex relationship between income and risk attitude. This implies a convex relationship between age and warranty duration and a concave relationship between income and warranty duration. Jaeger et al. (2007) find that married people and people with young children are more risk averse, which implies that they will buy longer warranties. Fellner and Maciejovsky (2007) and Rosen, Tsai, and Downs (2003) find that women are more risk averse than men, which implies that women will buy longer warranties.

To check whether this is the case, we regress household automobile warranty duration on household demographics and automobile characteristics (see Table 11). The results are consistent with our expectations. Warranty duration and age of the household head have a convex relationship. Automobile warranty duration first decreases and then increases with age. As people get older, they become more risk averse and buy longer warranties. Warranty duration and household income have a concave relationship. Warranty duration first rises and then decreases with income. This is the joint effect of affordability and risk aversion. Low-income households are more risk averse, but they may not be able to afford longer warranties. High-income households are less risk averse and thus do not need to buy longer warranties. Married people buy longer warranties, as do people with more dependent children. In general, women buy longer warranties than men. Together, the findings are consistent with the insurance role of warranties.

Sorting theory. We check whether the key assumption underlying the sorting theory (i.e., consumers are heterogeneous) holds in the automobile market. Automobile buyers are individuals and households that differ substantially in household size and composition, education, income, age, gender, family life cycle, employment, marital status, quality preference, and many other attributes. All these are closely related to risk preferences, as Table 11 shows. The sorting theory posits that manufacturers should offer a menu of warranties, which is evident in Table 6. Toyota, Honda, Ford, General Motors, and Nissan offer a menu of warranties for their car models, and these five automakers accounted for 70.78% market share in 2008.

The sorting theory also predicts that, in equilibrium, households with the same observable characteristics will buy different automobile warranties. This is evident in the consumer expenditure data. We use household income to illustrate this. Table 12 shows the distribution of powertrain warranty ownership across different income groups. Consistent with the insurance theory, higher-income households tend to buy shorter warranties because of their lower level of risk aversion. However, households of the same income levels also buy different warranties. Income can be a proxy for household risk preference, but it is not a perfect measure. Manufacturers cannot price-discriminate their warranty policies solely on the basis of household income. To extract more consumer surplus, they choose to offer a menu of warranties and let households self-select into different warranty contracts in accordance with their risk preference. This is the essence of second-degree price discrimination through warranty contracts.

TABLE 11
Regression of Automobile Warranty Duration on Household Characteristics

	DV: Basic Warranty Years		DV: Basic Warranty Miles		DV: Powertrain Warranty Years		DV: Powertrain Warranty Miles	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	5.028	.050	67.068	.685	5.730	.079	71.427	1.382
Income	.091	.028	1.286	.384	.028	.044	.516	.775
Income^2	–.017	.010	–.275	.132	–.010	.015	–.027	.267
Family size	–.012	.003	–.166	.041	–.013	.005	–.275	.082
Children <18	.010	.004	.139	.050	.014	.006	.215	.102
Age	–.054	.008	–.779	.111	–.010	.013	–.277	.225
Age^2	.007	.001	.096	.010	.002	.001	.020	.021
Married	.013	.005	.162	.072	.017	.008	.163	.145
Female	.010	.004	.159	.056	.013	.006	.170	.112
White	.011	.006	.175	.082	.012	.009	–.091	.165
Overall MPG	–.040	.001	–.658	.019	–.033	.002	–.367	.039
Engine size	–.237	.006	–3.659	.076	–.217	.009	–2.804	.154
Horsepower/100	–.046	.008	–.759	.113	.014	.013	.344	.229
Test car price	.028	.000	.421	.007	.025	.001	.187	.013
Manufacturer1	–1.193	.035	–17.865	.473	–2.122	.055	–17.410	.954
Manufacturer2	–.223	.024	–3.193	.332	–1.230	.038	–11.035	.669
Manufacturer3	–1.096	.017	–15.513	.228	.080	.026	34.385	.460
Manufacturer4	–.919	.017	–13.058	.233	–.011	.027	1.783	.470
Manufacturer5	–.952	.017	–13.353	.235	–.142	.027	39.457	.475
Manufacturer6	–.666	.022	–8.466	.306	.280	.035	3.321	.618
Manufacturer7	1.090	.019	11.454	.265	5.075	.031	40.889	.534
Manufacturer8	–.315	.055	–4.431	.750	–1.359	.087	–10.201	1.513
Manufacturer9	1.036	.022	10.532	.296	5.026	.034	39.961	.598
Manufacturer10	–.686	.107	–10.281	1.462	–.759	.169	–4.259	2.949
Manufacturer11	–.971	.022	–13.528	.294	.010	.034	.159	.593
Manufacturer12	–1.297	.033	–19.231	.453	–2.209	.052	–16.504	.914
Manufacturer13	–1.598	.025	–23.188	.345	–.488	.040	–4.043	.696
Manufacturer14	–.775	.018	–9.580	.243	.194	.028	2.075	.491
Manufacturer15	–1.515	.062	–22.529	.850	–2.433	.098	–19.931	1.714
Manufacturer16	–.337	.072	–5.031	.989	–.338	.114	37.410	1.996
Manufacturer17	–.959	.022	–13.369	.304	.023	.035	.550	.613
Manufacturer18	–1.012	.033	–14.303	.456	–.941	.053	–7.014	.921
Manufacturer19	–.963	.017	–13.388	.228	.026	.026	.840	.460
N	13,744		13,744		13,744		13,744	
R^2	.811		.790		.898		.896	

Notes: DV = dependent variable.

TABLE 12
Percentage of Households Buying Different Powertrain Warranty Years by Household Income Level

Income Group	3 Years	4 Years	5 Years	6 Years	7 Years	10 Years
<20th percentile	.99	1.98	84.16	1.98	2.97	7.92
30th percentile	.45	1.34	84.82	3.13	3.13	7.14
40th percentile	.34	.34	85.91	2.41	4.12	6.87
50th percentile	1.70	.24	84.67	4.01	2.55	6.81
60th percentile	1.79	.64	86.30	3.59	1.41	6.27
70th percentile	.68	.79	88.14	2.26	3.05	5.08
80th percentile	1.48	.68	87.98	2.28	1.99	5.58
90th percentile	1.23	3.86	83.16	5.40	1.70	4.65

Signaling theory. We first check whether there is information asymmetry in the automobile market and whether other quality signals are available. Automobile manufacturers may have better knowledge about product quality than buyers, but buyers have a variety of sources to obtain information on product quality. One important source is Consumer Reports National Research Center, the publisher of *CR*. The center conducts annual surveys on product reliability and service quality among *CR* subscribers and provides owner satisfaction and reliability information for hundreds of automobiles based on responses from hundreds of thousands of car owners for the sole purpose of informing and protecting. Consumers can also obtain quality information through repeat purchases, word of mouth, and online search. Thus, information asymmetry in the automobile market may not be serious. Furthermore, consumers may

use other cues, such as manufacturer reputation and brand, to infer product quality and thus do not need to rely on warranties for quality information.

To test whether manufacturer base warranties have any information content in the automobile market, we run two sets of regressions of automobile quality indicators (overall quality score and accident avoidance score) on warranty duration (years or mileage), product price, and major product attributes. One set of regressions includes manufacturer dummies as regressors, and the other set does not. The results appear in the upper and middle panels of Table 13. When we do not account for automobile manufacturer fixed effects, the powertrain warranty years are positively correlated with the overall car quality score, indicating some quality signaling effect of warranties. However, when we account for manufacturer fixed effects, regardless of which warranty measures or quality indicators we use, the warranty coefficient is not statistically different from zero. This implies that warranties have little information content or that their quality signal is weak. When other quality signals (i.e., manufacturer reputation reflected in the fixed effect) are present, warranty durations are no longer diagnostic of product quality.[7]

Incentive theory. The insignificant warranty coefficient in the preceding analysis also implies that automobile warranties do not play an incentive role for manufacturers to reveal product quality to consumers. We now examine how automobile manufacturers' warranty policies affect their incentives to improve product quality. If warranties work as an incentive mechanism for quality improvement, manufacturers of longer warranties should invest more to improve new product quality because this will reduce future warranty costs and increase firm profits. Thus, we would expect new product reliability and warranty duration to be positively correlated.

We regress the predicted reliability of new vehicles on warranty, product attributes, price, and/or manufacturer dummies. The results appear in the lower panel of Table 13. If we do not account for manufacturer fixed effects, of the four warranty measures, only the year of powertrain warranty is positively correlated with the predicted reliability of new vehicles. However, after we account for manufacturer fixed effects, the predicted reliability of new vehicles is not correlated with any warranty measures. Therefore, we conclude that there is no evidence to support the incentive theory of warranties in the automobile market. A reason for the nonexistence of the incentive role of warranties might be the fierce competition in the automobile market, which forces manufacturers to provide the most reliable products. In summary, in the automobile market, we also find empirical support for the insurance and sorting roles of warranties but not for the signaling and incentive roles.

[7]This might seem to contradict articles in the popular press that talk about Hyundai and Ford signaling quality through warranties. However, we estimate an "average" effect across cars that suggests that there is no signaling effect.

Conclusion and Implications

In this article, we assess four competing theories on the economic roles of warranties in the U.S. computer server and automobile markets. We combine data on product warranties with data on product quality, prices, and other attributes to accomplish the task. We find that warranties in these two markets primarily provide customers with insurance against product failure and work as a sorting mechanism for second-degree price discrimination. They are not used to signal product quality or to provide incentives for manufacturers to reveal or improve product quality.

To our knowledge, this is the first empirical study to examine systematically the different theories on warranties. Thus, it fills the void in the warranty literature on the roles of warranties in actual markets. Furthermore, this study assesses the four theories of warranties in both business-to-business and business-to-consumer markets. Given the abundance of theories and the scarcity of empirical work in the warranty literature, this study should help inform the validity of different theories and their applications to actual markets.

Because the primary value buyers want from base warranties is the insurance they provide when the product fails, one managerial implication of this finding is that when manufacturers and resellers/dealers promote computer servers and automobiles to buyers, they should focus more on the insurance value the warranties provide. They can creatively design promotions to emphasize warranty and insurance, and some manufacturers (e.g., Dell) already realize this and act on it. Many other sellers may benefit from focusing on the insurance value of base warranties.

Manufacturers also provide computer server and automobile basic warranties as a means for second-degree price discrimination. Buyers of servers include various institutions that have vastly different risk profiles, but most manufacturers provide only one- or three-year warranties. Thus, manufacturers should consider offering more warranty options for buyers to choose from. For example, they could offer a menu of warranties with three-month, six-month, one-year, two-year, or three-year options to cater to customers' risk profiles more effectively. Similarly, automobile manufacturers could enlarge their menus of warranties offered to consumers. Manufacturers that currently offer uniform warranties might consider offering a menu of warranties to extract more consumer surplus. The service nature of warranties makes it a more effective price discrimination mechanism. In markets in which retailers and sellers are the primary sellers of extended warranties, designing product lines on the basis of warranty duration and price may be an effective strategy for manufacturers to capture some of the profits from lucrative extended warranty sales.

When manufacturer name and advertising are present, base warranties contain limited quality information to consumers. Therefore, manufacturers should focus more on manufacturer reputation and advertising as quality signals and deemphasize the signaling role of warranties. In turn, buyers should look for quality information from manufacturer branding and advertising efforts rather than warranty durations.

TABLE 13
Regression of Automobile Quality on Warranty and Product Attributes

	Car Warranty Years				Car Warranty Mileage				Powertrain Warranty Year				Powertrain Warranty Mileage			
	No Automaker Dummy		With Automaker Dummy		No Automaker Dummy		With Automaker Dummy		No Automaker Dummy		With Automaker Dummy		No Automaker Dummy		With Automaker Dummy	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Dependent Variable: Overall Score																
Intercept	48.262	6.291	61.425	7.222	47.682	6.197	59.494	6.854	46.199	6.179	49.726	13.701	70.642	6.466	47.738	16.010
Warranty	1.171	.836	–.559	1.512	.110	.067	.006	.108	.765	.364	1.989	2.491	–.146	.033	.199	.249
Overall MPG	.363	.159	.342	.154	.367	.159	.348	.154	.398	.160	.360	.154	.120	.162	.360	.154
Engine liter	–6.273	1.082	–3.390	1.045	–6.207	1.084	–3.309	1.047	–6.545	1.074	–3.206	1.038	–5.376	1.080	–3.206	1.038
Horse power	.089	.016	.065	.014	.089	.016	.065	.014	.092	.016	.065	.014	.077	.016	.065	.014
Price ($1,000)	.235	.066	.270	.067	.229	.067	.260	.067	.275	.066	.247	.065	.176	.066	.247	.066
N	424		424		424		424		424		424		424		424	
R^2	.189		.485		.190		.485		.194		.485		.222		.486	
Dependent Variable: Accident Avoidance																
Intercept	2.050	.531	2.223	.744	2.042	.524	2.181	.706	2.171	.524	1.564	1.411	2.372	.558	1.396	1.649
Warranty	.078	.071	.060	.156	.007	.006	.006	.011	.022	.031	.167	.257	.000	.003	.017	.026
Overall MPG	.053	.013	.062	.016	.053	.013	.063	.016	.053	.014	.063	.016	.051	.014	.063	.016
Engine liter	–.121	.091	–.069	.108	–.118	.092	–.065	.108	–.135	.091	–.067	.107	–.132	.093	–.067	.107
Horse power	.003	.001	.002	.001	.003	.001	.002	.001	.003	.001	.002	.001	.003	.001	.002	.001
Price ($1,000)	–.006	.006	–.001	.007	–.006	.006	–.002	.007	–.004	.006	–.002	.007	–.004	.006	–.002	.007
N	424		424		424		424		424		424		424		424	
R^2	.077		.128		.078		.128		.076		.129		.075		.129	
Dependent Variable: Predicted Reliability of New Cars																
Intercept	1.286	.674	1.317	.854	1.326	.662	1.119	.810	.753	.677	.926	1.595	1.705	.717	.085	1.870
Warranty	.103	.095	–.010	.186	.008	.007	.005	.013	.107	.043	.076	.300	.000	.004	.008	.030
Overall MPG	.068	.017	.085	.019	.068	.017	.086	.019	.074	.017	.086	.019	.066	.017	.086	.019
Engine liter	.323	.120	.370	.138	.326	.121	.387	.138	.295	.119	.379	.136	.308	.122	.379	.136
HP	–.003	.002	–.003	.002	–.003	.002	–.003	.002	–.003	.002	–.003	.002	–.003	.002	–.003	.002
Price ($1,000)	–.003	.008	–.001	.010	–.004	.008	–.003	.010	.001	.008	–.002	.010	–.002	.008	–.002	.010
N	350		350		350		350		350		350		350		350	
R^2	.078		.209		.077		.209		.091		.209		.074		.209	

Notes: Automaker fixed effects are not reported for space reasons.

A direction for further research is to assess these theories in other markets in other countries to determine whether the conclusions hold. Markets differ substantially in their degree of information asymmetry, availability of other quality cues, and consumer risk aversion and moral hazard. It is likely that warranties assume different roles in different markets, and thus more assessment in different markets should help inform these theories. However, we note that the data collection effort required for any given product market is substantial.

Manufacturers provide both base warranties and extended warranties. Soberman (2003) analyzes a situation in which a seller uses base and extended warranties to signal and screen simultaneously. We focus on manufacturer base warranties. An important question is how base warranties and extended warranties interact with each other and how manufacturers assign their resources across these two markets. We do not have data on extended warranties, and thus we do not explore the insurance and sorting roles of extended warranties. We hope to conduct further research in this area.

We used aggregate server sales data to different institutions and firms of different sizes to test the different warranty theories. Because of the aggregate nature of the data, we were not able to find other proxies for risk aversion. Future work could try to obtain firm-level warranty purchase data and firm characteristics and examine their relationships.

In summary, we examine four theories on the economic rationales of warranty provision in the U.S. computer server and automobile markets. In both markets, we find support for the insurance and sorting roles of warranties but do not find support for the signaling and incentive roles.

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