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Do Consumers Understand TCO? : An
Empirical Study of Consumer Decision Making
in the U.S. Automobile Market

by

Satoshi Myojo and Yuichiro Kanazawa

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UNIVERSITY OF TSUKUBA
Tsukuba, Ibaraki 305-8573
JAPAN

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Satoshi Myojo* Yuichiro Kanazawa†

Institute of Policy and Planning Sciences

The University of Tsukuba

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Abstract

At the beginning of the 1980's, there was a gap in quality between cars made by the U.S. "Big Three" and those made by the Japanese. Since then, the Big Three have adopted Japanese production techniques, parts procurement practices, and labor relations, dramatically improving the quality of their automobiles. During the period, the Japanese manufacturers kept their automobiles more expensive than the comparable models made by the Big Three to slow

*Graduate Student, Graduate School in System & Information Engineering.

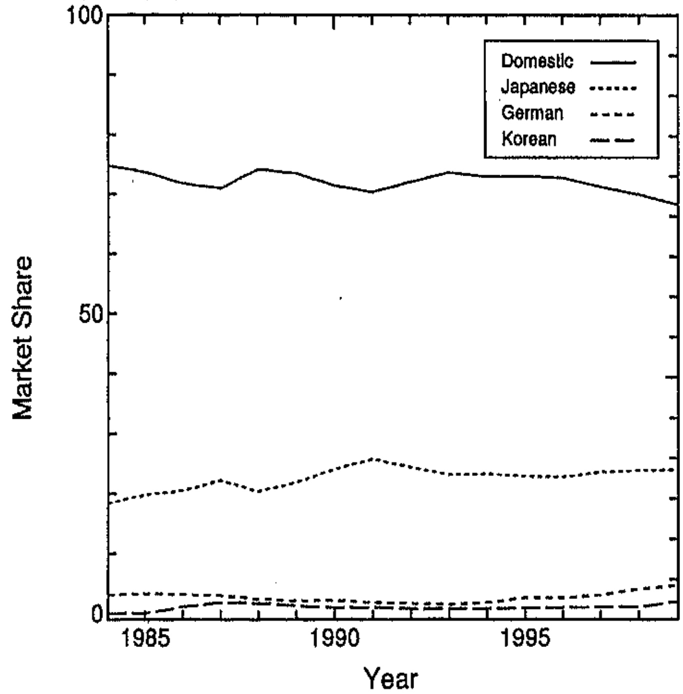
†Associate Professor of Statistics, Institute of Policy and Planning Sciences, The University of Tsukuba. Correspondence: 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573, Japan E-mail Address: kanazawa@sk.tsukuba.ac.jp. This research is partially supported by the Grants-in-Aid No.12680310 and No.14653015 for the Scientific Research from the Japanese Ministry of Education.

their sales, thereby blunting trade frictions, and preventing possible dumping complaints by the Big Three. Yet the Big Three seem to be losing overall U.S. market share, dipping to 68.3% in 1999 after fluctuating between 70–74% for the preceding two decades, while that of the Japanese automobiles increased from 19.8% in 1985 to 24.0% in 1999. To find an economic rationale underlying this trend, we formulated a hypothesis that U.S. consumers' automobile purchase decisions were influenced not by the initial purchasing prices, but by the total cost of ownership (TCO). We first proposed and illustrated a method to convert the automobiles' reliability scores in *Consumer Reports* into monetary maintenance and repair expenditure. We then calculated those expenditures, and incorporated them into the TCO calculation for the twenty-six most popular 1996-model-year vehicles. The proposed statistical model takes care of the bias introduced by partially missing reliability data. We found that the market shares of vehicles generally reflected their TCO differential when U.S. consumers chose from U.S automobiles. In medium passenger car market where the Japanese had already been offering credible alternatives by 1996, however, U.S automobiles seem to have been given "buy American" TCO premium of about $2,000.

1 Introduction

At the beginning of the 1980's, there was a gap in quality between cars made by the U.S. "Big Three" and those made by the Japanese. Since then, the Big Three have adopted Japanese production techniques, parts procurement practices, and labor relations, dramatically improving the quality of their automobiles. During the period, the Japanese manufacturers kept their automobiles more expensive than the comparable models made by the Big Three to slow their sales, thereby blunting trade frictions, and preventing possible dumping complaints by the Big Three as we see in our review of the U.S. automobile market in section 2. Yet the Big Three seem to be losing overall U.S. market share, dipping to 68.3% in 1999 after fluctuating between 70–74% for the preceding two decades, while that of the Japanese automobiles increased to 24.0% in 1999 from 19.8% in 1985. See Figure 1.

Figure 1: Transition of market shares for passenger cars and light trucks combined in the United States.



We know that reliable automobiles are less expensive to maintain and repair. They may even be able to command higher resale prices. Nichols and Fournier (1999), after having examined how reputation for quality affect pricing in the U.S. used-car markets, concluded that "adverse reputation has reduced the prices of U.S. automobiles through 1990." The question is then: did the long-term savings from reliable automobiles warrant U.S. consumers' opting for them even with their higher initial prices? Were U.S. consumers' automobile purchase decisions influenced not by the initial price, but by the total cost of ownership (TCO)—the initial price, the fuel cost, the maintenance and repair expenditure minus the resale price? We wrote this paper to investigate the validity of the hypothesis.

To answer the question concretely, we estimated the vehicle-specific TCOs in U.S. dollars for twenty-six popular 1996-model-year vehicles[1] in their first eight years[2] of ownership. They were selected from the thirty bestselling passenger cars and the twenty bestselling minivans, SUVs, and pickup trucks[3] in the United States during 1992–1999[4] and were consistently on the bestselling list throughout the period.[5] Since these popular fifty vehicles and their siblings covered 73.1% of all the vehicles sold in 1996 and covered all market segments—passenger car, minivan, SUV, and pickup truck—important to average consumers, we believe the choice is representative. We then discussed the relationship between the estimated TCO and the market share of these vehicles.

The initial price, fuel cost, and resale price components of TCO were immediately available from standard industry references (*Ward's Automo-*

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[1]The 1996 model year vehicles were selected not only because they were new enough to make the conclusions of this paper relevant, but because they were old enough to have their reliabilities well documented.

[2]The rounded median age of the vehicles on the road in the United States.

[3]Minivans, SUVs, and pickup trucks were classified as light trucks—trucks weigh less than 14,000 lb..

[4]The detailed sales figures were available to us up to and including 1999.

[5]We included Ford Windstar minivans though they were introduced in 1994 because we needed a vehicle against which the TCO of Dodge Grand Caravans could be compared.

tive Yearbook, *Consumer Reports*, and *Edmund.com*), and were adjusted for inflation. Maintenance and repair expenditure by model and year were not directly available, so we used predicted maintenance and repair expenditures based on reliability and problem rate statistics from *Consumer Reports*, the number of vehicles on the road from *Ward's Motor Vehicle Facts and Figures* and maintenance and repair cost figures from *Mitchell Mechanical Parts & Labor Estimating Guide*, calibrated to give their average corresponding to actual expenditures reported in the *Consumer Expenditure Survey.*

This paper is organized as follows. We review the outlook of the U.S. automobile market and the narrowing quality gap between U.S. and Japanese automobiles during 1985–1999 in section 2. The methods for estimating the statistical model, and for converting the information derived from the model into the maintenance and repair expenditures are described in section 3. In section 4, we present the results and discussion on the TCO vs the market share follows in section 5. Appendix A explains how we estimated the statistical model. Appendix B describes in detail how we calculated the vehicle-specific ratio for maintenance and repair expenditure.

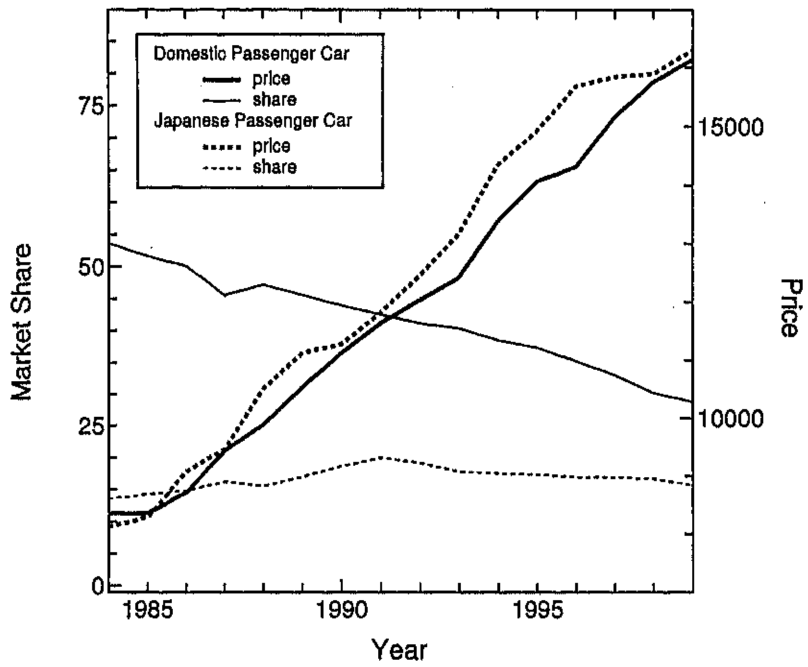
2 The U.S. Automobile Market 1985–1999

The outlook for the U.S. automobile market changed entirely during the 1985–1999 period: the share of light trucks increased from 28.8% in 1985 to 48.4% in 1999. If you look closely you will find that the share of SUVs and minivans respectively surged to 19.1% and 10.4% from 5.0% and 6.5%, while that of pickup trucks rose slowly to 18.9% from 17.3% during the period. These changing consumer preferences for automobiles require us to examine closely all four market segments.

Passenger Cars

In Figure 2, we computed the average of the lowest sticker prices quoted in the *Consumer Reports* for small (subcompact), compact, and medium cars weighted by the number of units sold (we call this the lowest average sticker price).[6] We found from the figure that the average price of passenger cars

Figure 2: The lowest average sticker price and market share of passenger cars.



with Japanese nameplates had consistently been higher than that of the

[6]This index calculation included both the U.S. manufactured and imported passenger cars. Manufacturers typically make similar versions, or trim lines, of the same model, differing mainly in standard equipment and distinctive options. We chose the lowest sticker price because the U.S. and Japanese models with basic trim lines tended to be more comparable in standard equipment and options. We did not include the automobiles categorized as "large cars" and "luxury cars" because Japanese manufacturers have rarely produced "large cars" and they introduced luxury models only in the late 1980s.

similarly equipped cars made by the Big Three since 1986, one year after the Plaza accord. An article titled "Japanese Raising Prices to Head off Trouble," Automotive News, February 24, 1992, clearly explained Japanese manufacturers' intentions in that they kept the price of their passenger cars high to slow their sales, thereby blunting trade frictions, and preventing possible dumping complaints by the U.S. car manufacturers. Yet the market share of passenger cars with Japanese nameplates increased from 13.6% in 1984 to 20.1% in 1991 mainly at the expense of the U.S. manufacturers (from 53.7% in 1984 to 42.6% in 1991) as shown in Figure 2.

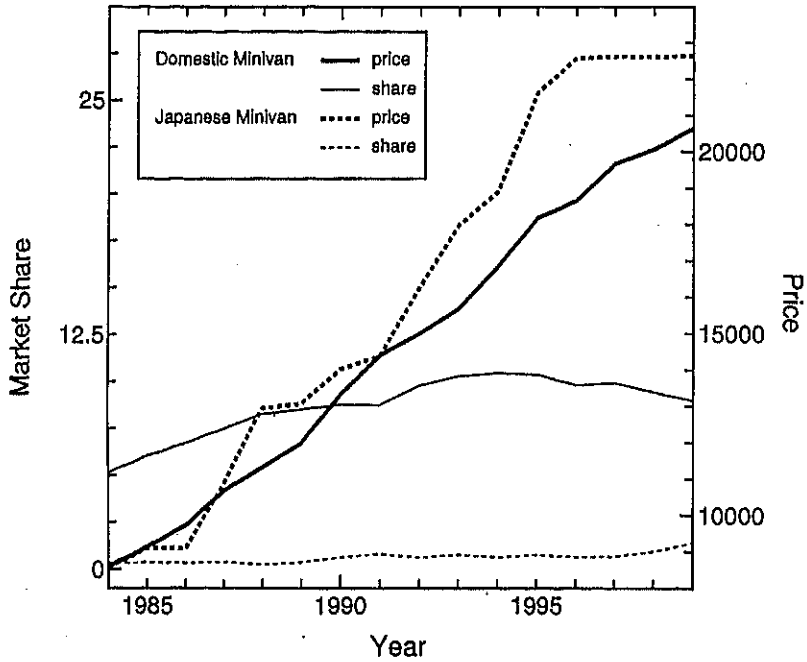
Although Japanese manufacturers had successfully moved production of cars with volume sales to the United States by 1993,[7] they maintained the pricing policy. Their market share slowly declined to 15.7% in 1999 from 19.2% in 1992 due to the changing consumer preferences to light trucks, during which the share of U.S. passenger cars shrunk by almost one-third to 28.9% in 1999 from 41.2% in 1992. In short, the fraction of consumers in this segment who purchased Japanese nameplates rose even though they were more expensive than comparable U.S. models for the 1985–1999 period.

Minivans

Since 1987 the lowest average sticker price of Japanese minivans have been higher than that of U.S. minivans as in Figure 3. The pricing policy for Japanese minivans may be explained similarly to pricing of Japanese passenger cars. However the Japanese minivans were 19.0% ($3,454) more expensive than the U.S. minivans by 1995, while the Japanese passenger cars were only

[7] The sales of Japanese passenger cars made in North America increased from 12.4% in 1986 to 51.0% of total Japanese passenger cars in 1993. This number stood at 70.5% in 1999.

Figure 3: The lowest average sticker price and market share of minivans.



6.1% ($856) more expensive than the U.S. passenger cars. This much larger price differential resulted because the Japanese manufacturers had only a few models, and until 1992 all of them had to be imported from Japan. In addition, the Japanese manufacturers raised their minivan prices after the lawsuit was filed by the Big Three in 1991, accusing some of them for exporting their minivans to the U.S. below cost. As shown in Figure 3, the share of Japanese minivans in the overall automobile market only slightly increased from 0.1% in 1983 to 0.8% in 1995, while U.S. manufactures rapidly expanded their minivans' share from 4.3% to 10.4% during the same period. Since 1997 two Japanese automakers—Toyota and Honda—have been producing minivans in North America.[8] For minivans imported from Japan, the weakening of the

[8]Toyota Motor Manufacturing, U.S.A. began producing the "Sienna" in 1997 in Kentucky. This model was designed specifically for the North American market. Honda of

Japanese yen relative to the U.S. dollar—from about 85 yen to the dollar in mid–1995 to about 110 yen in mid–1996—enabled the Japanese manufacturers to keep the price of their minivans at the level of 1996, and accordingly the Japanese minivan price differential over those made by the Big Three shrunk from $3,924 in 1996 to $1,990 in 1999. In the meantime, the share of Japanese minivans increased to 1.4% by 1999 while that of U.S. manufacturers decreased to 9.0%. In short, Japanese manufacturers' effort in the U.S. minivan market in the latter half of 1990s has made this market, which was dominated earlier by the Big Three, more competitive.

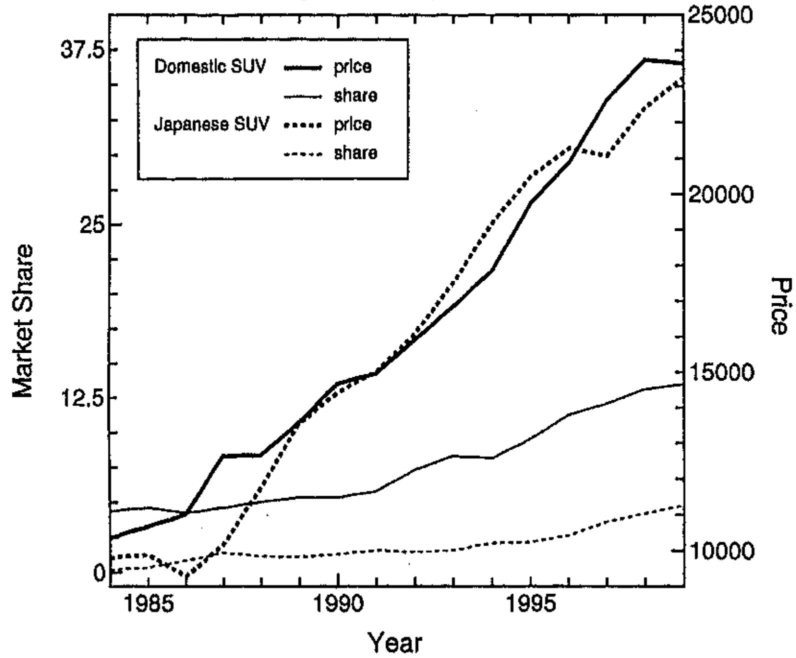
SUVs

Japanese SUVs were on the average $549 cheaper than the U.S. SUVs in 1984. The price of SUVs with Japanese nameplates, almost all were imported from Japan, increased rapidly since 1986 due to the appreciation of the Japanese yen. The U.S. government began imposing 25% tariff on imported cargo-carrying SUVs in 1989,[9] and the price increase further accelerated. By 1991 Japanese SUVs were more expensive than U.S. SUVs. See Figure 4. In 1996 Japanese manufacturers began importing car-based SUVs introduced two years earlier in the Japanese market. Those car-based smaller SUVs were broadly accepted in the U.S. market for their comfortable ride and of lower prices relative to the mainstream truck-based SUVs. Unlike passenger cars and minivans, the number of SUVs imported from Japan increased to 660,245 units in 1999 from 128,205 units in 1992 and SUVs with Japanese nameplates made in North America increased relatively slowly to 151,021

America began producing the "Odyssey" in Ontario, Canada in 1998 and in Alabama in 2001.

[9]The U.S. government also imposed a 2.5% tariff on imported passenger cars.

Figure 4: The lowest average sticker price and market share of SUVs.

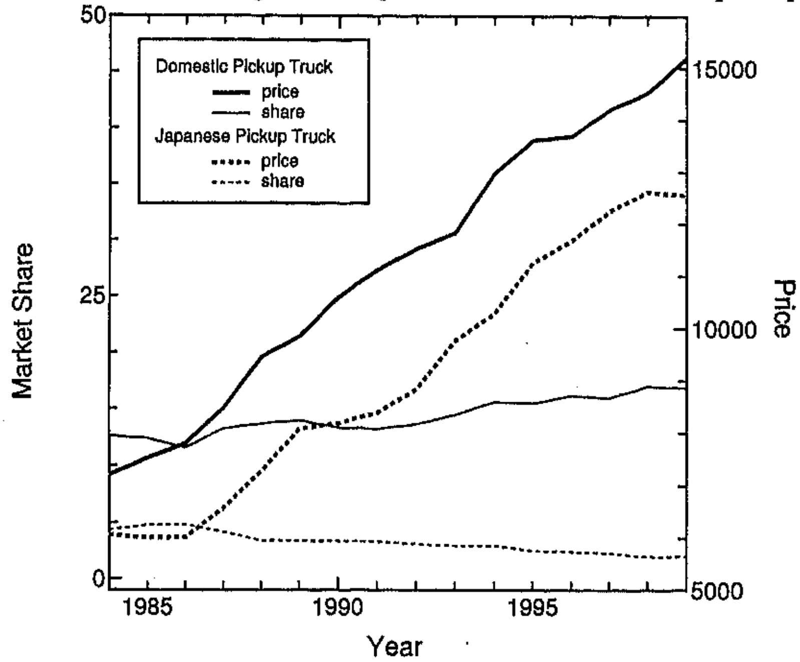


units in 1999 from 59,912 units in 1992. The Big Three, on the other hand, took different path and introduced bigger, more expensive, and thus more profitable models. They also recorded big sales during the same period. For example, sales of U.S. SUVs increased dramatically to 2,278,956 units in 1999 from 940,790 units in 1992. As a result, both U.S. and Japanese manufacturers increased SUVs' share to 13.5% and 4.8% in 1999 respectively from 4.6% and 0.4% in 1985 as shown in Figure 4. The lowest average sticker price of U.S. SUVs have been higher than that of Japanese SUVs over the past five years as seen in Figure 4 because the Big Three concentrated on bigger and more expensive models.

Pickup Trucks

Figure 5 shows the lowest average sticker price of pickup trucks. It shows that

Figure 5: The lowest average sticker price and market share of pickup trucks.



Japanese pickup trucks have consistently been about $2,000 less expensive than U.S. ones. This was because Japanese manufacturers produced mainly compact pickup trucks and the price differential reflects the difference in the target market. The share of pickup trucks by U.S. manufacturers expanded from 13.0% in 1985 to 17.0% in 1999, while the share of Japanese pickup trucks have gradually decreased from 5.0% to 2.5% as shown in Figure 5 as the U.S. consumer preference for pickup trucks shifted toward larger ones. Although Toyota introduced a full-sized pickup truck—the Tundra—in 1999 and the model has sold well, pickup trucks have remained one of the strongest and the most profitable segments for the Big Three.

The Quality Gap between The Big Three and Japanese Automobiles

In the last two decades, U.S. automobile manufacturers have made noticeable quality improvements. According to Kwoka (1998), "internal studies by the companies and some outside reports were showing that Japanese models had only 205 defects per hundred cars, whereas U.S. cars had 700 to 800 such defects" in 1980. However he noted that "GM recorded 740 defects per 100 cars assembled, it had only 162 in 1989. Ford's defect rate fell from 670 to 143 and Chrysler's from 810 to 178 respectively." Japanese automobiles' defect rates fell from 205 to 119 in the same period.

A similar trend occurs in complaints by consumers. Each year, *Consumer Reports* ask its readers to report "serious problems" on sixteen trouble spots on cars going back for eight years. A "serious problem" is one that requires a costly repair, puts the car out of commission for a time, or causes vehicle failure or a safety problem (April 1995 *Consumer Reports*). Then the data are compiled and analyzed by *Consumer Reports'* statisticians. The average number of problems its subscribers experienced with their cars in the preceding 12 months dropped to 23 in 2000 from 105 problems per 100 new cars and minivans in 1980 for U.S. manufacturers. For SUVs and pickup trucks, the Big Three improved the numbers to 24 in 2000 from 114 problems in 1980. For Japanese manufacturers, the problems for cars and minivans dropped to 11 from 34 and those for SUVs and pickup trucks improved to 12 from 41 (April 2001 *Consumer Reports*). The quality gap between the Big Three and the Japanese manufacturers narrowed considerably since 1980.

Although the quality gap have substantially narrowed, some quality differential between U.S. and Japanese–nameplate vehicles remained. In fact, the same *Consumer Reports* noted that "despite that dramatic progress, new

U.S. cars in 2000 have only improved to about the level where new Japanese cars were in 1985. And while a trouble rate of 23 problems per 100 cars is pretty good, it's still twice as many as the average Japanese car."

3 Methods

As mentioned, data for the other components of TCO is readily available, but repair and maintenance expenditure must be estimated. Ideally we would like data on maintenance and repair by year and model. What we have are:

1. Yearly data on average expenditure for automobile maintenance and repair over *all* consumers from the *Consumer Expenditure Survey*;

2. Estimates of "typical" itemized maintenance and repair cost by model for eight major mechanical systems for 1996-model-year vehicles compiled from *Mitchell Mechanical Parts & Labor Estimating Guide* 2002 part of which is listed in Table 1;

3. Design characteristics of 1996-model-year vehicles and their sales data from *Ward's Automotive Yearbooks* in 1996 and 1997;

4. The total number of up-to-eight-year-old vehicles of on the road in 1999 from *Ward's Motor Vehicle Facts and Figures* in 2000 in Figure 7;

5. The likelihoods of problems in each of the eight major systems for 1996-model-year vehicle between 1996-2001 from April 1997–2002 *Consumer Reports* part of which is also listed in Table 1;

6. Annual (1996–2001) Classifications of 1996-model-year vehicles into five (three in April 2000 issue and thereafter) reliability categories from April 1997–2002 *Consumer Reports*;

Table 1: Subsytem and total repair costs for eight major mechanical systems including labor and their reliabilities for 1996-model-year vehicles in 1999.

Major System	Subsytem	Ford Taurus	Honda Accord	Toyota Camry	···
A/C	Blower + Heater Core	$461	$973	$551	
	Compressor	$559	$594	$886	
	Total	**$1,020**	**$1,567**	**$1,437**	···
	Reliability	4	4	5	
Cooling	Water Pump	$260	$408	$324	
	Radiator + Hose	$671	$383	$558	
	Total	**$931**	**$791**	**$882**	···
	Reliability	2	5	5	
Electrical	Window Motor	$150	$182	$316	
	Wiper Motor	$148	$265	$240	
	Total	**$298**	**$447**	**$556**	···
	Reliability	2	4	4	
⋮	⋮	⋮	⋮	⋮	

Subsystems corresponding to Augst 2000 issue of *Consumer Reports* were listed.

7. Annual (1992–2001) estimates of the number of problems of 1992–2001-model-year vehicles by reliability categories in April 1993–2002 *Consumer Reports.* Table 2 is the estimates for 1996-model-year vehicle.

We will use these data to construct estimates of lifetime maintenance and repair expenditure. The *Consumer Expenditure Survey* is based on a carefully designed sample, the estimates of "typical" itemized maintenance and repair cost and design characteristics of 1996-model-year vehicles are engineering data, and the total number of up-to-eight-year-old vehicles of on the road is based on sales data. These may be presumed statistically reliable. However the samples on which reliability calculations are based are self-selected: they are solicited by *Consumer Reports.* It seems possible that owners of unreliable automobiles are overrepresented in the sample, leading to a sample selection bias. This is aggravated by the fact that if there are too few responses for a given model/model-year in some year, *Consumer Reports* reports a missing value. We next turn to a careful description of the reliability data, and the statistical methodology applied to reduce selection biases.

Predicted Reliability Score vs Reliability Summaries

There have been two automobile reliability scores published in *Consumer Reports*, "predicted reliability score" and "reliability summaries." The reliability summaries are the weighted sum of the problem rates of all problem spots year by year, car by car. *Consumer Reports* described that "the reliability summaries show how each model compares with the overall average for that model year" and "the scores in reliability summaries are on relative scale, compared with the average for all models of the same year, from much worse than average to much better than average" on a five-point scale (April 1998 *Consumer Reports*). The predicted reliability scores, on the other hand, are the judgment based on the three most recent years of reliability summaries. With their auto engineers' knowledge of the current year's models and the reliability data for the past models, *Consumer Reports* claim that they have been able to give reliability prediction for most current models.

Past experiences, however, showed that predicted reliability scores might not be as accurate as the name implied. For example, out of 103, 163 and 150 of 1996-model-year vehicles surveyed in April 1998–2000 issues respectively, 46.6 %, 45.4 %, and 44.0 % of them registered reliability summaries that were different from the reliability scores predicted in April 1997 issue. In this study we chose reliability summaries as the measurement of reliability for two reasons: first it reflected the actual response, not prediction, from the readers in Annual Questionnaire; second the way it was computed—relative to the average for all models of the same year, which can be easily determined—enabled us to calculate vehicle-specific reliability summaries.

Nonignorable Missing Value Problem

As mentioned, there are two potential problems in *Consumer Reports'* reliability summaries: the number of responses from owners of automobiles with few sales might be too limited to reliably evaluate these cars, making "insufficient data" entries to appear in their reliability summaries; comparatively more owners might have responded to their surveys if they had been dissatisfied with the reliability of their own vehicles, either out of obligation to make the information available to public, or simply to convey their frustration.

Especially the "non-ignorable" non-response problem of the latter—in sample survey terminology, a variable Y with unit nonresponse is categorized as "non-ignorably missing" if some of the Y are missing because of the underlying values it takes—could make the responses from owners of unreliable automobiles overrepresented in the sample and seriously distort the analysis. See appendix A for how these problems were addressed.

Data for estimating the statistical models

Reliability summaries were the response variable for the multinomial cumulative probability logistic regression model in equation (1) in Appendix A. We used reliability summaries for 1996 model years published in April 1997–2002 *Consumer Reports.* We assigned scores 5 to 1 to entries from much better than average to much worse than average in 1997 to 1999 issues. In

April 2000 issue and thereafter, reliability summaries were recorded on a 3 point-scale—better than average, average, worse than average—and called the "reliability verdict."[10] We assigned scores 3 to 1 to them. There were 84 (47.7%), 35 (19.9%), 47 (26.7%), 48 (27.3%), 53 (30.1%) and 63 (35.8%) missing reliability summaries out of 176 models in 1996, 1997, 1998, 1999, 2000 and 2001 respectively. We coded them as "NA" and included them. The observed data indicator was the response variable for the binomial logistic regression model in equation (3) in Appendix A. The models in (1) and (3) were simultaneously estimated.

Due to the quality of the parts, the nature of the design, or the production technique, some models suffer problems at a rate far lower or higher than what one might expect from sheer aging. Explanatory variables for model (1) were: cars' design characteristics—maximum horsepower, displacement in liters, weight in pounds and length in inches; three dummy variables, which we named "origin," indicating country of origin—U.S., Japan, and Europe[11]—of automobile manufacturers; nine "segment" category dummy variables indicating whether a vehicle was small, medium, large, luxury, sport/sporty, coupe, pickup truck, SUV and minivan; one dummy variable indicating whether the model was completely redesigned or newly introduced in 1996 by the Big Three (redesigned for short).[12] These data were taken

[10]We have strong reason to believe the five-point scale in 1997 to 1999 issues can be converted to the three-point scale in 2000–2002 issues by merging two extreme categories into one category. Thus the "much better than average" and "better than average" reliability summaries in 1997–1999 *Consumer Reports* jointly corresponded to the "better than average" reliability verdict in 2000–2002 issues. So did the "much worse than average" and "worse than average" reliability summaries in 1997–1999 issues to the "worse than average" reliability verdict in 2000–2002 issues. See Table 4.

[11]In the 1996 model year, they were German and Swedish automobiles.

[12]This variable was introduced to capture the relatively large decline in reliability re-

from *Ward's Automotive Yearbook* in 1996. Design characteristics of an automobile were those of the mid-priced models. We assume sales volume and reliability summary of each model could affect missingness of its reliability summary, and used the sales figure and reliability score as explanatory variables in model (3).

Converting the Predicted Reliability Summaries into Maintenance and Repair Expenditure Figure

To estimate the maintenance and repair expenditures that are in line with those in *Consumer Expenditure Survey*, we proceed as follows. In step 1, we obtain the average maintenance and repair expenditure *per problem* for all 1996-model-year vehicles. In step 2, we calculate *the expected number of problems* a 1996-model-year vehicle was to encounter each year from 1996 to 2003; In step 3, we calculate a series of ratios of maintenance and repair expenditure *per problem* for the particular vehicle relative to that for the "average" 1996-model-year vehicle[13] as they—both the particular vehicle and the "average" vehicle—become older from 1996 to 2003; In step 4, we multiply the three numbers in steps 1–3 to obtain the maintenance and repair expenditure for the vehicle from 1996 to 2003. Steps 2–4 were conducted for each of the thirty passenger cars and the twenty light trucks.

The method depends on availability in step 2 of annual estimates of the number of problems of 1996-model-year vehicles as they age for each of the

ported by *Consumer Reports* of the automobiles made by the Big Three in the first year of introduction or of complete redesign. We tried similar variables for automobiles made by European and Japanese manufacturers, but they were insignificant.

[13]The "average" 1996-model-year vehicle is defined as the one whose maintenance and repair expenditure *per problem* was average

five (three in 1999 and thereafter) reliability categories. Their 1996–2001 estimates were from *Consumer Reports.* Their 2002 and 2003 estimates were not yet available, but we could substitute those of 1995- and 1994-model-year vehicles in April 2002 *Consumer Reports.* Thus the 1996–2003 estimates were as shown in Table 2. The method also requires in step 3 engineering

Table 2: The annual estimates of the number of problems of 1996-model-year vehicle when its reliability falls into one of the five (three in 1999 and thereafter) categories.

	Reliability Summary				
Year	1 (1)	2 (1)	3 (2)	4 (3)	5 (3)
1996	0.490	0.402	0.283	0.258	0.190
1997	0.775	0.640	0.503	0.382	0.256
1998	0.981	0.859	0.661	0.519	0.297
1999	1.124		0.747	0.450	
2000	1.225		0.889	0.503	
2001	1.362		0.950	0.530	
2002	1.451		1.099	0.679	
2003	1.558		1.223	0.705	

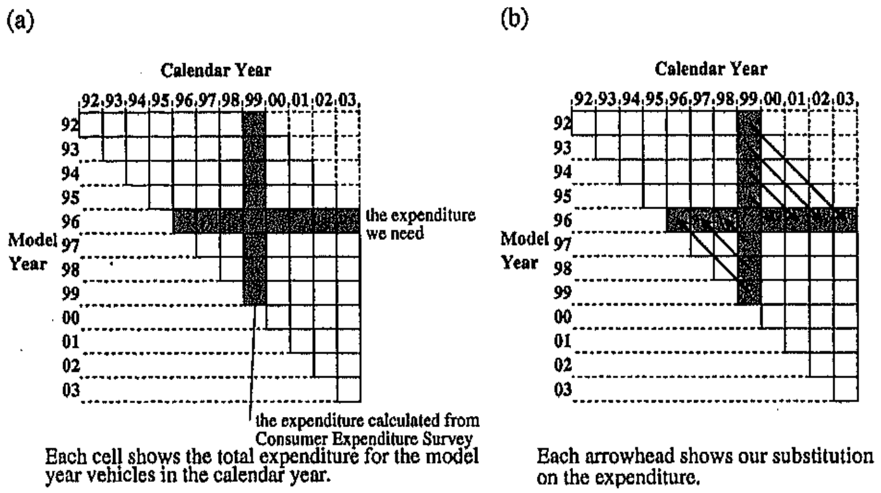
data on vehicle-specific maintenance and repair costs. They were compiled from *Mitchell Mechanical Parts & Labor Estimating Guide* and were partially listed in Table 1.

If the maintenance and repair expenditure of a vehicle depended only on how often that vehicle broke down over the eight year period, steps 1 and 2 would suffice. Step 3 is necessary because the maintenance and repair costs vary with vehicles. For instance, we found that in general vehicles made by the Big Three were more problem-prone but less expensive to fix than those made by the Europeans and Japanese because their parts were less expensive. So the maintenance and repair expenditure for vehicles made by the Big Three would be overestimated without step 3. We describe steps 1 to 3 in detail below.

Step 1

What we needed was the *longitudinal* 1996-model-year row sum in Figure 6(a) corresponding to the 1996–2003 total maintenance and repair expenditure. Dividing this total expenditure by the total number of problems in 1996–2003

Figure 6: Substituting the total maintenance and repair expenditures for the up-to-eight-year-old vehicles on the road in 1999 to those for 1996-model-year vehicles from 1996 to 2003.



for 1996-model-year vehicles with an average reliability obtains the average maintenance and repair expenditure *per problem* over the eight years.

However, what we had in the expenditure for automobile maintenance and repair in *Consumer Expenditure Survey* was *cross-sectional*, that is, it was calculated annually over all households which had varying number of vehicles of diverse models and ages. The column sum corresponding the calendar year 1999 in Figure 6(a) is the total maintenance and repair expenditure for the vehicles up to eight year old in 1999. Dividing this column sum by the number of up-to-eight-year-old vehicles on the road in 1999 and multiplying the resulting *per vehicle* expenditure figure by 1.93 vehicles *per consumer unit* in 1999 roughly obtains $664 expenditure *per consumer unit* for automobile maintenance and repair in 1999 *Consumer Expenditure Survey.* Here we assumed that the expenditure for vehicles more-than-eight-year-old resembles that for vehicles up-to-eight-year-old.[14]

However, note first that the total number of problems 1996-model-year vehicles were estimated to have encountered during 1996–1999 were close to those of 1999–1996-model-year vehicles in 1999 as shown in Table 3.[15]

Table 3: The total numbers of problems of 1996-model-year vehicles in 1996–1999 were close to those of 1–4 year old vehicles in 1999.

	Calendar Year			
Model Year	96	97	98	99
89	20,623,884			
90	17,349,773	18,173,723		
91	14,087,572	16,408,082	16,480,277	
92	10,882,526	12,999,231	14,214,657	15,451,516
93	10,015,812	11,148,243	13,151,564	15,171,855
94	8,761,880	9,350,964	11,194,401	13,577,824
95	7,024,337	10,102,470	11,061,703	12,955,254
96	**2,907,825**	**6,802,572**	**8,665,049**	**9,696,060**
97		2,166,770	6,927,226	8,846,058
98			2,231,270	6,176,128
99				3,207,738

Note also that the expenditures for automobile maintenance and repair in

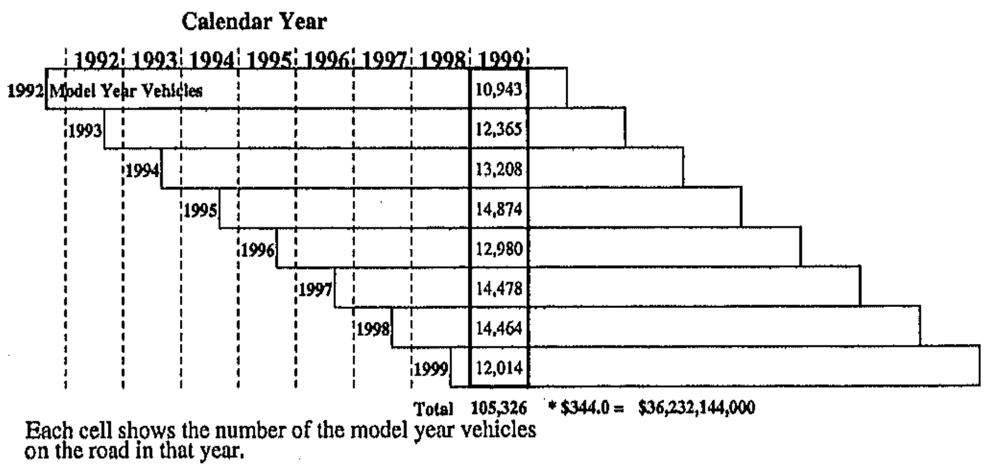
[14]Although older vehicles tend to break down more often, this does not necessarily translate into their higher maintenance and repair expenditures: owners of those vehicles are more likely to postpone some repairs or defer some maintenance work, and if they choose to have their vehicles repaired, they are more likely to opt for used or rebuilt parts.

[15]To obtain the total number—2,907,825—of problems 1996-model-year vehicles were expected to have had in 1996, we multiplied the estimated number of problems—0.283 in Table 2—of 1996-model-year vehicle with average reliability in 1996 by the number—10,275,000 in *Ward's Motor Vehicle Facts and Figures* in 2000—of 1996-model-year vehicles on the road in 1996.

Consumer Expenditure Survey were stable at $651 per consumer unit with average number of 1.9 vehicles in 1992–1999. These two facts allowed us to substitute, for instance, the total maintenance and repair expenditure for one-year-old vehicles in 1999—cell in 1999 model year row and 1999 calendar year column—for the total maintenance and repair expenditure for 1996-model-year vehicles in their first year—cell in 1996 model year row and 1996 calendar year column—as indicated in Figure 6(b).

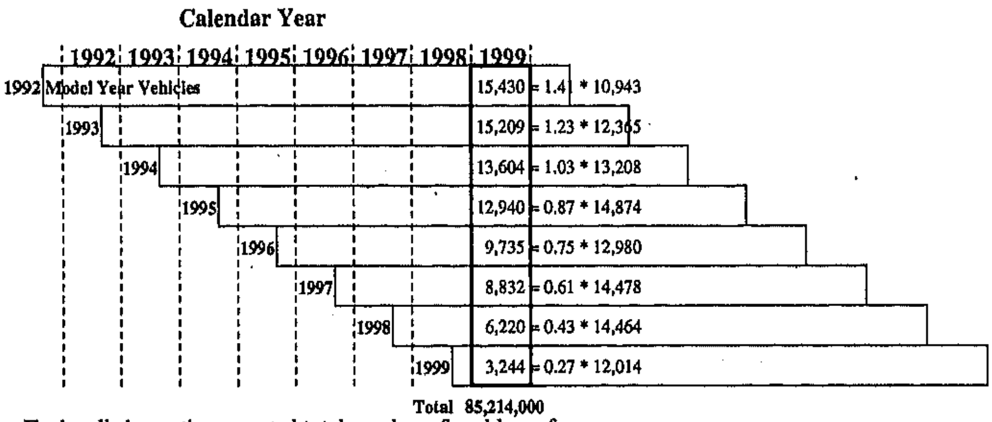
To turn the total expenditure figure into a *per problems* one, we used two numbers other than the $344 expenditure per vehicle (that is, $664 per consumer unit with 1.93 vehicles in 1999 *Consumer Expenditure Survey*) for automobile maintenance and repair: the total number—105,326,000—of up-to-eight-year-old vehicles on the road in 1999 in Figure 7 from *Ward's Mo-*

Figure 7: The total number of up-to-eight-year-old vehicles on the road in 1999 (in thousands) and their total maintenance and repair expenditure.



tor Vehicle Facts and Figures in 2000 to obtain the total maintenance and repair expenditure of $36,232,144,000≈$344×105,326,000; the numbers of problems—0.27 to 1.41—for 1992–1999 model year vehicles with average reliability in Figure 8 to obtain the total number—85,214,000—of problems for up-to-eight-year-old vehicles on the road in 1999. The average maintenance

Figure 8: The total number of problems for up-to-eight-year-old vehicles on the road in 1999.



Each cell shows the expected total number of problems for the model year vehicles on the road in that year.

and repair expenditure per problem for up-to-eight-year-old vehicles was thus \$425≈\$36,232,144,000/85,214,000. This will be used in step 4. Notice that a mechanism was embedded here in step 1 to guarantee that our estimated maintenance and repair expenditure match the expenditure for automobile maintenance and repair in *Consumer Expenditure Survey.*

Step 2

In step 2, we first used model (1) in Appendix A to predict five-category—much better than average to much worse than average—reliability distributions (three categories in 1999 and thereafter) of the thirty best-selling passenger cars and the twenty best-selling light trucks each year from 1996 to 2003. Since we could not estimate these probabilities for 2002 and 2003,[16] we used the average of 1996 to 2001 as a proxy for these two years. For instance, 1996 Ford Taurus—the most popular passenger car in 1996—was estimated to have the reliability distribution in Table 4. From Tables 2[17]

Table 4: Estimated reliability distribution for 1996 Ford Taurus.

	Reliability Summaries						
Year	1 (1)	2 (1)	3 (2)	4 (3)	5 (3)	Average	*Consumer Reports*
1996	0.113	0.281	0.421	0.140	0.045	2.72	1
1997	0.121	0.297	0.421	0.117	0.043	2.66	1
1998	0.638	0.230	0.115	0.012	0.005	1.52	2
1999	0.617		0.329	0.054		1.44	1
2000	0.528		0.389	0.083		1.55	2
2001	0.763		0.201	0.036		1.27	2
2002–03	0.598		0.313	0.089		1.49	NA

and 4, 1996 Ford Taurus' expected numbers of problems in 1996–2003 was obtained as in Table 5.[18] This process was repeated for all the fifty vehicles.

Table 5: 1996 Ford Taurus' expected number of troubles.

Calendar Year							
96	97	98	99	00	01	02	03
0.33	0.55	0.91	0.96	1.03	1.24	1.27	1.38

[16] Reliability verdicts were not yet available and so statistical models could not be estimated for these two years.

[17] In order to derive the total number of problems in 1999 in Figure 8, we used the estimates of the number of problems—0.27 to 1.41—for one-to-eight-year-old vehicles in 1999 with average reliability. In Table 2, on the other hand, we listed the estimates of the number of problems as 1996-model-year vehicles aged. Therefore the estimate of the number of problems in average reliability entry in Table 2 did not have to coincide with those in Figure 8 except that of 0.747 (rounded to 0.75 in the figure) for 1996-model-year vehicle in 1999.

[18] For instance, 1996 Taurus' expected number of problems was calculated in the year 1996 to be $0.113 \times 0.490 + \cdots + 0.045 \times 0.190 = 0.33$.

Step 3

In step 3, we calculated yearly ratio of maintenance and repair expenditure *per problem* for each vehicle relative to that for the 1996-model-year vehicle whose maintenance and repair expenditure *per problem* was average from 1996 to 2003. Taking the best selling 1996 Ford Taurus as an example, we explain how we proceeded.

Table 1 in an unabridged form gives how likely one is to face problems in eight major mechanical systems—air conditioner, cooling system, electrical system, engine, fuel system, ignition system, suspension, and transmission—and their itemized approximate repair costs for the fifty most popular 1996-model-year vehicles. If we multiply the likelihoods and their associated costs and add them up over the eight major mechanical systems to obtain yearly maintenance and repair cost of a 1996-model-year Ford Taurus in 1999, the resulting figure of $1,034 overshoot by far the actual maintenance and repair expenditure because this calculation implies that this Ford Taurus requires complete repair or replacement with new parts of the eight systems every time one of those systems breaks down. If we conduct the same calculations for the fifty vehicles,[19] the resulting estimated average figure of $1,216 far exceeds the actual maintenance and repair expenditure as reported in *Consumer Expenditure Survey*. However we assume that the ratio of the maintenance and repair *cost* per problem for the 1996 Ford Taurus relative to the "average" 1996-model-year vehicle approximates the ratio of maintenance and repair *expenditure* per problem for 1996 Ford Taurus relative to

[19]Essentially we assume here that the joint distribution of the overall repair costs and of the annual expected number of problems for the excluded vehicles is similar to that of the included vehicles. As mentioned, these popular fifty vehicles and their siblings covered 73.1% of all the vehicles sold in 1996, and we believe the choice is reasonable.

the vehicle with average realiability. The assumption implies that a vehicle whose maintenance and repair expenditure would be high if it was repaired completely or its parts was replaced by the new ones should cost owners proportionally higher when it was repaired partially or its parts were replaced with used or rebuilt ones. The assumption was needed because *Consumer Reports* were asking for reliabilities on the major systems, but not on their subsystems. Thus we could not estimate the average cost of breakdowns, some of which require replacement of the whole major system, others which require partial replacement and still others might require only minor adjstments. For instance, the maintenance and repair expenditure ratios of 1996 Ford Taurus were shown in Table 6. Their details are in Appendix B.

Table 6: The maintenance and repair expenditure ratios of 1996 Ford Taurus relative to the average of the fifty popular vehicles.

	Calendar Year							
	96	97	98	99	00	01	02	03
Weight	0.93	0.79	0.79	0.85	0.88	0.88	1.10	1.25

4 Results

Reliability Model Estimation

The final models are listed in Table 7. Confirming conventional wisdom, 1996-model-year vehicles made by Japanese manufacturers had consistently higher reliability summaries than those made by the U.S. or European manufacturers in 1996–2001 at 99% level of significance.

Other covariates were significant in some years. The 1996-model-year European (German and Swedish) vehicles were more reliable than U.S. vehicles

Table 7: Estimated parameters of the multinomial logistic regression models.

Model (1) for reliability summaries						
Variable	1996	1997	1998	1999	2000	2001
θ_1	−4.88***	−3.59***	−3.86***	−3.06***	−2.87***	−1.92*
	(-4.46)	(-4.45)	(-3.66)	(-3.34)	(-2.98)	(-1.89)
θ_2	−3.25***	−1.94**	−2.55**	-0.672	-0.581	0.194
	(-3.19)	(-2.57)	(-2.50)	(-0.77)	(-0.63)	(0.19)
θ_3	-1.34	0.0464	-0.415			
	(-1.37)	(0.06)	(-0.42)			
θ_4	0.240	1.48*	0.816			
	(0.24)	(1.93)	(0.80)			
Displacement	0.608**					
	(2.33)					
Max. horsepower		0.00805*	0.00849*	0.0177***	0.0149***	0.0155**
		(1.81)	(1.75)	(3.22)	(2.58)	(2.45)
Japan	−3.36***	−3.27***	−2.94***	−2.80***	−3.74***	−4.48***
	(-5.25)	(-7.00)	(-6.22)	(-5.57)	(-6.15)	(-6.34)
Europe		−1.30**	-0.76	-0.99	-1.07	−2.14***
		(-2.01)	(-1.11)	(-1.45)	(-1.56)	(-2.97)
Small	2.13***		0.87			
	(3.06)		(1.35)			
Large		-0.94		−1.33**	−1.54**	−2.00***
		(-1.47)		(-1.98)	(-2.20)	(-2.68)
Luxury		-1.40		−2.09**	-1.88	−2.59*
		(-1.25)		(-2.54)	(-1.50)	(-1.89)
Coupe	4.27***	2.57***	2.59***	0.98	1.20	
	(3.46)	(3.22)	(3.01)	(1.06)	(1.28)	
Sporty		1.89***	1.98**			2.15
		(2.70)	(2.42)			(1.27)
Minivan	2.67***	1.91***	1.54**	0.79	0.83	1.48*
	(3.15)	(3.32)	(2.53)	(1.34)	(1.36)	(1.74)
SUV	1.34**	1.47***	2.02***	2.05***	1.47**	
	(1.96)	(2.75)	(3.58)	(2.97)	(2.19)	
Pickup truck	1.80***	1.62***	1.26**			-0.83
	(2.70)	(2.64)	(2.05)			(-1.16)
Redesigned	1.00		2.73***			
	(1.03)		(2.82)			
Model (3) for observed indicator						
Variable	1996	1997	1998	1999	2000	2001
Intercept	−1.46*	−2.82**	−1.44*	−2.80***	−1.68**	−2.48***
	(-1.87)	(-2.45)	(-1.83)	(-2.75)	(-1.96)	(-3.30)
Sales Volume	$3.70 * 10^{-5}$***	$15.8 * 10^{-5}$***	$7.01 * 10^{-5}$***	$10.9 * 10^{-5}$***	$7.31 * 10^{-5}$***	$6.12 * 10^{-5}$***
	(5.70)	(4.76)	(5.06)	(5.28)	(5.32)	(5.70).
Reliability summary	-0.234	0.203	0.0294	0.294	-0.0112	0.293
	(-1.53)	(0.79)	(0.15)	(0.75)	(-0.04)	(1.05)
AIC	320.34	411.16	399.77	281.5	273.69	248.07

*,**, and *** represent significance at the ten, five, and one percent level respectively.

Asymptotic t–values of the coefficients appear in parentheses.

in 1997 and 2001. Coupes, minivans, and pickup trucks were significantly less reliable than medium cars in three years following their purchases, but their reliabilities held up well afterwards. On the other hand, there were persistent reliability problems for SUVs relative to medium cars. The automobiles completely redesigned or newly introduced in 1996 by the Big Three were possibly unreliable in 1996 and they were significantly unreliable at 99% level of significance in 1998.

Missingness in reliability summaries consistently showed that it was highly correlated with the sales volume. A vehicle with higher sales volume was less likely to have its reliability summary missing. We could not totally exclude the possibility that owners of a relatively new automobile whose reliability was worse than average responded to *Consumer Reports'* Annual Questionnaire more frequently than owners whose automobile showed better than average reliability. For example, in 1996 automobiles with higher reliabilities were more likely to have their reliability summaries missing, implying that the overall reliability average for 1996-mode-year vehicles could have been deflated by this self-selection bias. Because *Consumer Reports* evaluates the reliability of automobiles on a relative scale within a model year, this meant that the reliability summaries of 1996–model–year vehicles in 1996 could have been inflated.

Maintenance and Repair Expenditures

We listed the estimated maintenance and repair expenditures for the twenty-six consistently popular passenger cars and light trucks mentioned on page 4. In decreasing order of sales in 1996 within their categories, they were: Ford Escorts, Saturn SLs, Honda Civics, Chevrolet Cavaliers, and Toyota Corollas as small cars; Ford Tauruses, Honda Accords, Toyota Camries, Chevrolet Luminas, Nissan Maximas, and Pontiac Grand Prixes as medium cars; Buick LeSabres, Ford Crown Victorias, Cadillac DeVilles, and Lincoln Town Cars as large cars;[20] Ford Explorers, Chevrolet Blazers, Jeep Grand Cherokees as SUVs; Dodge Grand Caravans and Ford Windstars as minivans; Ford Rangers, Chevrolet S-10 pickup trucks, and Dodge Dakotas as compact pickup trucks; Ford F-150s, Chevrolet C1500s, Dodge Ram pickup trucks as fullsize pickup trucks. Their estimated maintenance and repair expenditures

Table 8: Vehicle-specific expected maintenance and repair expenditures for the twenty-six 1996-model-year vehicles (in 1996 U.S dollars).

		Estimated Maintenance and Repair Expenditure(U.S.$)								
	Model	1996	1997	1998	1999	2000	2001	2002	2003	Total
Small Car	Ford Escort	127	152	222	229	247	339	396	388	2,100
	Saturn S	153	191	340	353	509	717	676	703	3,641
	Honda Civic	95	129	178	200	206	232	399	372	1,810
	Chev. Cavalier	109	185	258	323	350	510	580	543	2,858
	Toyota Corolla	111	144	197	239	223	227	298	320	1,758
Medium Car	Ford Taurus	132	185	306	349	386	463	598	734	3,153
	Honda Accord	127	164	197	288	410	416	414	558	2,574
	Toyota Camry	106	163	180	297	368	411	446	545	2,516
	Chev. Lumina	116	219	308	390	408	603	650	458	3,151
	Nissan Maxima	110	186	225	331	282	274	346	463	2,218
	Pontiac Grand Prix	116	235	367	456	465	530	569	647	3,386
Large Car	Buick LeSabre	116	174	308	353	387	557	490	464	2,849
	Ford Crown Victoria	128	168	245	303	278	360	378	500	2,360
	Cadillac DeVille	248	329	440	516	609	738	779	938	4,596
	Lincoln Town Car	106	145	239	286	310	313	408	349	2,157
SUV	Ford Explorer	116	199	262	302	337	423	370	540	2,549
	Chev. Blazer	364	355	432	446	484	506	580	612	3,779
	Jeep Grand Cherokee	121	241	349	422	504	610	626	719	3,592
Minivan	Dodge Grand Caravan	155	203	298	341	377	528	510	551	2,963
	Ford Windstar	136	184	231	346	419	500	679	734	3,229
Compact Pickup Truck	Ford Ranger	138	172	232	257	242	331	302	484	2,160
	Chev. S-10 Pickup	313	367	292	369	442	467	588	512	3,350
	Dodge Dakota	155	311	333	433	423	570	627	607	3,457
Fullsize Pickup Truck	Ford F-150	137	195	276	288	352	351	459	542	2,600
	Chev. C1500 Pickup	132	259	301	359	378	478	446	499	2,852
	Dodge Ram Pickup	172	308	392	476	483	549	648	603	3,630

[20] Cadillac DeVilles, and Lincoln Town Cars were categorized as luxury cars in April 2000 *Consumer Reports*, but they were classified as large cars in April 1996.

adjusted for the rate of inflation in the CPI[21] are listed in Table 8.

We found that on average owners would pay $2,434, $2,833, $2,991, $3,307, $3,096, or $3,008 in 1996 U.S. dollars during 1996–2003 respectively if they operated one of the listed small cars, medium cars, large cars, SUVs, minivans, or pickup trucks purchased in 1996. As expected the small cars were least expensive to maintain and repair and the medium cars follow.

The small and medium passenger cars produced by Japanese manufacturers were inexpensive to maintain and repair relative to the comparable models from the Big Three because they were more reliable, although their higher parts costs partially offset their reliability advantage. For instance, Ford Escorts would encounter 1.6 times more troubles than Honda Civics in their lifetime, but their maintenance and repair expenditures differed by only $290 for the first eight years. Similarly Ford Tauruses was nowhere near as expensive as their trouble rates indicated because their cost of repair was lower than that of Honda Accords, Toyota Camries, or Nissan Maximas.

Vehicle Total Cost of Ownership (TCO)

We calculated TCOs for the twenty-six 1996-model-year vehicles for the first eight years of ownership. They included the initial price, the fuel cost, the maintenance and repair expenditure minus the resale price. We assumed that differences in insurance costs and costs of financing were negligible within a market segment because vehicles were compared with others in the same segment, and did not include them. We adjusted the fuel cost, the maintenance and repair expenditure stream, and the resale price at the end of eight years of ownership using the rate of inflation in the CPI to obtain the TCOs in 1996 U.S. dollars when the vehicle was purchased. In Table 9, the figures for

[21] Average rate of inflation in CPI during 1996–2001 was 2.45% a year.

each model were in dollar amount relative to that of the vehicle listed at the top within its own segment.

Table 9: Inflation adjusted total cost of ownership of the twenty-six 1996-model-year vehicles for the first eight years of ownership (in 1996 U.S. dollars) relative to the vehicle listed at the top within its own segment.

			Relative Price				TCO
	Model	Trim Line	Initial Price	Maintenance and Repair	Fuel	Resale Price	Differential
Small Car	Ford Escort	4Dr LX Sedan	0	0	0	0	0
	Saturn SL	4Dr SL2 Sedan	780	1,541	-256	516	1,548
	Honda Civic	4Dr LX Sedan	2,075	-290	-480	1,568	-262
	Chev. Cavalier	4Dr LS Sedan	1,490	758	143	-17	2,408
	Toyota Corolla	4Dr DX Sedan	2,423	-342	-372	1,020	689
Medium Car	Ford Taurus	4Dr LX Sedan	0	0	0	0	0
	Honda Accord	4Dr LX V6 Sedan	1,350	-579	0	2,386	-1,614
	Toyota Camry	4Dr LE V6 Sedan	1,338	-636	-416	2,022	-1,736
	Chev. Lumina	4Dr LS Sedan	-2,935	-1	0	189	-3,125
	Nissan Maxima	4Dr SE Sedan	1,554	-935	-597	2,015	-1,993
	Pontiac Grand Prix	4Dr SE Sedan	-3,901	234	503	257	-3,421
Large Car	Buick LeSabre	4Dr Custom Sedan	0	0	0	0	0
	Ford Crown Victoria	4Dr LX Sedan	1,285	-488	264	205	856
	Cadillac DeVille	4Dr Sedan	0	0	0	0	0
	Lincoln Town Car	4Dr Signature Sedan	2,965	-2,439	-721	7	-203
SUV	Ford Explorer	4Dr 4WD XL Wagon	0	0	0	0	0
	Chev. Blazer	4Dr 4WD STD Wagon	604	1,230	0	28	1,806
	Jeep Grand Cherokee	4Dr 4WD Laredo Wagon	3,681	1,043	787	534	4,977
Minivan	Dodge Grand Caravan	LE Passenger Van	0	0	0	0	0
	Ford Windstar	LX Passenger Van	350	266	-264	94	258
Compact	Ford Ranger	2Dr XLT Regular Cab SB	0	0	0	0	0
Pickup Truck	Chev. S-10 Pickup	2Dr LS Regular Cab SB	467	1,190	328	-72	2,058
	Dodge Dakota	2Dr XLT Regular Cab SB	1,095	1,298	328	-176	2,897
Fullsize	Ford F-150	2Dr XL Regular Cab SB	0	0	0	0	0
Pickup Truck	Chev. C1500 Pickup	2Dr Reglar Cab SB	346	252	418	170	846
	Dodge Ram 1500	2Dr LT Regular Cab SB	-44	1,030	1,448	-272	2,706

For the initial price, we used the *manufacturer suggested retail price* quoted from the *Ward's Automotive Yearbook* in 1997. For the fuel cost, we assumed that each model traveled 12,000 miles per year for eight years and the yearly prices for regular and premium gasoline were the U.S. city average retail prices in 1996–1999.[22] Fuel mileages for these models were

[22] 2000–2003 prices were the average of the first four years.

taken from April 1997 *Consumer Reports*. The inflation adjusted maintenance and repair expenditures were the eight-year total in Table 8. Since 1996-model-year vehicles will be eight years old only in 2004, we used resale prices in September 2002 of the twenty six 1994-model-year vehicles quoted from *Edmund.com*.

The initial purchasing price advantage of Ford Escorts relative to Honda Civics or Toyota Corollas was respectively totally reversed or considerably narrowed in terms of the TCO. Particularly, Honda Civics whose high initial price differential with respect to Ford Escorts were considerably narrowed by their high resale price had the lowest TCO among the five models in the segment due to their lower maintenance and repair expenditure and higher mileage.

The maintenance and repair expenditure and resale price advantages for Honda Accords and Toyota Camries totally reversed more than $1,300 of their initial price disadvantages relative to Ford Tauruses. Nissan Maximas showed similar pattern as Accords and Camries. On the other hand two medium passenger vehicles from GM kept their TCO advantage over Ford Tauruses almost solely because of their lower initial prices.

The initial price difference of $1,285 between Buick LeSabres and Ford Crown Victorias was reduced to $856 TCO difference. In the luxury car segment, difference in the initial prices between Cadillac Devilles and Lincoln Town Cars was close to $3,000, but the TCO of the latter was $203 lower due to much lower maintenance and repair expenditure and fuel cost for Lincoln Town Cars. Ford Explorers had smaller TCO than Chevrolet Blazers due to their lower initial price and maintenance and repair expenditure advantage. Dodge Grand Caravans were somewhat less expensive to purchase and maintain relative to Ford Windstars. Their TCO advantage rose to about $258 for the first eight years of ownership.

5 Discussion

In section 4, we discussed how differences in each of the components affected the TCO differences within a market segment. We also learned that some vehicles were noticeably more expensive to own and operate than the others even if they were offered to the same market segment. In section 5, we discuss the relationship between the TCO and the market share of these vehicles.

Consumers typically choose automobiles for price, safety, reliability, fuel economy, performance, comfort, convenience, availability, brand-name recognition/loyalty, design, and/or availability of certain features/options. So we do not necessarily expect low TCO vehicles to sell well, nor should we. In volume sales segments where utility and value of an automobile is critically scrutinized, however, it is reasonable to expect that U.S. consumers are aware of the cost of owning a vehicle for an extended period of time at least to some extent. Over time competing models within the same market segment tend to converge and become even more similar. That should mean that TCO should be meaningful. Notice that TCO differential column in Table 9 should have shown monotonically increasing patterns within a segment if U.S. consumers in 1996 were basing their automobile purchase decisions solely on the TCO.

The market shares for large passenger cars, SUVs, minivans, compact and full size pickup trucks all seemed to reflect their TCO differentials faithfully. Buick LeSabres with $856 smaller TCO than Ford Crown Victorias were the best selling large cars in 1992–1999 period. Ford Explorers with the smallest TCO have been the best selling SUVs since it first appeared in 1992 and Chevrolet Blazers had been trailing. Dodge Grand Caravans with

$258 TCO advantage over Ford Windstar had long dominated the minivan market with their sibling Chrysler Town & Countries. Ford Rangers with $2,058 smaller TCO than Chevrolet S-10s and Ford F150s with about $846 TCO advantage over Chevrolet C1500s had been the best selling compact and full size pickup trucks respectively. It was interesting that vehicles in these five market segments were all manufactured by the Big Three.

In luxury passenger car segment, Cadillac Devilles with $203 higher TCO than Lincoln Town Cars have been the best selling vehicles with 1992–1999 average sales of 109,000 units, but Town Cars trailed Devilles only by 8,000 units on the average. There are two possible explanations for this. One is that the almost $3,000 higher initial purchasing price of Town Cars was too much upfront for some U.S. consumers to take even if it was eventually more than offset by their strikingly low maintenance and repair expenditure. The other is that consumers in this market may not be so sensitive to cost of owning a vehicle and the $203 higher TCO for Devilles did not amount to much.

In small and medium passenger car segments where the Japanese had already been offering credible alternatives by 1996, however, the market shares recorded in that year did not seem to have reflected their TCO differentials. For instance, Honda Civics should have been selling better than Ford Escorts in small passenger car segment. Also any one of the five cars should have been selling better than Ford Tauruses in medium passenger car segment.

In small passenger car segment, however, there was at least a reasonable correspondence between the TCO and the market share among the three U.S. cars—Ford Escorts, Saturn SLs, and Chevrolet Cavaliers. In medium passenger car segment, on the other hand, even among U.S. cars we were surprised to have found that Chevrolet Luminas and Pontiac Grand Prixes had not been able to attract enough customers during 1992–1999, despite the fact that their respective initial price advantages of $2,900 and $3,900 over Ford Tauruses almost remained as their TCO advantages.

The $262 TCO advantage of Honca Civics over Ford Escorts might not have been apparent to U.S. consumers, but the $1,614, $1,736, and $1,993 TCO advantage of Honda Accords, Toyota Camries, and Nissan Maximas respectively over Ford Tauruses should have been. Thus an interesting new hypothesis coming out of Table 9 is that U.S. consumers were willing to pay a premium of about $2,000 for American medium passenger cars. When you looked the market shares over the period of several years, however, we could portray pictures more sympathetic to our original hypothesis. For instance, Toyota Camries with relatively small TCO in the medium car segment increased their sales volumes significantly from 257,466 units in 1989 to 448,162 units in 1999 as Toyota's production capacity in the U.S. increased significantly during these years. To learn whether U.S. consumers were willing to pay premium for American cars or their purchase decisions were based strictly on TCO, we first need to examine the extent to which the sales figures in these markets were distorted by the fleet sales to rental car companies some of the automobile manufacturers owned at least partially. Then we need to track the TCO fluctuations over a period of time and how they correlate with the sales figures. We leave these efforts for future research.

A Multinomial Regression Model for Potentially Nonignorably Missing Survey Responses

In appendix A, we summarize the method for estimating parameters in multinomial logistic regression models when the response variable **Y** was partially missing and the missing data mechanism was potentially nonignorable, and the explanatory variables were fully observed. This framework was presented by Ibrahim and Lipsitz (1996) for binomial logistic regression model. We extended the model to multinomial logistic regression.

The model consists of the joint distribution of the multinomial ordinal response variable $\mathbf{Y}$ and the binomial observed data indicator $\mathbf{R}$, ith of which takes 0 when the ith of the $\mathbf{Y}$ is not oberved. Since the explanatory variables $\mathbf{X}$ are fully observed, they are treated as fixed throughout. In this paper $\mathbf{Y}$ represents reliability scores and takes integral value from 1 (much worse than average) to 5 (much better than average) and $\mathbf{X}$ includes several design characteristics, car types, and the country origins of car manufacturers. We express the joint distribution $\mathbf{R}$ and $\mathbf{Y}$ by specifying the conditional distributions $\mathbf{Y}|(\boldsymbol{\theta},\boldsymbol{\beta})$ and $\mathbf{R}|\mathbf{Y},\boldsymbol{\alpha}$, where $(\boldsymbol{\theta},\boldsymbol{\beta})$ and $\boldsymbol{\alpha}$ are assumed to be distinct sets of indexing parameters for their respective distributions.

Suppose y_i, $i = 1,\ldots,n$, are independent multinomial observations with the cumulative probability ψ_{ij} up to and including jth category. Further, let $\boldsymbol{x_i} = (x_{i1},\ldots,x_{ip})$ denote the $1\times p$ observed vector of explanatory variables for the ith observation, $\mathbf{X}$ is an $n\times p$ matrix of explanatory variables, and let $\boldsymbol{\beta} = (\beta_1,\ldots,\beta_p)^T$ denote the corresponding $p\times 1$ column vector of regression coefficients. We use a parallel logistic regression model for the ψ_i's

$$\log\{\psi_{ij}/(1-\psi_{ij})\} = \theta_j - \boldsymbol{\beta}^T\boldsymbol{x}_i, \quad j = 1,\ldots,k-1 \tag{1}$$

with the likelihood for $y_i|\boldsymbol{x}_i$ is given by

$$\begin{aligned} & L_{y_i}(\boldsymbol{\theta},\boldsymbol{\beta}) \\ = \; & \Pi_{j=1}^{k}(\psi_{ij}-\psi_{ij-1})^{y_{ij}} \\ = \; & \Pi_{j=1}^{k}\left\{\frac{\exp(\theta_j-\boldsymbol{\beta}^T\boldsymbol{x}_i)}{1+\exp(\theta_j-\boldsymbol{\beta}^T\boldsymbol{x}_i)} - \frac{\exp(\theta_{j-1}-\boldsymbol{\beta}^T\boldsymbol{x}_i)}{1+\exp(\theta_{j-1}-\boldsymbol{\beta}^T\boldsymbol{x}_i)}\right\}^{y_{ij}}, \end{aligned} \tag{2}$$

where $y_{ij} = 1$ if $y_i = j$, $y_{ij} = 0$ otherwise.
The negative sign in (1) is a convention ensuring that large values of $\boldsymbol{\beta}^T \boldsymbol{x}$ lead to an increase of probability in the higher–numbered categories. Since θ_j estimates logistic transformation of the cumulative probability up to and including category j, $\theta_1 \le \theta_2 \le \cdots \le \theta_{k-1}$ must be satisfied.

The observed data indicator for the ith response y_i can be written as

$$r_i = \begin{cases} 1 & \text{if } y_i \text{ is observed,} \\ 0 & \text{if } y_i \text{ is missing,} \end{cases}$$

for $i = 1, \ldots, n$. The vector $\boldsymbol{r} = (r_1, \ldots, r_n)^T$ is $n \times 1$ column vector of observed data indicators. We specify a logistic regression model for the r_i's. Let $\boldsymbol{z}_i = (\boldsymbol{x}_i, y_i)$ and let $\boldsymbol{\alpha} = (\alpha_1, \ldots, \alpha_{p+1})^T$ be a $(p+1) \times 1$ column vector of indexing parameters for r_i. We define $p_i = \Pr\{r_i = 1 | \boldsymbol{z}_i, \boldsymbol{\alpha}\}$ and the logisitic regression model for the p_i's is

$$\log\{p_i/(1-p_i)\} = \boldsymbol{z}_i \boldsymbol{\alpha}, \tag{3}$$

where the likelihood for r_i is

$$\begin{aligned} L_{r_i|y_i}(\boldsymbol{\alpha}) &= \left(\frac{p_i}{1-p_i}\right)^{r_i} (1-p_i) \\ &= \exp\left[r_i \boldsymbol{z}_i \boldsymbol{\alpha} - \log\{1 + \exp(\boldsymbol{z}_i \boldsymbol{\alpha})\}\right]. \end{aligned} \tag{4}$$

If $\alpha_{p+1} \neq 0$ or α_{p+1} is significantly different from zero, then the missing data mechanism depends on y_i and thus nonignorable. If $\alpha_{p+1} = 0$, then $f(r_i | \boldsymbol{z}_i, \boldsymbol{\alpha})$ does not depend on y_i, but may depend on $\boldsymbol{x}_i$. When this happens the missing data mechanism is referred as ignorable. If $\alpha_2 = \cdots = \alpha_{p+1} = 0$, then the observed sample is effectively random subsample of the sample.

Under the assumption that $\boldsymbol{\alpha}$ and $(\boldsymbol{\theta}, \boldsymbol{\beta})$ are distinct sets of indexing parameters, the log–likelihood for all of the observations can be decomposed from (2) and (4) as

$$
\begin{aligned}
l(\boldsymbol{\tau}) &= \sum_{i=1}^{n} l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i) = \sum_{i=1}^{n} \{l_{y_i}(\boldsymbol{\theta}, \boldsymbol{\beta}) + l_{r_i|y_i}(\boldsymbol{\alpha})\} \\
&= \sum_{i=1}^{n} \left[y_{ij} \log \left\{ \frac{\exp(\theta_j - \boldsymbol{\beta}^T \boldsymbol{x}_i)}{1 + \exp(\theta_j - \boldsymbol{\beta}^T \boldsymbol{x}_i)} - \frac{\exp(\theta_{j-1} - \boldsymbol{\beta}^T \boldsymbol{x}_i)}{1 + \exp(\theta_{j-1} - \boldsymbol{\beta}^T \boldsymbol{x}_i)} \right\} \right. \\
&\qquad \left. + r_i \boldsymbol{z}_i \boldsymbol{\alpha} - \log\{1 + \exp(\boldsymbol{z}_i \boldsymbol{\alpha})\} \right], \qquad (5)
\end{aligned}
$$

where $\boldsymbol{\tau} = (\theta_1, \ldots, \theta_{k-1}, \beta_1, \ldots, \beta_p, \alpha_1, \ldots, \alpha_{p+1})^T$ is a $(k + 2p) \times 1$ column vector of logistic regression parameters and $l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i)$ is the contribution to the log–likelihood from the ith observation. The log–likelihood in (5) essentially treats the y_i's as missing covariates in the model for $(r_i|\boldsymbol{z}_i, \boldsymbol{\alpha})$. Thus following Ibrahim (1990) and Abe et.al (1998), the maximum likelihood estimates of $\boldsymbol{\tau}$ can be obtained via the EM algorithm by maximizing the expected log–likelihood whose ith individual contribution is

$$
E[l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i)] = \begin{cases} \sum_{y_i=1}^{k} l(\boldsymbol{\tau}, \boldsymbol{x}_i, y_i, r_i) f(y_i|r_i, \boldsymbol{x}_i, \boldsymbol{\tau}) & \text{if } y_i \text{ is missing,} \\ l(\boldsymbol{\tau}; \boldsymbol{x}_i, y_i, r_i) & \text{if } y_i \text{ is observed.} \end{cases} \qquad (6)
$$

The E–step in (6) takes the form of a weighted log–likelihood with the conditional probabilities $f(y_i|r_i, \boldsymbol{x}_i, \boldsymbol{\tau})$ of the missing data given the observed data playing the role of ratios. The M–step maximizing the function in (5), which is equivalent to completing data maximum likelihood with each incomplete observation replaced by a set of weighted "filled–in" observations with weight $f(y_i|r_i, \boldsymbol{x}_i, \boldsymbol{\tau})$.

B Calculating vehicle-specific ratios of maintenance and repair expenditure

We obtained the yearly ratio of maintenance and repair expenditure in six stages. First, we calculated vehicle-specific expected repair cost using the frequency-of-repair charts in April 2000 *Consumer Reports*[23] and the cost figures of the eight major mechanical systems for the fifty models from the *Mitchell Mechanical Parts & Labor Estimating Guide* in 2002. For instance, with the frequency-of-repair charts in Table 10 and the cost figures in Table 11 of 1996-model-year Ford Tauruses, we calculated in Table 12 1996–2003 expected repair costs of 1996-model-year Ford Tauruses in 1996–2003 if complete repair or replacement with new parts were required for the eight major mechanical systems everytime at least one of their subsystems broke down.

Table 10: Frequency of repair charts of 1996–model–year Ford Taurus in 1996–2003.

	Calendar Year							
Major System	96	97	98	99	00	01	02	03
A/C	0.010	0.010	0.035	0.035	0.035	0.035	0.121	0.121
Cooling	0.010	0.035	0.035	0.121	0.072	0.072	0.181	0.181
Electrical	0.035	0.072	0.072	0.121	0.121	0.121	0.121	0.121
Engine	0.010	0.010	0.010	0.035	0.035	0.035	0.121	0.181
Fuel	0.035	0.035	0.035	0.035	0.072	0.072	0.072	0.072
Ignition	0.010	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Suspension	0.035	0.121	0.121	0.121	0.121	0.121	0.121	0.121
Transmission	0.035	0.072	0.072	0.072	0.072	0.072	0.072	0.181
Total	0.180	0.389	0.414	0.573	0.561	0.561	0.841	1.012

Second, we obtained the expected repair cost *per problem* for each of the

[23]The frequency-of-repair charts show the proportion of owners who have reported serious problems for each trouble spot of each model on a five–point scale. The best score 5 indicates that 2.0% or fewer vehicles suffered a serious problem, score 4—2.0% to 5.0%, score 3—5.0% to 9.3%, score 2—9.3% to 14.8% and score 1—more than 14.8% were afflicted with the problem. We assigned the midrange trouble rates respectively for the first four of the five categories. We assigned 18.1% for the score 1 category. To do so, we first estimated a simple regression model of how the percentage increment between the neighboring categories were correlated with the category increment using the first four categories and then extrapolating the result to the score 1 category.

Table 11: 1996-model-year Ford Taurus' costs of complete repair or replacement with new parts for the eight major mechanical systems.

Major Mechanical System	Repair Cost
A/C	1,019
Cooling	931
Electrical	298
Engine	4,001
Fuel	1,378
Ignition	587
Suspension	748
Transmission	1,535

Table 12: 1996-model-year Ford Taurus' expected repair costs for the eight major mechanical systems in 1996–2003 if complete repair or replacement with new parts were required everytime one of their subsystems broke down.

	Calendar Year							
Major System	96	97	98	99	00	01	02	03
A/C	10	10	36	36	36	36	123	123
Cooling	9	33	33	112	67	67	169	169
Electrical	10	21	21	36	36	36	36	36
Engine	40	40	40	140	140	140	482	725
Fuel	48	48	48	48	98	98	98	98
Ignition	6	21	21	21	21	21	21	21
Suspension	26	90	90	90	90	90	90	90
Transmission	54	110	110	110	110	110	110	278
Expected Repair Cost	204	373	398	592	597	597	1,129	1,540

fifty vehicles. For 1996-model-year Ford Tauruses, for instance, this meant that dividing the expected repair cost at the bottom of Table 12 by the total frequency of repairs at the bottom of Table 10. The result was shown in Table 13.

Third, we obtained the expected total repair cost for each of the fifty vehicles first by multiplying the expected repair cost in 1996–2003 for the 1996-model-year vehicle with the numbers of 1996-model-year vehicles on the road in 1996–2003 respectively and then by aggregating the resulting

Table 13: The expected repair cost per problem for 1996-model-year Ford Taurus if complete repair or replacement with new parts were required everytime one of their subsystems broke down.

Calendar Year							
96	97	98	99	00	01	02	03
204/0.180 =1,133	373/0.389 =959	398/0.414 =963	592/0.573 =1,034	597/0.561 =1,065	597/0.561 =1,065	1,129/0.841 =1,341	1,540/1.012 =1,522

numbers. We assumed all the vehicles purchased in 1996 remained on the road during the period. The sales volume information was taken from *Ward's Automotive Yearbook* in 1997. For instance, Ford Taurus' expected total repair cost was $2,177,736,000 in Table 14. We repeated this process for the fifty vehicles and added them to obtain the expected total repair cost for the fifty vehicles of up to eight year old combined—$42,051,478,000.

Table 14: 1996 Ford Taurus' 1996–2003 expected total repair cost if complete repair or replacement with new parts were required everytime one of their subsystems broke down (in thousand dollars).

	Calendar Year								Expected Total
	96	97	98	99	00	01	02	03	Repair Cost
Repair Cost per Vehicle	204	373	398	592	597	597	1,129	1,540	
Number of the Vehicle	401,049	401,049	401,049	401,049	401,049	401,049	401,049	401,049	
Total	81,779	149,465	159,684	237,583	239,451	239,451	452,593	617,731	2,177,736

Fourth, we computed the total number of problems each of the fifty 1996-model-year vehicles was expected to have encountered. For example, the expected total number of problems 1996-model-year Ford Tauruses had/will have in 1996–2003 was 1,816,000 as in Table 15. We aggregated them to obtain the expected total number of problems in 1996–2003 for the fifty vehicles combined—34,594,000.

Table 15: The expected total number of problems for 1996-model-year Ford Taurus during 1996–2003 period.

	Calendar Year								Total Number
	96	97	98	99	00	01	02	03	of Troubles
Number of Troubles per Vehicle	0.180	0.389	0.414	0.573	0.561	0.561	0.841	1.012	
Number of the Vehicle	401,049	401,049	401,049	401,049	401,049	401,049	401,049	401,049	
Total (thousand)	72	156	166	230	225	225	337	406	1,816

Fifth, we obtained the average repair cost per problem—$1,216—by dividing their expected total repair cost—$42,051,478,000—for the fifty models combined by their expected total number—34,594,000—of problems.

Sixth, we divided the expected repair costs per problem in 1996–2003 for a 1996-model-year vehicle by the average repair cost per problem—$1,216—for the fifty models combined to obtain the yearly ratio for the particular vehicle in 1996–2003. The 1996–2003 ratios of 1996-model-year Ford Tauruses were calculated in Table 16.

Table 16: The maintenance and repair expenditure ratios for 1996 Ford Taurus.

	Calendar Year							
	96	97	98	99	00	01	02	03
Weight	1,133	959	963	1,034	1,065	1,065	1,341	1,522
	/1,216	/1,216	/1,216	/1,216	/1,216	/1,216	/1,216	/1,216
	=0.93	=0.79	=0.79	=0.85	=0.88	=0.88	=1.10	=1.25

We think these calculations were warranted because there were significant differences in repair costs among the eight major mechanical systems and because there were significant vehicle-to-vehicle differences in likelihoods of breakdown in the eight major mechanical systems. For example, engine is in general much more costly to repair than electrical system, but much less likely to break down. Thus vehicles with many electrical system breakdowns may end up having smaller ratio than vehicles with a single engine trouble.

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