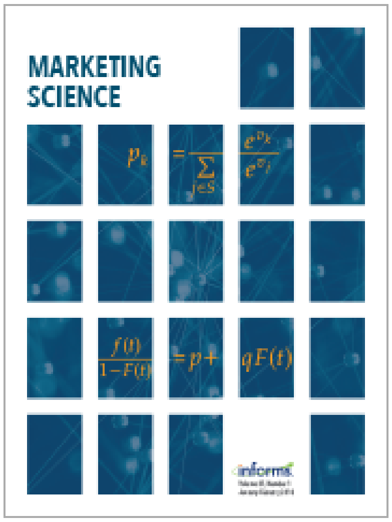

Marketing Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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MARKETING SCIENCE
Vol. 28, No. 1, January–February 2009, pp. 99–121
ISSN 0732-2399 | EISSN 1526-548X | 09 | 2801 | 0099

DOI 10.1287/mksc.1080.0380

Quantifying the Economic Value of Warranties in the U.S. Server Market

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We quantify the economic value of hardware base warranties in the U.S. server market to manufacturers, channel intermediaries, and customers. We further decompose the value of a warranty into its insurance value and its price discrimination value, which are the two main rationales for warranty provision in the server market. We use structural modeling and counterfactual experiments to accomplish the empirical task. We derive our demand model from utility maximization, which accounts for a customer's risk aversion behavior and heterogeneity. We obtain our pricing model from the profit maximization behavior of manufacturers and downstream firms in indirect channels, accounting for the institutional realities in the server market. Our empirical analysis uses quarterly data from 1999 to 2004 on server wholesale prices, retail prices, and sales for direct and indirect channels in the U.S. market. We find that manufacturers and downstream firms benefit from warranty provision and from sorting across heterogeneous customers by offering a menu of warranties. Customers also benefit from manufacturer warranty provision as well as from the menu of warranties offered. The insurance value of warranties increases and the price discrimination value of warranties decreases with warranty duration.

Key words: server market; warranty; insurance; sorting; price discrimination; structural modeling
History: Received: March 30, 2007; accepted: January 15, 2008; processed by Wagner Kamakura. Published online in *Articles in Advance* December 4, 2008.

1. Introduction

Warranties are prevalent in many markets. In the U.S. server market, every piece of hardware is sold with some form of warranty. For example, in the product specification of Hewlett-Packard (HP) ProLiant ML 150 servers on HP's website, along with processor, memory, and hard drive is a warranty that "includes 1 year parts, 1 year labor, 1 year on-site support." Thus, a server's warranty is an essential product attribute in this market and plays an important role in buyers' and sellers' decision making.

There are two types of hardware warranties: base warranties and extended warranties. The key difference between these two is that base warranties are bundled with the product and cannot be purchased separately, and extended warranties are optional and can be purchased at an additional cost. For example, under the "recommended supplies and accessories" for HP ProLiant ML 150 servers are "hardware service, support and upgrades" that include many extended warranty options such as "4 years, 4 hours, 13×5, hardware support [add $434.00]," and "4 years, 4 hours, 24×7, hardware support [add $690.00]."

In this paper we focus only on hardware base warranties. Base warranties in the server market cover the costs of labor and parts (repair and replacement) when a server breaks down during the warranty period and services are provided on site, on the next business day during normal business hours.

Laboratory experiments have shown the value of warranties in decision making under risk and uncertainty (Shimp and Bearden 1982). Buyers implicitly or explicitly pay for warranties, and sellers have to incur costs to provide warranties. Therefore, buyers may be interested to know the trade-offs between warranty durations and prices, and sellers may want to know whether warranties generate enough demand to cover the costs of warranty provision. This requires determining the value of warranties to both buyers and sellers. *The first objective of this paper is to quantify the economic value of base warranties to manufacturers, channel intermediaries, and customers in the U.S. server market*. Although base warranties are characterized by several attributes such as service response time, warranty duration, etc., the variation across server models is in the duration of the warranty. Hence, quantifying the value of a base warranty is equivalent to quantifying the value of the warranty's duration.

Warranties in general have four economic roles—insurance, sorting, signaling, and incentive (see Emons

1989b for a review of the theories on the economic rationales for warranty provision): (i) They can provide insurance to customers and work as a risk-sharing mechanism (Heal 1976a, b). The key assumption of insurance theory is that consumers are risk averse. (ii) Warranties can be a sorting or screening mechanism and work as a means for second-degree price discrimination (Kubo 1986, Matthews and Moore 1987). The key assumption of sorting theory is consumer heterogeneity in some unobserved (to sellers) attributes such as income, quality valuation, and risk aversion. (iii) Warranties can work as a signal of product quality to customers (Spence 1977, Courville and Hausman 1979, Grossman 1981, Gal-Or 1989, Lutz 1989). The key assumption of signaling theory is information asymmetry in the sense that sellers have better information about product quality than buyers do (Akerlof 1970). (iv) Warranties can work as a commitment mechanism, providing an incentive for sellers to reveal product quality to customers and to improve product quality, or at least not to cheat on product quality (Cooper and Ross 1985; Dybvig and Lutz 1993; Emons 1988, 1989a; Lutz 1989; Mann and Wissink 1990). The key assumption of incentive theory is risk endogeneity, in the sense that both buyers' and sellers' actions can affect the probability of product failure.

The insurance role of warranties will always exist as long as (1) buyers are risk averse and (2) there is a nonzero probability of product failure. Both conditions hold in the U.S. server market; therefore, we would expect warranties to play an insurance role in this market. Further, buyers of servers are various institutions that differ substantially in size, revenue, usage, technical capability, quality valuation, and risk aversion. Manufacturers offer a menu of warranty durations for their servers. Therefore, we would expect warranties to play a sorting role among heterogeneous buyers. In other words, economic roles (i) and (ii) described in the previous paragraph are applicable to the U.S. server market.

Because different manufacturers offer similar warranty durations for their server products, the quality information content of warranties is likely to be limited. For example, Dell, IBM, and HP all offer one-year or three-year base warranties for their products, and these warranties have similar coverage. Thus it is difficult for buyers to infer the quality of servers from warranty duration. The incentive role of warranties is closely related to the signaling role. Major manufacturers do not change their server warranty policies over time as their product quality improves, so the incentive role of warranties in the server market should be limited. Further, although not reported here, we also find that perceived server quality is not correlated with warranty duration, indicating that warranties do not appear to contain information on product quality (Chu and Chintagunta 2008). In other words, economic roles (iii) and (iv) of warranties described above do not appear to be critical drivers of warranty provision in the U.S. server market.

In sum, there are two main rationales for warranty provision in the server market. One is to provide insurance to customers, and the other is to sort among heterogeneous customers. Therefore, *the second objective of this paper is to decompose the value of a warranty into its insurance value and its sorting value*. This implies that our empirical model needs to incorporate (1) consumer risk aversion, a feature required by the insurance rationale, and (2) consumer heterogeneity, an assumption required by the sorting rationale.

There are three features of base warranties in the U.S. server market: (1) all servers are sold with a warranty of nonzero duration, (2) all major manufacturers offer nonuniform warranties for their products, and (3) a given server model is usually associated with a single warranty duration. A hedonic regression with warranty duration as one regressor can tell how price changes with warranty duration. However, to quantify the value of warranties to firms, we also need to know the impact of warranties on demand and how warranty costs change with warranty duration. Neither of these relationships can be obtained from a hedonic regression.[1]

Further, the value of warranties to customers is likely to be different from the price of warranties, as customers may or may not derive some surplus from warranty provision. Moreover, the price of base warranties is *not* observable to customers. We therefore use structural modeling and counterfactual experiments to compute these quantities of interest. Our structural model consists of a demand model and a pricing model. The demand model is derived from customers' utility maximization behavior. This model has two features: (1) It accounts for customer risk aversion to accommodate the insurance role of warranties, and (2) it incorporates customer heterogeneity to allow for the price discrimination role of warranties. Deriving the pricing model for the firms in this market is a nontrivial task. The server market is characterized by manufacturers selling both directly to end users and indirectly through intermediaries. Some of the intermediaries are exclusive and some are nonexclusive. Further, these intermediaries compete both among themselves and with manufacturers that sell directly to some of their customers. Our pricing model tries to account for these institutional realities.

[1] To get a feel for the difficulty in estimating warranty costs, please see the Securities and Exchange Commission's formal probe of Dell's accounting practice "relating to accruals, reserves and other balance-sheet items" (Lawton 2006, Johnson 2006).

Table 1 **Summary Statistics of Server Manufacturers in the U.S. Market**

Manufacturer	No. of observations	No. of brands	No. of models	No. of CPU types	No. of channels	Warranty durations
HP/Compaq	1,055	6	49	13	2	1 year, 3 years
IBM	699	5	38	11	2	1 year, 3 years
Dell	476	1	18	9	3	1 year, 3 years
Sun	117	3	8	5	2	3 months, 1 year, 3 years
Others*	2,754	29	187	20	5	3 months, 1 year, 3 years
Total	5,101	44	300	25	5	3 months, 1 year, 3 years

*Includes AST, Acer, Apple, Concurrent, Data General, Fujitsu/Fujitsu-Siemens, Gateway, Intergraph, MPC, NCR, Olivetti, Premio, SGI, Sequent Computer System, Stratus, Systemax, Toshiba, Unisys, Verari Systems, other branded manufacturers, and white-box server manufacturers.

The contributions of this paper are primarily empirical and substantive in nature. We find that manufacturers and downstream firms benefit greatly from warranty provision. In particular, we find that if all manufacturers offered three-month warranties (the shortest warranty duration observed in the data), total manufacturer and retail profits in 1999–2004 would respectively be 82.8% and 81.1% of the current levels. Manufacturers and downstream firms also benefit from price discrimination by offering a menu of warranties. If all manufacturers offered two-year uniform warranties for all their products, their 1999–2004 profits would respectively be 86.3% and 87.1% of the current levels, which is about $168 less per server to manufacturers and $163 less per server to downstream firms.

Customers also benefit from manufacturer warranty provision as well as from the menu of warranties offered. Customers would require a total compensation of $5.972 billion or $498 per server if all manufacturers offered uniform three-month warranties. They would require $1.633 billion total compensation or $136 per server if two-year uniform warranties were provided for all servers. The sorting value of warranties decreases while the insurance value increases with warranty length. Customers would be willing to pay an extra $665 million in total, or $55 per server, in addition to the implicit price they already pay, if all manufacturers offered three-year uniform warranties for all servers. Compared against the three-month warranty scheme, the total insurance value for customers is $1.970 billion under one-year uniform warranties and $6.637 billion under three-year uniform warranties. We are also able to compute warranty elasticities across manufacturers and channels. Given the current warranty scheme, we find that a 1% increase in warranty duration will increase manufacturer shares by about 0.35%.

The rest of the paper proceeds as follows. We describe the data used for the empirical analysis in §2. We derive the econometric model in §3 and discuss estimation issues in §4. We report major results in §5 and conclude in §6 with a summary and directions for future research.

2. Data

We use quarterly data from 1999 to 2004 on server wholesale prices, retail prices, and sales in direct and indirect channels in the U.S. market for the empirical analysis. The data are provided by Gartner® and have information on server unit sales, manufacturer revenues, retail revenues, manufacturer, brand, processor or CPU, and warranty duration (in months) of computer servers. For x86-based servers, the information is at the manufacturer brand-model level (e.g., HP ProLiant DL100 servers); for non-x86 servers or high-end servers,[2] the information is at the manufacturer level. We obtain wholesale and retail prices by dividing manufacturer revenues and retail revenues by unit sales. The servers are produced by 26 manufacturers, including big players such as HP/Compaq, IBM, Dell, and Sun Microsystems as well as small players such as AST, Acer, Apple, Concurrent, Data General, Fujitsu/Fujitsu-Siemens, Gateway, MPC, Stratus, Systemax, Toshiba, and Unisys. Table 1 provides basic information on these manufacturers. There are 44 brands and 300 server models, which are jointly sold through five distribution channels—direct fax/phone/Web, direct sales force, indirect fax/phone/Web, local dealer, and value-added resellers (VARs). There are 25 CPU types for x86 servers and special processors for high-end servers. In total there are 5,101 observations, of which 93.9% are x86-based servers and 6.1% high-end servers.

2.1. Warranties in the U.S. Server Market

All manufacturers in the U.S. server market offer hardware base warranties ranging from three months to three years, with one year and three years the most commonly seen; all server models are

[2] Gartner® defines high-end servers as servers priced at $50,000 or more.

Table 2 **Sales-Weighted Wholesale Price, Warranty Duration (in Months), and Perceived Product Quality for x86-Based Servers**

	2002			2003			2004		
Manufacturer	Wholesale price	Warranty duration	Perceived reliability	Wholesale price	Warranty duration	Perceived reliability	Wholesale price	Warranty duration	Perceived reliability
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

Note. Ratings out of 7-point scale with 7 the highest quality; data provided by Technology Business Research Inc.

sold with some base warranties. Three-month, one-year, and three-year warranties account for, respectively, 4.21%, 38.25%, and 57.54% of data observations, 7.54%, 42.36%, and 50.40% of unit sales, and 1.64%, 70.66%, and 27.70% of manufacturer revenues. Warranties vary across manufacturers and across the different models from the same manufacturer. But for a given server model, warranties do not change over time. HP offers one-year or three-year uniform warranties for each model and varies warranty durations across models: the more advanced the model, the longer the warranty duration. IBM varies warranty durations primarily across models and offers longer warranties for more advanced models. Dell offers one-year warranties for base models and enhanced models and three-year warranties for advanced models. Sun has three-month, one-year, and three-year warranty options, offering longer warranties for low-priced and high-priced entry-level servers, but shorter warranties for medium-priced entry-level servers. Other manufacturers either offer uniform three-month, one-year, and three-year warranties for all machines, or vary warranty durations across x86 models. All manufacturers offer one-year hardware base warranties for high-end servers, which helps explain the low unit share but high revenue share of a one-year warranty.

In our data, we find that the higher the price, the longer the warranty. The sales-weighted average wholesale price of x86 servers is $4,471, and the average warranty duration is 25.0 months. However, servers in the first price quartile have an average 13-month warranty, those in the second price quartile have an average 25-month warranty, and those in the third and fourth quartiles have 33-month and 34-month warranties. In Table 2, we report sales-weighted wholesale price, warranty duration, and perceived product quality of x86 servers for 2002–2004 for HP, IBM, and Dell. Perceived product quality across these three firms is very much the same, and there does not seem to be much of a correlation between warranty duration and perceived product quality. For example, in 2004 IBM had the longest warranty but lowest perceived quality, and HP had a longer warranty than Dell but similar perceived product quality to Dell. Therefore, our focus on the insurance and sorting roles of warranties in the U.S. server market seems to be justified.

To more formally investigate the relationships between price, warranty, and product attributes, we run a separate hedonic regression of log wholesale and retail prices on warranty, manufacturer, brand, quarter, and CPU dummies for all servers as well as for x86 servers. The results for all servers are shown in Table 3. We find that price and warranty duration are positively correlated: across all servers, a 1% increase in warranty duration results in a 0.67% increase in price; for x86 servers (not reported), a 1% increase in warranty duration leads to a 0.68% increase in price.

2.2. Server Sales in the U.S. Market

Table 4 reports 1999–2004 annual (summed over quarters) unit sales and manufacturer revenues of all servers and of x86 servers sold in the U.S. market. The 2004 sales (2.83 million) more than doubled the 1999 level (1.27 million), but total revenues only increased from $17.7 billion to $19.1 billion, or by 7.91%. The x86 server market is the most dynamic part of the entire server market: total sales increased from 1.02 million to 2.62 million, up by 1.56 times, and total revenues doubled from $5.04 billion to $10.04 billion. Consequently, the unit shares of x86 servers increased from 80.5% to 88.5%, and the revenue shares increased from 37.9% to 42.3%.[3]

Our empirical analysis covers all server manufacturers in the U.S. market. We group manufacturers other than HP/Compaq,[4] IBM, Dell, and Sun into one composite manufacturer "Others" because individually each has a small market share. Table 5 shows manufacturers' market shares by units and by revenues. In the entire server market, in terms of unit

[3] To account for variations in sales levels over the years, as we describe later, we include year dummies in our model. We also allow the effects of these year dummies to differ across direct and indirect channels so as to accommodate the differential diffusion of servers across channel types.

[4] HP and Compaq merged in 2001. We accord special treatment to these firms. See §§3.1 and 3.2 for details.

Table 3 Hedonic Regression of Log Wholesale and Retail Prices on Product Attributes: All Servers

	Wholesale price		Retail price			Wholesale price		Retail price	
Independent variable	Estimate	Std. error	Estimate	Std. error		Estimate	Std. error	Estimate	Std. error
Log(warranty)	0.671	0.018	0.671	0.018	1Q1999	0.241	0.076	0.249	0.076
Compaq	9.265	0.160	9.263	0.160	2Q1999	0.217	0.072	0.225	0.072
Hewlett-Packard	9.029	0.117	9.026	0.117	3Q1999	0.180	0.070	0.179	0.070
IBM	9.640	0.126	9.617	0.126	4Q1999	0.287	0.071	0.287	0.071
Dell Inc.	8.721	0.120	8.721	0.120	1Q2000	0.294	0.071	0.294	0.071
Sun Microsystems	8.210	0.126	8.189	0.126	2Q2000	0.279	0.070	0.280	0.070
Gateway	8.488	0.130	8.490	0.130	3Q2000	0.237	0.068	0.238	0.068
Apple	6.028	0.283	6.026	0.283	4Q2000	0.188	0.068	0.188	0.068
Acer	8.325	0.133	8.324	0.133	1Q2001	0.216	0.067	0.217	0.067
Data General	9.778	0.131	9.777	0.131	2Q2001	0.186	0.066	0.187	0.066
NEC	11.189	0.126	11.182	0.126	3Q2001	0.224	0.067	0.225	0.067
MPC	8.925	0.145	8.924	0.145	4Q2001	0.205	0.068	0.205	0.068
NCR	12.368	0.141	12.368	0.141	1Q2002	0.177	0.066	0.177	0.066
Systemax	8.974	0.149	8.974	0.149	2Q2002	0.256	0.067	0.257	0.067
Toshiba	8.733	0.123	8.731	0.123	3Q2002	0.237	0.066	0.237	0.066
Unisys	10.902	0.135	10.901	0.135	4Q2002	0.188	0.064	0.188	0.064
Fujitsu/Siemens	9.137	0.187	9.137	0.187	1Q2003	0.269	0.063	0.269	0.063
AST Research	8.824	0.178	8.822	0.178	2Q2003	0.194	0.061	0.194	0.061
Concurrent	10.666	0.487	10.667	0.487	3Q2003	0.166	0.060	0.166	0.060
Intergraph	10.129	0.298	10.135	0.298	4Q2003	0.143	0.060	0.144	0.060
Olivetti	8.784	0.311	8.785	0.311	1Q2004	0.103	0.059	0.104	0.059
Premio Computer	9.425	0.151	9.422	0.151	2Q2004	0.069	0.059	0.070	0.059
SGI	9.415	0.182	9.419	0.182	3Q2004	0.077	0.059	0.077	0.059
Stratus	11.322	0.144	11.326	0.144	Direct sales force	0.012	0.053	0.011	0.053
Verari Systems	8.497	0.187	8.500	0.187	Indirect fax/phone/Web	0.096	0.112	0.229	0.112
Other branded	9.111	0.113	9.109	0.113	Local dealer	−0.002	0.173	0.142	0.173
Other unbranded	9.534	0.181	9.534	0.181	VARs	−0.018	0.056	0.126	0.056
P2	−2.969	0.097	−2.968	0.097	P3 Xeon	−2.124	0.089	−2.123	0.089
P3	−3.014	0.087	−3.013	0.087	Xeon/Xeon32	−2.450	0.090	−2.450	0.090
P4	−3.137	0.096	−3.137	0.096	PPC G3	−0.526	0.328	−0.525	0.328
PM/Celeron	−2.915	0.117	−2.916	0.117	PPC G4	−0.562	0.294	−0.561	0.294
PPro	−2.043	0.111	−2.042	0.111	Athlon	−2.823	0.145	−2.822	0.145
P2 Xeon	−1.748	0.118	−1.747	0.118	Opteron	−2.892	0.106	−2.892	0.106
No. of observations	5,101		5,101						
R^2	0.805		0.805						

Note. Brand coefficients are not reported for space reasons.

sales, HP is the largest player during 1999–2004, followed by Dell and IBM. In terms of revenues, IBM is the largest player, followed by HP and Sun. In the x86 server market, HP, Dell, and IBM are the top three players both in units and in revenues. Market shares changed dramatically over time, particularly in the x86 server market. From 1999 to 2004, Dell's unit shares increased from 23.4% to 29.7% and its revenue shares increased from 23.9% to 27.0%, while HP's unit shares dropped from 48.5% to 26.0% and its revenue shares slid from 42.1% to 31.7%. Dell surpassed HP in unit sales in 2002 and became the largest x86 server producer in the U.S. market, although its revenues still fell behind HP. IBM remained the number 3 player throughout. Sun entered the x86 server market in 2002 and has a low presence in this market, although it is the fourth-largest producer in the entire server market.

Table 4 Server Unit Sales and Manufacturer Revenues in the U.S. Market: 1999–2004

	All servers		x86 servers			
Year	Units (thousand)	Revenue (million$)	Units (thousand)	Revenue (million$)	Units share (%)	Revenue share (%)
1999	1,271	17,700	1,023	5,042	80.47	28.49
2000	1,882	21,798	1,600	9,328	85.01	42.79
2001	1,704	17,671	1,483	6,695	87.03	37.89
2002	1,944	17,142	1,736	7,202	89.29	42.01
2003	2,364	17,997	2,155	8,839	91.14	49.11
2004	2,829	19,103	2,615	10,040	92.45	52.56
Total	11,994	111,411	10,612	47,146	88.47	42.32

Note. Data provided by Gartner®, summed over quarters.

Of the five distribution channels for servers, direct sales force and direct fax/phone/Web are direct channels whereby manufacturers sell their products directly to end users, and indirect fax/phone/Web,

Table 5 Market Shares by Manufacturer: 1999–2004

	All servers					x86 servers				
Year	HP/Compaq	IBM	Dell	Sun	Others	HP/Compaq	IBM	Dell	Sun	Others
					By units					
1999	42.12	15.68	18.68	10.56	12.95	48.50	12.39	23.37		15.74
2000	32.72	12.76	18.67	7.39	28.46	35.45	9.92	21.79		32.85
2001	29.24	12.75	22.70	7.06	28.26	30.46	10.69	26.34		32.50
2002	26.67	11.94	24.88	6.67	29.83	27.83	10.48	28.14	0.04	33.51
2003	25.14	13.04	26.14	5.44	30.24	26.16	11.99	28.65	0.26	32.95
2004	25.26	11.98	27.08	5.73	29.95	26.02	11.06	29.70	0.54	32.68
Total	29.03	12.82	23.69	6.80	27.65	30.62	11.06	26.94	0.19	31.19
					By revenues					
1999	24.22	39.81	5.73	22.07	8.17	42.08	13.00	23.92		21.00
2000	26.12	33.53	9.39	16.59	14.37	32.84	10.69	25.30		31.18
2001	29.98	35.24	8.34	13.68	12.77	30.91	11.75	26.27		31.07
2002	30.10	32.61	9.91	14.09	13.28	32.07	13.49	26.58	0.03	27.83
2003	28.19	32.69	12.13	11.77	15.22	32.71	14.13	26.10	0.17	26.90
2004	30.19	29.52	12.83	12.41	15.05	31.66	14.16	27.00	0.61	26.57
Total	27.99	34.01	9.62	15.30	13.08	33.24	12.90	25.98	0.17	27.72

Table 6 Distribution of Unit Sales by Channel: 1999–2004

	All servers					x86 servers				
Manufacturer	Direct fax/ phone/Web	Direct sales force	Indirect fax/ phone/Web	Local dealer	VAR	Direct fax/ phone/Web	Direct sales force	Indirect fax/ phone/Web	Local dealer	VAR
HP		40.37			59.63		40.89			59.11
IBM		59.24			40.76		59.95			40.05
Dell	22.84	76.91			0.25	22.84	76.91			0.25
Sun		40.08			59.92		39.35			60.65
Others	0.53	77.62	0.02	0.05	21.78	0.54	77.86	0.02	0.05	21.54
All	5.56	61.73	0.01	0.01	32.69	6.32	64.23	0.01	0.01	29.43

local dealer, and VARs are indirect channels whereby manufacturers sell their products via intermediaries. Table 6 shows sales distribution across channels by manufacturers. HP and Sun use more of the VAR channel, and IBM depends more on its own sales force. In addition to its sales force, Dell also relies on direct fax/phone/Web to sell its products. Table 7 shows the evolution of shares across channels. The VAR channel saw its share decline from 47.6% in 1999 to 29.0% in 2004 for the entire server market, and the direct sales force channel gained from 52.4% to 62.6%. The direct fax/phone/Web channel entered in 2001 and steadily increased its share to 8.3%. Similar patterns are observed for x86 servers.

As we observe both wholesale and retail prices for those servers sold in the indirect channels, we can compute downstream markups. Downstream firms on average have a 15.6% markup over wholesale prices, with a standard deviation of 1.4%, a minimum of 6.4%, and a maximum of 18.5%. Downstream markups do not vary much across products of different price ranges, nor do they change much over time.

3. Model Setup

Firm v markets a product (i.e., a computer server model) ω with price p_ω and warranty duration w_ω months to a group of risk-averse customers.[5] The warranty is bundled with the product and its price is included in product price p_ω. Buyers do not have the option to buy or not buy warranty w_ω. This is how base warranties are marketed in the server market.

3.1. Consumer's Problem

A consumer decides whether to purchase the product. If the consumer purchases the product, she enjoys a level of utility[6] that depends on whether the prod-

[5] Although warranty durations take on a finite number of values, we treat this as a continuous variable. This facilitates the setup of the model as well as subsequent counterfactual experiments at intermediate warranty levels. Note that from an empirical perspective it is straightforward to account for the discrete nature of the warranties.

[6] Even though customers are various businesses, we still treat them as consumers and assume them to maximize expected utility. In this context, utility can be interpreted as the contribution to firm productivity, profits, sales, or other financial indicators.

Table 7 Evolution of Unit Sale Shares by Channel: 1999–2004

	All servers					x86 servers				
Year	Direct fax/ phone/Web	Direct sales force	Indirect fax/ phone/Web	Local dealer	VAR	Direct fax/ phone/Web	Direct sales force	Indirect fax/ phone/Web	Local dealer	VAR
1999		52.44			47.56		55.18			44.82
2000		63.31		0.03	36.66		67.05		0.03	32.92
2001	5.29	63.34	0.02	0.02	31.33	6.14	66.79	0.02	0.02	27.03
2002	7.79	61.83	0.01	0.02	30.36	8.81	64.00	0.01	0.02	27.16
2003	8.07	63.34	0.01	0.01	28.57	8.84	64.62	0.01	0.01	26.52
2004	8.33	62.62	0.00	0.01	29.03	9.14	64.54	0.00	0.01	26.31
All	6.32	64.23	0.01	0.01	29.43	5.56	61.73	0.01	0.01	32.69

uct works or fails and the warranty compensation if the product fails. We make the following two assumptions:

Assumption A. *The quality of product ω is public information. The product is subject to probabilistic failure. The probability that the product functions well, denoted by ρ_ω, is assumed to be exogenous and independent of a consumer's use. The treatment of product quality is consistent with the assumptions in the insurance and sorting theories of warranties* (*Heal* 1977*a*, *Matthews and Moore* 1987). *This appears to be a reasonable assumption for the server market, given how servers are manufactured and used after purchase.*

Assumption B. *Consumers are risk averse. They obtain a monetary value m_ω when the product functions well and receive the warranty value of κw_ω when the product fails. κ is the monetary equivalent of per unit of warranty. It converts warranty duration into monetary value of compensation. We further assume that a customer's utility is additively separable in income and the derived monetary value m_ω, as well as in income and warranty compensation κw_ω.*

The assumption of additive separability has been used widely in the literature (e.g., Soberman 2003, Dybvig and Lutz 1993, Basu et al. 1985, Rao 1990). It is made for the purpose of tractability, which appears to be a reasonable assumption in the warranty context, given the temporal separation of current server purchase and future utilities derived from machine use and potential future warranty compensation. Customer i's expected indirect utility (*EU*) of purchasing product ω is

$$EU_{i\omega} = \rho_\omega U(y_i - p_\omega, m_\omega, X_\omega, \xi_\omega, \varepsilon_{i\omega}) + (1-\rho_\omega)U(y_i - p_\omega, \kappa w_\omega, X_\omega, \xi_\omega, \varepsilon_{i\omega}), \quad (1)$$

where y_i is customer i's income, X_ω is the vector of observed product attributes, ξ_ω is unobserved product attributes, and $\varepsilon_{i\omega}$ is customer i's idiosyncratic utility. The assumption of customer risk aversion implies $\rho_\omega U(\cdot, m_\omega) + (1-\rho_\omega)U(\cdot, \kappa w_\omega) \le U(\cdot, \rho_\omega m_\omega + (1-\rho_\omega)\kappa w_\omega)$, which, by Jensen's inequality, is a defining property of any concave function. Therefore, we choose the following functional forms for the utility function when the server works (Equation (2a)) or fails (Equation (2b)):

$$U(y_i - p_\omega, m_\omega, X_\omega, \xi_\omega, \varepsilon_{i\omega}) = X_\omega \alpha_1 + \beta \ln(y_i - p_\omega) + \theta \ln(m_\omega) + \xi_\omega + \varepsilon_{i\omega}, \quad (2a)$$

$$U(y_i - p_\omega, \kappa w_\omega, X_\omega, \xi_\omega, \varepsilon_{i\omega}) = X_\omega \alpha_1 + \beta \ln(y_i - p_\omega) + \theta \ln(\kappa w_\omega) + \xi_\omega + \varepsilon_{i\omega}, \quad (2b)$$

where α_1 is the vector of marginal utility of observed product attributes X_ω, β, and θ are, respectively, marginal utility of log(income) and log(warranty) with $\beta > 0$ and $\theta > 0$. Note that $X_\omega \alpha_1$, $\beta \ln(y_i - p_\omega)$, ξ_ω, and $\varepsilon_{i\omega}$ are the same when a product works as when it fails. This utility function is concave in the derived monetary value when the product functions well and in warranty compensation.[7] With this functional form, the expected utility is

$$EU_{i\omega} = \rho_\omega \theta \ln m_\omega + X_\omega \alpha_1 + \beta \ln(y_i - p_\omega) + (1-\rho_\omega)\theta \ln(\kappa w_\omega) + \xi_\omega + \varepsilon_{i\omega}. \quad (3)$$

[7] In addition to risk aversion, customer firms might have planned server replacement cycles that could affect their choice of warranty duration. According to Gartner's survey of businesses, the top three reasons for PC replacement are "improve user productivity" (36%), "reduce support costs" (27%), and "new software requirements" (23%) (Dunn 2005). We would expect similar reasons for server replacement. The survey shows an average life span of 43 months for desktop PCs and 36 months for notebooks. Gartner recommends that customers not deviate from a 48- to 60-month server replacement plan to minimize potential disruption in services to end users (Wright et al. 2005). We would expect the life span for servers to be at least as long as that for desktops. Given that the recommended server replacement cycles and the actual life spans for desktops all exceed the maximum warranty duration in our data (36 months), for the same planned replacement cycles, it is reasonable to assume that more risk-averse customers will buy servers with longer warranties and less risk-averse customers will buy servers with shorter durations. This implies that, even in the presence of planned replacement cycles, risk aversion is still a key driver in the purchase of servers with an associated warranty. In this case, our estimation provides an upper bound for the insurance value of warranties.

Customers have the option of not buying any of the products, or choosing the outside good, which has a zero price and a zero warranty. To avoid the mathematical problem associated with zero warranty under the logarithmic specification, we assume the outside good has a warranty duration ς, a small number.[8] Customer i chooses a product with the highest expected utility, subject to the participation constraint:

$$EU_{i\omega} \geq U(y_i, \kappa\varsigma, \varepsilon_{i0}). \tag{4}$$

The utility of the outside good is

$$U_{i0} = U(y_i, \kappa\varsigma, \varepsilon_{i0}) = \alpha_0 + \beta \ln y_i + \theta \ln(\kappa\varsigma) + \varepsilon_{i0}. \tag{5}$$

α_0 is normalized to 0 for identification purposes. As we assume the probability of functioning well ρ_ω is exogenous, it will be a constant for a given product. Differencing the expected utility with the utility of the outside good and after some manipulation, we have

$$\begin{aligned} EU_{i\omega} - U_{i0} = {} & \rho_\omega \theta \ln(m_\omega/\kappa) - \theta \ln\varsigma + X_\omega \alpha_1 \\ & + \beta \ln(1 - p_\omega/y_i) + (1-\rho_\omega)\theta \ln w_\omega \\ & + \xi_\omega + \varepsilon_{i\omega} - \varepsilon_{i0}. \end{aligned} \tag{6}$$

Define

$$\alpha_\omega \equiv \rho_\omega \theta \ln(m_\omega/\kappa) - \theta \ln\varsigma \text{ and } \lambda_\omega \equiv (1-\rho_\omega)\theta.$$

We can see that the choices of κ and ς do not affect model estimation. Assuming the εs follow i.i.d. extreme value distribution and there are Ω products available for customers to choose from, we have the logit probability of choosing product ω:

$$s_{i\omega} = \frac{\exp(\alpha_\omega + X_\omega\alpha_1 + \beta\ln(1-p_\omega/y_i) + \lambda_\omega \ln w_\omega + \xi_\omega)}{1 + \sum_{\omega'=1}^{\Omega} \exp(\alpha_\omega + X_{\omega'}\alpha_1 + \beta\ln(1-p_{\omega'}/y_i) + \lambda_{\omega'} \ln w_{\omega'} + \xi_{\omega'})}. \tag{7}$$

The sorting role of warranties enters the above equation as follows: (1) Customers may derive a different value m_ω from a well-functioning product, and the monetary equivalent of per unit warranty compensation κ may differ across customers. This implies that α_ω can be individual specific; (2) customers may have differing valuations of product attributes, which implies that α_1 can be individual specific; (3) the marginal utility of the same warranty duration may differ across customers, which implies that θ (thus λ_ω) can be individual specific; and (4) customers may have different valuations of income, which implies that β can be individual specific.

The unit of analysis in our empirical analysis is a server model (ω)-channel (d)-quarter (t) combination. The observed product attributes (X_ω) include dummies for manufacturer v, brand j, CPU k, and channel d.[9] $\alpha_\omega + X_\omega\alpha_1$ forms the product intercept, which varies across server models as product attributes vary across server models. λ_ω is server model specific. However, because warranty duration for a given server model does not change over time, we cannot separately identify a λ for each server model. Although warranty duration for some brands changes over time because of changes in the brands' model mix, the temporal variations in warranty duration at the brand level are not large enough to separately identify a warranty coefficient for each of the 44 brands. As major manufacturers offer similar warranty policies, we would expect the warranty coefficients to be similar across manufacturers. To check this, we estimate a manufacturer-specific warranty coefficient λ for a simpler version of our model without customer heterogeneity. We found the λs for HP, IBM, Dell, and "Others" are not statistically different from each other; although the λ for Sun is marginally different from the rest at 10% level, the magnitude of the difference is small and the model fit does not improve much. Taken together, we assume λ_ω is the same for all products; i.e., $\lambda_\omega = \lambda$. Thus, customer i's probability of choosing model ω from channel d in quarter t is

$$\begin{aligned} s_{i\omega dt} = {} & \exp(\alpha_{i\omega d} + \gamma_1 I_{Yt} I_D + \gamma_2 I_{Yt} I_{ID} \\ & \quad + \beta_i \ln(1 - p_{\omega dt}/y_i) + \lambda_i \ln w_{\omega d} + \xi_{\omega dt}) \\ & \cdot \Bigg(1 + \sum_{d=1}^{D_t} \sum_{\omega'=1}^{\Omega_{dt}} \exp(\alpha_{i\omega' d} + \gamma_1 I_{Yt} I_D + \gamma_2 I_{Yt} I_{ID} \\ & \quad + \beta_i \ln(1 - p_{\omega' dt}/y_i) + \lambda_i \ln w_{\omega' d} + \xi_{\omega' dt})\Bigg)^{-1}, \end{aligned} \tag{8}$$

where $\alpha_{i\omega d} = \alpha_{iv} + \alpha_j + \alpha_{ik} + \alpha_{id}$. $\alpha_{i\omega d}$, α_{iv}, α_j, α_{ik}, and α_{id} are, respectively, the intrinsic preferences for model, manufacturer, brand, CPU, and channel. Note that we allow all these preferences to vary across customers except for brand j, because of the large number (44) of brands in our data. I_{Yt} is a year dummy, and I_D and I_{ID} are indicators for direct and indirect channels. We have two interaction terms to allow for differential diffusion effects for the two types of channels. β_i and λ_i are, respectively, customer i's marginal utility of log (income) and log (warranty). With logarithmic specification of income and warranty effects, the interaction effect between income (price) and warranty is implicitly built into the model. Ω_{dt} is the set of products sold in channel d in quarter t, and D_t is the set of channels available in quarter t.

[8] Another way to deal with zero warranty is to add "1" to the warranty duration as $\ln[\kappa(w_\omega + 1)]$. Empirically, the two specifications produce similar results.

[9] Other product attributes such as memory and hard drive may also affect a customer firm's choice of servers, but we do not observe these attributes in the data. This is a shortcoming of our data.

Define $\boldsymbol{\alpha}_{iv}$ as the vector of manufacturer preference parameters. We assume $\boldsymbol{\alpha}_{iv} \sim N(\bar{\boldsymbol{\alpha}}_v, \boldsymbol{\Sigma}_v)$ with $\boldsymbol{\Sigma}_v$ a full variance-covariance matrix to allow for preference correlation and thus a flexible substitution pattern across manufacturers. We assume CPU and channel preferences vary across customers as $\alpha_{ik} \sim N(\bar{\alpha}_k, \sigma_k^2)$ and $\alpha_{id} \sim N(\bar{\alpha}_d, \sigma_d^2)$. Price and warranty coefficients vary across customers as $\beta_i \sim N(\bar{\beta}, \sigma_\beta^2)$ and $\lambda_i \sim N(\bar{\lambda}, \sigma_\lambda^2)$. Thus, we assume that the distributions of preferences for CPU, channel, price, and warranty are independent from one another as well as independent from manufacturer preferences. This assumption is necessary because with aggregate data we are unable to estimate the full covariance matrix of preferences. Special consideration needs to be given to HP and Compaq. The two firms merged in 2001, and the data do not report Compaq servers separately thereafter. In the demand model, we constrain the distribution of manufacturer preference coefficients for Compaq and HP to be the same. We checked the robustness of our results to having different mean preference parameters prior to the merger and a single mean preference parameter after.

Define

$$\delta_{\omega dt} \equiv \bar{\alpha}_v + \alpha_j + \bar{\alpha}_k + \bar{\alpha}_d + \gamma_1 I_{Yt} I_D + \gamma_2 I_{Yt} I_{ID} + \bar{\beta}\overline{\ln(1-p_{\omega dt}/y_i)} + \bar{\lambda}\ln w_{\omega d} + \xi_{\omega dt}$$

as the portion of mean utility that is common across customers. Define

$$\mu_{i\omega dt} \equiv (\alpha_{iv} - \bar{\alpha}_v) + (\alpha_{ik} - \bar{\alpha}_k) + (\alpha_{id} - \bar{\alpha}_d) + [\beta_i \ln(1-p_{\omega dt}/y_i) - \bar{\beta}\overline{\ln(1-p_{\omega dt}/y_i)}] + (\lambda_i - \bar{\lambda})\ln w_{\omega d}$$

as the customer-specific utility, where $\overline{\ln(1-p_{\omega dt}/y_i)}$ is the mean of $\ln(1-p_{\omega dt}/y_i)$ across customers. We have the following market share equation after integrating over the distribution of customer heterogeneity $\phi(\mu)$:

$$s_{\omega dt} = \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} \frac{\exp(\delta_{\omega dt} + \mu_{i\omega dt})}{1 + \sum_{d=1}^{D_t} \sum_{\omega'=1}^{\Omega_{dt}} \exp(\delta_{\omega' dt} + \mu_{i\omega' dt})} \phi(\mu)\partial\mu. \quad (9)$$

3.2. Firm's Problem

In the server market, manufacturers sell both directly to end users and indirectly via intermediaries. Retail prices are the outcomes of vertical strategic interactions among manufacturers and channel members in the indirect channels, as well as horizontal strategic interactions among manufacturers and among channel members. To fully model the horizontal and vertical relationships, we make the following assumptions: (1) Manufacturers are engaged in a Bertrand-Nash pricing game, (2) downstream firms are engaged in a Bertrand-Nash pricing game, and (3) the vertical interactions between manufacturers and downstream firms are a manufacturer-led Stackelberg game (Choi 1991). Under these assumptions, manufacturers set wholesale prices to maximize product line profits, taking rival manufacturers' wholesale prices as given and taking into account the reaction functions of downstream firms. Downstream firms set retail prices, taking as a given wholesale prices, retail prices of all rival downstream firms, and retail prices of direct channels.

One added complexity in specifying downstream firms' profit maximization problem is the presence of exclusive and nonexclusive downstream firms. Some downstream firms are exclusive dealers that only carry a particular manufacturer's product lines; other downstream firms are nonexclusive and carry several product lines. As our data are aggregated at the channel level, not at the individual downstream firm level, it is not possible to tell what products each downstream firm carries and thus write down each firm's objective function. From the *VARBusiness 500*, we obtain the product lines that major VARs carry, their total revenues and percentages of revenues derived from product sales, technology services, and consulting services. From this, we estimate for each manufacturer the percentages of sales coming from exclusive and nonexclusive dealers. Then we decompose the sales of indirect channel d into two parts: (1) sales by V_d exclusive dealers—one for each manufacturer in that channel—and (2) sales by one nonexclusive dealer, which is assumed to carry all product lines of all manufacturers selling in that channel.[10]

In the presence of manufacturers selling both directly and indirectly as well as in the presence of exclusive and nonexclusive dealers, the derivation of downstream firms and manufacturers' pricing equations is very involved. The basic procedure, however, is as follows. (1) Set up the objective functions for manufacturers and downstream firms, (2) take derivatives with respect to prices to get the first-order conditions (FOCs), (3) obtain pricing equations from the FOCs, (4) obtain marginal cost equations from the pricing equations, and (5) differentiate downstream firms' FOCs with respect to wholesale prices to get downstream reaction functions. To improve readability, we put the technical details of the derivation in the

[10] Given the nature of our data, we make two simplifying assumptions: (1) the proportion of sales coming from exclusive versus nonexclusive dealers is not affected by the pricing behavior of firms, and (2) the sales in a given channel come from a single exclusive dealer for *each* of the manufacturers and a single nonexclusive dealer for *all* the manufacturers distributing in that channel. Note that these assumptions can be relaxed if we have access to data from individual downstream firms.

Technical Appendix.[11] Below, we only report downstream firms and manufacturers' objective functions, FOCs, derived pricing equations, marginal cost equations, and downstream firms' reaction functions.

3.2.1. Downstream Firm's Product Line Pricing. Under the assumption that downstream firms play a Bertrand-Nash pricing game, the objective function of the *nonexclusive* downstream firm r_0 in indirect channel d is[12]

$$\max_{\{p_{\omega dt}\}} \Pi_{dt}^{r0} = \sum_{v'=1}^{V_d} \sum_{\omega=1}^{\Omega_{dt}^{v'}} (p_{\omega dt} - mc_{\omega dt}^{r0}) s_{\omega dt} \varpi_{v'dt} M_t. \tag{10a}$$

The objective function of the *exclusive* downstream firm r_v in indirect channel d is

$$\max_{\{p_{\omega dt}\}} \Pi_{dt}^{rv} = \sum_{\omega=1}^{\Omega_{dt}^{v}} (p_{\omega dt} - mc_{\omega dt}^{rv}) s_{\omega dt} (1-\varpi_{vdt}) M_t, \quad v = 1, \ldots, V_d, \tag{10b}$$

where $p_{\omega dt}$ and $s_{\omega dt}$ are model ω's retail price and market share, $mc_{\omega dt}^{r0}$ is marginal cost for nonexclusive downstream firm r_0, and $mc_{\omega dt}^{rv}$ ($v = 1, \ldots, V_d$) is marginal cost for exclusive downstream firm r_v. Downstream firms may incur cost beyond wholesale price $p_{\omega dt}^{w}$. Let $c_{s\omega dt}^{r0}(c_{s\omega dt}^{rv})$ be this residual retail marginal cost; then $mc_{\omega dt}^{r0} = p_{\omega dt}^{w} + c_{s\omega dt}^{r0}(mc_{\omega dt}^{rv} = p_{\omega dt}^{w} + c_{s\omega dt}^{rv})$.[13] ϖ_{vdt} is the proportion of manufacturer v's products sold nonexclusively. ϖ_{vdt} is the same for all models made by manufacturer v, as we do not have detailed information about each product line. M_t is market size in quarter t, Ω_{dt}^{v} is manufacturer v's products sold in channel d in quarter t, and V_d is the set of manufacturers in channel d. We use uppercase letters to denote vectors, so S_{dt}, P_{dt}, P_{dt}^{w}, $MC_{dt}^{r0}(MC_{dt}^{rv})$, $C_{sdt}^{r0}(C_{sdt}^{rv})$, and W_{dt} are, respectively, vectors of unconditional market shares, retail prices, wholesale prices, retail marginal costs, residual retail marginal costs, and proportion of nonexclusive sales. Taking derivatives of Equations (10a) and (10b) with respect to retail prices, we get the FOCs for the nonexclusive downstream firm (Equation (11a)) and the exclusive downstream firms (Equation (11b)) in channel d in matrix form as

$$\begin{aligned} &S_{dt} \cdot W_{dt} + \Delta_{dt}^{r}(P_{dt} - MC_{dt}^{r0}) \cdot W_{dt} \\ &\quad = S_{dt} \cdot W_{dt} + \Delta_{dt}^{r}[P_{dt} - (P_{dt}^{w} + C_{sdt}^{r0})] \cdot W_{dt} = 0, \end{aligned} \tag{11a}$$

$$\begin{aligned} &S_{dt} \cdot (1-W_{dt}) + (\Gamma_{dt}^{r} \cdot \Delta_{dt}^{r})[(P_{dt} - MC_{dt}^{rV_d}) \cdot (1-W_{dt})] \\ &\quad = S_{dt} \cdot (1-W_{dt}) + (\Gamma_{dt}^{r} \cdot \Delta_{dt}^{r}) \\ &\quad\quad \cdot \{[P_{dt} - (P_{dt}^{w} + C_{sdt}^{rV_d})] \cdot (1-W_{dt})\} = 0, \end{aligned} \tag{11b}$$

where Δ_{dt}^{r} is nonexclusive downstream firm r_0's retail response matrix, which is the matrix of first derivatives of shares with respect to *retail* prices with the (ω, ω')th element defined as $\partial s_{\omega' dt}/\partial p_{\omega dt}$. Γ_{dt}^{r} is the *within*-channel downstream firm ownership matrix with the (ω, ω')th element being 1 if both ω and ω' are carried by exclusive downstream firm r_v (i.e., produced by the same manufacturer v) and 0 otherwise. From these FOCs we obtain the pricing equations for the nonexclusive (Equation (12a)) and exclusive downstream firms (Equation (12b)) in channel d as follows:

$$P_{dt} \cdot W_{dt} = MC_{dt}^{r0} \cdot W_{dt} - (\Delta_{dt}^{r})^{-1}(S_{dt} \cdot W_{dt}) \tag{12a}$$

$$\begin{aligned} P_{dt} \cdot (1-W_{dt}) &= MC_{dt}^{rV_d} \cdot (1-W_{dt}) \\ &\quad - (\Gamma_{dt}^{r} \cdot \Delta_{dt}^{r})^{-1}[S_{dt} \cdot (1-W_{dt})]. \end{aligned} \tag{12b}$$

Let Γ_t be the *channel* ownership matrix with the (ω, ω')th element being 1 if both ω and ω' are carried by channel d and 0 otherwise. Let Γ_t^{r} be a block-diagonal matrix with Γ_{dt}^{r} as its block elements. The pricing equations for all nonexclusive firms and all exclusive firms across *all indirect* channels can be written as[14]

$$\tilde{P}_t \cdot W_t = MC_t^{r0} \cdot W_t - (\Gamma_t \cdot \tilde{\Delta}_t^{r})^{-1}(\tilde{S}_t \cdot W_t), \tag{13a}$$

$$\begin{aligned} \tilde{P}_t \cdot (1-W_t) &= MC_t^{rV} \cdot (1-W_t) \\ &\quad - (\Gamma_t \cdot \Gamma_t^{r} \cdot \tilde{\Delta}_t^{r})^{-1}[\tilde{S}_t \cdot (1-W_t)], \end{aligned} \tag{13b}$$

where $\tilde{\Delta}_t^{r}$ is the retail response matrix (first derivatives of shares with respect to retail prices) for downstream firms in *all indirect* channels. From Equations (13a)

[11] The Technical Appendices can be found at http://mktsci.pubs.informs.org. In Technical Appendix A, we illustrate the derivation with a special case—two single-product manufacturers each distributing its product through one direct channel and one indirect channel. In Technical Appendix B, we show the derivation for the general case.

[12] Unlike extended warranties, downstream firms do not get separate commissions by selling manufacturer base warranties, nor do they obtain payments for servicing these warranties. Hence, they do not impact profits other than through the sales of severs with different warranty durations.

[13] In studies of grocery items, retail marginal costs are often assumed to be the same as wholesale prices (e.g., Chintagunta et al. 2003, Draganska and Jain 2006, Villas-Boas 2007, Sudhir 2001). This assumption may be reasonable for grocery items, but it may not be tenable in the server market, where the retailers have to provide end user services and thus incur costs beyond wholesale prices. As we observe wholesale prices in our data, we are able to estimate the residual retail marginal costs. Our entire analysis goes through if the residual retail marginal costs are assumed to be zero.

[14] We use "∼" to distinguish vectors or matrices of products sold in all *indirect* channels from those sold in *all* channels. For example, $\tilde{S}_t$ and $\tilde{P}_t$ refer to vectors of market shares and retail prices of products sold in all *indirect* channels; S_t and P_t refer to vectors of shares and retail prices of products sold in all channels, both direct and indirect.

and (13b), we can obtain the equations for computing retail marginal costs as

$$MC_t^{r0} \cdot W_t = \tilde{P}_t \cdot W_t + (\Gamma_t \cdot \tilde{\Delta}_t^r)^{-1}(\tilde{S}_t \cdot W_t) \quad (14a)$$

$$MC_t^{rV} \cdot (1-W_t) = \tilde{P}_t \cdot (1-W_t) + (\Gamma_t \cdot \Gamma_t^r \cdot \tilde{\Delta}_t^r)^{-1}[\tilde{S}_t \cdot (1-W_t)]. \quad (14b)$$

The retail marginal cost for a particular product is a weighted average of the marginal costs obtained from Equations (14a) and (14b):

$$\begin{aligned} MC_t^r &= MC_t^{r0} \cdot W_t + MC_t^{rV} \cdot (1-W_t) \\ &= \tilde{P}_t + \{(\Gamma_t \cdot \tilde{\Delta}_t^r)^{-1}(\tilde{S}_t \cdot W_t) \\ &\quad + (\Gamma_t \cdot \Gamma_t^r \cdot \tilde{\Delta}_t^r)^{-1}[\tilde{S}_t \cdot (1-W_t)]\}. \end{aligned} \quad (15)$$

The first derivatives of shares with respect to retail prices are

$$\frac{\partial s_{\omega' dt}}{\partial p_{\omega dt}} = \begin{cases} -\dfrac{\beta s_{\omega dt}(1-s_{\omega dt})}{y - p_{\omega dt}} & \text{if } \omega = \omega', \\ \dfrac{\beta s_{\omega' dt} s_{\omega dt}}{y - p_{\omega dt}} & \text{if } \omega \neq \omega'. \end{cases} \quad (16)$$

3.2.2. Manufacturer's Product Line Pricing. Under the Bertrand-Nash pricing assumption, manufacturer v chooses wholesale prices for all its server models across all channels to maximize product line profits. Its objective function is

$$\max_{\{p_{\omega dt}^w\}} \Pi_t^v = \sum_{d=1}^{D_t^v} \sum_{\omega=1}^{\Omega_{dt}^v} (p_{\omega dt}^w - mc_{\omega dt}^w) s_{\omega dt} M_t - FC_{vt}, \quad (17)$$

where D_t^v is the set of distribution channels used by manufacturer v in quarter t, $mc_{\omega dt}^w$ is manufacturer marginal cost, and FC_{vt} is fixed cost. Taking derivatives of Equation (17) with respect to wholesale prices, and after some manipulation, we can obtain manufacturer v's FOCs in matrix form as

$$S_t^v + \Delta_t^{wv}(P_t^{wv} - MC_t^{wv}) = 0, \quad (18)$$

where S_t^v, P_t^{wv}, and MC_t^{wv} are, respectively, manufacturer v's vectors of shares, wholesale prices, and marginal costs. Δ_t^{wv} is the matrix of first derivatives of shares with respect to *wholesale* prices, or manufacturer v's response matrix with the (ω, ω')th element defined as $\partial s_{\omega' dt}/\partial p_{\omega dt}^w$. Define Γ_t^w as the *manufacturer* ownership matrix with the (ω, ω')th element being 1 if both ω and ω' are produced by manufacturer v and 0 otherwise. Define Δ_t^w as the manufacturer response matrix for *all* manufacturers. Thus, the FOCs across all manufacturers can be written compactly as

$$S_t + (\Gamma_t^w \cdot \Delta_t^w)(P_t^w - MC_t^w) = 0. \quad (19)$$

From Equation (19), we can obtain manufacturers' pricing equations as

$$P_t^w = MC_t^w - (\Gamma_t^w \cdot \Delta_t^w)^{-1} S_t. \quad (20)$$

Changes in wholesale prices will first affect retail prices, which then affect market share. Define Δ_t as the matrix of first derivatives of *retail* prices with respect to *wholesale* prices. It is the downstream firm's reaction function whose (ω, ω')th element is defined as $\partial p_{\omega' dt}/\partial p_{\omega dt}^w$, by the chain rule, $\Delta_t^w = \Delta_t \Delta_t^r$, where Δ_t^r is the matrix of first derivatives of shares with respect to *retail* prices for products sold in *all* channels. Thus, manufacturers' pricing equations become

$$P_t^w = MC_t^w - [\Gamma_t^w \cdot (\Delta_t \Delta_t^r)]^{-1} S_t. \quad (21)$$

Note that $\tilde{\Delta}_t^r$ in Equations (13)–(15) is a submatrix of Δ_t^r in Equation (21) that corresponds to products sold in the indirect channels. From Equation (21), we can obtain the equations for computing manufacturer marginal costs as

$$MC_t^w = P_t^w + [\Gamma_t^w \cdot (\Delta_t \Delta_t^r)]^{-1} S_t. \quad (22)$$

3.2.3. Downstream Firm's Reaction Function. To obtain the downstream firm's reaction function in the presence of direct and indirect channels, we first partition downstream reaction matrix Δ_t as follows:

$$\Delta_t = \begin{bmatrix} \tilde{\Delta}_t & 0 \\ 0 & I_{Dt} \end{bmatrix}, \quad (23)$$

where I_{Dt} is an identity matrix for products sold in direct channels. By totally differentiating downstream firms' FOCs (Equations (11a) and (11b)) with respect to wholesale prices of products sold in indirect channels, we can obtain $\tilde{\Delta}_t$ as

$$\tilde{\Delta}_t^0 = (\tilde{\Delta}_t^{r\prime} \cdot \Gamma_t' \cdot W_t)\Upsilon_t^{-1} \quad \text{(nonexclusive)} \quad (24a)$$

$$\tilde{\Delta}_t^V = [\tilde{\Delta}_t^{r\prime} \cdot \Gamma_t' \cdot \Gamma_t^{r\prime} \cdot (1-W_t)]\Upsilon_t^{-1} \quad \text{(exclusive)}, \quad (24b)$$

where Υ_t is a square matrix corresponding to products sold in all *indirect* channels. Its ωth column is defined as $\{\tilde{\Delta}_{t,\cdot,\omega}^r \varpi_{\omega t} + H_\omega[(\tilde{P}_t - MC_t^r) \cdot \Gamma_{t\omega,\cdot}' \cdot W_t] + \tilde{\Delta}_{t\omega,\cdot}^{r\prime} \cdot \Gamma_{t\omega,\cdot}' \cdot W_t\}$ for the nonexclusive firms and as $\{\tilde{\Delta}_{t,\omega}^r(1-\varpi_{\omega t}) + H_\omega[(\tilde{P}_t - MC_t^{rV}) \cdot \Gamma_{t\omega,\cdot}' \cdot \Gamma_{t\omega,\cdot}^r \cdot (1-W_t)'] + [\tilde{\Delta}_{t\omega,\cdot}^r \cdot \Gamma_{t\omega,\cdot} \cdot \Gamma_{t\omega,\cdot}^r \cdot (1-W_t)]'\}$ for the exclusive firms. $H_\omega = \partial \tilde{\Delta}_t^r / \partial p_{\omega dt}$.

After obtaining the downstream reaction functions (Equations (24a) and (24b)), we substitute for $\tilde{\Delta}_t$ to the matrix Δ_t in Equation (23). Then, from Equation (22), we obtain manufacturers' marginal costs for the nonexclusive case and the exclusive case, respectively. The final manufacturer marginal cost is a weighted average of these two cases:

$$\begin{aligned} MC_t^w = P_t^w &+ \{\{[\Gamma_t^w \cdot (\Delta_t^0 \Delta_t^r)]^{-1} S_t\} \cdot W_t \\ &+ \{[\Gamma_t^w \cdot (\Delta_t^V \Delta_t^r)]^{-1} S_t\} \cdot (1-W_t)\}. \end{aligned} \quad (25)$$

3.2.4. The Impact of Warranty Duration. Increasing (or decreasing) the duration of a particular server model's warranty has two main effects. From Equation (8) we see that an increase in warranty duration increases the demand for that server model. At the same time, a longer warranty duration increases the marginal cost of that model to the manufacturer ($mc^{w}_{\omega dt}$ in Equation (17)). This increases wholesale and retail prices and thereby reduces demand. A change in prices also influences the markups and hence the profits that accrue to manufacturers and downstream firms. Hence, the net effect of an increase in warranty duration would involve a series of trade-offs involving these factors.

4. Estimation

4.1. Estimation of Demand Parameters

We follow the estimation procedure in recent literature (e.g., Nevo 2001) and adopt a two-step sequential approach by first estimating the demand parameters and then the parameters of the pricing equations. Although less efficient than a simultaneous approach, it will nevertheless provide consistent estimates of the demand parameters even in the presence of misspecified pricing equations. The simultaneous approach, in contrast, will produce inconsistent estimates when pricing equations are misspecified.

One challenge in estimating the demand parameters is the nonlinear, customer i-specific income effect. The nonlinear income effect hinders our ability to use the typical contraction mapping with generalized method of moments (GMM) approach that has been used with such models. Instead, we modify the contraction mapping approach in Berry, Levinsohn, and Pakes (Berry et al. 1995; referred hereafter as BLP) to simultaneously account for customer heterogeneity in price sensitivity, price endogeneity, and the nonlinear income effect. Specifically, we decompose the price term in Equation (8) as follows:

$$
\begin{aligned}
&\beta_i \ln(1-p_{\omega dt}/y_i)\\
&\quad=[\bar\beta+(\beta_i-\bar\beta)]\ln(1-p_{\omega dt}/y_i)\\
&\quad=(\bar\beta+\Delta_{\beta_i})\ln(1-p_{\omega dt}/y_i)\\
&\quad=\bar\beta\ln(1-p_{\omega dt}/y_i)+\Delta_{\beta_i}\ln(1-p_{\omega dt}/y_i)\\
&\quad=\bar\beta\{\overline{\ln(1-p_{\omega dt}/y_i)}+[\ln(1-p_{\omega dt}/y_i)-\overline{\ln(1-p_{\omega dt}/y_i)}]\}\\
&\qquad\quad+\Delta_{\beta_i}\ln(1-p_{\omega dt}/y_i)\\
&\quad=\bar\beta\{\overline{\ln(1-p_{\omega dt}/y_i)}+\Delta_{\ln(1-p_{\omega dt}/y_i)}\}+\Delta_{\beta_i}\ln(1-p_{\omega dt}/y_i)\\
&\quad=\underbrace{\bar\beta\overline{\ln(1-p_{\omega dt}/y_i)}}_{\text{mean price effect}}+\underbrace{[\bar\beta\Delta_{\ln(1-p_{\omega dt}/y_i)}+\Delta_{\beta_i}\ln(1-p_{\omega dt}/y_i)]}_{\text{customer-specific price effect}}.
\end{aligned}
$$

The first term $\bar\beta\overline{\ln(1-p_{\omega dt}/y_i)}$ will enter into the mean utility, and the second and third terms enter into the customer-specific utility. This customer-specific utility differs from the one under the specification of linear income effect in that it has the additional term $\bar\beta\Delta_{\ln(1-p_{\omega dt}/y_i)}$. In particular, embedded in this term is $\bar\beta$, which should equal the $\bar\beta$ in the mean utility term. The following steps comprise our modified contraction mapping procedure:

(1) Obtain draws for y_i from the empirical distribution of firm revenue, obtained from the U.S. Census Bureau's economic surveys of firms, and treat them as empirical data.

(2) For each draw of y_i, compute $\ln(1-p_{\omega dt}/y_i)$, $\Delta_{\ln(1-p_{\omega dt}/y_i)}$, and $\overline{\ln(1-p_{\omega dt}/y_i)}$.

(3) Choose starting values for $\bar\beta$ and for the nonlinear parameters (i.e., the parameters associated with the variances of the heterogeneity distributions that go into the individual-specific terms) to compute the individual-specific utility, and apply the contraction mapping in BLP (1995) to obtain the mean utility.

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

(5) Replace $\bar\beta$ in Step 3 with the $\bar\beta$ estimate from Step 4 and iterate until convergence.

Retail prices ($p_{\omega dt}$) might be correlated with unobserved product attributes ($\xi_{\omega dt}$), which results in a potential price endogeneity problem. We use an instrumental variables technique to account for such endogeneity. We use the following cost shifters as instruments: (1) product characteristics including dummies for manufacturer, brand, channel, CPU, and time trend; (2) current and lagged producer price indices (PPI) for memory and CPU, which are obtained from the Bureau of Labor Statistics—we interact the PPI with manufacturer dummies to allow for manufacturer-specific effects; and (3) average weekly wage rates for the computer hardware industry and for the business-to-business electronic markets, agents, and brokers, obtained from BLS. Together, these instruments explain 63% of the price variation and 74% log (price) variation.

In the demand model specification, we allow the customers to have the option of not choosing any of the servers, to allow the market to contract or expand based on retail price change. We use the number of establishments in the United States (ranging from 7.01 million in 1999 to 7.39 million in 2004 (http://www.census.gov)) as the potential market for servers, and we assume each establishment has, on average, two servers. Thus, our market potential is around 14 million.

We believe this is a reasonable number for the following reasons. First, based on the structure of the customer base for the U.S. server market, we think it is appropriate to use the number of establishments as the potential market. According to the International Data Corporation®, U.S. server buyers spread across a wide variety of commercial and other establishments. In 1999–2004, 5.41% of x86 servers in the United States were sold to education, 12.10% to governments, 10.92% to small offices (1–9 employees), 15.62% to small businesses (10–99 employees), 21.78% to medium businesses (100–499 employees), 15.28% to large businesses (500–999 employees), and 18.78% to very large businesses (1,000+employees). Given this structure, it would appear appropriate to include all establishments in the potential market for servers. Second, the market potential defined should be large enough relative to the sale levels observed in the market. In 1999–2004, nearly 12 million servers were sold in the U.S. market, about 2 million per year. The recommended server replacement cycle by Gartner® is 48–60 months (Wright et al. 2005), implying that the installed base of servers likely lies between 8 million and 10 million. Given this, we believe our market size definition is reasonable. We further checked the sensitivity of our results to different numbers of servers each establishment might use. We found the results to be robust to this number (see §4.5 on robustness checks).

4.2. Estimation of Parameters in the Pricing Equations

Manufacturers marginal costs consist of the following: the costs of providing the various attributes of the server (CPU, memory, etc.), warranty costs, and other costs. To estimate the cost of warranties, we first estimate manufacturer marginal costs MC_t^w (Equation (25)), and we then project these manufacturer marginal costs on warranty duration and other product attributes. As we do not know the shape of the warranty cost function, we need to use a flexible functional form. We tried a variety of different approaches and settled on the following semilog regression that allows warranty coefficients to vary with quarters to account for potentially changing warranty costs over time.

$$\ln(MC_{\omega dt}^{w}) = X_{\omega dt}\kappa_{0t} + \kappa_t w_{\omega d} I_{qt} + \zeta_{\omega dt}, \tag{26}$$

where I_{qt} is a quarter dummy, κ_{0t} is the vector of the effect of product attributes on marginal cost, and κ_t is the effect of warranty on marginal cost. Note that downstream firms are assumed not to incur any additional costs associated with manufacturer warranty provision.

4.3. Assessing the Value of Warranties

To assess the value of warranties, we need to choose a benchmark warranty scheme to compare against. One choice is the three-month warranty scheme, the shortest warranty duration observed in the data. The procedures are as follows: (1) Set warranty duration of all models to three months; (2) compute the corresponding warranty costs; (3) recalculate the new equilibrium prices and shares by solving the system of demand and pricing equations; and (4) compute changes in firm profits and consumer welfare. The differences in firm profits and consumer welfare will be the *total value* of warranties to firms and to customers. As firms and customers still get some value of warranty from a three-month warranty, this benchmark will give us a *lower* bound for the value of warranties to firms and customers.

Another choice is the zero-warranty scheme. We can obtain the value of warranties by setting the level of warranties to ς for all server models. This approach is in the same spirit as in Ackerberg (2003), where the author estimates the value of advertising by setting advertising levels and costs to zero and computes changes in firm profits and consumer welfare. Because zero warranty is not observed in the data, computing the value of warranties this way requires us to assume that consumer behavior under the zero-warranty scenario is not fundamentally different from that under the observed warranty scheme. To the extent that this assumption is valid, this approach will provide an *upper* bound for the value of warranties. We compute the value of warranties against both benchmarks. This allows us to obtain a range for the value of warranties to firms and customers. We use the compensating variation metric as in Chintagunta et al. (2003) and McFadden (1999) to measure consumer welfare. We checked the robustness of our results to several values of ς close to zero. We also checked whether this approach can reasonably estimate the value of warranties (see §4.5 on robustness checks).

To compute the sorting value of warranties, we first compute the new equilibrium prices and shares under uniform warranties, such as six months, one year, two years, and three years. We then compare firm profits and consumer welfare under uniform warranties with those under nonuniform (the existing) warranty scheme. This gives us the *sorting value* of warranties. The difference between the total value of warranties and the sorting value of warranties will give us the *insurance value* of warranties. As the mean warranty duration across all servers is 23.4 months, the insurance value and the price discrimination value under the two-year uniform warranty scheme best approximate the actual value in the server market. However, we do not actually observe manufacturers offering two-year warranties. So we also compute these values under other warranty schemes to compare the value of different warranty schemes for manufacturers, channel intermediaries, and customers.

4.4. Model Identification

The demand model has 66 linear parameters and 27 nonlinear parameters. Given our data, we need to impose some constraints to identify these parameters. We only allow for customer heterogeneity in preferences for manufacturer, processor, and channel and in price and warranty sensitivity. We assume customer homogeneity in brand preferences because of the large number of brands in the data. Further, as noted previously, we also assume that manufacturer preferences are correlated but that processor and channel preferences as well as price and warranty sensitivities are independently distributed and uncorrelated with manufacturer preferences. Hence, our model specification is a compromise between model flexibility and computational feasibility that is necessitated by our data. We group manufacturers other than HP/Compaq, Dell, IBM, and Sun into "Others" because individually each has a very small market share. Further, as described in the model setup, we constrain the warranty coefficient to be the same across all server models. The identification of price coefficients comes from temporal variations of prices of the same server models, as well as from the large variations in prices across server models. From the hedonic regression (Table 3) we can see that prices of servers vary substantially across models and over time. The mean sales-weighted wholesale price is \$10,623 for high-end servers and \$4,471 for x86 servers. The identification of the warranty coefficient comes from cross-sectional variations of warranty duration across server models as well as from temporal variations of warranty duration across brands and manufacturers from changes in product mix.

The cost equation has 88 linear parameters. As we observe wholesale and retail prices and sales in direct and indirect channels, once the demand parameters are consistently estimated, we can calculate price-cost margins for manufacturers and downstream firms. Then we can recover manufacturer marginal costs as the difference between wholesale prices and manufacturer price-cost margins and recover downstream marginal costs as the difference between retail prices and retail price-cost margins. Once we have manufacturer marginal costs and retail marginal costs, we can project these marginal costs onto exogenous cost shifters (Petrin 2002, Villas-Boas 2007). We include manufacturer, brand, CPU, channel, time, and warranty duration as cost shifters for servers. We allow warranty costs to vary with quarters to account for the possible changes in labor and parts costs over time. As shown in Villas-Boas and Hellerstein (2004), the coefficients for these cost shifters can be easily identified for differentiated product markets, particularly when wholesale prices are available.

4.5. Robustness Checks

We conduct a series of robustness checks on the model assumptions, functional form choices, and estimation methods.

4.5.1. Channel-Specific Price Sensitivity. We tested whether customers exhibit channel-specific price sensitivity and found the data do not support this.

4.5.2. Interaction Effects. We also tried various interactions between manufacturers and channels, manufacturers and time, and channels and time. Although a subset of these interactions shows some statistically significant effects, including them did not materially affect our results. Hence, we only retained the channel type by year interactions in the final model to capture the differential diffusion of these channels over time.

4.5.3. The Effect of Channel Entry. We see entries of three channels in the data, indirect fax/phone/Web, local dealer, and direct fax/phone/Web. The first two channels account for less than 0.1% of shares, so their entry does not materially affect the competition landscape. To examine the effect of entry of direct fax/phone/Web, we reestimate the model after dropping this channel. We find that the entry makes customers slightly less price sensitive, but the difference is not significant. Nevertheless, we acknowledge that we do not explicitly model the channel-entry decision.

4.5.4. Assumptions on the Potential Market Size. We checked the sensitivity of our results against different numbers of servers each establishment might use and found the results very robust to this number. Although it is not reported, we find that this number mainly shifts manufacturer intercepts up or down, and all other estimates are very robust. For example, the price coefficient changes only in the first decimal place and the warranty coefficient changes only in the third decimal place. Correspondingly, we find that price and warranty elasticities are not statistically different from each other under these alternative assumptions. We also computed other quantities (implied warranty costs, manufacturer margins, values of warranties under different warranty scenarios) for the case of *one* server per establishment. These quantities are very close to what we report in the paper based on the assumption of *two* servers per establishment.

4.5.5. The Impact of Unobserved Product Attributes. We observe manufacturer, brand, CPU, channel, price, and warranty duration of a server; therefore, we can only include these product attributes into our model. Other attributes such as memory and hard drive might affect the choice of a server. To check whether these unobserved attributes might impact our estimates, we estimated a model that replaced all server attributes with server-model dummies. These server-model dummies will soak up the effects of all attributes including the unobserved ones. We find that the estimates of the other model parameters are not significantly influenced by this approach to estimation. This provides us with some reassurance that the non-included attributes do not negatively impact our estimates of other model parameters. Additionally, we find that the fit of the specification with server-model dummies is not substantially better than the specification we report. That indicates that most of the information on these dummies is reflected in the attributes that we include.

4.5.6. The Impact of Other VAR Services. In addition to selling computer hardware, VARs provide many other services, such as software, information technology (IT), and consulting services. These services are charged and accounted for separately. We do not have information on them. The key question is whether these unobserved services are correlated with base warranties. One way to check whether VAR services are correlated with manufacturer base warranties in a manner that influences sales of specific server models is to check whether the distribution of server sales by warranty duration is similar or different across VAR and direct channels. We find the sales distribution by warranty duration is very similar across channels. Therefore, VAR services are unlikely to be correlated with base warranties in a way that influences the sales of server models with different warranty durations in the VAR channel.

4.5.7. Assumptions on Customer Heterogeneity Distribution. Consistent with recent literature (e.g., Nevo 2001), we assume customer preferences for product attributes and price and warranty coefficients follow continuous distributions, and we estimate the parameters of these distributions with observed data. To check whether our main results are sensitive to the assumptions on customer heterogeneity distributions, we estimate a two-segment and a three-segment logit model, assuming customer preferences for manufacturer, channel, and CPU as well as customer sensitivities to price and warranty following discrete distributions. We obtain similar price and warranty elasticities to those from our current model.

4.5.8. The Reasonableness of Using Zero Warranty as a Benchmark. Because zero warranty is not observed in the data, one may question whether we can reasonably estimate the shares and prices associated with zero warranty. Here is our logic of reasoning: If we can recover the prices and shares of three-month warranties using a model that is estimated based only on data of one-year and three-year warranties, then we will be more confident in estimating the prices and shares associated with zero warranty with our structural model, which is based on three-month, one-year, and three-year warranties. Therefore, we checked whether a structural model estimated with one-year and three-year warranty data can recover prices and shares for three-month warranties. To accomplish this, we did the following: (1) estimated a structural model (both demand and pricing models), using only observations with one-year or three-year warranties; (2) "introduced" those observations with three-month warranties and simulated prices and shares for all observations; (3) computed the ratios of simulated prices to observed prices for *all* observations; and (4) computed the means and standard deviations of the price ratios by manufacturers and by warranty durations. We find that the price ratios across all observations range from 0.987 to 1.024. This means that a structural model based on one-year and three-year warranties can recover prices and shares reasonably well, even for three-month warranties that are *not* included in the data for estimation. By this premise, we think our structural model based on three-month, one-year, and three-year warranties should be able to reasonably estimate prices and shares associated with zero warranties.

5. Major Results

First, we discuss the estimates of the demand parameters. Then we report cost parameter estimates and warranty costs implied by our pricing equations. Finally, we provide results on the value of warranties in the server market.

5.1. Demand Parameter Estimates

Table 8 shows the parameter estimates of various logit demand models: the first two columns are the estimates for the ordinary least-squares model, followed by two columns for the 2-stage least-squares model, and then by four columns for the mean and heterogeneity parameters of the random coefficients logit model. The last two columns are the heterogeneity parameter estimates. We find that consistent with previous marketing literature (e.g., Villas-Boas and Winer 1999, Chintagunta et al. 2003), it is important to account for price endogeneity and customer heterogeneity. The implied median price elasticity without accounting for either effect is less than unity (0.52), which is not consistent with firms' profit maximizing behavior. After accounting for price endogeneity, the median price elasticity increases to 7.18, and after accounting for customer heterogeneity, it further increases to 8.84. To get a sense as to whether this estimate is reasonable given our data, we note that the average downstream markup over wholesale price ($(p-p^w)/p^w$) is about 15%, implying a 13% downstream markup over retail price ($(p-p^w)/p$). As these firms have to incur other costs, such as cost of end user services to do business, downstream marginal costs should be higher than wholesale price. In other words, the actual downstream gross markup is likely to be lower than 13%. By the inverse elasticity rule,

Table 8 Demand Parameter Estimates

					Random coefficients			
	OLS		2SLS		Linear parameters		Heterogeneity parameter	
Independent variable	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error
HP	−8.684	0.308	2.511	0.887	1.870	0.868	1.856	1.607
IBM	−6.425	0.326	5.807	0.965	−2.537	0.778	6.034	3.225
Dell	−7.972	0.325	3.128	0.887	0.767	0.292	6.593	3.034
Sun	−6.004	0.318	1.554	0.650	−12.035	3.535	9.518	5.360
Others	−6.399	0.430	6.671	1.065	12.005	1.978	7.928	4.234
CPU1	0.949	0.213	−5.465	1.046	−18.153	12.475	7.290	2.515
CPU2	0.658	0.193	−5.022	0.930	−7.853	2.446	1.064	1.398
CPU3	−0.194	0.199	−5.190	0.847	−7.693	1.641	0.642	1.520
CPU4	0.017	0.194	−3.718	0.685	−7.779	2.250	3.055	1.288
CPU5	0.283	0.196	−4.317	0.794	−10.035	3.116	3.721	1.374
CPU6	−2.310	0.405	−10.853	1.520	−25.508	29.903	7.483	3.758
CPU7	0.672	0.221	−4.745	0.924	−21.030	13.279	8.776	2.456
Direct fax/phone/Web	−0.861	0.239	−1.502	0.511	−1.716	1.045	0.276	0.269
Direct sales force	0.143	0.218	−0.425	0.466	−1.105	0.754	0.879	0.139
VARs	0.182	0.193	−0.296	0.411	−0.728	0.649	0.216	0.034
Direct channel 2000	0.182	0.107	−0.500	0.247	−1.954	0.781		
Direct channel 2001	−0.060	0.108	−0.755	0.248	−1.097	0.665		
Direct channel 2002	−0.283	0.109	−0.985	0.251	−2.263	0.779		
Direct channel 2003	−0.095	0.108	−0.540	0.236	−1.048	0.636		
Direct channel 2004	0.142	0.108	−0.641	0.255	−1.423	0.564		
Indirect channel 2000	0.282	0.115	−0.189	0.250	−1.516	0.810		
Indirect channel 2001	−0.014	0.118	−0.876	0.279	−1.193	0.672		
Indirect channel 2002	−0.283	0.122	−1.062	0.282	−2.398	0.751		
Indirect channel 2003	−0.227	0.120	−1.267	0.295	−2.063	0.670		
Indirect channel 2004	−0.211	0.119	−1.180	0.287	−2.235	0.564		
Price	3.004	0.296	41.837	5.762	62.509	12.761	7.989	3.896
Warranty	−0.119	0.039	0.276	0.067	0.332	0.105	0.206	0.124
Std. deviation of dependent variable	2.722		2.722		2.722			
RMSE	1.425		1.407		0.184			
MAPE	0.107		0.105		0.018			
GMM obj. function			574.110		172.953			

Notes. Brand coefficient estimates are not reported for space reason. All of the brand coefficient estimates are statistically significant with $|t|$ statistics between 5.21 and ~20.65.

the implied price elasticity corresponding to a 13% gross markup should be no smaller than 7.7, which is consistent with our estimate of 8.84. Therefore, the elasticities from the random coefficients model appear to be reasonable. This adds some face validity to our model estimates. Our discussion below focuses on the random coefficients logit model.

Of the four major manufacturers, HP commands the highest customer intrinsic preference, followed by Dell and IBM; Sun has the lowest customer preference. This is consistent with HP and Dell's market leader position and Sun's low presence in the x86 server market. The most preferred channel is VAR, and the least preferred channel is direct fax/phone/Web. From Table 7, we know that direct channels and indirect channels follow different sale trends. Sales in direct channels increased over the years: the shares of servers sold in the direct channels went up from 52.44% in 1999 to 70.95% in 2004, and sales in the indirect channels decreased: the shares slid from 47.56% in 1999 to 29.05% in 2004. The share changes might be caused by changes in customer's intrinsic channel preference or by other factors such as price, or both. After we control for all other factors, we find that direct and indirect channels have similar sale trends, as reflected in the coefficients for the channel-year dummies. This implies that the observed differences in sale trends across channels are primarily driven by these other factors.

Our results also show that server customers are heterogeneous in their preferences for manufacturers, CPU and channel, risk (warranty) preference, and price sensitivity. The majority of the heterogeneity parameters are significant at the 5% or 10% level. This indicates that the sorting role of warranties is consistent with our demand estimates. Account-

Table 9 Manufacturer Substitution Pattern (Standard Errors in Parentheses)

Manufacturer	HP/Compaq	IBM	Dell	Sun	Others
			Price change		
HP/Compaq	−8.061 (1.790)	0.568 (0.331)	0.505 (0.237)	0.016 (0.008)	0.167 (0.072)
IBM	1.165 (0.432)	−8.672 (2.559)	0.132 (0.082)	0.063 (0.034)	0.083 (0.044)
Dell	0.693 (0.311)	0.105 (0.065)	−8.024 (1.731)	0.008 (0.005)	0.131 (0.073)
Sun	0.039 (0.023)	0.036 (0.022)	0.060 (0.025)	−8.615 (2.908)	0.202 (0.095)
Others	0.266 (0.122)	0.053 (0.031)	0.155 (0.068)	0.008 (0.005)	−9.324 (1.621)
			Warranty change		
HP/Compaq	0.337 (0.108)	−0.024 (0.012)	−0.029 (0.013)	0.000 (0.000)	−0.008 (0.004)
IBM	−0.063 (0.020)	0.317 (0.107)	−0.008 (0.005)	−0.002 (0.001)	−0.004 (0.003)
Dell	−0.041 (0.015)	−0.005 (0.002)	0.324 (0.104)	0.000 (0.001)	−0.006 (0.003)
Sun	−0.001 (0.001)	−0.001 (0.002)	−0.003 (0.002)	0.372 (0.130)	−0.009 (0.005)
Others	−0.017 (0.006)	−0.003 (0.001)	−0.009 (0.004)	0.000 (0.000)	0.397 (0.100)

Notes. Impact on row manufacturers' shares of 1% change of column manufacturers' price or warranty. Elasticities are computed for each observation, and the medians are reported here. Standard errors are computed via bootstrapping.

ing for customer heterogeneity also produces flexible substitution patterns across manufacturers and channels, as shown in the price and warranty elasticity matrices in Tables 9 and 10, respectively. HP and IBM primarily compete with each other, and Dell primarily competes with HP. Sun competes first with IBM and second with HP. As Dell does not make high-end servers and Sun is a minor player in x86-based servers, Dell and Sun do not seem to compete much with each other. The channel substitution is asymmetric as well: the two direct channels primarily compete with each other: when direct fax/phone/Web (sales force) changes prices, it affects direct sales force (fax/phone/Web) the most. However, when VARs change prices, it primarily affects the direct sales force.

A majority of customers derive positive utilities from warranties. The warranty coefficient (λ_i) follows a normal distribution $N(0.332, 0.206)$, so about 5.35% of individual-level warranty coefficients will be negative, implying that a small fraction of customers do not value warranties and warranties bring them negative utility. These might be large business buyers who have their own IT teams and therefore would prefer to buy servers without warranties at lower prices. It is also interesting to look at firm competition in warranties. When we look at the warranty substitution matrix across manufacturers and across channels, we find that when warranty duration increases by 1%, shares will increase by around 0.35%. There are not large differences in own warranty elasticities across manufacturers or channels. The pattern of cross-elasticities for warranties looks qualitatively similar to the pattern for prices.

5.2. Manufacturer Marginal Cost and Warranty Costs

We run a semilog regression of manufacturer marginal costs on product attributes; the results are reported in Table 11. We use dummy variables for CPU, channel, and years. A negative coefficient means that CPU (channel or year) has a lower cost than the base CPU (channel or year), and a positive coefficient means a higher cost than the base. The vast majority of the

Table 10 Channel Substitution Pattern (Standard Errors in Parentheses)

	Direct fax/ phone/Web	Direct sales force	VARs	Indirect fax/ local dealer
		Price change		
Direct fax/phone/Web	−8.635 (1.828)	1.367 (0.331)	0.330 (0.140)	0.000 (0.000)
Direct sales force	0.085 (0.030)	−8.470 (2.040)	0.707 (0.210)	0.000 (0.000)
VARs	0.046 (0.021)	1.070 (0.271)	−8.872 (1.769)	0.000 (0.000)
Indirect fax/local dealer	0.035 (0.018)	0.644 (0.338)	0.148 (0.095)	−7.111 (1.174)
		Warranty change		
Direct fax/phone/Web	0.394 (0.144)	−0.072 (0.032)	−0.018 (0.007)	0.000 (0.000)
Direct sales force	−0.005 (0.002)	0.360 (0.116)	−0.035 (0.010)	0.000 (0.000)
VARs	−0.003 (0.002)	−0.052 (0.024)	0.380 (0.121)	0.000 (0.000)
Indirect fax/local dealer	−0.001 (0.001)	−0.026 (0.014)	−0.007 (0.005)	0.412 (0.129)

Notes. The impact on row channels' shares of 1% change of column channels' price or warranty. Elasticities are computed for each observation, and the medians are reported here. Standard errors are computed via bootstrapping.

Table 11 Regression of Log Manufacturer Marginal Cost on Product Attributes

Independent variable	Coeff.	Std. error	t-stat.	Warranty∗ quarter	Coeff.	Std. error	t-stat.
HP	10.5456	0.1516	69.5474				
IBM	11.2013	0.1604	69.8339	1Q1999	0.0035	0.000201	17.1683
Dell	10.2855	0.1588	64.7672	2Q1999	0.0032	0.000197	16.2613
Sun	9.7181	0.1604	60.5869	3Q1999	0.0027	0.000195	13.7471
Others	11.1517	0.2139	52.1378	4Q1999	0.0028	0.000207	13.7773
CPU1	−3.5021	0.1036	−33.8184	1Q2000	0.0032	0.000201	15.9769
CPU2	−3.3585	0.0939	−35.7788	2Q2000	0.0032	0.000201	16.0551
CPU3	−3.2046	0.0978	−32.7579	3Q2000	0.0030	0.000204	14.5623
CPU4	−2.4668	0.0970	−25.4222	4Q2000	0.0031	0.000204	14.9331
CPU5	−2.8084	0.0969	−28.9732	1Q2001	0.0032	0.000183	17.3584
CPU6	−4.4062	0.2005	−21.9773	2Q2001	0.0030	0.000186	16.2898
CPU7	−3.2256	0.1089	−29.6090	3Q2001	0.0032	0.000187	17.0166
Direct fax/phone/Web	−0.0578	0.1192	−0.4844	4Q2001	0.0031	0.000191	16.2950
Direct sales force	−0.0445	0.1088	−0.4092	1Q2002	0.0030	0.000191	15.7174
VARs	−0.1042	0.0963	−1.0814	2Q2002	0.0032	0.000192	16.5958
Direct 2000	−0.2608	0.1063	−2.4537	3Q2002	0.0029	0.000191	15.2602
Direct 2001	−0.2404	0.1021	−2.3555	4Q2002	0.0027	0.000195	13.5883
Direct 2002	−0.1926	0.1034	−1.8630	1Q2003	0.0034	0.000189	17.9527
Direct 2003	−0.2672	0.1002	−2.6659	2Q2003	0.0031	0.000188	16.6128
Direct 2004	−0.2096	0.0992	−2.1117	3Q2003	0.0031	0.000186	16.8546
Indirect 2000	−0.1924	0.1055	−1.8230	4Q2003	0.0030	0.000179	16.5154
Indirect 2001	−0.2524	0.1020	−2.4740	1Q2004	0.0026	0.000173	14.8942
Indirect 2002	−0.2106	0.1046	−2.0131	2Q2004	0.0024	0.000180	13.5433
Indirect 2003	−0.2712	0.1012	−2.6786	3Q2004	0.0025	0.000177	13.8445
Indirect 2004	−0.1652	0.0995	−1.6607	4Q2004	0.0021	0.000175	12.1996
No. of observation	5,101			R^2	0.791		
RMSE	0.709			MAPE	0.061		

Note. Brand coefficient estimates are not reported for space reasons.

cost coefficients are significant at the 1% level. IBM has the highest cost, followed by HP, Dell, and Sun. As we use indirect fax/phone/Web and local dealer as the base for channels, after controlling for other factors, servers sold via indirect fax/phone/Web and local dealer have the highest cost, followed by direct fax/phone/Web and direct sales force. Servers sold by VARs have the lowest cost. The coefficients on year-channel interactions are significantly different from zero, but not significantly different from each other. This implies that after controlling for other factors, server costs do not change much over time after 1999. All warranty coefficients are positive and highly significant, implying higher costs associated with longer warranties. Warranty coefficients fluctuate over the quarters, but there does not appear to be any trend in warranty compensation costs. Warranty costs include cost of labor and of parts. The cost of parts may have declined over time, but the cost of labor may have increased. The effects of these two costs could cancel out, resulting in insignificant temporal changes in warranty cost.

We report estimates of manufacturer margins and warranty costs in Table 12. Manufacturers on average have an 18.2% margin, varying from 22.7% for HP to 10.8% for Sun. Dell and IBM are in the middle, with 20.0% and 18.3%, respectively. Warranty costs on average account for 7.1% of manufacturer marginal costs. IBM and Dell's warranty costs make up 8.5% of marginal costs, which are only 4.9% for Sun. Are these warranty cost estimates reasonable? We assess the estimates using additional information on observed product failure rates, on the cost of extended warranties in the server market, and on manufacturer warranty accruals.

5.2.1. Observed Product Failure Rates and Implied Warranty Costs. There are no publicly available data on actual PC/server hardware reliability and repair costs. Thus, we cannot directly estimate warranty costs. Gartner obtains some hardware reliability information on business-class desktops and

Table 12 Estimates of Manufacturer Margins and Warranty Costs

		Percentage of warranty costs in total costs		
Manufacturer	Margin (%)	Mean	Median	Std. deviation
HP	22.72	7.14	7.07	3.76
IBM	18.29	8.47	9.40	3.68
Dell	20.01	8.47	9.58	3.93
Sun	10.80	4.88	3.57	3.50
Others	13.71	6.60	5.26	4.20
All	18.21	7.10	6.59	4.08

notebook PCs from PC manufacturers and warranty repair providers. Desktops purchased in 2003–2004 have an annual failure rate (AFR)[15] of 7% in Year 1 and 15% in Year 3, and the figures for notebooks are 20% and 28%, respectively. For desktops, motherboards and hard drives are the two largest sources of failures (Fiering 2006). As servers—particularly x86 servers—are close to desktops in technology, we assume servers have similar failure rates. Assuming a linear increase in desktop AFR, the Year 2 AFR will be around 11%. The simple cumulative two-year and three-year failure rates will be 18% and 33%, respectively. If the costs of parts account for 1/6–1/3 of system prices, which is roughly the cost ratio of motherboard and hard drive, two-year warranty costs of parts will be 3.0%–6.0% of prices (1/6–1/3 of 18%). This translates to 3.7%–7.3% of marginal costs, assuming 18% gross margin (the estimated margin is 18.2%—see Table 12). Warranty costs would be higher if product reliability improved over time. The average warranty duration in the data is 23.4 months, so the costs of parts in the server market should be slightly below 3.7%–7.3%. Because warranty contracts also cover labor costs, warranty costs should be higher than the above figures. Therefore, our estimated warranty cost of 7.1% of manufacturer marginal cost seems like a reasonable number.

5.2.2. Cost of Extended Warranties. As another check of the reasonableness of our warranty cost estimates, we look at the prices and implied costs for extended warranties. IBM's "3-year, onsite, 9×5, 4-hour" extended warranties cost $599.99, and the "4-year, onsite, 9×5, 4-hour" costs $1,251.99, a difference of $652. An average IBM x86 server costs $5,500, implying that extra charges for one year more warranties account for 12% of price. As manufacturers earn 30%–70% margins on extended warranty services, the increased one-year warranty costs will be 3.5%–8.3% of price, or 4.3%–10.1% of costs, and two-year warranty costs will be 8.6%–20.2% of costs. Let us take HP as another example. HP's "3 years, 4 hours, 24×7" warrenty costs $599; "4 years, 4 hours, 24×7" costs $843; and "5 years, 4 hours, 24×7" costs $1,088. A two-year increase in warranty duration will increase the price by $489. An average HP server costs $4,800, implying that two more years of warranty will take up 10.2% of server price. After accounting for manufacturer margins on extended warranties, the increased cost of warranties will be 3.1%–7.1% of price, or 3.8%–8.8% of marginal cost. Our estimates of base warranty costs are within the ranges for extended warranty costs.

[15] AFR is defined as percentage of systems within an installed base that require a hardware component replacement over a 12-month period. The replacement can be as big as the entire machine or as small as a keyboard.

5.2.3. Manufacturer Warranty Accruals. As warranty costs are future expenses, firms are required to use accrual accounting for such expenses: they first estimate future warranty expenses, charge the estimated amount (accounted for as a warranty reserve) when the sale is made, and make necessary adjustments to the estimated amount in future periods if the estimate was not correct. Thus, the average of management estimates of warranty expenses over several quarters should be a reasonable estimate of actual warranty costs. Dell's revenue deferred and costs accrued for new warranties as a percentage of total revenue range from 6.0% to 9.5% for the nine quarters from October 2003 to April 2006. Six of the nine quarters are below 8.0%. Further, there does not appear to be a trend in the percentages accrued (*Stock Market Beat* 2006). The average of our estimated warranty cost for Dell is 8.47% of total marginal cost, with a median value of 9.58% (Table 12). These numbers correspond to 7.06% and 7.98% of wholesale price, given Dell's estimated average margin of 20.0% (Table 12). Our estimates of Dell's warranty costs are well within the ranges of its warranty accruals in total revenues. Based on these three approaches, we feel that our estimates for warranty costs are reasonable. This adds further face validity to our model parameter estimates.

5.3. Value of Warranties

We first calculate the new equilibrium prices and shares under different warranty schemes by solving the system of demand and pricing equations. We then recompute manufacturer and downstream profits. The results are reported in Table 13. We next compute the change in profit between the existing warranty scheme and the hypothetical warranty schemes. The results are shown in Table 14. We can see that all manufacturers' profits increase by providing warranties. If manufacturers all offered three-month warranties, their total profits would be 82.8% of the current levels; if manufacturers did not offer any warranties, their total profits would only be 64.8% of the current levels. Sun benefits the most from offering warranties, followed by Dell, and IBM benefits the least. Sun and IBM's profits would respectively be 75.9% and 89.1% of the current numbers if all manufacturers offered three-month warranties; their profits would only be 54.6% and 73.0%, respectively, of the actual profits if no manufacturer offered warranties.

Manufacturers' warranty provision also greatly benefits downstream firms. Downstream profits would only be 81.1% of the current level if all manufacturers offered three-month warranties and only 62.6% of the current level if manufacturers did not provide any warranties. Compared with the three-month warranty scheme, warranties bring $212 in

Table 13 Estimates of Firm Profits (Million US$) Under Different Warranty Schemes

			Uniform warranty scheme					
Manufacturer	Current warranty	No warranty	3-month	6-month	9-month	1-year	2-year	3-year
HP	4,466	2,898	3,744	4,159	4,319	4,366	4,151	3,778
IBM	3,683	2,690	3,280	3,461	3,437	3,333	2,728	2,173
Dell	2,363	1,354	1,793	2,034	2,152	2,214	2,235	2,123
Sun	1,909	1,043	1,449	1,675	1,776	1,815	1,712	1,464
Others	2,327	1,578	1,943	2,111	2,251	2,195	1,905	1,820
All manufacturers	14,749	9,562	12,210	13,440	13,935	13,923	12,730	11,358
All downstream firms	4,996	3,126	4,053	4,505	4,667	4,699	4,350	3,812

Note. Standard errors are computed via bootstrapping and are available from authors.

profits per server to manufacturers and $238 in profits per server to downstream firms; compared with the zero-warranty scheme, warranties bring $432 in profits per server to manufacturers and $472 in profits per server to downstream firms.

Consistent with the theoretical predictions (Tirole 1988), manufacturers and downstream firms benefit from second-degree price discrimination by offering nonuniform warranties. As the observed mean warranty duration is close to 24 months, we compute the sorting value of warranties under the two-year uniform warranty scheme. The 1999–2004 manufacturer and channel profits would be 86.3% and 87.1% of the current levels, respectively, if all manufacturers offered two-year uniform warranties for all their products, about $168 less per server to manufacturers and $163 less per server to downstream firms. The price discrimination value of warranties varies substantially across manufacturers. Under uniform two-year warranties, HP's profits would be 92.9% of its actual level, and the corresponding numbers for IBM, Dell, and Sun are, respectively, 74.1%, 94.6%, and 89.7%. The total sorting value of warranties for HP, IBM, Dell, and Sun in 1999–2004 are, respectively, $316 million, $956 million, $128 million, and $198 million.

The counterfactual experiments also allow us to evaluate the "best" uniform warranty schemes for each manufacturer. As the analysis assumes all manufacturers provide the same uniform warranties, the best schemes are not the best in equilibrium, but the best for each firm if all firms move to that uniform warranty scheme. Firm profits change nonlinearly with warranty duration. For manufacturers as a whole, the demand-enhancing effect outweighs the cost-increasing effect up to nine-month

Table 14 Value of Warranties (Million US$)

	Total value		Price discrimination value				
Manufacturer	Against zero warranty	Against 3-month warranty	6-month	9-month	1-year	2-year	3-year
HP	1,568	722	307	148	101	316	689
IBM	993	404	222	246	350	956	1,510
Dell	1,010	570	330	212	149	128	240
Sun	867	460	234	133	94†	198	445
Others	749	383	216	76	131	422	507
All manufacturers	5,186	2,539	1,309	814	826	2,019	3,391
All downstream firms	1,870	943	491	329	298	646	1,185
Compensating variation[a]	6,557	5,972	5,266	4,621	4,002	1,633	−665
Insurance value against zero warranty[b]		585	1,291	1,936	2,555	4,924	7,222
Insurance value against 3-month warranty[c]			706	1,351	1,970	4,339	6,637

Notes. Standard errors are computed via bootstrapping and are available from authors. †denotes not significant at 10% level.

[a]Compensating variation is computed against the existing nonuniform warranty schemes; thus it captures the value of second-degree price discrimination to consumers. A positive value implies consumers are worse off.

[b]Utility differences between uniform warranty scheme and zero-warranty scheme.

[c]Utility differences between uniform warranty scheme and three-month warranty scheme.

uniform warranties. Beyond that, the cost-increasing effect will exert more weight and firm profits begin to decline with warranty duration. There are substantial variations across manufacturers. The turning point is one year for HP and Sun, six months for IBM, but two years for Dell, although the differences in Dell's profits under one-year and two-year uniform warranties are small. If all manufacturers offered three-year uniform warranties, their profits would be 77.0% of the current level, about $283 less per server, and downstream profits would be 76.3% of the current level, about $299 less per server. Therefore, the best uniform warranty schemes for HP, IBM, Dell, and Sun are, respectively, one year, six months, two years, and one year. Downstream profits will increase up to one-year uniform warranties and decrease afterwards. So, from a downstream firm's perspective, the best uniform manufacturer warranty is one year.

We compute the change in customer welfare under different warranty scenarios and the results are shown in the third row from the bottom of Table 14. We take the difference between the total value and the sorting value of warranties to obtain the insurance value of warranties to customers, which is shown in the last two rows of Table 14. We use compensating variations to measure customer welfare, so a positive value implies that customers are worse off under the hypothetical warranty scheme. We find that customers are better off with manufacturers' warranty provision. In 1999–2004, customers would require $5,972 million compensation in total, or $498 per server, to maintain the current utility level if all manufacturers offered three-month warranties, which equals 4.69% of the current server price. Customers would require $6,557 million compensation in total, or $547 compensation per server to maintain the current utility level if no warranties were provided, which is about 5.15% of the current mean server price.

Customers also benefit from the menu of warranty provision. They would require $1,633 million total compensation or $136 per server if two-year uniform warranties were provided for all servers. The associated insurance value to customers is $4,339 million in total or $362 per server if compared against the three-month warranty scheme and is $4,924 million in total and $411 per server if compared against the zero-warranty scheme.

The price discrimination value of warranties decreases, and the insurance value increases with warranty length. Customers would be willing to pay an extra $665 million in total or $55 per server, in addition to the implicit price they already pay, if all manufacturers could offer three-year uniform warranties for all their servers, which would provide $6,637 million in total and $533 per server in insurance compared with the three-month warranties, or $7,222 million in total and $602 per server in insurance if compared with the zero-warranty scheme. Compared with the three-month warranty scheme, the total insurance value for customers under six-month and one-year uniform warranty schemes is, respectively, $706 million and $1,970 million; compared with the zero-warranty scheme, the total insurance value under these two uniform schemes is $1,291 million and $2,555 million, respectively. We can see that whatever benchmark is used, the insurance value of warranties for customers is large.

6. Conclusions

Although laboratory experiments have shown the value of warranties in decision making under risk and uncertainty, and U.S. federal law requires the explicit provision of a warranty policy to buyers for any purchase exceeding $15, the value of warranties to buyers and sellers has not been empirically quantified. Moreover, there are several theoretical rationales such as insurance and sorting for warranty provision; however, such economic roles have not been investigated using market data. In this paper, we quantify the total value of warranties in the U.S. server market to manufacturers, channel intermediaries, and customers and decompose the value of a warranty into its insurance value and its sorting/price discrimination value. We find that manufacturers and channel intermediaries benefit from warranty provision and from price discrimination by offering nonuniform warranties. Customers also benefit from manufacturers offering a menu of bundled warranties. Hence, this study lends some economic justification for observed warranty policies in the server market.

One limitation of our study is that we only observe a subset of product attributes that influence a customer's choice of servers. If customers value the unobserved product attributes and if warranties are positively correlated with the unobserved attributes, the value of warranties estimated will be overstated. Our discussions with industry experts reveal that manufacturer, brand, price, CPU, and warranty are the most important factors in choosing a server, and these attributes are already included into the model, so this will reduce the severity of this problem. Further, our robustness checks seem to indicate that this is unlikely to be a major issue in our case. Nevertheless, this could be an issue in general.

In the server market, manufacturers provide hardware base warranties, extended warranties, and software and IT services. We only investigate base warranties in this paper. Customers are likely to buy extended warranties and special IT services such as data backup and recovery for mission-critical servers.

We cannot incorporate these into our model, as we do not have information on extended warranties and IT services. This is a caveat to our paper and also a venue for future research. An interesting question is how base warranties and extended warranties interact with each other, how manufacturers allocate their resources across these two types of warranties, and how customers value base warranties vis-à-vis extended warranties. Soberman (2003) provides a situation where a seller uses base warranties and extended warranties to simultaneously signal and screen, and finds that signaling can limit a seller's ability to screen. Extended warranties are provided primarily for insurance and price discrimination purposes. The market for extended warranties is growing rapidly (Lang 2004). The extant literature on extended warranties is primarily analytical (e.g., Padmanabhan and Rao 1993, Padmanabhan 1995, Lutz and Padmanabhan 1995). It will be profitable for the firms to know what type of customers are more likely to buy extended warranties and why. We hope to continue in this direction of research.

Downstream firms do more than simply sell server computers (the hardware). They provide many other services, including extended warranties and software, IT, and consulting services. These services are charged and accounted for separately. We do not have the identity of downstream firms and do not know their specific roles in the server market, nor do we have information on these services. We only estimate their markups and their costs beyond wholesale prices, which is a common approach in the empirical literature (e.g., Sudhir 2001). This is another caveat of our paper, although we provide a robustness check on the potential impact of unobserved downstream services on our results. Extended warranty service by downstream firms is another interesting area for further research. Desai and Padmanabhan (2004) study how extended warranties can be used as a channel coordination mechanism in the durable good market. A related issue is the interactions between manufacturer and retailer warranty provisions—whether they are complements or substitutes, whether warranties are overprovided and consumers are overprotected, and whether these two are mutually profit enhancing.

A third area for further research is to examine the optimality of warranty policies and to measure individual buyers' degree of risk aversion. This can be studied with more detailed warranty information like individual warranty purchases.

In sum, we have taken the first steps in empirically quantifying the value of warranties in the context of the U.S. server market. We find that warranties add significant value to manufacturers, customers, and downstream firms. We hope future research will shed further light on this important substantive issue.

Acknowledgments
This research is partially funded by the Singapore Ministry of Education's AcRF R-316-000-064-112. The second author thanks the Kilts Center for Marketing for financial support. The authors thank Jean-Pierre Dubé, Puneet Manchanda, Peter Rossi, Trichy Krishnan, V. Padmanabhan, Ivan Png, Rajiv Surendra, Soo Jiuan Tan, Julian Wright, and seminar participants at The Wharton School of the University of Pennsylvania, Columbia University, and the National University of Singapore for helpful comments. The authors thank Mary Lee for copyediting. The usual disclaimer applies.

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