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From Consumer Incomes to Car Ages: How the Distribution of Income Affects the Distribution of Vehicle Vintages

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Abstract

This paper studies the relationship between consumer incomes and ages of the durable goods consumed. At the household level, it presents evidence from the Consumer Expenditure Survey of a negative correlation between incomes and ages of the vehicles owned. At the aggregate level, it constructs a dynamic, heterogeneous agents, discrete choice model, to study the relationship between the distribution of consumer incomes and the distribution of vehicle vintages. The model's parameters are calibrated to match vehicle ownership data for 2001. The moments of the income distribution are then varied to generate predictions for mean and median ages of vehicles. The model predicts that higher levels of income inequality lead to older vehicle stocks. If the initial incomes are low, increasing mean income may lead to the aging of vehicles by encouraging entry of lower income consumers into vehicle ownership via purchases of older vehicles. Beyond a certain income level, however, economies with higher mean incomes have younger vehicle stocks.

Keywords: income distribution, motor vehicles, heterogeneous agents models, intertemporal consumer choice, discrete choice

JEL classification: D12, D91, E21

1 Introduction

Expenditures on motor vehicles comprise the largest part of consumer expenditures on durable goods.¹ The durability property allows a vehicle to yield utility over a prolonged period of time, and potentially to more than one owner during its lifetime. This paper studies the role of consumer incomes in vehicle ownership decisions, such as the age of the vehicle at the time of purchase and the length of the ownership period, and the aggregate implications of these decisions for the distribution of vehicle vintages.

The relationship between per capita incomes and vehicle ages has been studied previously by environmental engineers in Miller et al. [6]. The determinants of the vehicle age distribution are of interest to the environmental scholars, since ages of vehicles are positively related to the emission levels. Miller et al. [6] find a strong negative relationship between mean per capita incomes and median vehicle ages for counties in Tennessee, with correlation coefficients of -0.996 for passenger cars and -0.979 for light trucks. At the cross-country level, Storchmann [8] finds that car prices depreciate slower in developing countries than in industrialized countries, and that the economic life of automobiles is negatively related to real incomes. At the micro level, Adda and Cooper [1] use data on French household vehicle replacement decisions to find that higher-income households are more likely to replace their vehicles, controlling for the vehicle's age.

This paper presents additional evidence from the Consumer Expenditure Survey on the importance of income in vehicle ownership decisions. It uses a model that can generate predictions consistent with the empirical evidence at both individual and aggregate levels, to study how the distribution of consumer incomes affects the distribution of vehicle vintages. The model is dynamic, with infinitely lived, heterogeneous in income agents. The agents are allowed to own up to one vehicle at a time, and can trade both new and used vehicles. The vehicles are differentiated by age, and younger

¹Approximately 45% on average since the 1950s for the US.

vehicles are assumed to be superior to the older ones in terms of quality. The prices of vehicles decline with age at an endogenous rate.

The agent's decisions depend on his income and prices of vehicles. The incomes of different agent types are calibrated to match the empirical income distribution for the US in 2001.² Aggregation across individual agents determines demand for different vehicle vintages, and the resulting vehicle age distribution. The model's parameters are calibrated to match vehicle ownership data for 2001. The model generates a strong negative relationship between agents' incomes and the ages of vehicles owned.

The estimated model is then used to study how changes in the underlying distribution of consumer incomes affect the aggregate vehicle ownership statistics, in particular, the mean and median ages of the vehicle stock. The model predicts that higher levels of income inequality lead to older vehicle stocks. If the initial incomes are low, increasing mean income may lead to the aging of vehicles by encouraging entry of lower income consumers into vehicle ownership via purchases of older vehicles. Beyond a certain income level, however, economies with higher mean incomes have younger vehicle stocks.

The layout of the paper is as follows: Section 2 presents micro level evidence of a negative relationship between incomes and holdings of vehicle vintages, using the Consumer Expenditure Survey data on household vehicle ownership for 2001. Section 3 describes the model. Section 4 discusses the solution method, while Section 5 focuses on the estimation procedure and data used in the estimation. Section 6 presents the results and analyzes the model's predictions for the US in 2001. In Section 7, the moments of the income distribution are varied to generate predictions for the aggregate vehicle ownership patterns, including the mean and median ages of the total vehicle stock. This section also contains some empirical evidence on the relationship between moments of the income distribution and vehicle registrations.

²The year 2001 was chosen since it is the last year for which R.L. Polk & Co. provided the data on the distribution of motor vehicles by model year to the Ward's Automotive Yearbook. Thus, these are the most recent age distribution data that are publicly available.

Section 8 concludes.

2 Evidence: Consumer Incomes and Vehicle Ownership Decisions

The data on vehicle ownership by households in the US for 2001 were obtained from the Consumer Expenditure Survey (CE) [3]. The survey is administered by the Bureau of Labor Statistics (BLS), and includes detailed information on expenditures for over 7,000 households in the given year. The household characteristics and income data are part of the Interview Survey component of the CE; the data for this component are collected on a quarterly basis, with households in the sample interviewed every three months over a fifteen-month period. However, income questions are asked only in the first and fourth quarter. The data on household size, number of earners, geographic location and population, age of the reference person, and total income before taxes over the past twelve months were chosen for every household interviewed in the first quarter. The households with incomplete income responses were removed from the sample, resulting in the sample size of 6,381 units.

The data on vehicles owned or leased by each of the households are reported in the Detailed Expenditure Files component of the survey. The survey asks detailed questions about every household vehicle, including its make and model year, the year it was purchased, and whether it was new or used at the time of purchase. The information on the vehicle's model year is particularly important for the purposes of this project, since it is used to compute the age of the vehicle. Unfortunately, the model year is recorded precisely only for the model years 1986 or newer, with the survey giving ranges for older vintages. Thus, the methods for censored data need to be used to perform the analysis.

The household decision on whether to own or lease a vehicle is modeled with a probit regression. The independent variables include the income and the squared

income of the household, the household size, the number of earners, the dummy variables for geographic location and population size, and the age and the age squared of the reference person. The dependent variable is an indicator that equals one if the household owns or leases at least one vehicle. The results are presented in Column I of Table 1. They demonstrate that higher-income households are more likely to own or lease a vehicle, and that the effect is non-linear in income. Households with a larger number of earners are more likely to be vehicle-owners, possibly because they need this transport mode in order to get to work. Also, households in urban locations have greater excess to alternative means of transportation, such as public transport, and thus are less likely to have a vehicle. More expensive parking and maintenance may also discourage vehicle ownership in urban locations.

Table 1: Modeling household vehicle ownership decisions

Independent variable	I. Probit: Own a vehicle	II. Tobit: Vehicle's age	III. Probit: Purchased used	IV. OLS: Number of years own new
Income, \$1000	0.0203 (15.86)	-0.0525 (-18.8)	-0.0140 (-20.27)	-0.0115 (-2.51)
Income squared	-0.00004 (-12.18)	0.00011 (11.47)	0.00003 (13.55)	0.00003 (1.71)
Number of earners	0.2062 (5.41)	-0.2253 (-2.92)	0.0856 (4.62)	-0.3536 (-2.71)
Urban location	-0.2258 (-2.09)	-0.1815 (-0.76)	-0.0126 (-0.21)	-0.1473 (-0.29)
Num. of other vehicles		1.0606 (20.93)	0.1359 (11)	0.5280 (4.42)
R^2	0.1899	0.0203	0.0975	0.0824
Number of obs.	6,381	10,334	10,283	3,757

1) t-statistics are given in parentheses.

2) Other controls include a constant, family size, geographic location and population dummies, origin of the vehicle (Domestic, European or Asian) and luxury vehicle dummies, truck indicator, age and age squared of the reference person.

The tobit model for censored data was used to study the ages of vehicles owned by households. The results in Column II in Table 1 demonstrate that higher-income

households tend to have younger vehicles. The results in Columns III and IV of Table 1 indicate that this is due to higher-income households being more likely to purchase a new vehicle instead of a used one, and hold on to this vehicle for a fewer number of years.³ A positive and highly significant coefficient on the number of other vehicles owned or leased by the household shows that vehicles of different ages may be substitutes at the household level. The coefficient values for this variable in Columns III and IV of the table indicate that households with more vehicles are more likely to purchase a larger fraction of them used, and also tend to replace each of the vehicles less frequently.

The above analysis demonstrates that income plays an important role in vehicle ownership decisions at the level of the consumption unit, including the ages of vehicles held. The next part of the paper presents a simple model that generates the relationships between income and vehicle ownership decisions of the same sign as the ones observed in the data.

3 Model

The economy is populated with a finite number of infinitely lived heterogeneous agent types $j = 1, \dots, N$. Each agent type j consists of a unit measure of identical consumers. The time period in the model is equal to one year. In every period t , agents of type j are endowed with income y_j , which is deterministic and constant over time. The agent types are ordered according to their income levels so that $y_1 < y_2 < \dots < y_N$.

In every period the agents decide on their consumption of non-durable and durable goods. The durable goods are vehicles heterogeneous in age $a = 1, \dots, A$. A vehicle of age $a = 0$ is a new vehicle and its price p_0 is exogenous in every period.⁴ The agents

³The analysis for the number of years a vehicle is held was restricted to the vehicles that were new when purchased. The reason is that, in general, the number of years a vehicle is held depends on the age of the vehicle, so the sample was limited to control for this effect.

⁴As in Adda and Cooper ([1] and [2]), the supply of new vehicles is assumed to be characterized by a constant returns to scale production function. Together with the assumption of constant mark-ups, this implies that the price of a new vehicle is independent of the demand for new vehicles. This

can trade both new and used vehicles. A used vehicle of age $a > 0$ is traded at price $p_a = p_0 \exp(-\tau a)$, where τ parameterizes the rate of price depreciation.

In every period the agents derive utility from consuming non-durable goods c and vehicle vintages a according to the following utility function:

$$U(a, c) = v(a) + u(c), \quad (1)$$

where

$$v(a) = \begin{cases} \exp(-\eta a^2), & \text{if } a = 0, \dots, A \\ 0, & \text{if } a > A \end{cases} \quad (2)$$

and

$$u(c) = \frac{\left(\frac{c}{\lambda}\right)^{1-\gamma}}{1-\gamma}. \quad (3)$$

The utility from vehicle ownership is discontinuous at age A , with the assumption that agents derive no utility from consuming a vehicle older than A .⁵ The functional form for v is motivated by the percentage of total US vehicle stock remaining in use as a function of age. For small values of η the utility declines slowly in the earlier stages of vehicle's life, then picks up the pace in midlife, and slows down again when the vehicle is old.⁶ The utility from the consumption of nondurables has a CRRA form with a scale factor λ .

Each agent of type j arrives in a period with a vehicle of age a .⁷ In the beginning

assumption of the exogenous new vehicle's price greatly simplifies the analysis. However, it may be too strong, since the time-series analysis shows that moments of the distribution of vehicle vintages significantly predict future prices of new vehicles.

⁵An upper bound on vehicle's useful life is necessary for computational reasons. However, for A sufficiently large this assumption is not restrictive. The results here were obtained for $A = 30$.

⁶Greenspan and Cohen [4] use a similar functional form to estimate the scrappage of vehicles. They find that it fits the data well everywhere except for the higher ranges of vehicle ages, where it declines too fast resulting in the tail that is not "thick" enough.

⁷In this setup, the agent is allowed to own at most one vehicle. The results in Table 1 show that the number of vehicles owned plays an important role in the decisions on what vehicle vintages to hold and how often to replace them. Thus, modeling vehicle ownership decisions at the individual

of the period, he decides whether to retain this vehicle or replace it with a vehicle of vintage a' . Whatever his decision, next period he starts with a vehicle that is one year older than the one he consumes in the current period. Formally, in every period each agent of type j solves:

$$V_j(a) = \max_{a'=0,\dots,A+1} \{v(a') + u(y_j + \pi_a - p_{a'}) + \beta V_j(a' + 1)\}, \quad (4)$$

where

$$\pi_a = \begin{cases} p_a, & \text{if } a = a' \\ \phi p_a, & \text{otherwise, } \phi < 1 \end{cases} \quad (5)$$

is the selling price of vehicle aged a , with ϕ parameterizing the fraction of value recovered by consumer from selling his current vehicle. The option of not owning a vehicle is embedded in the problem's setup. If the agent derives no utility from owning a vehicle that is older than A and the price $p_{a>A} = 0$, then holding a vehicle aged $a > A$ is equivalent to having no vehicle.

Trade in the secondary market is motivated by the differences in consumer incomes. The decisions of which vintages to replace and which ones to hold on to depend on the prices of vehicle vintages. Ideally, these prices should be such that the markets clear for every vintage. However, this is a very difficult problem due to the linkages between markets for all vintages. Licandro, Puch and Sampayo [5] obtain analytical solution for the market-clearing price in a simpler model of a secondary market for vehicles with only two types of agents. The model presented here is more general, and the approach is to approximate the equilibrium price function with an exponential function $p_a = p_0 \exp(-\tau a)$. The depreciation rate τ is estimated within the model with a moment condition that supply equals demand at given prices across vintages. The cost of this approach is that the prices and the decision rules obtained with it are not the equilibrium solutions, but rather their approximations.

level with the assumption of at most one vehicle per agent may be restrictive.

4 Solving the Model

For every agent type $j = 1, \dots, N$ the decision rules $a' = f_j(a)$, where $f_j : [1, \dots, A + 2] \rightarrow [0, \dots, A + 1]$, can be solved for using the value function iteration method. These decision rules are then used to obtain the steady-state holdings of vehicle ages \tilde{a}_j .

If the transaction cost to replacing a vehicle is positive ($\phi < 1$), the agents may choose to hold a vehicle for several periods, that is, \tilde{a}_j is a vector. In general, the number of periods will depend on the income level. Let $T_j \in [1, A + 1]$ denote the steady-state number of periods a vehicle is held by every agent of type j . If $T_j \neq T_k$ for some $j \neq k$, the holdings of different agent types need to be weighted accordingly in order to obtain aggregate predictions for the distribution of vehicle vintages in the steady state.

To illustrate, suppose that there are only two types of agents, X and Y , and the agents of type X have a higher income than the agents of type Y . Suppose also that in the steady state the agents of type X replace their current vehicle with a new one in every period, so that $T_X = 1$ and $\tilde{a}_X = 0$. For agents of type Y , the vector of the steady-state vehicle age holdings $\tilde{a}_Y = [0 \ 1]$ is of length $T_Y = 2$, that is, the agents of type Y replace their vehicle with a new one every other period.

The weight assigned to the agents of type X is the least common multiple of T_X and T_Y , equal to 2. For agents of type Y , the weight assigned to the agents with a new vehicle is 1, and the weight assigned to the agents with a one-year old vehicle is also 1. This way, there are equal measures of agents of each type in the steady state. For computational purposes, this is equivalent to saying that in the steady state there are three agents purchasing a new vehicle (two agents of type X and one agent of type Y) and one agent holding a one-year old vehicle. Thus, in the steady state, three quarters of the total vehicle stock are new and one quarter of vehicles is one year old. The per capita vehicle holdings can be computed by dividing the total vehicle stock, which is 4 in this case, by the total weighted number of agents (also 4).

In general, let \bar{T} denote the least common multiple of T_1, \dots, T_N . The weight

assigned to the holdings of agent type j with a vehicle of age $\tilde{a}_j(t_j)$, where $t_j = 1, \dots, T_j$, is equal to (\bar{T}/T_j) for every element of \tilde{a}_j . The distribution of vehicle ages is computed using these weight assignments, similar to the example above with agents X and Y .

5 Estimation

The economic environment is characterized by a set of parameters. Parameters describing the income distribution and prices of new vehicles in 2001 $\left\{ \{y_j\}_{j=1, \dots, N}, p_0 \right\}$ are estimated from the data. The preference parameters $\{\eta, \gamma, \lambda\}$ are chosen to match the data moments on the total number of vehicles registered per capita, the new vehicle registrations per capita, and the mean age of vehicles, all for 2001. The price depreciation parameter τ is estimated with a moment condition that supply should equal demand at given prices across vintages.

The remaining parameters are the number of agent types N , the upper bound on vehicle ages A , the fraction of the vehicle value recovered by the agent ϕ , and the time discount rate β . Parameter values $N = 100$ and $A = 30$ are chosen to optimize on the computational time, while still resulting in meaningful predictions from the model. The annual discount rate $\beta = 0.96$ is chosen to match previous studies. In the price data from Kelley Blue Book and Edmunds.com, the wedge between the trade-in and retail values is anywhere from 5% to 10%. Here I assume that it is 7%, and set parameter $\phi = 0.93$.

Next I describe the procedure and data used to estimate $\left\{ \{y_j\}_{j=1, \dots, N}, p_0, \eta, \gamma, \lambda \right\}$.

5.1 Parameters estimated outside the model

The income distribution in 2001 is approximated with a lognormal density function, with parameters μ and σ calibrated to match two moments from the data, the mean household income and the Gini coefficient in 2001. These data were obtained from

the Historical Income Tables compiled by the US Census Bureau from the Annual Social and Economics Supplements to the Current Population Survey. The estimated lognormal distribution function was used to calculate the mean household incomes for each of the 100 percentiles. The number of people per household is positively correlated with income. Thus, to account for these differences in household size by income groups, the mean incomes of households were computed in per capita terms. The average number of people over the age of 16 by income percentiles was obtained from the Consumer Expenditure Survey. These estimates were used to calculate the mean incomes per person over the age of 16 for each of the income percentiles $\{y_j\}_{j=1,\dots,100}$.

The price of a new vehicle, p_0 , comes from the Ward's Automotive Yearbook [10]. The estimate used is the average expenditure per new car in 2001.

5.2 Parameters estimated within the model

The values of preference parameters η , γ , and λ are chosen to bring the model's aggregate predictions as close as possible to the data on the total number of vehicles per capita, the new vehicle registrations per capita, and the mean ages of vehicles in 2001. These statistics are published by the Ward's Automotive Yearbook [10], and the original source of the data is R.L. Polk & Co.

The data are presented separately for cars and trucks. For the purposes of this project, the numbers of cars and trucks were added to obtain aggregate statistics. The total number of vehicles and the new vehicle registrations were divided by the civilian noninstitutional population over sixteen years of age acquired from the Bureau of Labor Statistics, to obtain per capita values of these data moments. The data on the mean age of vehicles are also presented separately for cars and trucks. The mean age of the total vehicle stock was computed as the weighted average of the mean ages of cars and trucks, with fractions of each vehicle type as weights.

The estimation procedure seeks to minimize the distance between the data and

the model’s predictions in the least squares sense. The criterion used is a weighted sum of the distances between actual and predicted moments, with each component weighted by the empirical inverse of the moment’s variance from the trend over a 35 year period (1967-2001).

The moment for the market clearing conditions across vehicle ages was also added to the criterion. The moment used to estimate τ is the distance between supply and demand, averaged over vehicle vintages. The final criterion was minimized via the simplex algorithm due to Nelder and Mead [7].

6 Results

The estimated parameter values and moments from both model and data are presented in Table 2. The model has a total of 100 agents, so in per capita terms it can generate predictions with a maximum of two non-zero elements after the decimal point. With the assumption of at most one vehicle per person, the model cannot generate more than 1 vehicle per capita. The estimated model predicts 0.99 vehicles per capita, versus 1.0074 vehicles per capita observed in the data.⁸ The model does well matching two other data moments, the new vehicle registrations per capita and the average age of vehicles.

The estimated rate of price depreciation τ is equal to 0.1694. For comparison, Cooper and Adda [2] estimate $\tau = 0.2$ using the Kelley Blue Book Data. At this value of the parameter, 8.9% off all vehicles are misallocated, meaning that they are either in excess supply or demand. This is a measure of distance from the equilibrium, and it is arguably not too large.

Figure 1 plots the average ages of vehicles held by income percentiles, from lowest

⁸The data on the total vehicle stock in the US obtained from the Ward’s Automotive Yearbook includes all motor vehicles, including heavy trucks and buses. The data on the number of passenger cars and light trucks only would be more suitable for the purposes of this project; however, this data is not publicly available. The estimate obtained from the Consumer Expenditure Survey for 2001 puts the number of vehicles per person over the age of 16 at around 0.9. This is likely to be a lower estimate, since the survey tends to oversample from the lower income part of the population.

Table 2: Estimation results

Parameter	Estimate	Moment (2001)	Model	Data
λ	15,733	Total veh., PC	0.9900	1.0074
η	0.0006	New veh., PC	0.0800	0.0813
γ	3.4755	Mean age of veh.	8.5859	8.6
		Least sq. dist.		% misall.
τ	0.1694	Market clearing	$1.7176e - 005$	8.9226

to highest. The model predicts a strong negative relationship between income and ages of vehicles owned. The predicted average ages of vehicles are the outcome of two decisions: what vehicle vintage to buy and how long to keep it for. Figure 2 depicts these decisions by income percentiles. Figure 2a shows that higher-income consumers choose to purchase younger vehicles. In Figure 2b, the number of years a vehicle is held is not strictly monotone in income, since it depends on the age of the vehicle at the time of purchase. However, overall there is a negative relationship between income and the frequency of replacement.

Figure 1: Average age of vehicles owned by income percentiles

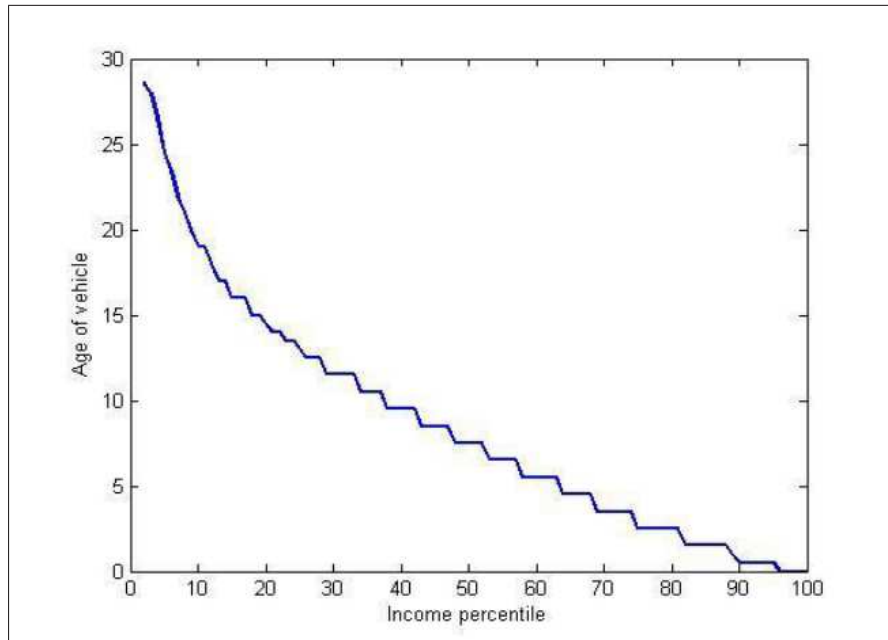


Figure 2: Decision rules by income percentiles

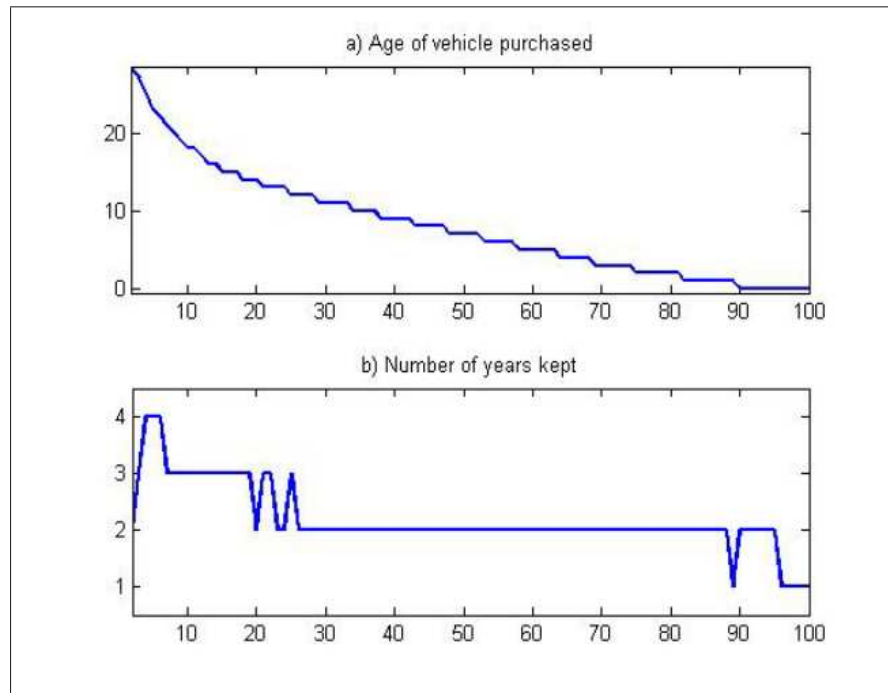
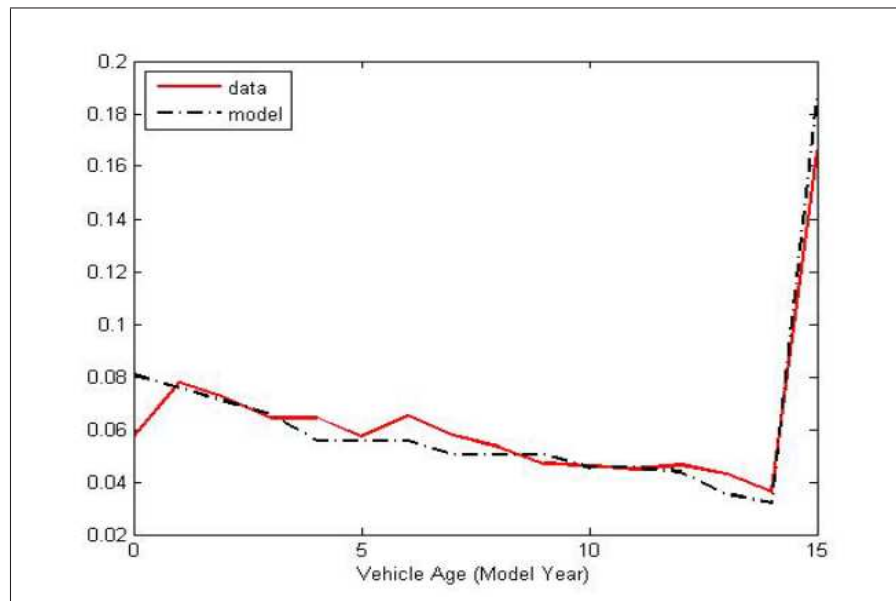


Figure 3: Age distribution of vehicles



To evaluate the fit of the model, additional statistics from both model and data have been computed and compared. Figure 3 plots the age distribution of vehicles

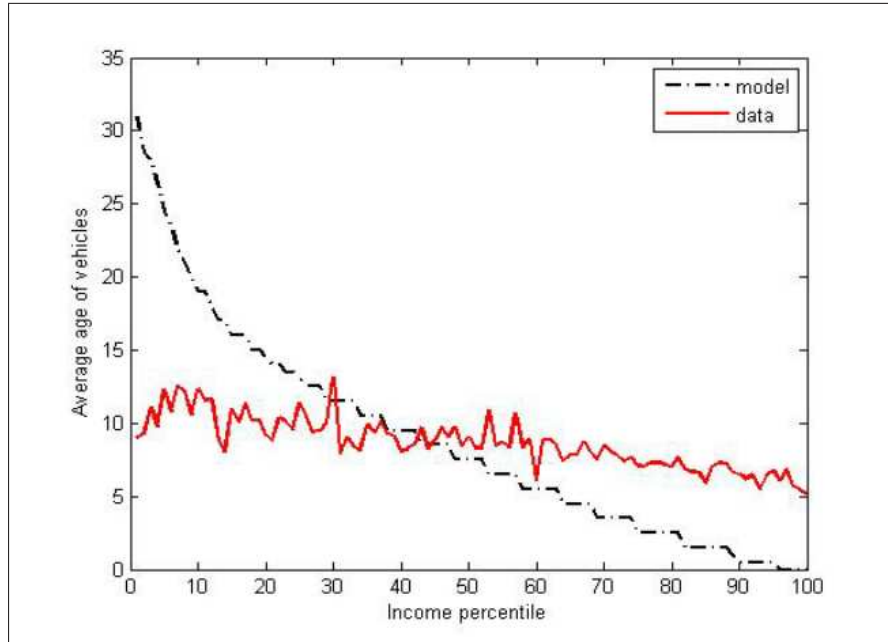
in 2001. The data on the distribution of vehicles in use by model year have been obtained from the Ward's Automotive Yearbook. All of the vehicles 15 years of age and older are grouped together in the data, so the same aggregation was done for the vehicle ages generated by the model. The two distributions look similar, so the conclusion is that the model does well matching the distribution of vehicle vintages in the US in 2001.

On the other hand, the model generates a much stronger negative relationship between consumer incomes and ages of vehicles held than the one observed in the data. Figure 4 plots the average ages of vehicles owned by income percentiles from model and data. The data come from the Consumer Expenditure Survey for 2001. The model also significantly underpredicts the average number of years a vehicle has been held, 1.6 in the model versus 4.8 in the data. A modification of the model with larger monetary and/or utility costs to replacing a vehicle would result in a higher value for the average number of years a vehicle is held, as well as a less dramatic relationship between incomes and ages of vehicles owned. Another option would involve changing the utility function for vehicle ownership. The current functional form assumes that the utility from vehicle ownership declines every year a vehicle is owned, and at increasingly higher rates at the later stages of a vehicle's life.

The model also assumes that the agents cannot own more than one vehicle at a time, and that all vehicles of the same vintage are homogeneous. Allowing for additional dimensions of quality differentiation and/or ownership of multiple vehicles would give higher-income agents other options for increasing their utility from vehicle ownership, besides buying a younger vehicle. Thus, these modifications of the model would also produce a weaker relationship between incomes and ages of vehicles held. However, computationally, this would be a much more difficult task.

For the purposes of this project, a simpler model is sufficient to evaluate the direction, if not the magnitude, of the effect of changes in the distribution of income on the distribution of vehicle vintages.

Figure 4: Average age of vehicles by income percentiles, model and data, 2001



7 Changing the Income Distribution

This part of the paper studies how changes in the distribution of consumer incomes affect aggregate vehicle ownership patterns, with particular interest in the predictions for the mean age of the total vehicle stock. Subsection 7.1 considers the effect of changing the mean household income relative to the 2001 benchmark, holding the level of income inequality and the price of a new vehicle fixed at their US in 2001 levels. In Subsection 7.2, the mean household income and a new vehicle's price are the same as in 2001, and it is the level of income inequality that is allowed to vary.

In both subsections, the values of preference parameters η , γ , and λ are as estimated in the benchmark model. The price depreciation parameter τ , however, is reestimated for every change in the income distribution with a moment condition that the demand should equal the supply across vehicle vintages.⁹

⁹Suppose that the price of a new vehicle is set globally, while the trade in used vehicles is limited to the boundaries of a given economy.

Subsection 7.3 tests the model’s predictions for the total number of vehicles and the sales of new vehicles using the data for fifty states. The state-level data on vehicle ownership were obtained from the Ward’s Automotive Yearbook [10], and the income data come from the summary tables for the 2002 American Community Survey administered by the U.S. Census Bureau.

7.1 Mean Household Income and Vehicle Ownership

This subsection studies how changes in mean household income affect the model’s predictions for the total number of vehicles owned per capita, the new vehicle sales per capita, and the mean age of vehicles. The mean household income is allowed to vary relative to the 2001 benchmark, from 25% of the 2001 level, to 200%. The parameters of the lognormal density function were reestimated to match each level of mean household income and the same value for the Gini coefficient as in 2001. The estimated distribution functions were used to calculate mean per capita incomes for each of the 100 percentiles via the same procedure as described in Section 5.1.

For each value of the mean household income, the price depreciation parameter τ was reestimated using the average of market clearing conditions across vehicle vintages. Figure 5 shows that prices tend to depreciate faster in higher-income economies, a result consistent with the findings of Storchmann [8]. The uneven shape of the line is the outcome of a discrete number of agent types (100), and only a fraction of them making buying and selling decisions in every economy. The low-income economies have the majority of consumers with very low incomes. If prices were to depreciate faster, these consumers would purchase very old vehicles. However, there would not be a sufficient number of higher-income consumers purchasing younger vehicles and supplying the older ones, so the value of the market clearing moment would be large. A lower value is obtained when the price depreciation rate is small, and the lower-income consumers choose to not own a vehicle. As incomes grow, prices depreciate faster to stimulate demand for older vintages.

Figure 5: Price depreciation rate τ and mean household income

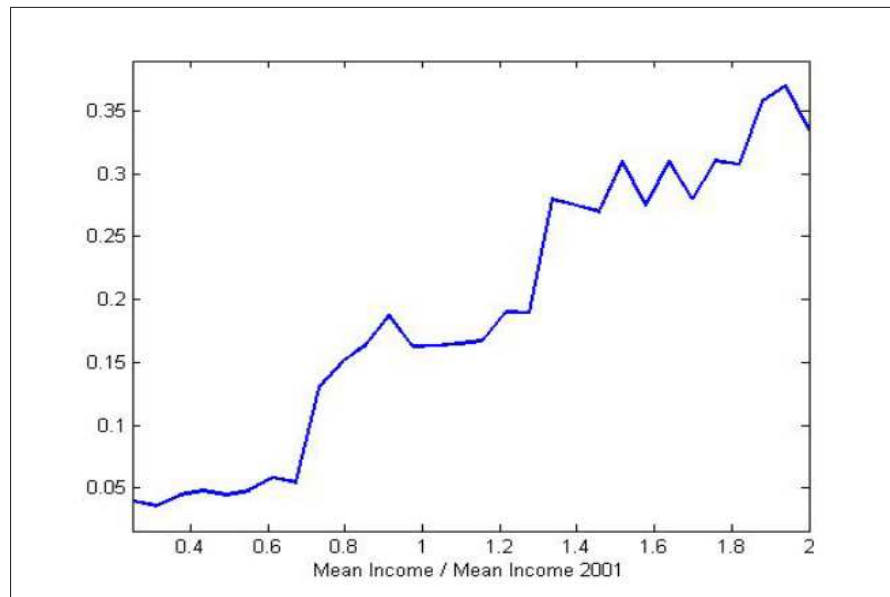


Figure 6: Mean household income and the total number of vehicles and sales of new vehicles per capita

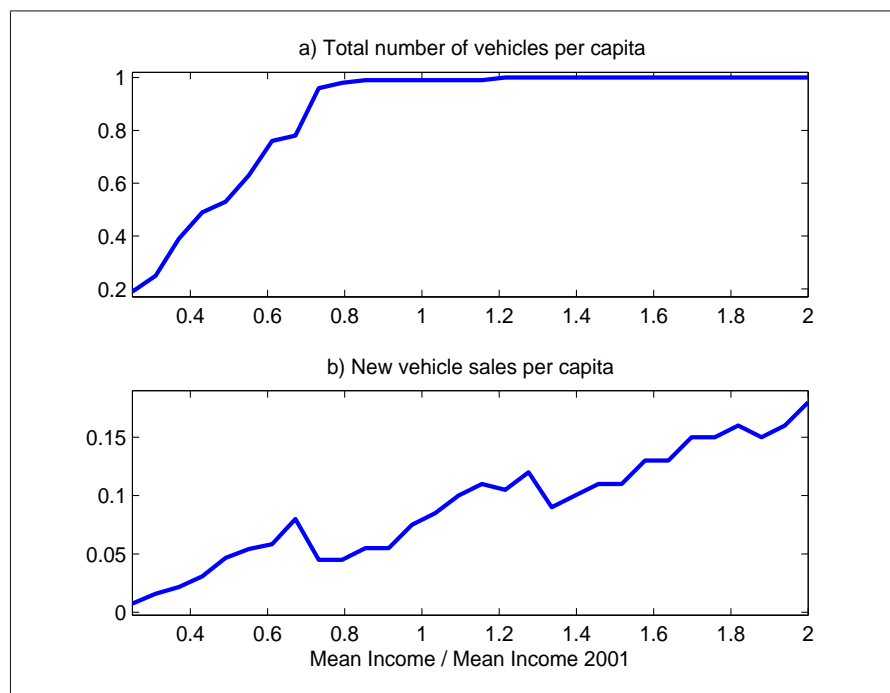


Figure 6a shows a significant increase in per capita vehicle ownership over this range of relative mean income values, and Figure 6b shows that the new vehicle sales are increasing in relative income. The jagged nature of the new vehicle sales line is due to a small sample size, since only a few agent types choose to purchase a new vehicle in every economy.

Figure 7: Mean and median ages of vehicles and mean household income

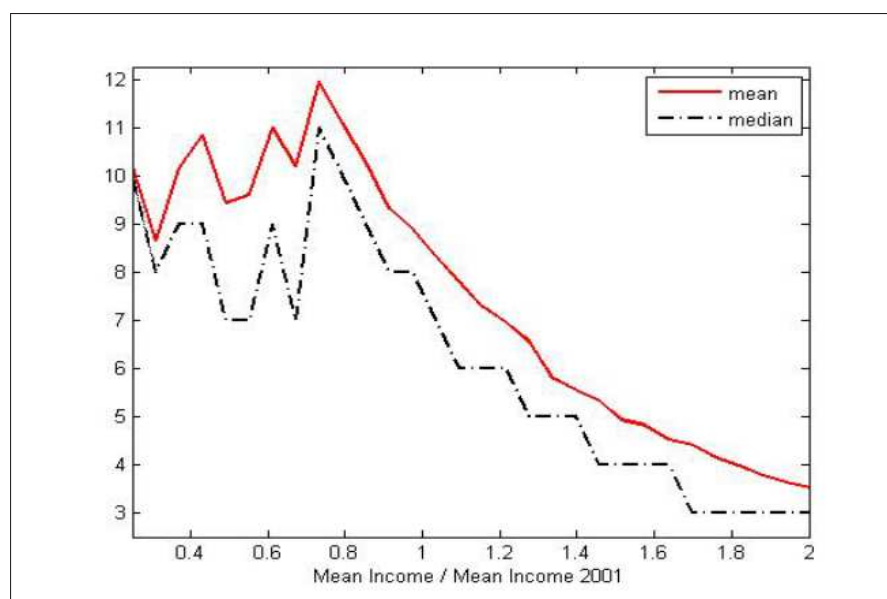


Figure 7 shows that the mean age of vehicles is non-monotone in mean household income. In low-income economies, increases in mean income may lead to the aging of the vehicle stock. This is due to the lower-income consumers choosing to become vehicle owners for the first time as their incomes increase. These consumers choose to hold older vehicles, so their decisions shift the mass of the age distribution towards older vintages. The jagged nature of the predicted average age in low-income economies is again due to a small number of households choosing to own a vehicle. For the economies with the mean income above a certain level, and with the majority of consumers owning a vehicle, additional increases in income result in the younger vehicle stock. Thus, the average age of vehicles declines in the mean income, when the

mean income is above this threshold value. The result for the median ages of vehicles is consistent with findings by Miller et al. [6] of a negative relationship between per capita incomes and median ages of vehicles for counties in Tennessee.

7.2 Income Inequality and Vehicle Ownership

In this subsection, the mean household income and the price of a new vehicle are the same as in the benchmark model, and the Gini coefficient is allowed to vary from 0.19 to 0.74, which corresponds to the largest range of values for this coefficient measured across countries.¹⁰ As before, the incomes of agent types $j = 1, \dots, 100$ for each value of the Gini coefficient were computed using the estimates for the lognormal distribution function.

Figure 8: Price depreciation rate τ and income inequality

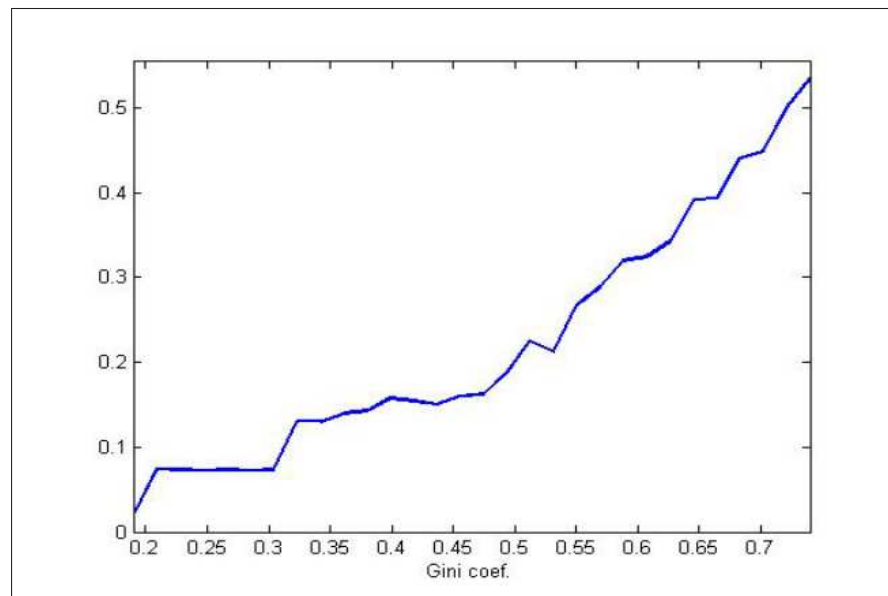


Figure 8 shows that the price depreciation rate τ is increasing in the degree of income inequality. Figure 9 illustrates the relationship between income inequality and

¹⁰See the United Nations Development Programme's "Human Development Report" for 2006 and 2007/2008 [9].

the distribution of vehicle vintages with an example of four economies with different values for the Gini coefficient. The blue solid lines in the graphs are the income probability density functions, and the grey shaded areas represent the vehicle age distributions. When the value of the Gini coefficient is low, the income distribution is more concentrated around the mean. Low degree of income heterogeneity means that consumers are more similar to each other. Thus, they make similar vehicle ownership decisions and the resulting vehicle age distribution is also concentrated. Higher values of the price depreciation parameter τ would lead to the majority of consumers wanting to purchase older vehicles. However, the supply of these vehicles would be low, due to a much smaller number of higher-income consumers. Therefore, in the economies with low degree of income heterogeneity, price depreciation rate needs to be low in order to induce purchases of newer vehicles.

Figure 9: Income inequality and vehicle age distribution

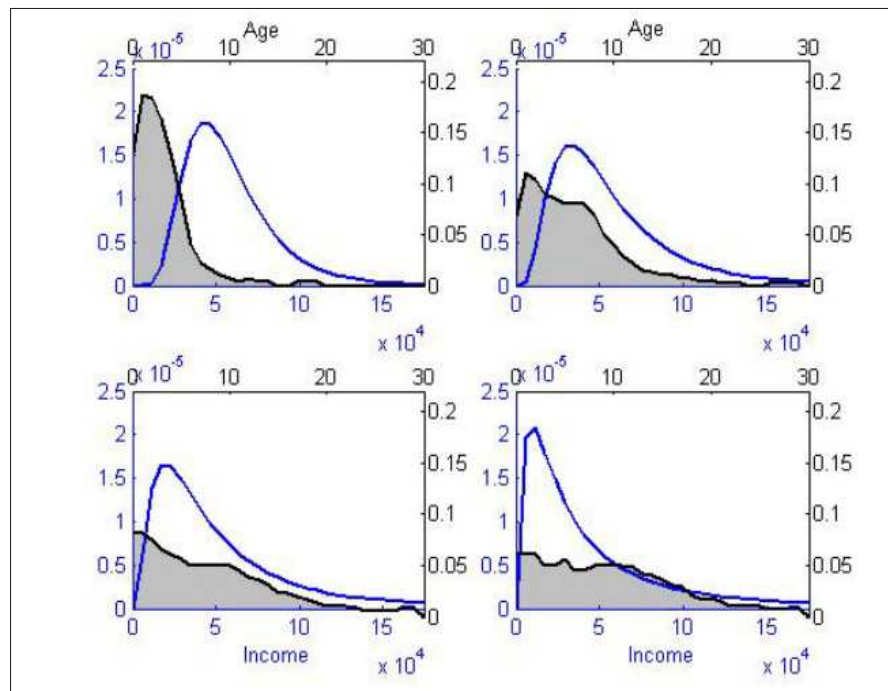


Figure 10: Income inequality and the total number of vehicles and sales of new vehicles per capita

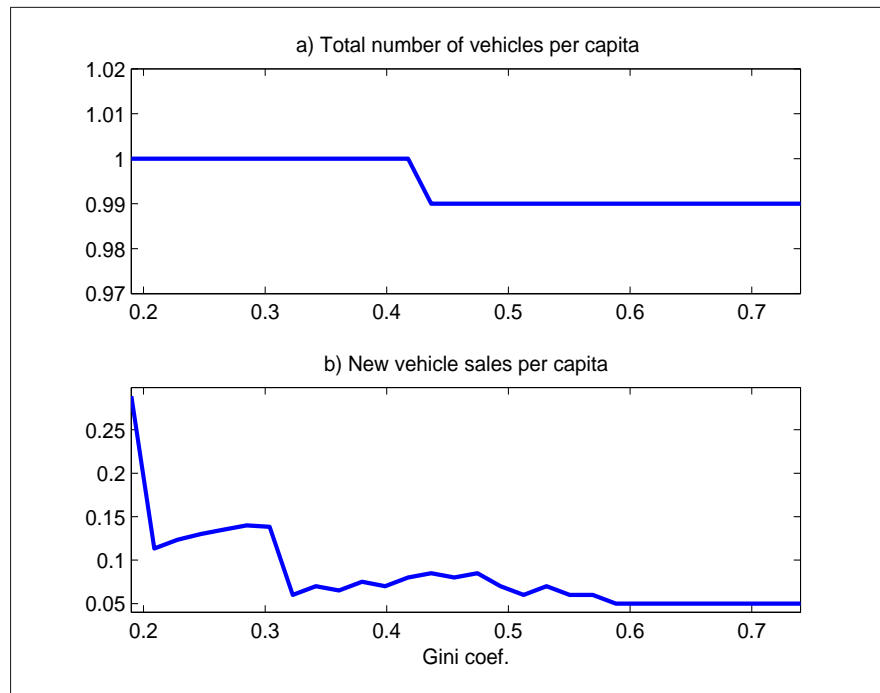
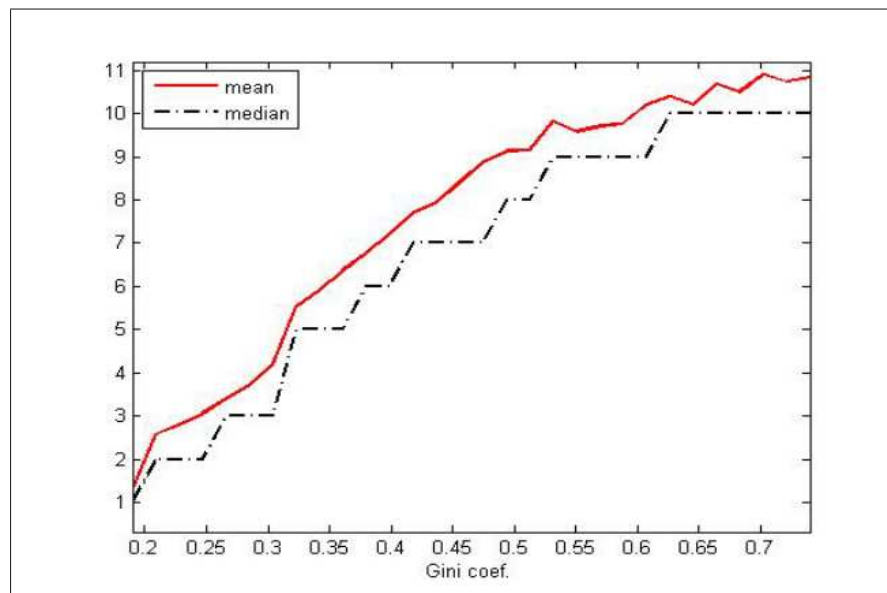


Figure 11: Mean and median ages of vehicles and income inequality



Higher variability in incomes results in higher variability in prices of vehicles, through larger values of the price depreciation parameter τ . More dispersed income distributions lead to greater heterogeneity in vehicle age holdings. Figure 10 shows that the number of vehicles per capita declines slightly in income inequality, while the sales of new vehicles are non-monotone. Overall, there is a declining pattern for the sales of new vehicles over the whole range of the Gini coefficient values; however, there are significantly large regions with the new sales increasing or approximately constant.

The mean and median ages of vehicles are depicted in Figure 11. The model predicts that the vehicle stocks should be older in the economies with higher levels of income inequality. As income inequality increases, the mass of the income distribution shifts to the left, so the majority of the population becomes relatively more poor. Their decisions cause the mean and median ages of the vehicles to increase.

7.3 Vehicle ownership and sales of new vehicles: model and data

This subsection compares the model's predictions for the total number of vehicles per capita and the sales of new vehicles per capita to these statistics at the state level.

The state-level data on vehicle ownership were obtained from the Ward's Automotive Yearbook [10]. This publication presents the data on vehicle registrations and sales separately for cars and trucks for every state. For the purposes of this exercise, the data for cars and trucks were combined to obtain data for all motor vehicles. The per capita numbers were generated by dividing the aggregate values by the total number of people sixteen years of age and older, obtained from the 2001 American Community Survey.

The average number of vehicles per person over the age of sixteen for fifty states is high at 1.05. For comparison, the statistic used for the estimation at the country level is 1.0074. The higher values at the state level are due to the state-level population

data being limited to the household population only. American Community Survey excludes the population living in institutions, college dormitories, and other group quarters from its population estimates. As long as the fractions of population covered by the survey are approximately the same across the states, the analysis in this section should still be valid. The average number of new vehicle sales per person over the age of sixteen is 0.08, similar to the country level statistic. This suggests that the discrepancy in the population numbers is not that large.

The income data were obtained from the 2002 American Community Survey. The data on the fractions of households in different income groups were used to compute the state-level Gini coefficients, as well as to obtain the average per capita incomes for each percentile and state. For every state, the computed incomes of $N = 100$ agent types were fed into the model, to obtain predictions for the total number of vehicles per capita and the sales of new vehicles per capita.

Are the relationships between the moments of the income distribution and the vehicle ownership patterns similar in model and data? To address this question, the reduced form analysis has been performed separately for vehicle ownership data and the model's predictions. Table 3 presents results from the regression analysis of the total number of vehicles registered per capita on the average household income and the Gini coefficient. Table 4 contains the results from a similar exercise for the sales of new vehicles per capita.

The results in column I of Table 3 show that in the data, the number of vehicle registrations per capita does not depend on the state's average household income or the level of income inequality. Other controls include the average household size, the population density, the fraction of population employed, and an indicator for the state containing at least one city with population over a million. Only the last two variables significantly affect the state-level vehicle registrations.

The coefficients on the average household income and the Gini coefficient are not significant. The most likely explanation for this rather surprising finding is that at

these high levels of income, vehicle ownership is also very high, and is no longer affected by small variations in income. The majority of consumers can afford to have a vehicle of some age as long as they want one. The desire to have a vehicle is stronger among consumers living in rural areas and needing a convenient transport mode to get to work.

As expected, the model predicts a positive relationship between the average household income and the number of vehicles registered per capita at the state level. Also, higher levels of income inequality have a negative effect on vehicle ownership. The variation in the predicted number of vehicles per capita is very low. For 29 states, the predicted number of vehicles per person is equal to 1. For the rest of them it is equal to 0.99, with the exception of Louisiana, for which it is 0.98. The overall conclusion from Table 3 is that when incomes are high, the model is not a good tool for explaining the differences in the per capita vehicle registration numbers across regions.

**Table 3: OLS: Total vehicle registrations by state.
Model versus data, 2001**

Independent variable	I. Data	II. Model
Average HH income, \$1000	-0.0028 (-1.02)	0.0002 (3.46)
Gini coef.	-0.4718 (-0.67)	-0.0825 (-4.23)
Fraction empl.	1.3556 (2.35)	
City over mil.	-0.0759 (-2.58)	
R^2	0.4524	0.5105
Number of obs.	50	50

1) t-statistics are given in parentheses.

2) Other controls for the data regression include average household size and population density. Both regressions also include a constant.

Table 4 presents the results for the per capita sales of new vehicles. In both model and data, the effect of the average household income is positive and significant. The

model predicts a stronger relationship, however, with a larger value for the coefficient on the average household income. The Gini coefficient is not significant in neither data nor model. This is consistent with the results in Figure 10b for the predicted new sales in this range of values for the Gini coefficient (from 0.38 to 0.51). The correlation between the new vehicle sales in the model and data is equal to 0.54.

**Table 4: OLS: New vehicle registrations by state.
Model versus data, 2001**

Independent variable	I. Data	II. Model
Average HH income, \$1000	0.0007 (2.79)	0.0017 (9.93)
Gini coef.	-0.1152 (-1.39)	0.0381 (0.51)
R^2	0.3996	0.7045
Number of obs.	50	50

1) t-statistics are given in parentheses.

2) Other controls for the data regression include average household size, fraction of population employed in the non-farm sector, and an indicator for the state having at least one city with population over a million. Both regressions also include a constant.

8 Conclusion

The goal of this paper was to study the relationship between the consumer's income and his vehicle ownership decisions, and to analyze the implications of these decisions for the moments of the vehicle age distribution by aggregating over consumers with different income levels. For these purposes, a dynamic, discrete-choice, heterogeneous agents model of vehicle ownership was constructed. The agents in the model can choose to own up to one vehicle at a time. The vehicles are differentiated by age, and the utility from vehicle ownership is assumed to be decreasing in age. The agent's choice of a particular vintage depends on his income and the prices of vehicles. The price of a new vehicle is assumed to be exogenous, while the prices of used vehicles decline with age at an endogenous rate.

The model predicts that higher-income agents are more likely to own a vehicle, and that among vehicle-owners, the age of the vehicle held is a decreasing function of income. These outcomes are consistent with the empirical evidence on vehicle ownership patterns obtained from the Consumer Expenditure Survey. At the aggregate level, the estimated model, with incomes of different agent types calibrated to match the income distribution for the US in 2001, does a good job replicating the distribution of vehicle vintages in the US for the same year.

The model was used to analyze the effects of changes in the underlying distribution of consumer incomes on the aggregate vehicle ownership statistics, such as the number of vehicles per capita, the per-capita sales of new vehicles, and the mean and median ages of the vehicle stock.

The model predicts that economies with the same level of income inequality, but higher mean per-capita incomes, are characterized by larger vehicle stocks and higher sales of new vehicles. The mean and median ages of the vehicle stock may be higher or lower, however, depending on the endogenous vehicle-ownership rates. If two economies have large fractions of vehicle owners, the economy with higher average income has a younger vehicle stock, since higher-income vehicle owners hold newer vehicles. In poorer economies with low ownership rates, the economy with higher mean per-capita income may have an older vehicle stock, since a larger fraction of its lower-income consumers have enough income to own a vehicle, but only an older one. Miller et al. [6] report a strong negative relationship between per-capita incomes and median ages of vehicles for counties in Tennessee. Since these counties are characterized by high rates of vehicle ownership, the model would generate a relationship of the same sign as the one observed in the data.

The model predicts that for a given level of mean per-capita income, higher levels of income inequality lead to older vehicle stocks. The vehicle ownership rates are lower in more unequal economies, while the relationship between new vehicle sales and the level of income inequality is non-monotone. The empirical relationship between

income inequality and moments of the vehicle age distribution are harder to establish due to the unavailability of data. For the US, the data on income inequality at the state or the MSA levels are available from the US Census Bureau. However, the data on the vehicle age distribution at those levels of disaggregation are not publicly available.

The data on the total vehicle registrations and the sales of new vehicles at the state level are publicly available, however, so the predictions of the model for these variables can be tested. The analysis indicates that at high levels of income and vehicle ownership, the differences in the per capita vehicle registrations across regions cannot be explained by the differences in income distributions. The model produces very little variation in the number of vehicles per capita, with the majority of the states having one vehicle for every person over the age of sixteen.

The per-capita sales of new vehicles are increasing in mean household income and do not depend on the level of income inequality in both model and data. The latter finding is consistent with the model's prediction for the given range of the Gini coefficient values. The model can explain most of the variation in the new vehicle registrations per capita across states.

Overall, this paper makes an important step in studying the relationships between consumer incomes and the ages of durable goods consumed, at both the individual and the aggregate levels.

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