A HEDONIC-PRICE ANALYSIS OF THE 2MM PROGRAM IMPACTS ON U.S. AUTOMOBILE DEMAND AND PRODUCTION COST

BY

CIRO BIDERMAN
KAREN R. POLENSKE
AND
NICOLAS O. ROCKLER

JULY 2001

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
MULTIREGIONAL PLANNING GROUP
CAMBRIDGE, MASSACHUSETTS

PREPARED FOR THE
NATIONAL BUREAU OF ECONOMIC RESEARCH
SUMMER INSTITUTE 2001

A HEDONIC-PRICE ANALYSIS OF THE 2MM PROGRAM IMPACTS ON U.S. AUTOMOBILE DEMAND AND PRODUCTION COST

ABSTRACT

We evaluate the market-share effects of the 2 millimeter (2mm) program. Specifically, we examine two of the three major claims regarding the economic impact of the program as reported by Long (1999) in the NIST Special Publication *Performance of Completed Projects*. The major findings in that report were that the 2mm program had: (i) lowered the production cost in participating plants; (ii) increased the demand for U.S.-made vehicles, and (iii) helped distribute the technology to other non-auto companies. We use a hedonic-price model to conduct a partial assessment of whether the first two of these results were achieved. We contend that the 2mm program did help increase demand for domestically produced vehicles, while at the same time, boosting short-run costs; on balance, the net effect is positive. Had the 2mm program not been implemented, the U.S. automobile industry would probably have seen even larger declines in sales than those recorded. The effects on demand, although significant, are limited to the several years following initial adoption of the technology. As application of the technology approached saturation, the economic impacts on demand and vehicle price diminish.

D R A F T

INTRODUCTION

This report is derived from research concerning the economic impact of the 2 millimeter (2mm) program on the U.S. economy. The program was implemented in 1992 by the National Institute of Standards and Technology in collaboration with the Auto Body Consortium[1] to help increase the competitiveness of the U.S. automobile industry. Our evaluation of the program is comprised of case-study findings, model-based estimates of the program impacts on the domestic automobile market, and the macroeconomic impacts of the program. In this report, we present a hedonic-price model which we used to estimate the direct impacts on the US automobile market. We use the model to help determine whether the 2mm program helped to reduce the cost and increase the overall demand for U.S.-made vehicles. This paper is presented in five parts: First, we present a brief history of the 2mm program. Second, we discuss the methods and difficulties encountered in estimating demand and supply for complex products, such as vehicles. Third, we analyze the databases that we used for developing our estimates. The database consists of vehicle attributes, prices for virtually all U.S. cars and light trucks marketed from 1981 to 1998, and the characteristics of the plants in which they were produced. Among the characteristics is a variable indicating that a plant is “2mm-capable”. Using these data, we describe the market for cars and trucks for the 1981-1998 period. Fourth, we present the results from our estimates of the statistical significance of the 2mm program on the demand and supply for cars and for trucks. Finally, we discuss some of the limitations of this analysis and possibilities for further investigation.[2]

---

[1] At time of program implementation, called 2mm Auto Body Consortium.

[2] We would like to acknowledge the assistance of other researchers who contributed to this and other parts of our work concerning the 2mm program. We thank Stanley Abraham (Harvard Business School), Richard Roth and Daniel Whitney (MIT-Department of Mechanical Engineering), Eric Cahill and Alvaro Periera (MIT-Department of Urban Studies and Planning), and Susan Helper (Case Western Reserve University.)

HISTORY OF THE 2MM PROGRAM

During the 1980s, the U.S. automobile producers were losing their market share to Asian and European producers. In order to reverse this trend, the U.S. government made an effort in the 1990s to increase the competitiveness of the domestic automobile industry.[3] One of the efforts, called the "2 millimeter program" (hereafter 2mm program), was undertaken by the U.S. National Institute of Standards and Technology (NIST) with the Auto Body Consortium (ABC) —a group of domestic automobile assemblers and suppliers--in collaboration with researchers from the University of Michigan. The main goal of the 2mm program was to increase the competitiveness of the U.S. automobile firms by reducing the dimensional variation for the U.S. automobile body-in-white (BIW) openings. In the 1980s, U.S. car buyers were said to consider the fit, finish, and reliability of cars as the main factors affecting their purchase. By the late 1980s, the dimensional variation was about 2.0 mm for Japanese automakers, 2.5 mm for European makers, and more than 3.0 mm (even up to 10mm) for U.S. makers.

According to the NIST Special Publication "Performance of Completed Projects" (Long, 1999, pp. 38-39), the 2mm program had (i) lowered the production cost for the participating plants; (ii) increased the demand for U.S.-made vehicles, and (iii) distributed the technology to other non-auto companies. In this report, we conduct tests to determine whether or not the first two statements are correct.

FRAMEWORK OF ANALYSIS

Analysts must treat demand for complex heterogeneous products, such as housing, cars, or workers, by attempting to place value on the attributes that characterize such goods. Because we generally have no information on the price of each attribute, analysts use the hedonic approach. Griliches (1961) is generally considered to have introduced hedonic analysis and techniques into mainstream economics in his seminal paper that deals with commodity heterogeneity.[4] The idea is that each consumer may purchase a good with different quantities of its various attributes. Because there may be, in general, a difference in prices dependent on the quantity of the attribute, the analyst can infer the marginal price of each attribute.

---

[3] Throughout the remainder of this report, we use the term "U.S.-made" to designate a vehicle made domestically within the continental United States, and the term "American" to indiate vehicles that were made in the United States or Canada.

The "hedonic price function" for vehicles with various attributes, *P(Z),* is the result of consumer-utility maximization, where the attributes of cars, Z, all other goods, X, and their preferences, *a* , is given as:

$$\max_{Z,X} U(Z,X,\acute{a}) \qquad s.t. \qquad M \quad P(Z)+X \qquad (1)$$

The "hedonic price" of attribute *i*, P_i º $\partial P/\partial Z_i$, is the marginal utility and the marginal demand for attribute *i*. See Appendix A for the derivation of this demand function for vehicle attributes.

To close the model, we introduce the car's producers. Producers have a cost function given by *C*(*Z, N,g*) that depends on the quantity of attributes, the number of cars produced *N*, and a vector of parameters*g*. Producers maximize the profit function:

$$\max_{Z,N} Đ = P(Z)N \quad C(Z,N,\tilde{a}) \qquad \textbf{(2)}$$

The market equilibrium will be represented as the locus of tangencies between marginal cost and marginal demand and typically depends upon the probability distribution over consumers' preferences and producers' type. This represents a theoretically coherent foundation for explaining the relationship between the price of a car (or other heterogeneous good) and its attributes, but estimation of the attribute prices still presents many difficulties (theoretical and empirical) which we discuss in Appendix A. The main theoretical difficulty is that the attributes are discrete, i.e., a limited set of choices exist, as in the case of engine horsepower or wheelbase length. This yields a budget constraint that is non-linear and a demand function that is unconventional in that consumer preferences (over an attribute) are represented by nonconstant prices. To obtain an estimate of the attribute prices, we derive the aggregate supply function, where m_j is the marginal cost of vehicle j , w_j is a vector of cost characteristics (shown as equation (15) in Appendix A), and γ is the vector of vehicle attributes:

$$\ln(m_j) = w g + w_j \qquad (3)$$

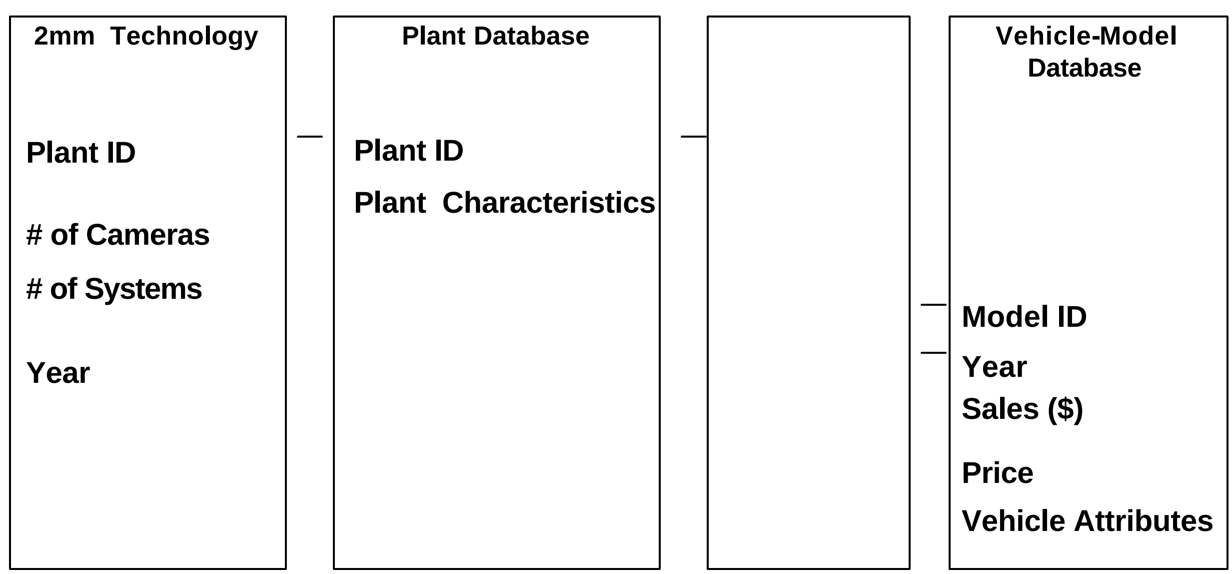
[4] Griliches (and many others) referred to Court (1939) as an earlier pioneer in the application of these techniques. However, Sheppard (1999, pp. 1597) claims that "the study of Waugh (1929) appears to be the first to provide a systematic analysis of the impact of "quality" on the price of a commodity."

The vector of marginal costs is shown in Appendix A to depend on demand system parameters and equilibrium attribute prices (assuming equilibrium throughout), and we can estimate the cost-shifting parameters of the different attributes by regressing vehicle price on vehicle attributes.

DATABASES

We have assembled three databases from various sources to meet our need to estimate attribute prices and production costs. The first database (the "model-vehicle" database), has vehicle attributes, sales, and prices for virtually all U.S. car and light truck models marketed each year from 1981 to 1998. The second database, (the "plant" database), contains annual information on the characteristics of plants that produced all domestic car and light-truck, including the number of assembly lines within in each plant, the annual production capacity, the line-rate, plant square-footage, employment, and the different models produced. The third database, (the "2mm technology" database) contains annual sales of 2mm hardware into assembly plants, by plant, including number of systems and sensors purchased. Figure 1 illustrates the interrelationship among those databases.

Figure 1
VEHICLE DATABASE RELATIONSHIPS



Source: The authors.

THE VEHICLE-MODEL DATABASE

For the vehicle-model database, we extended to 1998 the 1981-1990 data furnished to us by Barry, Pakes, and Levisohn (1995). Because models come and go over time, we consider the model to be the same from one year to another if its name is unchanged and its size characteristics or engine displacement remains within 10% of its prior years' figures.[5] We control for (i.e., estimate the hedonic prices of) the following car/light-truck attributes: number of cylinders, doors, horse power, engine displacement, length, width, height, weight, wheelbase, the drive-type (i.e., front-wheel drive (fwd), rear-wheel drive (rwd), or four-wheel drive (4x4)), and U.S. Environmental Protection Agency (EPA) miles per gallon. We use dummy variables to control for special vehicle body-types, such as mini-vans, sport-utilities, full-size vans, pickup trucks, and station wagons. We use another set of dummy variables to control for the origin of nondomestic manufacturer i.e., Japan, Korea, or Europe).[6]

Using data from *Wards Automotive Yearbook* (*Wards*) and *Automotive News Market Data Book (Automotive News),* our vehicle-model database is virtually identical in terms of market coverage to that of Barry, et. al., measuring such items as aggregate sales value, number of vehicles sold, average horsepower-to-weight ratio, or average vehicle size. However, we do show a significantly higher number of models (about 20% more), due to our inclusion of vehicles that share an identical name but have a different body style, e.g., a sedan and station wagon.

In the first half of the 1980s, car sales increased constantly (in unit and in dollar terms) reaching a peak in 1986 (Figure 2). After 1986, the number of cars sold decreased constantly and apparently stabilized around 8 thousand units after 1991; most of the decrease can be attributed to the increase in light-truck sales. The number of units sold decreased faster than that of dollar sales. Actually, starting in 1996, the two series diverge, i.e., consumers are buying fewer cars, but they are expending more on that good.

The database we constructed corresponds well to that given for industry overall. These figures are shown in Table 1. In some instances, large differences between imports and our database are evident.

---

[5] This is compatible with the BLP criteria. It is important to track the model because we want to allow for a correlation between the same model in different years.

[6] These variables can be constructed based on location of producers' headquarters or actual location of production. We use the first definition, but we consider a vehicle's import status to be one of its attributes.

During the last two decades, the US market for automobiles and light-trucks has undergone significant change in composition. We show the annual sales volumes for 1984-1998 in Figures 1 and 2 for cars and light-trucks, respectively. In the first half of the 1980s, car sales increased constantly (in unit and in dollar terms) reaching a peak in 1986 (Figure 2). After 1986, the number of cars sold decreased constantly and stabilized around 8 million vehicles after 1991; most of the decrease can be attributed to the increase in light-truck sales. The automobile unit-sales decreased faster than value. Actually, starting in 1996, the two series diverge, i.e., consumers are buying fewer cars, but more expensive ones.

TABLE 1
Automobile Sales, 1988-1998
MRP versus Universe (vehicles, thousands)

Year	Total			U.S. Firms			Asian Firms			Imports		
	Uni-Verse	MRP	Per-cent	Uni-verse	MRP	Per-cent	Uni-verse	MRP	Per-cent	Uni-verse	MRP	Per-cent
1988	10,594	9,908	94	7,303	7,062	97	2,713	2,389	88	3,068	2,286	75
1989	9,772	9,390	96	6,635	6,523	98	2,656	2,412	91	2,757	2,444	89
1990	9,296	8,690	93	6,113	5,913	97	2,724	2,405	88	2,453	2,028	83
1991	8,176	8,022	98	5,248	5,209	99	2,589	2,486	96	2,103	1,933	92
1992	8,211	8,122	99	5,301	5,246	99	2,579	2,572	100	1,994	1,546	78
1993	8,520	8,256	97	5,621	5,400	96	2,592	2,574	99	1,845	1,418	77
1994	8,991	8,749	97	5,809	5,742	99	2,794	2,636	94	1,809	1,432	79
1995	8,710	8,680	100	5,620	5,572	99	2,686	2,668	99	1,612	1,235	77
1996	8,529	8,453	99	5,328	5,289	99	2,699	2,677	99	1,389	1,137	82
1997	8,289	8,252	100	5,006	4,974	99	2,729	2,708	99	1,381	1,221	88
1998	8,187	8,139	99	4,701	4,698	100	2,789	2,728	98	1,441	1,227	85

Sources: Wards, Automotive News (multiple years). MRP tabulations using the MRP automobile and light-truck database.

FIGURE 1
CAR AND TRUCK SALES
U.S. MARKET, 1984-1998
(Units)

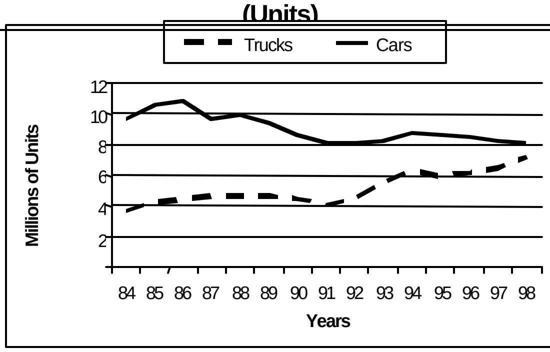
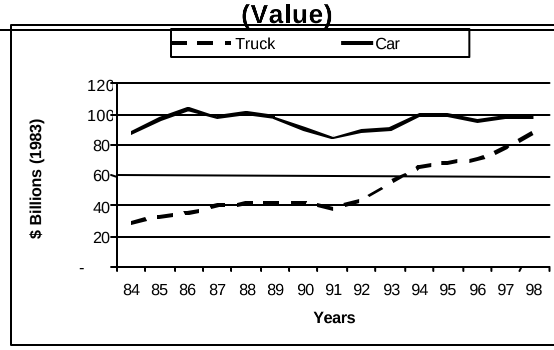


FIGURE 2
CAR AND TRUCK SALES
U.S. MARKET, 1984-1998
(Value)



Sources: Wards, Automotive News (multiple years). MRP tabulations using the MRP automobile and light-truck database.

Not only did the composition of sales change dramatically since the 1980s, but the domestic share of the market has seen considerable shrinkage. Sales by U.S. manufacturers (Chrysler, Ford, and General Motors) fell from 74% in 1981 to 57% in 1998 (Figures 3 and 4).[7] They seem unable to reverse that trend. In the late 1990s, the European market share started to increase. After 15 years of remaining at slightly over 4.0% of the total sales, the European market share more than doubled from 1995 to 1998 (from 4.2% to 8.8%).

[7] Chrysler became Daimler Chrysler in 1998.

FIGURE 3
SHARE OF U.S., ASIAN, AND EUROPEAN MANUFACTURERS IN THE U.S. AUTOMOBILE MARKET
1981

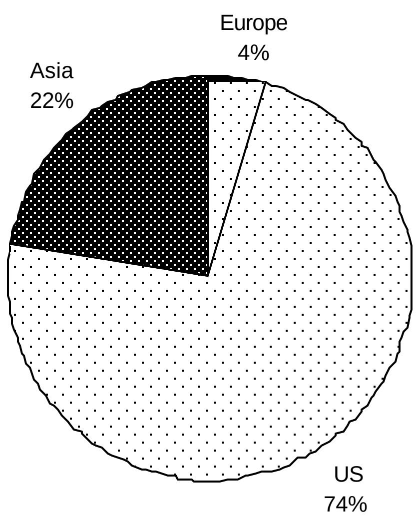
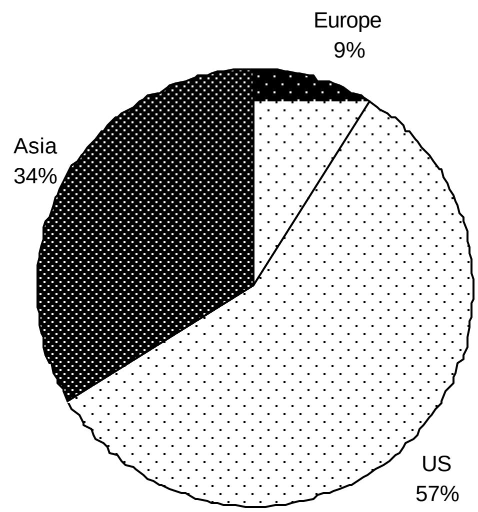


FIGURE 4
SHARE OF U.S., ASIAN, AND EUROPEAN MANUFACTURERS IN THE U.S. AUTOMOBILE MARKET
1998



Sources: Wards, Automotive News (many years). MRP staff tabulations using the MRP auto/light-truck database.

imports decreased from a high of 27% in 1981 to 15% in 1998 (Figure 5). Although there is considerable fluctuation during these years, the trend is clearly negative. The decrease in the market share of the U.S. manufacturers and the decrease in the imports can be mainly explained just by the increase in the transplanted import production (Figure 6). In the 1980s, the transplants in the United States started with a very low market share, less than 1% of the market. By 1998, the transplants represented more than 25% of the market.

From 1984 to 1998, the trend toward increasing light-truck sales is clearly evident. See Figures 1 and 2. Until the late 1970s, sellers of light trucks were mostly concerned with commercial uses in opposition to the "family" market, although the idea of an all-purpose family compact van had been circulating in the car industry since at least the 1950s (Yates,1996). In the early 1970s, Ford in its "mini/max" program recognized at least one shortcoming of the market. The result was a front-wheel-

FIGURE 5
SHARE OF IMPORTED CARS IN THE U.S. MARKET, 1981-1998

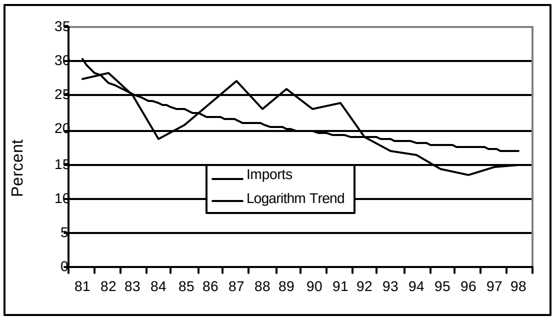
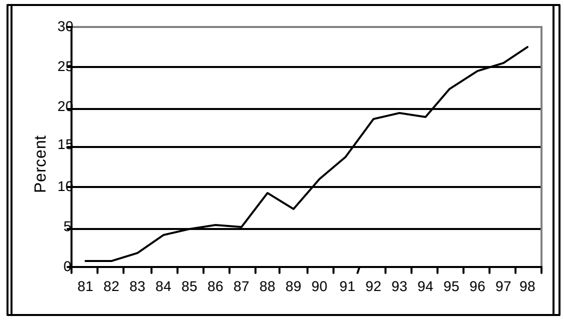


FIGURE 6
SHARE OF TRANSPLANTS IN THE U.S. MARKET, 1981-1998



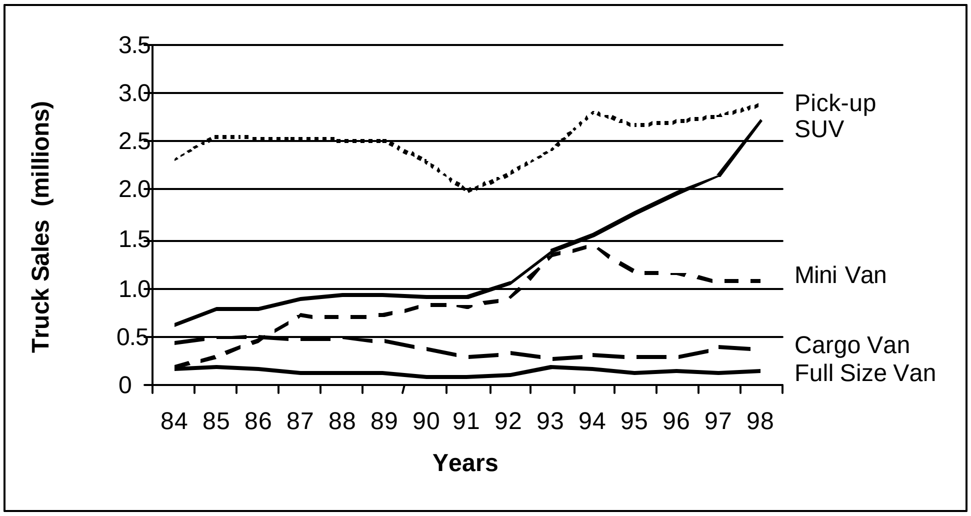
Sources: Wards, Automotive News, MRP staff tabulations using the MRP auto/light-truck database.

drive van better suited for the family than the station wagon, although Ford was afraid that this family of vehicles would cannibalize Ford's station-wagon sales. The mini-van market share increased rapidly starting in the early 1980s with Chrysler's Plymouth Voyager and Dodge Caravan.

In 1984, more than 50% (2.4 million) of the light-truck sales were pickups (Figure 7). The market for the just-created new vehicle, now called a "mini-van," was obviously very small at first. Even the sport-utility vehicle (SUV) market, the second largest market for light trucks, was small compared to that for pickup trucks with only slightly more than 600 thousand SUVs sold in 1984 compared to 2.3 million pickup trucks. By 1998, this situation had completely changed with the SUV market being about the same size as that for pickup trucks (2.7 versus 2.9 million vehicles, respectively), and more than 1 million mini-van vehicles were sold, despite an economic slow down in the early 1990s. The sales of cargo vans and full-size vans did not increase, remaining at less than 500 thousand units throughout the period, emphasizing that the huge growth noted in the light-truck market is due to the fact that light trucks are now substitutes for cars. Although pickup trucks were an exception in the 1990s, we do not view a pickup truck as just a commercial vehicle, because consumers now use small pickup trucks as personal vehicles as well.

Another important difference between these two markets is the behavior of the market share of U.S. companies. In 1984, they had 84% of the light-truck domestic market and 78% of the car market

FIGURE 7
LIGHT-TRUCK SALES BY VEHICLE TYPE
(Number)



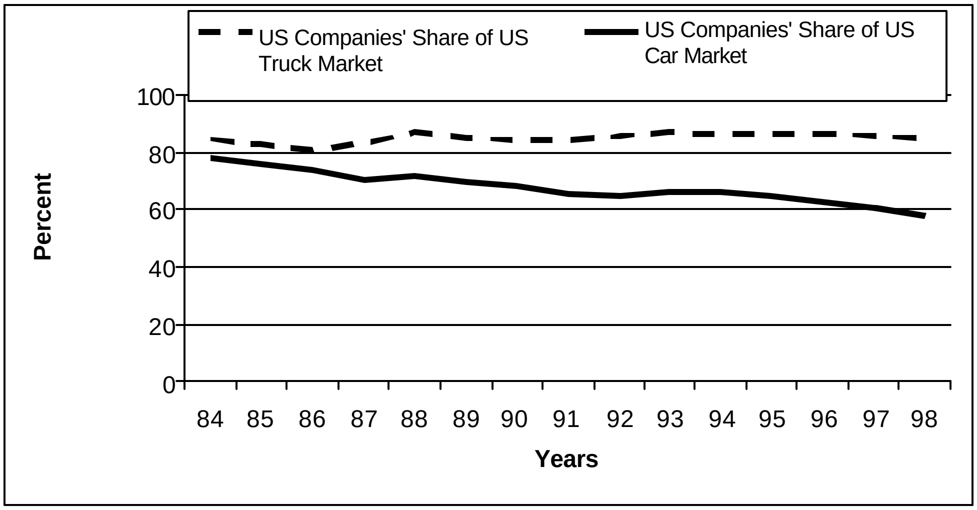
Sources: Wards, Automotive News (many years). MRP staff tabulation using the MRP auto/light-truck database.

pickup truck as just a commercial vehicle, because consumers now use small pickup trucks as personal vehicles as well.

Another important difference between these two markets is the behavior of the market share of U.S. companies. In 1984, they had 84% of the light-truck domestic market and 78% of the car market (Figure 8). By 1998, the domestic companies retained their share of the light-truck market, but lost a vast part of the market for cars, which fell to a 58% share.[8] Transplants represent a small share of the light-truck market. In 1984, 3.2% of the light trucks sold in the United States were produced by transplants, compared to 2.4% in 1998.

[8] We do not show European firms in the figure, but they are almost negligible in the light-truck market, so that Asian firms comprise most of the remaining 15% of that market.

FIGURE 8
U.S. MARKET SHARE IN LIGHT TRUCKS AND CARS,1984 TO1998



Sources: Wards, Automotive News (many years). MRP staff tabulations using the MRP auto/light-truck database.

THE 2MM-PLANT DATABASE

The 2mm database tracks the sales of the 2mm systems (workstations, software, and sensors) to assembly plant annual from 1988-1999. We consider the presence of the 2mm hardware to be indicative that the plant has adopted 2mm technology, which used the hardware to support statistically-based diagnostic procedure for fault identification and monitoring[9] We know that this assumption can be challenged on many grounds, not the least of which would be the case of Ford plants that were among the first to adopt the hardware in the mid-1980s, but which never joined the Autobody Consortium for this project and never learned the techniques and lessons learned in the program.

In defining the 2mm variable, we do not take into account the number of systems (workstations) in active use in each plant nor the number of sensors (cameras) per system. We do know that the number of sensors varies from 15 to 50 per workstation, and there are usually four workstations on a given assembly

---

[9] Some models of cars and light trucks are produced in several plants. For instance, the Oldsmobile 88 was produced in Wentzville, MO and Flint, MI; We do not have sufficient data to distinguish actual sales of each model by plant, and are forced to assume an ad hoc split of sales to be 50/50 in the case of two plants, and other even proportions in the case of more. Some plants have multiple assembly lines, We have assumed that all models produced in the plant are "2mm". It is possible that some models, however, were

line. As an alternative, we could have constructed a variable that takes into account the number of 2mm systems by vehicle truncated at 0 (for vehicles that are not under the program). However, because (1) any index is arbitrary and (2) the dummy variable has a very straightforward interpretation, i.e., the difference (in demand or cost) between a 2mm vehicle and a non-2mm vehicle, we adopted the simplified variable as our proxy. Even though the presence of the hardware is a necessary condition for a vehicle to be considered "2mm", we recognize that the presence of systems is not a perfect indicator that a plant is committed to the program.

At the start of the 2mm program, 11% of all vehicles sold in the US were produced in plants with the 2mm hardware, a share common to both trucks and cars. This share is seen to increase sharply during the program years, reaching 54% of all vehicles by 1995. It continued to grow afterward, but at a much slower pace, reaching 66% by 1998. Growth in those later years slowed dramatically, and even turned downward somewhat for cars. The higher rate at which the technology has been adopted for light-trucks versus cars highlights the tendency towards greater reliance on technical analysis characteristic of the truck engineering compared to automobiles, something we observed in the case-study research. While the origins of the difference between the two vehicle types are unclear, the data show it to be a sizeable one. Our anecdotal evidence does not indicate that it is market driven, i.e., that light-truck customers are more sensitive to the fit-and-finish characteristics that are the product of better dimensional variation control. It seems to be that engineers who have these concerns have been drawn to truck engineering, possibly as the product of greater emphasis put on engineering performance that is characteristic of the truck divisions of the domestic industry.

---

produced on a line not (yet) equipped with the 2mm hardware. Nevertheless, the analysis techniques could be applied on a very limited basis using substitute technology.

Table 5
VEHICLE SALES: 1992-1998 BY 2MM STATUS

YEAR	Cars			Light-Trucks			Total Vehicles		
	2mm	Total	Percent	2mm	Total	Percent	2mm	Total	Percent
1992	884	8,215	11	491	4,629	11	1,375	12,844	11
1993	1,327	8,518	16	1,963	5,346	37	3,290	13,864	24
1994	2,572	8,990	29	3,339	6,034	55	5,911	15,024	39
1995	3,799	8,636	44	4,164	6,054	69	7,963	14,690	54
1996	4,307	8,527	51	4,388	6,519	67	8,695	15,046	58
1997	4,351	8,272	53	5,498	6,797	81	8,695	15,046	58
1998	4,121	8,142	51	6,000	7,297	82	10,121	15,439	66

Sources*: Wards, Harbour Report,* Perceptron Co., and BEA

HEDONIC-PRICE MODEL RESULTS

In the Appendix, Tables B1 and B2 show the results of an ordinary least squares (OLS) estimation from a regression of "relative market shares" (d_j) on cars attributes.[10] The 2mm dummy is significant for cars and trucks in all specifications. The results are consistent with NIST's claim that the program increased the demand for vehicles produced by plants that joined the program, but it is lower than previous estimates. Using the hedonic-price model, we estimate that demand increased about 0.3% for cars and 0.4% for light

[10] Recall that we calculate d_j from the equation $\ln(s_j) - \ln(s_0) = d_j - \ln\left(1 + \sum_{j=1}^{J} e^{d_j}\right) + \ln\left(1 + \sum_{j=1}^{J} e^{d_j}\right) = d_j$ On the car's attributes, we therefore regress the logarithm of the market share of the model in a given year, minus the natural logarithm of the number of households, less the number of cars sold, over the number of households. We call this complex combination (in terms of syntax) as "relative market share," because it reflects the market share of the model relative to the total number of households.

trucks.[11] Our estimates are very stable in the different specifications, described further below. The only notable difference happens when we delete the domestic dummy. For cars, the economic impact of 2mm is reduced, and for trucks it is increased. The reason is that consumers demand U.S. cars less than other cars with the same observable (by us) attributes, while the opposite happens with light trucks.

In Tables B1 and B2, we present results from eight regressions using slightly different specifications. For specifications (1) and (2), we attempt to determine the best proxy for power. For cars, we found that the best proxy was the natural logarithm of the horse power, and for trucks, it was horse power over weight. An important issue concerned the proxy for size. We found that the use of length, width, and height at the same time is confusing. We might obtain negative signs for width and positive signs for height and length, for instance. The same applies for using size and height together. We decided that the best proxy seemed to be using volume defined as length time height times width. For regressions (4) through (7) for cars and (4) through (6) for trucks, we deleted some variables that were not significant to see the sensitivity of the results to changes in the specification. As a matter of fact, we can see no changes in sign and no significant change in level for most variables considered. For regression (7) for trucks and regression (8) for cars, we check the effect on the 2mm dummy parameter when we delete the domestic dummy.

One interesting result for cars is that the station wagon has a negative impact on consumer demand. That is, for cars with the same size, power, etc., consumers will demand fewer of them if it is a station wagon than if it is not. The elasticity of miles per gallon is significantly higher than 1 both for cars and trucks, meaning that firms may find it worthwhile to invest in improving fuel efficiency from the point of view of demand. The coefficients on the dummy for European cars and for U.S.-made cars were both negative; therefore, there might be an over-demand for Japanese cars or there are some attributes of Japanese car that we cannot observe in our data. This is not true for light trucks though. In that market, U.S.-made cars are the ones over-demanded (that is, the coefficient is positive), and the demand for the few European (light) trucks is not statistically different from the others. Consumers demand fewer imported cars or light trucks than similar cars that are produced in the United States or Canada.

[11] According to NIST, the return of the program was "at least $3 billion from quality improvement in U.S. produced automobiles and associated market share gains".

The trend for cars and for light trucks is negative. The first is consistent with Figure 1, but the latter is not. In Figure 1, the demand for cars is decreasing, but the aggregated demand for trucks is not. The problem is that the number of different light-truck models is also increasing; therefore, the market share by vehicle model is not changing, although the total demand is increasing. Furthermore, the trend is highly correlated (more than 50% in all specifications) with the 2mm variable. When we delete the trend in specification (8) for trucks, we note that the effect of the 2mm technology falls to 0.25%. Another interesting aspect of the demand for light trucks is the behavior of the different kinds of trucks. We can see that consumers under-demand all Vans compared with their demand for SUVs or Pickups. Actually, the smallest effect is on Minivans; consequently, we could make a sort of hierarchy (in terms of consumer demand) for the light-truck taxonomy: SUVs on the top, then Pickups, Mini-vans, and Cargo Vans, and, on the bottom, Full-Size Vans. From Figure 7, we see that SUVs and Pickups are indeed the leaders in the increased sales of light trucks.

One way we used to check the consistency of the 2mm variable is by changing the gap after the implementation of the 2mm technology or by reducing the sample of analysis. The idea is that as the program is spread among the plants, its impacts tend to vanish. Thus, by 1998, let us say, when almost all domestic plants were already under 2mm technology, we hypothesize that a plant probably would not receive additional profit from joining the program: the marginal cost for the last plants might be zero.[12] We tested that hypothesis in two ways. First, the advantage to a plant having the technology could vanish in some year after they implemented it, i.e., the direct competitors of the vehicle would react, and, after some years, that advantage would converge to zero. We confirm this hypothesis in Table 6 for cars and trucks: both the parameter and the significance decrease when we increase the gap. If we assume a 3-year gap, i.e., the vehicle will be considered "2mm" just 3 years after the acquisition of the first 2mm system, the parameter is not significant at 10% for both cars and trucks.

When we test the effect of restricting the sample, cars behave exactly as we expected. The impact of the 2mm technology decreases and is not significant at 5% when the sample is restricted to 1996 to 1998. For 1997 to 1998, it is not significant at all. These findings reinforce the results when we use the gaps. Besides, it is probably the case that the effects of the 2mm program for cars had already vanished by 1996;

however, trucks have a contradictory behavior on the restricted sample analysis. Although the parameter is decreasing at the beginning of the period, after 1997 it starts increasing again.

TABLE 6
EFFECT OF 2MM ON DEMAND CHANGING THE VARIABLE DEFINITION
(percent)

Gap/ Sample	CARS		TRUCKS	
	Impact	Significance	Impact	Significance
NO GAP	**0.33**	**100**	**0.39**	**100**
1 year gap	**0.28**	**100**	**0.37**	**100**
2 years gap	**0.23**	**99**	**0.17**	**84**
3 years gap	**0.16**	**87**	**0.14**	**71**
93 to 98	**0.33**	**100**	**0.44**	**100**
94 to 98	**0.31**	**100**	**0.45**	**100**
95 to 98	**0.25**	**100**	**0.41**	**100**
96 to 98	**0.18**	**94**	**0.37**	**99**
97 to 98	**0.14**	**80**	**0.41**	**99**
1998 Only	0.04	20	0.46	99

Source: Estimated by the Authors from MRP Auto and Light-Truck Data Base.

Furthermore, the 2mm parameter is significant at the 1% level for all samples considered. That result and the fact that the 2mm impact for trucks is very sensitive to specifications with no trend makes us suspicious about our estimation regarding the light-truck market. We believe that one explanation for this inconsistent result for trucks might be connected to the fact that the sample is not big enough.

To analyze the impact of the 2mm program on cost, we use the results of Equations (18a) and (19a) (See Appendix) to estimate the margin from the demand estimates. More specifically, note that if we define the market share as in Equation (13a), the partial derivative to price will be:

[12] This point was first pointed out to us by Daniel Whitney.

$$\frac{\partial s_j}{\partial p_r} = \begin{cases} -as_j(1-s_j) & j = r \\ as_j s_r & j \neq r \end{cases}$$

Thus, if we sort the shares by year and by firm, we can easily calculate the matrix defined in Equation (16a) using *a* estimated in the demand regression and the actual market shares. We will use the estimation of specification (7) for cars and the specification (6) for trucks (see Tables B1 and B2). We therefore compute **D** and calculate the margins[13] for each model using Equation (19a). In Tables A3 and A4, we show the results of some regressions using the calculated margin as the dependent variable.

The impact of introducing the 2mm program on the margin is significantly negative for cars in all specifications and not significant at the 1% level for some specifications for trucks; however, the variable is also significantly negative for trucks at the 10% level in all specifications (Table 7). This result is at odds with NIST's claim in their Status Report Number 1 (199?, p. ?) that "the 2mm Project developed a number of interrelated technologies and processes that have already cut net production costs (actual costs less the cost of implementing 2mm technologies) by $10 to $25 per vehicle in plants where they have been tested." According to our results, the 2mm program probably increased the cost of production. The effect, however, is very low: around 0.1% for cars and 0.05% for trucks.

Based on the adjusted R square, we find that the regression on margins fits better than the regression on relative market shares. We can also see that station wagons and four-wheel-drive vehicles have a higher margin than the other vehicles with the same characteristics. It is interesting to note that, on the one hand, European vehicles (both cars or trucks) have a higher margin than the

[13] Since it is very demanding in terms of computation to invert a 2,810x2,810 matrix, we took advantage of the characteristic of **D** and inverted it by partitioning the matrix in smaller matrices.

TABLE 7
IMPACT OF 2MM ON MARGIN CHANGING THE VARIABLE DEFINITION

Gap/ Sample	CARS		TRUCKS	
	Impact	Significance	Impact	Significance
NO GAP	**-0.07%**	**100%**	**-0.04%**	**95%**
1 year gap	**-0.07%**	**100%**	**-0.04%**	**95%**
2 years gap	**-0.04%**	**90%**	**-0.04%**	**94%**
3 years gap	**0.00%**	**5%**	**-0.03%**	**88%**
93 to 98	**-0.08%**	**100%**	**-0.04%**	**94%**
94 to 98	**-0.09%**	**100%**	**-0.04%**	**94%**
95 to 98	**-0.09%**	**100%**	**-0.04%**	**94%**
96 to 98	**-0.08%**	**100%**	**-0.04%**	**93%**
97 to 98	**-0.05%**	**92%**	**-0.03%**	**79%**
1998 Only	**-0.04%**	**71%**	**-0.03%**	**68%**

Source: Estimated by the Authors from the MRP Auto and Truck Data Bases.

average, while, on the other hand, domestic cars have a smaller margin, and domestic trucks have the average margin. Domestic producers therefore have a big problem in the car market. Although the Europeans have some problem with demand, we could argue that this is due to over-pricing because their margin is higher. However, we cannot say the same for U.S-made cars: they have both a lower demand and lower margin when compared to cars with the same (observable) attributes. We still have the problem that we do not know whether this under-valuation is connected to non-observable factors or to a bad reputation. Anyway, it is clear that the U.S. automobile industry must do something in order to catch up with other main producers in the world.

The history is not quite the same for trucks. Although they do have an advantage in demand, their margin is not below or above other trucks with the same attributes. Recalling our discussion about the truck

hierarchy, we can see that, in terms of margin, the leaders are minivans and trucks, followed by cargo and full-size vans. In terms of margin, pickup trucks are considerably below the average.[14] Considering these results and the fact that light trucks have saved the U.S. automobile industry from a complete disaster during the last two decades, analysts should consider what might be the effects of an EPA regulation on Mini-vans and SUVs. So far, EPA does not have a miles-per-gallon minimum standard on those vehicles; however, it is attempting to impose some regulations on light trucks. How will U.S. producers react to new regulations if they will really be enforced? As we mentioned above, on the one hand, the demand is elastic to changes in the fuel efficiency of the vehicle; on the other hand, the margin might be reduced due to an increase in the efficiency. This implies that consumers are willing to buy cars that are more fuel efficient, but they do not accept a total transfer of the costs associated with that improvement to the price of the vehicle. This might be an important consideration for the U.S. auto industry, especially if we consider the recent advances in hybrid cars by the Japanese companies that were not undertaken by U.S. automakers.
When we change the 2mm definition as we did for the demand, we can see that the effect again vanishes. Comparing the effects on the demand and margin for cars, we notice some differences. First, we see that the impact on margins vanishes faster than it does for the demand when we increase the gap. Second, the opposite happens when we restrict the sample: it vanishes faster for the demand. One possible interpretation is that when a plant implements the new technology, costs increase, but after two years, the plant is already adapted and the cost effects disappear. Because some plants, like the GM plant in Spring Hill, TN, implemented the program just in 1997, it might be the case that those plants were not completely adapted to the new technology and faced some extra costs.

The sensitivity of the impact of the new technology on the supply side for trucks follows a different pattern. It vanishes when we use a three-year gap, but it vanishes faster when we restrict the sample. Recall that this result is opposite from the demand-side result we reviewed earlier and also contradictory with the result we observed in the supply of cars. As mentioned above, we have to be very cautious with the results for trucks given the size of the sample.

---

[14] This is clear in specification (6) where we replaced the pickup dummy with the SUV dummy.

CONCLUSIONS AND EXTENSIONS

Based upon our hedonic-price analysis, we find that the 2mm program appears to have increased the demand for domestically produced vehicles. The effect on short-run (0-5 years) costs occurs, and the net effect is, on balance, a positive one. Without the program, the U.S. automobile industry would probably have lost a greater share of the market than it did. We note that the effect on demand, however, is short-lived. By the time the technology had become incorporated in the production at the majority of U.S. assembly plants, the impacts began to vanish. It is also important to recall that the demand for cars produced by U.S. firms has been decreasing since the early 1970s for a long-list of reasons, including those related to body-quality. The 2mm effort to reverse this trend was too small to alter that trend, although it probably helped stem some of the losses in market share.

We do not agree with the assertion that all the impacts observed was derived from the $20 million invested under 2mm. From our case-study interviews, the installation and operation of 2mm hardware was generally done simultaneously with the installation of new assembly-line tooling and conveyance systems. Improved tooling capability (some of which can be traced to 2mm research) and changes in the way assembly-lines are designed, engineered, and installed underwent significant changes from those prevalent among domestic producers. Combined with what appears to be a cultural change in the production of vehicles by U.S. firms, the 2mm effect may be dwarfed by such changes. The 2mm program was important as a catalyst to some changes, but certainly not all. Although results were good for light trucks, we do not know the effect of a new environmental regulation on those vehicles. In brief, the effort of the NIST was very important, and it was probably in the right direction; however, a real change in the cultural organization of the U.S. automakers is still needed.

Our analysis leaves several issues untested. First, we could test the effect of the new technology by pooling cars and trucks. Although this procedure could help solve the problem of the truck sample, today there is not a big difference between a light truck and a car. Thus, a consumer deciding to buy a car will make the decision looking at both types of vehicles. At least SUVs and Mini-vans compete directly with other cars.

Another problem with our analysis is that we cannot observe all car attributes that influence purchasing decisions and production costs. We therefore do not know if our results are accurate or if they are connected to the "non-observable factors." This is a problem if the non-observable factors are correlated with the attributes that we do observe, and we have reasons to believe they are. For instance, an expensive vehicle is more likely to have a more powerful motor than an inexpensive one, giving rise to endogeneity conditions. In order to correct for this, we could use an instrumental-variable approach. The difficulty is finding appropriate instruments, i.e., instruments that are orthogonal to *e* and *w* in Equations (11a) and (15a) (See Appendix). Appropriate instruments for our problem cannot rely on “exclusion

in the simultaneous-equation approach to the specification problem. Under certain conditions, Chamberlain (1986) shows how to find optimal instruments as a function of a set of endogenous variables.

Another problem is related to the simplifications on the demand side. Because there is just one market share associated with each d-vector in Equation (13a), two vehicle models with the same market share will have the same cross-price derivative with respect to a third car and the same own-price demand derivatives. For instance, in 1996, 36,000 KIA Sephias and 38,000 Mercedes 190s were sold, accounting for an almost identical market share. Equation (13a) implies that an increase in the price of a BMW, for instance, would generate an equal increase in the market share of Mercedes and KIA. Besides, it implies that both KIA and Mercedes have the same mark-up. One way to deal with the problem is allowing each individual to have a different preference for each different characteristic:

$$b_k = \bar{b}_k + s_k v_{ik} \tag{5}$$

Where v_{ik} is a zero-mean random variable. Scaling v_{ik} such that $E(v^2_{ik})=1$ implies that the mean and variance of the marginal utility of attribute *k* are $\bar{b}_k, s_k$. Substituting Equation (22a) into Equations (11a) and (11b), we have that:

$$U(c_i, x_j, p_j) = x_j \bar{b} - ap_j + \sum_k s_k x_{jk} v_{ik} + e_{ij} \equiv d_j + m_{ij} \tag{6}$$

We can still decompose the utility obtained from consuming good *j* into a mean and a deviation from the mean, but now the second term depends on the interaction between consumer preferences and product characteristics. Hence, consumers with preference for sport cars, for instance, will attach high utilities to all sport cars (since their characteristics are similar), which will induce large substitution effects between sport cars. Unfortunately that "random vector" model does not have a closed solution, so that we have to run simulations to aggregate the market share and solve the function by some robust method as maximum likelihood, method of moments, etc.

APPENDIX A
HEDONIC-PRICE MODEL FOR CARS

Let the preferences of the consumer be represented by the utility function:

$$\mathbf{u = u(Z, X, a)} \qquad ($$

where *Z* is the quantity vector of attributes of the car, *X* is the consumption of all other goods, and *a* is a vector of parameters that characterize the consumer preference. From the utility function, we can derive (implicitly) the consumer demand for cars as:

$$\mathbf{D = D(Z, Y, u, a)} \qquad ($$

where *Y* is the consumer's income. Consumers maximize utility, that is, they will choose the *Z* and *X* that solve the maximization problem:

$$\max_{Z,X} U(Z,X,á(\qquad s.t. \qquad M \geq P(Z) + X \qquad \textbf{(3a)}$$

where *P(Z)* is the vector price associated with attributes *Z* usually referred to as the "hedonic price function." First-order conditions for this problem imply that:

$$\frac{\partial u}{\partial Z_i} \bigg/ \frac{\partial u}{\partial X} = \frac{\partial P}{\partial Z_i} \qquad ($$

where Z_i is the quantity of attribute *i* in the car. Plugging Equation (2) into Equation (1), we can rewrite the utility of the consumer as *u* = *u*(*Z, Y- D, a*). Implicitly, the derivation of this utility function implies that

$$\frac{\partial D}{\partial Z_i} = \frac{\partial u}{\partial Z_i} \bigg/ \frac{\partial u}{\partial X} \qquad ($$

The "hedonic price" of attribute *i* ($P_i \equiv \partial P / \partial Z_i$) therefore is the marginal utility and the marginal demand for attribute *i*. To close the model, we have to introduce the car's producers. Producers have a cost function given by *C*(*Z, N, g*) that depends on the quantity of attributes, the number of cars produced *N*, and a vector of parameters *g*. Producers maximize the profit function:

$$\max_{Z,N} P(Z)N - C(Z,N,\gamma)$$ (

First-order conditions for this maximization problem imply that:

$$P_i = \frac{\partial C}{\partial Z_i}, \forall i \quad and \quad P(Z) = \frac{\partial C}{\partial N}$$ (

The first condition is the conventional maximization solution, i.e.,, the producer equates marginal cost and the unit price of each attribute. The second condition means that the producer will produce type *Z* cars until the marginal cost of producing another (type *Z*) car is equal to its total value *P*(*Z*). The market equilibrium is represented as the locus of tangencies between marginal cost and marginal demand and typically depends upon the probability distribution over consumers' preferences and producers' type.

This provides a theoretically coherent foundation for explaining the relationship between the price of a car (or other heterogeneous good) and its attributes. In addition, it provides a hint on how to estimate the hedonic prices. The estimation, however, has many difficulties (theoretical and empirical) that we stress below. The main theoretical difficulty is that the attributes are usually discrete so that the budget constraint is non-linear. Hence, the conventional demand function, i.e., one that shows consumer preferences (over an attribute) if they are faced with constant prices, is misleading.

To obtain a demand system, we depart from a discrete-choice model to one of individual consumer behavior. The idea is that consumers will buy a car *j* (*j* = 1, . . ., J) if the utility of buying this car is higher than the utility of buying any other car (or not buying any car at all, i.e., if *j* = 0). The level of utility is supposed to depend on the consumers' characteristics (*c*) and the car's characteristics (*x, p*), where *x* is a vector of a car's attributes, and *p* is the price of the car, i.e., consumer *i* will buy car *j* if:

$$U(c_i, x_j, p_j) \geq U(c_i, x_r, p_r) \quad r = 0, 1, \ldots, J \qquad \textbf{(8a)}$$

If we had micro-data, we could assume a distribution on the residuals and estimate the demand pattern; however, micro-data on car purchases are very hard to obtain and manage. For this analysis, we work with a data set aggregated by car model (see data section). To derive the aggregate demand system, we have to integrate out the choice function in Equation (8a) over the distribution of *c* in the population. Let

$$\mathbf{A}_j = \{\mathbf{c}:\mathbf{U}(c_i,x_j,p_j) \geq \mathbf{U}(c_i,x_r,p_r), \text{ for } r = 0,1,\ldots,\mathbf{J}\} \qquad \textbf{(9a)}$$

In Equation 9a, A_j is the set of values for *c* that induce the choice of car *j*. Then, assuming that consumers are distributed as *P*(*dc*), the market share of good *j* will be:

$$s_j(p,x) = \int_{c\in A_j} P(dc) \qquad \textbf{(10}$$

Although a more general specification to the utility function than Equation (8a)seems appealing, we have difficulty in obtaining any result using a non-parametric approach. We will therefore assume a linear-utility specification:

$$\mathbf{U}(\mathbf{c}_i, \mathbf{x}_j, \mathbf{p}_j) = \mathbf{x}_j\mathbf{b} - \mathbf{a}\mathbf{p}_j + \mathbf{e}_{ij} \equiv \mathbf{d}_j + \mathbf{e}_{ij} \qquad \textbf{(11a1)}$$

$$\mathbf{U}(\mathbf{c}_i,\mathbf{x}_0,\mathbf{p}_0) = \mathbf{e}_{i0} \qquad \textbf{(11a}$$

where *j* = 0 means that the consumer decided to buy no car at all. Assuming that e_{ij} is distributed independently and identically across both consumers' characteristics and cars' attributes, we can easily compute the market shares by:

$$s_j = \int_{\varepsilon} \prod_{q\neq j} P(\delta_j - \delta_q + \varepsilon)P(d\varepsilon) \qquad \textbf{(12}$$

If *e* has the Weibull distribution function exp[-exp(-*e*)], Equation (12a) has a closed form and the solution can be found analytically as:

$$s_j(p,x,\varepsilon) = e^{\delta_j} \Big/ \left(1 + \sum_{j=1}^{J} e^{\delta_j}\right) \qquad \textbf{(13}$$

Given Equation (13a), we can estimate d_j from:

$$ln(s_j) - ln(s_0) = \delta_j - ln\left(1 + \sum_{j=1}^{J} e^{\delta_j}\right) + ln\left(1 + \sum_{j=1}^{J} e^{\delta_j}\right) = \delta_j$$ **(14a)**

In this simplified model, we can therefore estimate the parameter of interest (*d*) from a simple ordinary least squares on market shares. To estimate the supply, we assume that there are *F* firms, each producing a subset G_f of the *J* products. The marginal cost of production (*m*) is log linear in a vector of cost characteristics (cost shifters, *w*):

$$\ln(m_j) = w_j g + w_j$$ **(15**

Assuming an oligopolistic market with markups, the profits of firm *f* will be:

$$\pi_f = \sum_{j \in G_f} (p_j - m_j) M s_j$$ **(16**

where *M* is the total production of cars and s_j is the market share of model *j* given by Equation (10a). The first-order condition on Equation (16a) implies that:

$$s_j + \sum_{r \in G_f} (p_r - m_r) \frac{\partial s_r}{\partial p_j} = 0$$ **(17**

We can write Equation (17a) in vector notation as:

$$s - D[p - m] = 0$$ **(17**

where **s**, **p** and **m** are the (1x*J*) vectors of market shares, prices and marginal costs, respectively. **D** is a *J*x*J* matrix defined as:

$$\Delta \equiv \begin{cases} -\partial s_r \big/ \partial p_j & ;r, j \in G_f \,(f = 1,\ldots,F) \\ 0 & Otherwise \end{cases} \quad \textbf{(18}$$

The vector of marginal cost therefore depends only on the parameters of the demand system and the equilibrium price vector (assuming that the market is in equilibrium), and we can estimate it as:

$$\text{m} = \text{p} - \text{D}^{-1}\text{s} \quad \textbf{(19}$$

We can then analytically find the marginal cost, and we can find the parameter of interest in the supply function by regressing the log of marginal costs on cost shifting:

$$\mathbf{ln(\mathit{m_j}) = \mathit{w_j g} + \mathit{w_j}} \quad \textbf{(20}$$

This is the model that we use to determine the hedonic prices for U.S. automobiles and light trucks.

APPENDIX B
REGRESSION SUMMARIES

TABLE B1
SUMMARY RESULTS FROM THE DEMAND REGRESSION FOR CARS

	(1)		(2)		(3)		(4)		(5)		(7)		(8)		(9)	
	β	σ	β	σ	β	σ	β	σ	β	σ	β	σ	β	σ	β	σ
CTE	**-19.58 (*)**	**4.98**	**-21.11 (*)**	**4.99**	**-20.48 (*)**	**4.97**	**-21.77 (*)**	**4.96**	**-21.96 (*)**	**4.94**	**-21.31 (*)**	**4.89**	**-22.19 (*)**	**4.80**	**-22.40 (*)**	**4.81**
P	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**	**-0.04 (*)**	**0.00**
L_DR	**0.31 (*)**	**0.07**	**0.31 (*)**	**0.07**	**0.34 (*)**	**0.07**	**0.39 (*)**	**0.07**	**0.39 (*)**	**0.07**	**0.41 (*)**	**0.07**	**0.40 (*)**	**0.07**	**0.41 (*)**	**0.07**
DRV	**0.04**	**0.05**	**0.04**	**0.05**	**0.04**	**0.05**	**0.07**	**0.05**	**0.07**	**0.05**						
FWD	**-0.61 (*)**	**0.25**	**-0.63 (*)**	**0.25**	**-0.59 (**)**	**0.25**	**-0.50 (**)**	**0.24**	**-0.49 (**)**	**0.24**	**-0.53 (**)**	**0.24**	**-0.54 (**)**	**0.24**	**-0.52 (**)**	**0.24**
SW	**-1.26 (*)**	**0.06**	**-1.26 (*)**	**0.06**	**-1.27 (*)**	**0.06**	**-1.24 (*)**	**0.06**	**-1.24 (*)**	**0.06**	**-1.23 (*)**	**0.06**	**-1.23 (*)**	**0.06**	**-1.25 (*)**	**0.06**
L_WB	**2.70 (*)**	**0.78**	**2.75 (*)**	**0.79**	**3.17 (*)**	**0.76**	**2.92 (*)**	**0.76**	**2.93 (*)**	**0.76**	**2.84 (*)**	**0.75**	**2.81 (*)**	**0.75**	**2.75 (*)**	**0.75**
L_LNG	**1.71 (*)**	**0.70**	**1.93 (*)**	**0.69**												
L_WDT	**-1.78 (**)**	**0.84**	**-1.70 (**)**	**0.84**												
L_HT	**2.52 (*)**	**0.63**	**2.48 (*)**	**0.63**	**2.64 (*)**	**0.63**										
SIZE					**0.21**	**0.45**										
VOLUME							**1.01 (*)**	**0.37**	**1.02 (*)**	**0.37**	**0.98 (*)**	**0.37**	**1.07 (*)**	**0.36**	**1.06 (*)**	**0.36**
L_WT	**-0.29 (*)**	**0.10**	**-0.24 (**)**	**0.10**	**-0.29 (*)**	**0.10**	**-0.30 (**)**	**0.10**	**-0.30 (*)**	**0.10**	**-0.31 (*)**	**0.10**	**-0.31 (*)**	**0.10**	**-0.32 (*)**	**0.10**
LN_CY	**0.21**	**0.15**	**0.24**	**0.15**	**0.13**	**0.15**	**0.17**	**0.15**	**0.19**	**0.14**	**0.13**	**0.14**				
L_DISP	**0.08**	**0.11**	**0.10**	**0.11**	**0.07**	**0.11**	**0.04**	**0.11**								

L_HP	**0.34 (**)**	**0.14**			**0.33 (**)**	**0.14**	**0.24 (**)**	**0.14**	**0.25 (**)**	**0.14**	**0.25 (***)**	**0.14**	**0.28 (**)**	**0.13**	**0.35 (**)**	**0.13**
HP/WT			**0.44**	**0.30**												
AT	**-0.05**	**0.06**	**-0.06**	**0.06**	**-0.03**	**0.06**	**-0.04**	**0.06**	**-0.04**	**0.06**						
L_MPG	**1.61 (*)**	**0.20**	**1.49 (*)**	**0.19**	**1.53 (*)**	**0.20**	**1.65 (*)**	**0.19**	**1.64 (*)**	**0.19**	**1.65 (*)**	**0.19**	**1.61 (*)**	**0.19**	**1.71 (*)**	**0.19**
EURO	**-0.59 (*)**	**0.07**	**-0.59 (*)**	**0.07**	**-0.60 (*)**	**0.07**	**-0.54 (*)**	**0.07**	**-0.54 (*)**	**0.07**	**-0.55 (*)**	**0.07**	**-0.56 (*)**	**0.06**	**-0.50 (*)**	**0.06**
DOM	**-0.23 (*)**	**0.07**	**-0.25 (*)**	**0.07**	**-0.26 (*)**	**0.07**	**-0.28 (*)**	**0.07**	**-0.28 (*)**	**0.07**	**-0.28 (*)**	**0.07**	**-0.27 (*)**	**0.07**		
IMPORTS	**-0.91 (*)**	**0.07**	**-0.91 (*)**	**0.07**	**-0.91 (*)**	**0.07**	**-0.87 (*)**	**0.07**	**-0.87 (*)**	**0.07**	**-0.88 (*)**	**0.07**	**-0.88 (*)**	**0.07**	**-0.70 (*)**	**0.05**
TWO_MM	**0.31 (*)**	**0.08**	**0.31 (*)**	**0.08**	**0.33 (*)**	**0.08**	**0.32 (*)**	**0.08**	**0.32 (*)**	**0.08**	**0.32 (*)**	**0.08**	**0.33 (*)**	**0.08**	**0.26 (*)**	**0.08**
TREND	**-0.04 (*)**	**0.01**	**-0.03 (*)**	**0.01**	**-0.04 (*)**	**0.01**	**-0.04 (*)**	**0.01**	**-0.04 (*)**	**0.01**	**-0.04 (*)**	**0.01**	**-0.04 (*)**	**0.01**	**-0.04 (*)**	**0.01**
Adjusted R^2		**0.51**		**0.51**		**0.51**	**0.51**	**0.50**		**0.50**		**0.50**		**0.50**		**0.50**

TABLE B2
SUMMARY RESULTS FROM THE DEMAND REGRESSION FOR LIGHT-DUTY TRUCKS

Variable	(1)		(2)		(3)		(4)		(5)		(7)		(8)		(9)	
	β	σ	β	σ	β	σ	β	σ	β	σ	β	σ	β	σ	β	σ
CTE	-19.96 (*)	7.14	-20.76 (*)	7.17	-20.74 (*)	6.93	-30.79 (*)	6.87	-21.48 (*)	6.92	-30.23 (*)	6.18	-28.23 (*)	5.79	-28.88 (*)	5.82
P	-0.04 (**)	0.02	-0.04 (**)	0.02	-0.04 (**)	0.02	-0.06 (*)	0.02	-0.04 (**)	0.02	-0.04 (*)	0.02	-0.04 (*)	0.02	-0.04 (*)	0.02
L_DR	0.84 (*)	0.18	0.84 (*)	0.18	0.84 (*)	0.17	0.85 (*)	0.18	0.81 (*)	0.17	0.95 (*)	0.17	0.94 (*)	0.16	0.88 (*)	0.16
DRV	0.25	0.16	0.25	0.16	0.25	0.16	0.01	0.16								
FWD	-0.62 (*)	0.13	-0.62 (*)	0.13	-0.62 (*)	0.13	-0.42 (*)	0.13	-0.63 (*)	0.13	-0.66 (*)	0.13	-0.68 (*)	0.13	-0.68 (*)	0.13
MINIVAN	-0.41 (*)	0.16	-0.41 (*)	0.16	-0.41 (*)	0.16	-0.37 (**)	0.16	-0.34 (**)	0.15	-0.34 (**)	0.15	-0.33 (**)	0.15	-0.32 (**)	0.15
FSVAN	-2.29 (*)	0.21	-2.28 (*)	0.21	-2.28 (*)	0.21	-1.89 (*)	0.21	-2.25 (*)	0.21	-2.26 (*)	0.21	-2.25 (*)	0.21	-2.24 (*)	0.21
CARGO	-1.65 (*)	0.19	-1.64 (*)	0.19	-1.64 (*)	0.19	-1.32 (*)	0.19	-1.61 (*)	0.19	-1.50 (*)	0.19	-1.47 (*)	0.18	-1.45 (*)	0.19
PICKUP	0.49 (*)	0.17	0.49 (*)	0.17	0.49 (*)	0.17	0.09	0.16	0.46 (*)	0.17	0.60 (*)	0.16	0.63	0.16	0.58	0.16
L_WB	2.22 (*)	0.84	2.25 (*)	0.84	2.25 (*)	0.76	0.51	0.72	2.18 (*)	0.76						
L_LNG	-1.35	1.05	-1.40	1.05												
L_WDT	-1.42	1.06	-1.41	1.06												
L_HT	6.08 (*)	0.94	6.05 (*)	0.94	6.05 (*)	0.89			5.77 (*)	0.87	5.55 (*)	0.83	5.40 (*)	0.82	5.37 (*)	0.82
SIZE					-1.41 (**)	0.72			-1.21 (***)	0.71	-0.19	0.61	-0.41 (*)	0.57	-0.29 (*)	0.57
VOLUME							1.66 (*)	0.52								
L_WT	-1.33 (*)	0.52	-0.75	0.58	-0.75	0.58	-0.70	0.59	-0.75	0.58	-0.54	0.57				
LN_CY	-1.16 (*)	0.35	-1.17 (*)	0.35	-1.17 (*)	0.35	-1.16 (*)	0.36	-1.16 (*)	0.35	-1.23 (*)	0.35	-1.23 (*)	0.35	-1.21 (*)	0.35
L_DISP	2.52 (*)	0.39	2.47 (*)	0.40	2.47 (*)	0.40	2.21 (*)	0.40	2.42 (*)	0.40	2.30 (*)	0.39	2.15 (*)	0.35	2.21 (*)	0.35

L_HP	0.50 (***)	0.31														
HP/WT			1.45 (***)	0.80	1.45 (***)	0.80	1.81 (**)	0.82	1.47 (***)	0.80	1.69 (**)	0.80	2.04 (*)	0.71	2.24 (*)	0.71
AT	-0.27 (**)	0.11	-0.27 (**)	0.11	-0.27 (**)	0.11	-0.39 (*)	0.11	-0.27 (*)	0.11	-0.26 (**)	0.11	-0.26 (*)	0.11	-0.24 (*)	0.11
L_MPG	2.62 (*)	0.45	2.61 (*)	0.45	2.61 (*)	0.45	2.46 (*)	0.46	2.65 (*)	0.45	2.54 (*)	0.45	2.57 (*)	0.45	2.61 (*)	0.45
EURO	0.25	0.31	0.24	0.31	0.24	0.31	0.45	0.31	0.19	0.31						
DOM	0.39 (*)	0.15	0.39 (*)	0.15	0.39 (*)	0.14	0.37 (*)	0.15	0.38 (*)	0.14	0.41 (*)	0.14	0.44 (*)	0.14		
IMPORTS	-0.50 (*)	0.14	-0.50 (*)	0.14	-0.50 (*)	0.14	-0.53 (*)	0.14	-0.51 (*)	0.14	-0.55 (*)	0.14	-0.54 (*)	0.14	-0.83 (*)	0.11
2mm	0.43 (*)	0.12	0.43 (*)	0.12	0.43 (*)	0.12	0.40 (*)	0.12	0.45 (*)	0.12	0.45 (*)	0.12	0.45 (*)	0.12	0.56 (*)	0.12
TREND	-0.03 (***)	0.01	-0.03 (**)	0.02	-0.03 (**)	0.01	-0.02	0.02	-0.03 (**)	0.01	-0.03 (**)	0.01	-0.03	0.01	-0.05	0.01
Adjusted R^2		0.46		0.46		0.46		0.44		0.46		0.45		0.45		0.45

TABLE B3
VARIABLES DESCRIPTION

Variable	Description
CTE	**Constant term**
P	**Real price (1983 US$)**
L_DR	**Natural log of number of doors**
DRV	**Dummy =1 if the vehicle is front wheel drive**
FWD	**Dummy =1 if the vehicle is four wheel drive**
SW	**Dummy =1 if the vehicle is a station wagon**
MINIVAN	**Dummy =1 if the vehicle is a mini van**
FSVAN	**Dummy =1 if the vehicle is a full size van**
CARGO	**Dummy =1 if the vehicle is a cargo van**
PICKUP	**Dummy =1 if the vehicle is a pick up**
L_WB	**Natural log of number of wheelbase**
L_LNG	**Natural log of length**
L_WDT	**Natural log of width**
L_HT	**Natural log of height**
SIZE	**Natural log of size (length times width)**
VOLUME	**Natural log of volume (size times height)**
L_WT	**Natural log of weight**
LN_CY	**Natural log of number of cylinders**
L_DISP	**Natural log of displacement**
L_HP	**Natural log of horse power**
HP/WT	**Horse power over weight**
AT	**Dummy =1 if the vehicle has automatic transmission**
L_MPG	**Natural log of miles per gallon (EPA)**
EURO	**Dummy =1 if the vehicle was produced by an European company**
DOM	**Dummy =1 if the vehicle was produced by an American company**
IMPORTS	**Dummy =1 if the vehicle was imported**
2mm	**2mm Dummy**

TREND	**Trend**

REFERENCES

Barry S., J. Levinsohn and A. Pakes. 1995. "Automobile Price in Market Equilibrium." *Econometrica*, Vol. 63, No. 4 (July), pp. 841-890.

Chamberlain, G. 1986. "Assymptotic Efficiency in Estimation with Conditional Moment Restrictions," *Journal of Econometrics*, Vol. 33, pp.

Court, A.T. 1939. "Hedonic Price Indexes with Automotive Examples." *The Dynamics of Automobile Demand*. New York: General Motors

Griliches, Zvi. 1961. "Hedonic Price Indexes for Automobiles: An Econometric Analysis of Quality Change." *The Price Statistics of the Federal Government*, No. 73.Long, William F. 1999. "Advance Technology Program: Performance of Completed Projects, Status Report Number 1." NIST Special Publication 950-1. U.S. Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Shepard, S. 1999. "Hedonic Analysis of Housing Markets." In *Handbook of Regional and Urban Economics*, edited by Paul Cheschire and Edwin S. Mills. Amsterdam: Elsevier.

Waugh, F.V. 1929. Quality as a Determinant of Vegetable Prices. New York: Columbia University Press.

Yates, B. 1996. The Critical Path: Inventing an Automobile and Reinventing Corporation. New York: Little, Brown.