

# The Substitutability of New and Used Goods: Highway Rollers \* (preliminary draft)

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## Abstract

This paper builds on recent advances in demand estimation for differentiated products by examining the substitutability of durable goods across vintages. Previous work on estimating cross-price elasticities of durable goods has mostly focused on the market of new goods, subsuming the market for used goods in the consumer's outside option. Using both detailed Census data on the stock of trucks in the U.S. and published used truck valuation data, we estimate a discrete choice model of demand in which firms have heterogeneous preferences for trucks based on price and physical characteristics.

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# 1 Introduction

In durable goods industries, the presence of secondary markets has important theoretical implications on equilibrium prices and quantities in the primary market. In particular, the existence of secondary markets may have a significant influence on new good prices if consumers view new and used varieties as close substitutes. Most work on estimating the elasticities of substitution for durable goods has only focused on new goods, either ignoring the secondary market altogether or lumping it into a composite, outside good. Given the size and sophistication of secondary markets for a number of durable goods, a more thorough analysis of used goods and their relationship with new goods seems warranted.

This paper analyzes the relationship between new and used goods by estimating the substitutability of trucks of various vintages. Specifically, we focus on a subset of trucks deemed ‘highway rollers’. These trucks primarily transport cargo long distances and are a particular type of truck-tractor or ‘tractor-trailer’. We focus on this particular durable good for a variety of reasons. First, the market for highway rollers is an important cyclical segment of the U.S. economy. Second, we argue that the market for highway rollers is both clearly defined and contains a relatively small number of producers and products. This limits the number of goods available to firms that purchase trucks, allowing us to estimate and analyze the substitution patterns across products and vintages. Lastly, there exist detailed data on the stock and value of used trucks that enables us to perform our analysis. Our results have broader implications as the market for highway rollers is similar to those of a number of durable goods, such as automobiles

We analyze the substitutability of highway-rollers following the random coefficients discrete choice approach taken in Berry, Levinsohn, and Pakes (1995). We adopt this approach, as it allows for flexible substitution patterns and the incorporation of consumer-level heterogeneity in tastes over observed product characteristics. Further, this approach enables us to incorporate average demographics of consumers and relate them to the characteristics of the products they produce, as done in Petrin (2002). This extra information is crucial in estimating demand characteristics, as estimates tend to be imprecise when constrained to only market-level data.<sup>1</sup>

We use data from two sources. The Census Bureau’s Vehicle Inventory and Use Survey (VIUS) provides information on the stock and characteristics of all highway

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<sup>1</sup>See Goldberg (1995) and Berry, Levinsohn, and Pakes (2003) for more details.

rollers registered in the U.S. This data provides an extraordinary amount of information on highway rollers, as survey respondents, i.e. truck owners, answer a large number of questions on the physical and operational characteristics of their truck. In addition, this survey contains a host of ‘demographic’ variables on each respondent, such as truck fleet size and major product hauled. To assign prices to the quantity information in the VIUS, we turn to the Truck Blue Book, a listing of truck prices conditional on characteristics. Based on truck characteristics, we are able to attach prices to trucks in the VIUS. The end result of this merger is data on the equilibrium price and quantity for all highway rollers registered in the U.S.

The results from our analysis are still preliminary. Currently our model is estimated using quite aggregated data. Our findings suggest this aggregation is costly, as the random coefficients model hardly improves upon a simply logit specification with instrumental variables. We anticipate the use of more disaggregated data to be much more fruitful.

Two important assumptions underly our work. First, we assume that firms seeking to transport goods by truck look only at market for highway rollers. As detailed later in the paper, we believe that railroads, ships, and other types of trucks are poor outside options for firms that are initially looking at highway rollers to transport their cargo. Second, our analysis is based on firms minimizing the cost of transporting cargo, rather than maximizing profits. We assume that firms have cargo to transport and are buying highway rollers in an attempt to minimize that cost.

This paper builds on a large literature that seeks to estimate consumer’s preferences over differentiated goods and further our understanding of the pricing of durable goods. (Fill this in)

The rest of the paper is organized as follows. Section 2 provides a brief overview of the market for highway rollers. Section 3 then explains the discrete choice estimation procedure and the specification of the firm’s cost minimization problem. Section 4 describes the data and the identifying assumptions. Results from demand estimation are presented in Section 5, and Section 6 concludes.

## 2 Overview of the Trucking Industry

The trucking industry is an important part of the U.S. economy, having transported almost 6 trillion dollars worth of goods in 1997.<sup>2</sup> Trucks dominate rail and water transportation as a means of moving merchandise, accounting for 72 percent of all shipments as measured by value or 69 percent of shipments as measured by weight. After discarding multiple-mode shipments (which makes up 13.6 percent of shipments as measured by value and are predominantly carried by parcel, U.S. Postal Service or couriers), trucks emerge as the preeminent mode of transportation, carrying 87 percent of shipments as measured by value.

The role of trucks as the major mode of transporting cargo across the U.S. is reinforced when analyzing shipments by commodity. Of the 43 commodities listed in the 1997 Commodity Flow Survey, the truck share of single mode shipments, as measured by value, is over 90 percent for all but 17 commodities and over 80 percent for all but 7 commodities. Outside of a few commodities such as cereal grain (for which railways are also used) and gasoline (where pipelines play an important role), the dominance of trucking implies that for most firms in the U.S., rail and water transport are poor substitutes.

While a variety of trucks are used to move commodities within the U.S., the workhorse of this sector, and the focus of our analysis, is the ‘highway roller’, a truck-tractor that is primarily designed for long distance hauling. Figure 1 shows two examples of highway rollers, a cabin-over-engine style truck on the left and a conventional cabin style truck on the right. Highway rollers are distinguished from other trucks by a number of structural characteristics that allow them to pull heavy cargo efficiently (for example, more axles and larger engines). As trucks in the complement of the set of highway rollers are designed for other tasks, they tend to be poor substitutes for these long distance haulers. Based on our conversations with industry analysts and reading of the trade press, we developed a list of criteria to identify highway rollers in the 1992 and 1997 VIUS.<sup>3</sup>

While there are many manufacturers of highway rollers, five companies dominate the market. Table 1 lists these five major firms as well as their stock of trucks and market share. Of the firms listed above, two are groups of manufacturers. We defined Freightliner as a combination of five brands (Autocar, Freightliner, GMC/Chevy, White, and White GMC) that either merged before 1997 or jointly marketed their trucks during

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<sup>2</sup>This fact and other shipment facts come from the 1997 Commodity Flow Survey.

<sup>3</sup>For more details, see Section 4.

Figure 1: Highway Rollers



Table 1: U.S. Stock and Market Share by Manufacturer

Manufacturer	1992		1997	
	Stock (units)	Market Share (%)	Stock (units)	Market Share (%)
International	134,114	21	129,581	19
Kenworth	104,101	16	86,032	13
Mack	70,949	11	59,135	9
Peterbilt	85,124	14	89,217	13
Freightliner	211,007	32	277,798	41
Other	44,468	7	43,267	6
Total	649,762	100	685,031	100

Table 2: Distribution by Model-Year and Cabin Type

Vintage	1992			1997		
	Stock (thousands)	Percent Share		Stock (thousands)	Percent Share	
		COE	Conv.		COE	Conv.
0	64.9	15	85	85.6	8	92
1	45.9	18	82	86.3	6	94
2	53.8	17	83	88.2	5	95
3	65.1	24	76	65.9	7	93
4	59.2	23	77	50.9	16	84
5	41.7	16	84	35.2	17	83
6	42.1	31	69	31.8	20	80
7	44.7	42	58	37.2	11	89
8	50.0	47	53	44.2	19	81
9	n.a.	n.a.	n.a.	36.1	12	88
Old	187.3	40	60	123.7	28	72
Total	649.8	29	71	685.0	13	87

Note: COE are cabin-over-engine trucks, and  
 Conv. are conventional cabin trucks.  
 Vintage 9 in 1992 is part of ‘Old’ trucks

this time. The Other group combines all the remaining manufacturers not otherwise listed, such as Ford, Volvo and Western Star.

As the table demonstrates, the market for highway rollers is highly concentrated with five manufacturers constituting over 90 percent of the market. Between 1992 and 1997, there was significant change within this market as Freightliner increased its market share 9 percentage points (a 28 percent increase), at the expense of all other manufacturers. Also, over this time period the stock of highway rollers increased 5 percent, in line with an overall rise in the stock of all trucks.

Table 2 provides a more detailed look at the stock of highway rollers, describing the distribution of these trucks by vintage and cabin type. Vintage is defined as the difference between the model-year of a truck and the calendar year of the VIUS survey. Vintage 0 trucks are defined slightly differently, as they include both 1992 and 1993 model-year trucks in the 1992 VIUS and 1997 and 1998 model-year trucks in the 1997 VIUS. ‘Old’ trucks are the aggregation of all remaining vintages not otherwise listed.<sup>4</sup> Cabin type

<sup>4</sup>There are common model-years across the two survey years. Specifically, vintages 1 through 4 in the 1992 survey are the same model-year trucks as vintages 6 through 9 in the 1997 survey. Vintage 0

describes the location of the driver’s cabin relative the engine and, in our sample, has two configurations: a conventional cab where the engine is in front of the driver, and cabin-over-engine where the driver is on top of the engine.

Turning first to the total line at the bottom, Table 2 illustrates a major change in the market for highway rollers. Between these two survey years, COE’s share of highway rollers fell from 29 to 13 percent, a decrease of more than 50 percent. In absolute numbers, the number of COE highway rollers dropped from 192,000 to 92,000. The popularity of COE style trucks have declined since 1981 when federal deregulation eliminated trucking requirements that favored the COE design.<sup>5</sup> Without the favorable regulations, the disadvantages of the COE design in terms of ease-of-maintenance and driver-comfort shifted a significant amount of sales from COE to conventional-cabin trucks.

Turning next to the distribution of trucks by vintage, Table 2 drives home the importance of used trucks in the market for highway rollers. Roughly 50 percent of the stock of highway rollers in 1992 have at least a 5 year-old vintage, and about 30 percent fall into the ‘Old’ vintage category. In 1997, the stock of highway rollers is slightly newer, but 50 percent of highway rollers are still at least a 4 year-old vintage and approximately 25 percent are of vintage of at least 8. The high level of durability among highway rollers suggests there should be large and active secondary markets. Indeed, as in the automobile industry, there are used truck dealers throughout the U.S., internet listings, and several nationally published price guides for new and used trucks.

### 3 Model

The demand for highway rollers is modeled using a discrete choice framework. There are  $i = 1, \dots, I$  firms choosing among  $j = 1, \dots, J$  trucks. We assume that firms have already chosen to transport goods by truck and are seeking to minimize that cost. The cost of the flow of services from truck  $j$  for firm  $i$  is given by

$$c_{ij} = \delta_j(\theta) + \mu_{ij}(\theta) + \varepsilon_{ij}. \tag{1}$$

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in 1992 partially overlaps with vintage 4 and 5 in 1997.

<sup>5</sup>See Stark’s Off-highway Ledger Vol 14, No 11

The first component is a product-specific term that is common to all firms, while the  $\mu_{ij}$  term captures heterogeneity in firm tastes for observable product characteristics.<sup>6</sup> The last term,  $\varepsilon_{ij}$  is an idiosyncratic cost term that is assumed to be independent and identically distributed across both products and firms. The last two terms,  $\mu_{ij} + \varepsilon_{ij}$ , represent a mean-zero heteroskedastic deviation from  $\delta_j$  and captures the effects of random coefficients.

The cost component that is common to all firms is given by

$$\delta_j = p_j + X_j\beta + \xi_j, \quad (2)$$

where  $p_j$  is the price of truck  $j$ ,  $X_j$  is a vector of observed characteristics,  $\beta$  is a vector of cost parameters associated with the observed characteristics, and  $\xi_j$  represents costs derived from unobserved product characteristics. The vector of observed truck characteristics includes the displacement of the engine, lifetime miles, the weight of the truck while empty, the miles per gallon the truck averaged over the past year, and the number of fuel conservation measures in place (e.g. aerodynamic bodywork). The unobserved characteristic includes differences in truck characteristics observed by firms but not observed by the econometrician, such as quality and styling.

The cost component that is heterogenous across firms,  $\mu_{ij}$ , is given by

$$\mu_{ij} = \sum_k \gamma_k \nu_{ik} x_{jk}, \quad (3)$$

where  $x_{jk} \in X_j$  is the  $k$ th observable characteristic of truck  $j$  for  $k = 1, \dots, K$ .  $\gamma_k$  measures the heterogeneity in costs for the observed characteristics in the population, and  $\nu_{ik}$  represents idiosyncratic firm  $i$  costs for these characteristics.

In future work, we want to allow for  $\gamma_k \nu_{ik}$  associated with the vintage of the truck, to depend on demographics. Specifically, we would like firms with different fleet sizes to have different evaluations of cost by vintage, so that, where  $v = 0, \dots, 9$ , designates vintage,

$$\gamma_v \nu_{iv} = \gamma_v \ln(s_i) \nu_{iv}, \quad (4)$$

and  $s$  is the fleet size of firm  $i$ . Hence,  $\gamma_v \nu_{iv}$  would act as a cost shifter that allows firms with different fleet sizes to value the vintage of a truck differently.

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<sup>6</sup>This discrete choice formulation closely follows Petrin (2002).

After integrating over  $\varepsilon_{ij}$ , which is assumed to have a type 1 extreme value distribution, the probability that firm  $i$  purchases truck  $j$  is given by

$$Pr(j|X, i) = \frac{\exp(p_j + X_j\beta + \sum_k \gamma_k \nu_{ik} x_{jk} + \xi_j)}{\sum_l \exp(p_l + X_l\beta + \sum_k \gamma_k \nu_{ik} x_{lk} + \xi_l)}. \quad (5)$$

As firms are characterized by  $(\nu_i, s_i)$ , aggregate demand is then obtained by integrating over the distribution of  $\nu$  and  $s$ . The distribution of demographics (fleet size) is taken from data as explained in Section 4.

## 4 Data

In this section we describe the data. We first explain how we constructed the data and describe its contents. We then report summary statistics of the variables we used in our estimation procedure.

### 4.1 Origin of the Data

The data we use is a compilation of two datasets, the Census Bureau’s VIUS and The Truck Blue Book.<sup>7</sup> The VIUS is a survey conducted every five years whose purpose is to track the stock of trucks operating in the U.S. The Census surveys a random sample of trucks registered or licensed in the U.S. as of July 1st of the survey year, and records both physical and operational characteristics of the sampled truck. A few of the many characteristics the VIUS records are make and model-year of the truck, the vehicle identification number (VIN), gas mileage, and lifetime miles. In addition, the VIUS records some information on the demographics of the owner of the truck. For example, information is recorded about the industry in which the truck is primarily used and the fleet size of the firm that owns the truck. This survey, then, provides a detailed look at the stock of trucks every five years as well as demographic information on the firms that own the trucks.

In this paper, we examine the 1992 and 1997 VIUS, and anticipate folding in the 2002 survey when it is released. We did not include earlier surveys as they are not yet available in electronic form. Each survey is quite large; the 1992 and 1997 VIUS

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<sup>7</sup>Before 1997, the VIUS was known as the Truck Inventory and Use Survey. The Truck Blue Book is currently published by Primedia.

contain 123,641 and 104,545 observations respectively. From this data on the stock of all trucks, we extract the subset of trucks that fit our definition of highway rollers, or trucks designed for long distance hauling. Based on conversations with industry analysts and a review of the trade press, we developed a list of criteria that trucks would need to satisfy in order to be classified as a highway roller. First, we eliminated any truck that is not a truck-tractor. Truck-tractors are trucks designed to pull trailers, a necessary requirement for long distance hauling. This restriction severely reduced the size of the VIUS in both census years, as observations on pickup trucks and other light trucks (e.g. straight trucks or ‘box’ trucks) were eliminated. For the 1992 VIUS, for example, the sample size fell from 123,641 observations to 42,108. This subset, however, still contained trucks that are clearly not used to haul goods over highways. Trucks, for example, that were extensively used off-road, or had a body type incompatible with long distance hauling (e.g. utility truck) remained in the sample. Consequently, we further refined the set of truck-tractors by only including those that satisfy the following criteria,

1. Have three axles,
2. Have a diesel engine and air brakes,
3. Have either a conventional or cabin-over-engine design,
4. Do not spend most of their time off-road,
5. Fit a list of body types.<sup>8</sup>

The first restriction mainly eliminates truck-tractors with two axles, as these trucks are limited by how much cargo they can pull. These trucks serve a niche market by hauling light loads. Similarly, this restriction rules out four or more axle trucks, which are a tiny subset of trucks catering to a extremely small niche of firms typically engaged in ‘severe service’ activities. After conditioning on three axled truck-tractors, almost all trucks fulfill criteria two and three. These constraints eliminate a few unusual trucks that are built to serve very particular demands. The fourth requirement is a check to make sure that the truck is operated in a manner consistent with highway rollers, while the last constraint ensures that the truck in question has a body type consistent with long distance hauling. These restrictions slimmed down the dataset, decreasing the number

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<sup>8</sup>The list of body types that were excluded from our refined samples are: pickup, panel or van, multistop or step van, garbage hauler, concrete mixer, yard tractor, sport utility, station wagon, minivan, and beverage, public utility, winch or crane, wrecker, service, oilfield and dump trucks.

of observations from 42,108 to 26,668 for the 1992 VIUS and from 27,956 to 17,385 for the 1997 VIUS. We believe the resulting sample of observations is representative of the stock of highway rollers in the U.S. for the two census years.

While the VIUS provides a detailed accounting of the stock of highway rollers in the U.S., it does not provide the prices of these trucks. For this missing information, we turn to the Truck Blue Book, a comprehensive listing of truck prices based on their characteristics. From the publisher, we obtained the October Truck Blue Books for 1992 and 1997. We then proceeded to assign prices to trucks in the VIUS based on their recorded characteristics. In order to be able to compare prices in these two years, we deflated the 1997 price into 1992 dollars using the Bureau of Labor Statistics's producer's price index for heavy trucks.

One difficulty we currently face is that the Truck Blue Book uses a different set of characteristics to describe a truck compared to the VIUS. Beyond more general characteristics such as make and model-year, it becomes difficult to distinguish trucks with different trim lines (e.g. differing engines or gross vehicle weight ratings). A solution to this problem is to use sections of the truck's VIN as a link between these two data sources. In the VIUS, however, the VIN is unpublished and we are still in the process of obtaining this information.

Excluding the VIN, the characteristics shared in both datasets are make, model-year and whether the style of the truck cabin is conventional or COE. While this involves a fair amount of averaging over different types of trucks, we still believe this data contains useful information on how firms substitute across trucks of various vintages. We anticipate obtaining the necessary VIN information in the VIUS that would allow us to assign prices based on a richer set of characteristics and so re-do our analysis at a less aggregated level.

## 4.2 Data Description

From the truck blue book, we were able to assign an average price for all but two categories of make, model-year, and cabin-style found in the VIUS. For each observation, the VIUS contains over 200 variables which provide information on a slew of operational and physical characteristics of the truck in addition to information on the owner of the truck. For our purposes, we focus on eight truck characteristics: year (i.e. 1992 or 1997), make, model-year, cabin type (i.e. conventional or cab-over-engine), engine size, weight when empty, lifetime miles, and miles per gallon (MPG). Combining the sample of highway rollers from the 1992 and 1997 VIUS and dropping observations with missing

Table 3: Truck Characteristics

Variable	Mean	Std Dev
Engine size	18.2	1.48
Empty weight	29,000	7,000
Lifetime mileage	406,000	255,000
MPG	5.74	1.03
Fuel conservation	2.82	1.62

Note: MPG is miles per gallon

values results in a dataset of 37,530 observations. For the 1992 market, there are 107 make, model-year, and cabin-style combinations, and for the 1997 market there are 109 combinations. We treat ‘Old’ vintage trucks differently, lumping them together regardless of make and cabin-style into a single category. The mean and standard deviation of the truck characteristic are listed in Table 3. Engine size is measured by the displacement of the engine in cubic inches, where a rating of 18 corresponds to a displacement of 700 to 800 cubic inches. Moving up or down a rating corresponds to a new displacement range of 100 cubic inches, where the top range is 1001 cubic inches and above. The empty weight of a truck is measured in pounds, lifetime mileage is in miles, and MPG is the miles per gallon that the truck averaged in the survey year. Finally, fuel conservation measures the number of features on the truck to conserve fuel. This variable is equal to the sum of five binary variables in the VIUS that measure the level of the truck’s fuel conservation prowess. The five binary variables record whether a truck has aerodynamic features, a fuel economy engine, variable fan drives, whether its axle or drive ratio is set to maximize fuel efficiency, and a catch-all category of other fuel conservation features. As Table 3 demonstrates, there is substantial variation across trucks in these five characteristics.

There is also tremendous variation in the price of trucks in our sample, particular over vintage. Figures 2 and 3 show the mean price of trucks by vintage, across cabin type and survey years. These figures illustrate the relatively smooth decline in price across vintage, and the significantly different pricing strategies of COE highway rollers between the two survey years. The dramatic fall in the price of newer vintage COE highway rollers from 1992 to 1997 is likely the result of the declining popularity of this style of trucks. Another difference between the two survey years is the flattening of the slope of the price curve from 1992 to 1997. For conventional-cabin trucks, vintage 8 models are valued at 20 percent of the vintage 0 type in 1992, while in 1997 they are valued at 33

Figure 2: Price Depreciation by Cabin Type in 1992

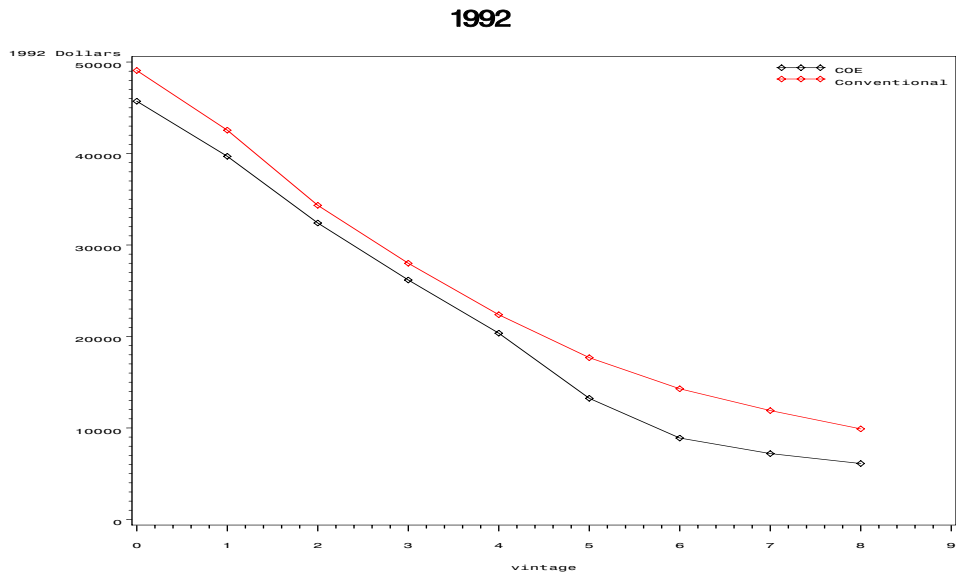


Figure 3: Price Depreciation by Cabin Type in 1997

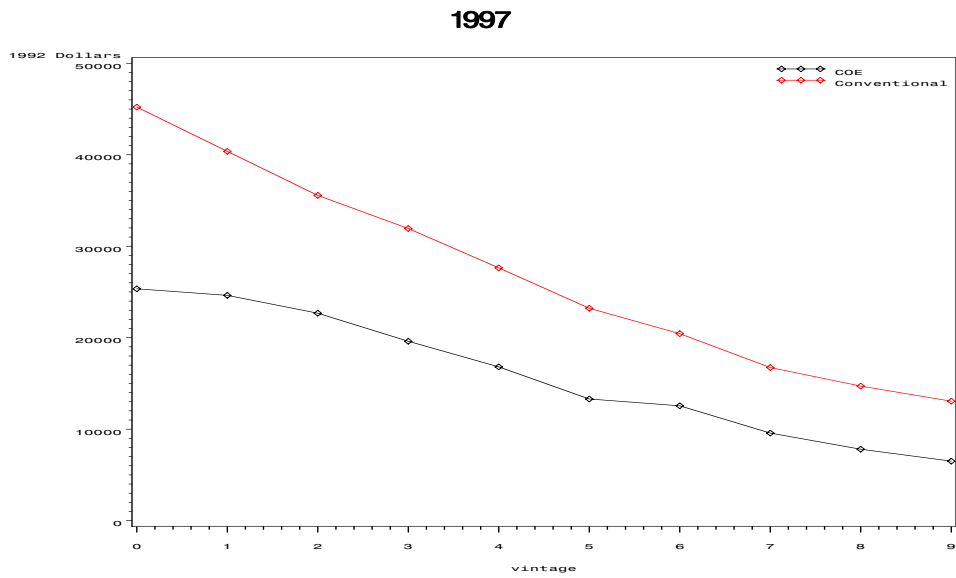


Table 4: Regression of Log Price on

Variable	Parameter Estimate	Standard Error
Intercept	10.56	0.0029
Vintage	-0.16	8.4e-4
Vintage sq.	-5.9e-5	9.8e-5
(Dummy variables)		
Year	0.14	0.001
International	0.07	0.003
Kenworth	0.13	0.003
Mack	0.12	0.003
Peterbuilt	0.24	0.003
Freightliner	0.13	0.003

percent of the vintage 0 type. This decline in the slope across years also holds for COE trucks. Older trucks could be depreciating more slowly in 1997 for a variety of reasons; our analysis in the next section will shed light on this issue.

The price depreciation of trucks looks roughly similar across manufacturers. The level of prices across manufacturers, however, varies widely. Table 4 reports the estimated coefficients of a regression of the log of the used price of conventional-cabin trucks on vintage, vintage squared, a survey year dummy, and manufacturer dummies, where the Other group of manufacturers is the benchmark manufacturer. We did not include COE trucks in the regression as their prices are heavily influenced by a decline in demand for this style of trucks in 1997. All of the parameter estimates, except for vintage squared, are strongly significant. These parameters indicate that prices, on average, declined 16 percent as vintage increased. Further, in line with our conversations with salespeople in the industry, Peterbuilt commands the highest premiums in the market while the Other group of manufacturers sell the least expensive conventional-cabin highway rollers.

Looking at prices across vintage and manufacturer provides some intuition on the trade-offs that firms face when buying a highway roller. Figure 4 plots prices for conventional cabin trucks by three manufacturers (Peterbuilt, International, and Other) and by vintage in 1997. When thinking about the purchase of a Peterbuilt truck of vintage 2, a firm compares prices across makes. As the figure shows, the mean price for a Peterbuilt of this vintage is a little under 40,000 1992 dollars, while the mean price for the Other make is slightly over 30,000 1992 dollars. A second dimension of comparison is across vintages; for 40,000 1992 dollars, the firm can purchase an International highway roller

Figure 4: Price Comparison of Selected Manufacturers in 1997

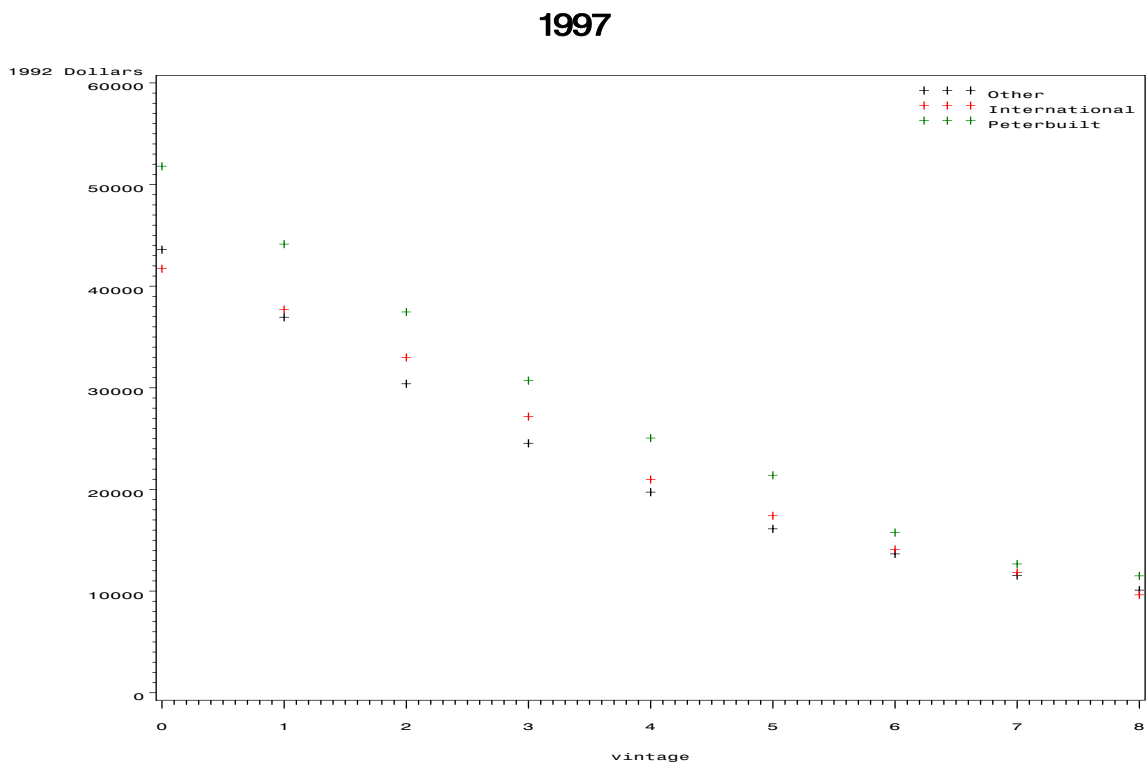


Table 5: Fleet Size by Vintage

Vintage	Fleet Size	
	1992	1997
0	1,556	3,170
1	1,211	3,247
2	1,417	3,423
3	1,290	2,778
4	1,094	1,571
5	830	858
6	508	817
7	261	507
8	251	344
9	n.a.	339
Total	1,000	2,140

Note: n.a. is not applicable

of vintage 1. Naturally, while comparing the prices of these various trucks, a firm takes into account the many characteristics of these trucks as well as their value in the future. The discrete choice approach we adopt in this paper allows us to take into account the relationship between truck characteristics and price as well as some heterogeneity among firms in how they value various characteristics.

Firm heterogeneity is captured by the demographic variable, fleet size. In the VIUS, several characteristics about the firm which owns the truck are recorded. The size of the firm's fleet, however, stands out as a characteristic that is strongly correlated with a firm's purchasing decision. Table 5 illustrates this point, showing how new vintage trucks are in larger fleets. In addition, between the two survey years the size distribution of firms has dramatically increased: the average fleet size of a firm has doubled. We plan to use demographics in our analysis. A problem with using the distribution demographics from the VIUS, however, is this sample distribution may not be a good approximation of the population demographics.

### 4.3 Identification

Identification in this model is standard, so we provide only a brief heuristic overview here. See Berry, Levinsohn, and Pakes (1995), among others, for a fuller discussion. As is standard in these types of discrete choice models, we assume that the observed and

unobserved characteristics are mean independent,

$$E[\xi_j|X] = 0.$$

Under this assumption, and given an initial estimate of the mean utility for each product,  $\delta_j$ , the  $\beta$  are then identified by market-level variation in observed product characteristics. The parameters that define consumers' heterogeneous tastes for observed product characteristics,  $\gamma_k$ , are identified by equating the product-level market shares in the data with the calculated market shares implied by aggregating individual-level choices, again taking mean utilities as given.

## 5 Results

The results presented in this section are quite preliminary, as we are waiting to receive the truck VINs so that we can conduct the analysis at a more disaggregated level. However, the results are suggestive of the forces at work in determining the demand for trucks of different vintages and with varied characteristics. Our estimation strategy closely follows the generalized method of moments approach taken by Berry, Levinsohn, and Pakes (1995). We anticipate supplementing their moments with a new set of micro moments, as done in Petrin (2002), in the future.

The first column of table 6 are from a least squares regression of

$$\log(s_{jt}) - \log(s_0)$$

on empty weight, engine size, lifetime milage, MPG, the number of fuel conservation measures, and dummy variables for the truck's vintage. Recall that  $s_{jt}$  is the market share of model  $j$  at time  $t$  and  $j = 0$  denotes the outside good. In this application, the outside good are the 'Old' vintage highway rollers, aggregated across make and cabin-style. A direct interpretation of these coefficients is difficult, as it is possible for correlation patterns among the regressors to give non-intuitive predictions about the marginal effect of an increase in any given variable. Nonetheless, the results in column 1 are suspicious. An increase in the price of a truck is predicted to lower the cost of the truck as does a larger engine. Because the unobserved characteristics may be correlated with price, we instrument for these characteristics using the sum of characteristics for

Table 6: Estimates of  $\theta_1$ 

Variable	Logit	Logit IV	Random Coefficients
price	-7.094	4.78	4.90
weight	0.713	1.33	1.44
engine	-5.743	0.12	0.56
mileage	-4.293	-5.68	-5.57
MPG	-4.349	-0.43	-0.33
fuel conservation	-0.686	-0.76	-0.10
Vintage:			
0	19.1	0.7	-0.1
1	19.4	2.5	1.7
2	18.8	3.1	2.3
3	18.3	4.0	3.3
4	18.0	4.8	4.0
5	17.7	5.6	4.9
6	17.9	6.6	5.9
7	17.5	6.9	6.2
8	17.0	6.9	6.2
9	17.6	7.5	6.8

the firm's other products and the sum of characteristics for other firms' products.<sup>9</sup> Note that the signs and magnitudes of the coefficients change dramatically, indicating that endogeneity is a significant problem even at the current level of aggregation.<sup>10</sup> Now, an increase in price, weight, or engine size boosts the cost of the truck. On the other hand, higher mileage trucks and those with higher MPG or fuel conservation measures are cheaper. The final column presents the  $\theta_1$  estimates for our random coefficients model. These results differ little from column 2. It is clear that truck buyers have idiosyncratic valuations of lifetime miles, weight, and the number of fuel conservation measures. While we have no independent information with which to confirm these results, it seems reasonable that firms in different industries or with different hauling needs would value these particular characteristics differently. Engine size and miles per gallon, on the

<sup>9</sup>These are the instruments suggested in Berry, Levinsohn, and Pakes (1995).

<sup>10</sup>Because a trucks are aggregated to the level of the make/model year/cab type, some endogeneity may be averaged out. For example, if the unobserved quality of 1995 Peterbilt conventional-cab trucks varies by model, then aggregation will mitigate any endogeneity. On the other hand, if all Peterbilt conventional-cab trucks built in 1995 are of particularly high unobserved quality, then prices will be correlated with the unobservable characteristics even at this high level of aggregation.

Table 7: Estimates of  $\theta_2$ 

Variable	Random Coefficients
weight	0.36
engine	0.01
mileage	0.99
MPG	0.00
fuel conservation	0.19

other hand, a likely to be valued similarly by all firms. With these results we can calculate the array of cross-price elasticities. Using these elasticities we can determine how truck buyers change trucks when prices rise.

## 6 Conclusion

This paper exploits the recent advances in demand estimation for differentiated products to explore the substitutability of goods across vintages. We study the long-distance trucking industry as not only is it an important cyclical segment of the U.S. economy, but also has several features that make it amendable for our analysis. In particular, the Census Bureau's VIUS provides an array of information on the physical and operational characteristics of the stock of highway rollers registered within the U.S. By combining this information with price data from the Truck Blue Book, we are able to construct a dataset of equilibrium prices and quantities of the used market for highway rollers. Using this data, we then estimate the elasticities of substitution for highway rollers.

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