Durables, Lemons, and Shocks

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1 Introduction

Households can self insure by holding assets. However, the literature has focused on savings without distinguishing the nature of the assets. In practice, people save in liquid assets and in durable purchases. Liquid assets have the greatest insurance value. However, durables also store value offering resale opportunities and consumption streams. In this paper, we set out to understand the role of durables as a source of insurance and consumption smoothing.

There are two major durables: housing and cars. We focus on cars here because they are widely owned, the leasing market is not well developed, and most importantly, they have important transaction costs which reduce their insurance value. So we assume that it is (almost) costless to borrow against housing since there are no adverse selection issues. However, cars are subject to important adverse selection leading to an endogenous transaction cost - the lemons premium. We specify and estimate a stochastic life cycle general equilibrium model of car ownership, consumption and other asset accumulation. Individuals have the choice of buying new or second hand cars or no car at all. In our model dealers buy old cars from consumers without knowing their exact quality, fix them and sell them back to consumers. Car dealers are offered cars that on average are of lower quality than similar cars in the population. Dealers therefore pay a lower price than what they would have if there was no asymmetric information and this difference is the lemons premium. This

introduces an endogenous transaction cost that reduces the insurance value of holding this durable asset.

We structurally estimate the model using a population-wide high quality administrative data set with complete information about car ownership for the period 1992-2009. The data is linked to longitudinal income-tax records of the owners with information about income and wealth of the owners as well as to information on the second hand prices for cars. We find that 1-year-old car has the biggest lemons premium. Then the lemons premium declines overtime. We also find that lemons problem strongly suppresses both used car sales and demands. We will also use the estimated model to characterize how people use cars to accommodate income shocks over the business cycle.

2 The model

This is a model of car ownership, income risk and transactions over the life cycle. We construct a model which consists of overlapping generations of ex ante identical consumers whose life span is T. At any point in time there are T generations alive. Time is discrete and denoted by t.

An individual can only own one car at a time. Cars differ by their quality q_t and the ownership duration $z_t \in \{0, 1, \ldots, \bar{z}\}$. A car is also indexed by $n_t = 1$ if the car is first-handed, and is indexed by $n_t = 0$ if the car is second-handed. A brand new car is first handed with 0 years of ownership duration and a fixed quality 1, so $\{n_t, z_t, q_t\} = \{1, 0, 1\}$. We assume a car can only be bought or sold using a dealer as an intermediary. Dealers buy used cars from consumers, fix them to have quality 1 (the max), reset the ownership duration to 0, but they remain second-hand cars. Therefore, all used cars purchased from dealers are homogeneous, i.e. $\{n_t, z_t, q_t\} = \{0, 0, 1\}$. There is an internationally set price for new cars p^n, and the price of fixed cars sold by dealers is p^u. As fixed cars are of quality 1, p^u can also be thought as the price for a unit of quality.

While owning a car, a consumer receives persistent quality shocks

$$q_{t+1} = \begin{cases} 0 & \text{with probability } \delta \\ d\epsilon_t q_t & \text{with probability } 1-\delta \end{cases} \tag{1}$$

δ is the probability that the car has to be scrapped at beginning of next period. With probability $1-\delta$, the car is not scrapped and depreciates at rate $d\epsilon_t$. d is the deterministic depreciation factor, which is common knowledge. $\epsilon \in [0, 1]$ is the private depreciation factor, observable only by the owner, and is logit normally distributed — $\text{logit}(\epsilon) \sim \mathcal{N}(\eta, 1)$. At the beginning of period t, if a consumer has a car of ownership duration z_t, she can sell it to a dealer at price $p^d_{z_t}$ (hereafter, dealer price). Otherwise, if she decides to keep her

existing car, it may become scrapped at the beginning of next period. In this case, she can get an insurance payment equaling the value of her car next period $p^d_{z_{t+1}}$. $\bar{z}$ is the maximum years that a car can be owned, which must be sold to a scrap yard at price $p^d_{\bar{z}}$ at the beginning of next period.

The utility function is assumed to take the CRRA form

$$\frac{c_t^{1-\gamma}}{1-\gamma}\left(1+\theta\left(n_t\right)q_t\right)^{\alpha}$$

α determines the utility premium of owning cars. If $q_t = 0$, i.e. not owning car, utility is only derived from non-durable consumption c_t. $\theta\left(n_t\right)$ determines the preference for first-hand car over second-hand car: $\theta(n_t) = 1$ if owning an old car $n_t = 0$, and $\theta(n_t) > 1$ if owning a new car $n_t = 1$.

Following MaCurdy (1982), households receive labor income y_t which has the following form in logs

$$\ln\, y_t = b_0 + b_1 t + b_2 t^2 + v_t$$

where $b_0 + b_1 t + b_2 t^2$ is a deterministic experience profile over the life cycle, being sold and being owned by vintage.and v_t is the stochastic portion of income. v_t follows a random walk

$$v_t = v_{t-1} + e_t, \quad e_t \sim \mathcal{N}\left(-\frac{\sigma_e^2}{2}, \sigma_e^2\right)$$

where initial shock v_0 is drawn from a Normal distribution with mean $-\frac{\sigma^2_{v_0}}{2}$ and variance $\sigma^2_{v_0}$. The shock e_t is independent over time and across households in the economy.

A consumer holds liquid assets a_t at the beginning of period t. The evolution of the liquid asset is governed by:

$$a_{t+1} = (1+r)\left\{a_t + y_t - c_t - B_t\left[n_t p^n + (1-n_t)\,p^u\right] + S_t p^d_{z_t}\right\} + D_{t+1} p^d_{z_{t+1}}$$

where p^d_z is the dealer price of her existing car, p^n is the retail price of a new car, and p^u is the retail price of a fixed car. $B_t\left(S_t\right) = 1$ if she buys (sells) a car, otherwise it equals 0. $n_t = 1$ if she buys a new car, and $n_t = 0$ if she buys a fixed car. $D_{t+1} = 1$ if her car becomes scrapped at the beginning of period $t+1$, otherwise it equals 0.

For ease of exposition, we denote end-of-period assets as $s_t = a_{t+1}$. Following Alessie et al. (1997), we assume consumers have access to both collateral and uncollateral debt. Car can be used as an collateral, but only up to the amount that it can be sold next period $p^d_{z_{t+1}}$. We assume the uncollateral debt is bounded

below by a threshold $-\underline{a}_t$. Hence, the borrowing constraint is

$$s_t \geq -p^d_{z_{t+1}} - \underline{a}_t \tag{2}$$

When a consumer buys a fixed car from a dealer, there is no asymmetric information, i.e. quality is 1. When a dealer buys an old car of ownership duration $z \in \{1, \ldots, \bar{z}-1\}$ from a consumer, she pays dealer price p^d_z, and is subject to the lemons problem due to private depreciation. To fix an old car of quality q_i, a dealer must pay $c\,(1-q_i)$, where c is the fixing cost for a unit of quality and $1-q_i$ is the depreciated quality of the car. As long as $q_i > 0$, the dealer don't have to pay the whole unit fixing cost c. In reality, fixing a car is very expensive, which includes the price of new car parts and the salary of mechanicians. As the fixing cost shouldn't be higher than selling price, we assume the unit fixing cost equals the price for a unit of quality, i.e. $c = p^u$. As the dealer can sell a fixed car for p^u, the profit from fixing the car is

$$\begin{aligned} & p^u - \left[p^d_z + c\,(1-q_i)\right] \\ =& p^u - \left[p^d_z + p^u\,(1-q_i)\right] \\ =& p^u q_i - p^d_z \end{aligned}$$

as the dealer can always scrap the car directly at price $p^d_{\bar{z}}$, the profit from scraping the car is

$$p^d_{\bar{z}} - p^d_z$$

so the dealer will scrap a car if it has severe quality problem

$$\begin{aligned} p^u q_i - p^d_z &\leq p^d_{\bar{z}} - p^d_z \\ q_i &\leq \frac{p^d_{\bar{z}}}{p^u} \end{aligned}$$

q_{t}otherwise, he will fix it. Let M_z be the quantity of cars of ownership duration z bought by dealers, and N_z be the quantity of repairable cars. We have $N_z < M_z$, as dealers scrap some cars. Then the total cost of buying cars of ownership duration z is $p^d_z M_z$, the total sales of them is $p^u N_z + p^d_{\bar{z}}\,(M_z - N_z)$, and the total cost of fixing them is $p^u\,(1-\bar{q_z})\,N_z$, where $\bar{q_z} = \mathbb{E}\left(q_i | z, p^d, q_i > \frac{p^d_{\bar{z}}}{p^u}\right)$ is the expected quality of a repairable

car of ownership duration z. In equilibrium, dealers make 0 profit, which imply

$$
\begin{aligned}
p^u N_z + p_{\bar{z}}^d \left(M_z - N_z\right) &= p_z^d M_z + p^u \left(1 - \bar{q_z}\right) N_z \\
p^u N_z + p_{\bar{z}}^d \left(M_z - N_z\right) &= p_z^d M_z + p^u N_z - p^u \bar{q_z} N_z \\
p_{\bar{z}}^d \left(M_z - N_z\right) &= p_z^d M_z - p^u \bar{q_z} N_z \\
p_z^d M_z &= p^u \bar{q_z} N_z + p_{\bar{z}}^d \left(M_z - N_z\right) \\
p_z^d &= \frac{N_z}{M_z} \bar{q_z} p^u + \left(1 - \frac{N_z}{M_z}\right) p_{\bar{z}}^d \quad \text{for } z \in \{1, 2, \ldots, \bar{z} - 1\}
\end{aligned} \tag{3}
$$

As p^u is the price for a unit of quality, $\bar{q_z} p^u$ is the expected value of a repairable car. $\frac{N_z}{M_z}$ is the proportion of repairable cars among cars being sold, $p_{\bar{z}}^d$ is the expected value of a non-repairable car, and $1 - \frac{N_z}{M_z}$ is the proportion of non-repairable cars among cars being sold. So equation 3 says that dealer price equals the expected value of a car being sold, which is the weighted average of the expected value of a repairable car and a non-repairable car.

3 Value Functions

$W_t\left(a_t, y_t\right)$ is the value function for a consumer who does not own a car at the start of period t, where a_t and y_t are the liquid asset and income. $V_t\left(a_t, y_t, n_t, z_t, q_t\right)$ is the value function for a consumer who owns a used car of type (n_t, z_t, q_t) at the start of period t.

First consider a consumer who does not own a car. At the start of the period, the discrete decision she makes is whether to buy a car or not. This discrete decision determines two conditional value functions, W_t^0 and W_t^b.

1. She do not buy in period t

$$
W_t^0\left(a_t, y_t\right) = \underset{\{c_t, a_{t+1}\}}{max} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} + \beta \mathbb{E}_t W_{t+1}\left(a_{t+1}, y_{t+1}\right) \right\}
$$

2. She purchases either a new car $\{n_t, z_t, q_t\} = \{1, 0, 1\}$ or a fixed car $\{n_t, z_t, q_t\} = \{0, 0, 1\}$. In the next period, the ownership duration of her car $z_{t+1} = 1$, and quality $q_{t+1} = d\epsilon_t$. With probability δ, the car

becomes scrapped at the beginning of next period.

$$W_t^b(a_t, y_t) = \max_{\{c_t, a_{t+1}, n_t\}} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} (1+\theta(n_t))^{\alpha} + \beta \mathbb{E}_t \left[(1-\delta) V_{t+1}(a_{t+1}, y_{t+1}, n_t, 1, d\epsilon_t) + \delta W_{t+1}(a_{t+1}, y_{t+1}) \right] \right\}$$

The unconditional value function W_t is then determined as:

$$W_t(a_t, y_t) = \max \left\{ W_t^0(a_t, y_t), W_t^b(a_t, y_t) \right\}$$

Then consider a consumer who owns a car. She can either upgrade (sell the old car and buy a new one), or sell the car completely, or stay with her existing car. This discrete decision determines three conditional value functions, V_t^k, V_t^b, and V_t^s.

1. She keeps her existing car $\{n_t, z_t, q_t\}$. In the next period, the ownership duration of her car $z_{t+1} = z_t + 1$, and quality $q_{t+1} = d\epsilon_t q_t$. With probability δ, the car becomes scrapped at the beginning of next period.

$$V_t^k(a_t, y_t, n_t, z_t, q_t) = \max_{\{c_t, a_{t+1}\}} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} (1+\theta(n_t) q_t)^{\alpha} + \beta \mathbb{E}_t \left[(1-\delta) V_{t+1}(a_{t+1}, y_{t+1}, n_t, z_t+1, d\epsilon_t q_t) + \delta W_{t+1}(a_{t+1}, y_{t+1}) \right] \right\}$$

2. She sells the existing car, and purchases either a new car $\{n_t, z_t, q_t\} = \{1, 0, 1\}$ or a fixed car $\{n_t, z_t, q_t\} = \{0, 0, 1\}$. In the next period, the ownership duration of her car $z_{t+1} = 1$, and quality $q_{t+1} = d\epsilon_t$. With probability δ, the car becomes scrapped at the beginning of next period.

$$V_t^b(a_t, y_t, n_t, z_t, q_t) = \max_{\{c_t, a_{t+1}, n_t\}} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} (1+\theta(n_t))^{\alpha} + \beta \mathbb{E}_t \left[(1-\delta) V_{t+1}(a_{t+1}, y_{t+1}, n_t, 1, d\epsilon_t) + \delta W_{t+1}(a_{t+1}, y_{t+1}) \right] \right\}$$

3. She sells her car completely

$$V_t^s(a_t, y_t, n_t, z_t, q_t) = \max_{\{c_t, a_{t+1}\}} \left\{ \frac{c_t^{1-\gamma}}{1-\gamma} + \beta \mathbb{E}_t W_{t+1}(a_{t+1}, y_{t+1}) \right\}$$

These conditional value functions are compared to determine the individual's durable decision:

$$V_t(a_t, y_t, n_t, z_t, q_t) = \max\left\{V_t^k\left(a_t, y_t, n_t, z_t, q_t\right), V_t^b\left(a_t, y_t, n_t, z_t, q_t\right), V_t^s\left(a_t, y_t, n_t, z_t, q_t\right)\right\}$$

4 Equilibrium

Equilibrium in the market is defined by:

1. Consumers maximize utility.
2. Dealers make zero profit.
3. Dealers don't keep inventory, so no excess demand of fixed cars. The total demand of fixed cars N^D from consumers equals to the total supply from dealers

$$N^D = \sum_{z=1}^{\bar{z}-1} N_z$$

$d\mathbb{E}\left(\epsilon\right) = 0.74$where N_z is the quantity of repairable cars of ownership duration z bought by dealers.

5 Algorithm

We want to calibrate the model, and at the same time find the equilibrium defined in Section 4. First, the equilibrium condition that dealers make zero profit implies equation 3. So we can satisfy this equilibrium condition by solving equilibrium dealer prices p_z^d. Second, in equilibrium, no excess demand of fixed cars. So by minimizing this moment in the calibration process alongside with other data moments, we could solve this equilibrium condition. The excess demand of fixed cars is determined by the preference for new cars over fixed cars θ. So the algorithm is as following.

1. Solve equilibrium dealer prices p_z^d
   (a) Assume dealer prices p_z^d and other unknown parameters.
   (b) Solve the model and calculate a new set of dealer prices $p_{z,new}^d$ according to 3,
   (c) Check whether $p_z^d = p_{z,new}^d$. If not, solve the model using $p_{z,new}^d$, and repeat until converging.
2. Given p_z^d, calibrate unknown parameters by targeting at data moments and minimizing the excess demand of fixed cars.

3. Solve the model using calibrated parameters, and calculate a new set of dealer prices $p^d_{z,new}$. Check whether $p^d_z = p^d_{z,new}$. If not, repeat Step 1 and 2.

6 Model calibration

6.1 External parameter values

The external fixed parameter values are listed in Table 1. We discuss them in turn.

Cars We normalize all the prices and income by the median book price of a new car – 181 thousand DKK in the data Central Register of Motor Vehicles (CRMV). So the new car price in the model $p^n = 1$. We assume bi-annual vintage, i.e. a one-year-old car in the model means 2-year-old in reality. In the model, we set the maximum years that a car can be owned $\bar{z} = 8$, which means a car is scrapped after being owned for 16 years. The we can account for 97% of cars in the data. We set the scrap price in the model $p^d_{\bar{z}} = 0.017$, which is the first decile of the normalized book price of a car that has been owned for 16 years.

The annual deterministic depreciation rate is 0.945, which is calculated by dividing the median book price of a first year old car by that of a new car. As we use bi-annual vintage in the model, the bi-annual deterministic depreciation $d = 0.893$. We set the bi-annual scrap rate $\delta = 0.088$, which is calculated as the bi-annual scrap rate conditional on ownership duration from the data.

A fixed car is of ownership duration 0, we think its price is related to p_z, the normalized book price of cars of ownership duration z. We use the following regression to derive the fixed car price p^u

$$\begin{aligned} p_z &= \kappa^z p^u \\ \ln(p_z) &= \ln(p^u) + z\ln(\kappa) \end{aligned} \tag{4}$$

where κ is the average decrease in the ownership duration price. Then we get the normalized fixed car price $p^u = 0.48$, which equals to the median book price of a 6-year-old car.

Demographics Consumers enter the model at age 23, retire after age 65 and leave the model at age 75. In Denmark, a Car license is valid until the driver reaches 70 years of age, although further driving tests combined with medical examinations allows the driver to retake his license every two years after the age of 70.

Income process We estimate the parameters of the household income process using Danish income tax records in 1992-2009. (b_0, b_1, b_2) are parameters for deterministic age profile. $\sigma^2_{v_0}$ is the cross-sectional variance of the initial income shock, and σ^2_e is the variance of the permanent shock. We normalize the income profile by p^n.

We estimate the parameters for high (some college and above) and low education groups separately. The results in Table 1 show that the high education group has a more hump-shaped income profile, a lower variance in initial shock, and a higher variance in permanent shocks than the low education group during the working lives. Income after retirement is given by a replacement rate of 50% of consumer's last annual income. Income is not subject to risk after retirement.

Initial conditions We set the initial distribution of financial assets for the two education groups at age 23 to match data on average over 20-26 years old, and we assume consumers have zero car endowments at age 23.

Interest rate process We calculate the real interest rate r using the interest rate of two-year Danish government bonds adjusted by consumer price index in 1996-2009, which gives a rate of 0.016. We assume the discount factor β is the inverse of the real interest rate, i.e. $\beta = \frac{1}{1+r}$.

Utility function The parameter for relative risk aversion γ is set to match the consumption elasticity of inter-temporal substitution of 0.7 (Attanasio et al. 2012), which corresponds to $\gamma = 1.43$.

Financial market In the benchmark calibration, the uncollateral debt is bounded below by

$$\underline{a} = d\mathbb{E}(\epsilon)p^u(1+r) - p_1^d$$

where d is deterministic depreciation, and $\mathbb{E}(\epsilon)$ is the expected value of private depreciation. Then $d\mathbb{E}(\epsilon)$is the overall expected depreciation. As the collateral debt for buying a new car is p_1^d, then, the borrowing constraint is

$$s_t \geq -p_1^d - \underline{a}_t$$
$$s_t \geq -d\mathbb{E}(\epsilon)p^u(1+r)$$

It implies the down payment requirement for buying a fixed car is $(1 - d\mathbb{E}(\epsilon))$.

6.2 Calibrated parameters

Given the parameters above, we calibrate remaining parameters using data of household heads aged 30-60 between 1992 and 2009, by education group. Our approach is to choose the parameters to minimize the relative deviations between moments calculated in the data and corresponding simulated moments. The moments we use are ownership duration of new cars[1], the fraction of buyers who buy new cars for the young (aged 30˜40) and for the old (aged 41˜60), and the ownership rates for the young and for the old. Besides, we also minimize the excess demand of fixed cars in the calibration.

We use the moments listed above to pin down 4 parameters: location parameter of the private depreciation factor η, the utility premium of owning car α, and the preference for first-hand car over second-hand car by education groups $\left(\theta^H, \theta^L\right)$. Parameter values from the calibration are in Table 2. Table 3 presents the moments from the data and from the model[2].

From our calibration, location parameter of the private depreciation factor $\eta = 1.613$. Using numerical integration, we compute the expected mean of private depreciation factor $\mathbb{E}(\epsilon) = 0.79$. The bi-annual deterministic depreciation factor $d = 0.893$, then the overall expected depreciation factor $d\mathbb{E}(\epsilon) = 0.71$. The bi-annual depreciation factor in the book price from CRMV data is 0.8. Given the fact that book price is the recommended price for dealers who should have fixed some depreciated quality, the calibrated overall depreciation factor seems reasonable. Given the calibrated utility parameters, a new car is 1.7 times and 1.74 times more preferred than a fixed car for the low education group and the high education group respectively. The share of car quality is about 36% of consumption in the utility function.

7 Result

7.1 Lifetime profile

Figure 1 shows the lifetime income, saving, and log consumption profile. Figure 2 shows the age profiles of ownership and selling in the baseline simulation. The black solid line show the measure of people buying new cars, it increases before retirement and then becomes flat. The red dotted line show the measure of people buying fixed cars. It decreases slightly over the life time. The measure of people who own each vintage of used cars decreases with the increase of vintage, as people sell their cars gradually before it become scrapped. The bottom graph shows that most people sell their cars at the second and third he year of ownership.

[1] Given the fixed car in our model is an abstraction from the reality, we do not match its ownership duration.
[2] The minimized excess demand of fixed cars from the calibration is 0.1% of the total demand.

7.2 The lemons premium

Due to asymmetric information, dealers are offered cars that on average are of lower quality than expected value of cars being owned in the population. Dealers therefore will not pay the expected value of cars being owned to an offered car. They will ask for a price discount, which is the lemons premium.

The first row of Table 4 shows the dealer price, which equals the expected value of cars being sold, according to equation 3. The second row of Table 4 shows the expected value of cars being owned. The difference between them is the lemons premium, which is showed in the third row. 1-year-old car has the biggest lemons premium. Then the lemons premium declines overtime. Figure 3a plots the distribution of car value conditional on being sold and being owned by vintage. The vertical line is the dealer price for each vintage. Those owners whose cars are on the right of the dealer price make a loss when selling their cars, so very few of them sell their cars at 1-year-old. On the contrary, those owners whose cars are on the left of the dealer price make a profit when selling their cars, so many of them sell their cars at 1-year-old. In the end, for the 1-year-old car, the average value of cars being sold are far less than the value of cars being owned, which gives rise the biggest lemons premium. The 4th row of Table 4 shows the percentage of cars being sold for each vintage, and the 5th row shows the cumulative percentage. Only 11% of 1-year-old cars are sold. The interpretation is that consumer will only get rid of her car quickly when it is really bad.

According to Figure 3a, the distributions of car value conditional on being sold and being owned get more close to each other. It means the lemons problem gets smaller. As a result, the sales of used cars increase from 11% in year 1 to 54% in year 3.

7.3 Comparison with full information

To understand the lemons problem, we compare asymmetric information model with full information model. In the full information model, if a consumer has a car of quality q_t, she can sell it at its true value $q_t p^u$. Reminding that, in the asymmetric information model, if a car becomes scrapped at the beginning of next period, the owner can get an insurance payment equaling the value of her car next period $p^d_{z_{t+1}}$. In the full information model, we assume the insurance payment equals the expected car value next period $d\mathbb{E}(\epsilon) q_t p^u$.

After eliminating asymmetric information from the model, the aggregate demand of fixed cars changes, and thus the fixed car price p^u changes. Then expected car value also changes, as it is proportional to p^u. In order to compare it with asymmetric information model, as a first step, we keep the fixed car price constant, i.e. $p^u = 0.48$, although this means aggregate demand of fixed cars is different from aggregate supply. The 6th row of Table 4 shows the average dealer prices, and the 7th row shows the expected value of cars being

owned in this case.

In the full information model, cars are sold at their true quality — no one makes a loss or a profit. In the asymmetric information model, cars are sold at average quality of cars on the market. So good cars can be sold at a better price in the full information model than in the asymmetric information model. In the asymmetric information model, dealer prices are lower than the expected value of cars being owned, so only bad cars are sold. In the full information model, average dealer prices are close to the expected value of cars being owned, so both good and bad cars are sold. Figure 3b plots the distribution of car value conditional on being sold and being owned by vintage in the full information model. The two distributions are very close to each other. The 8th row of Table 4 shows the percentage of cars being sold in this case. 79% of 1-year-old cars are sold, comparing to only 11% of 1-year-old cars being sold in the asymmetric information model. Therefore, good cars are sold earlier in the full information model than in the asymmetric information model. It shows lemon's problem strongly suppresses used car sales. Comparing the 1st and 6th row of Table 4, we find:

1. The average dealer prices of vintage 1–3 are higher in the full information model than the dealer prices in the asymmetric information model. As good cars are sold earlier, the quality of cars sold in 1–3 years old market are better in the full information model than in the asymmetric information model.

2. The average dealer prices of vintage 4–7 are lower in the full information model. Good cars are sold earlier in the 1–3 years old market in the full information model. This makes cars left in the 4–7 years old market in the full information model are worse than those in the asymmetric information model.

The rest of table 4 show the simulated data for the full information model after allowing p^u to change. As cars can be sold at a better price in the full information model, consumers demand more cars: the total demand of fixed cars increases from 20% to 39% of the population. As a result, the fixed car price p^u increased by 10% from 0.48 to 0.53. So lemons problem also strongly suppresses used car demands.

Table 1: Parameter Values

Parameters	Descriptions	Value	Source
Preference:			
r	interest rate	0.016	Government bond
γ	relative risk aversion	1.43	Attanasio et al. (2012)
Cars:			
p^n	new car price	1	CRMV
p^u	fixed car price	0.48	Regression 4
$p^d_{\bar{z}}$	Scrap price	0.017	CRMV
d	bi-annual deterministic depreciation	0.893	CRMV
δ	bi-annual scrap rate	0.088	CRMV
Income:			
$\left(b^H_0, b^H_1, b^H_2\right)$	deterministic age profile – high edu	(0.029, 0.063, -0.0012)	Income tax records
$\left(b^L_0, b^L_1, b^L_2\right)$	deterministic age profile – low edu	(0.284, 0.026, -0.0006)	Income tax records
$\sigma^2_{v_0 H}$	initial shock variance – high edu	0.15	Income tax records
$\sigma^2_{v_0 L}$	initial shock variance – low edu	0.209	Income tax records
σ^2_{eH}	permanent shock variance – high edu	0.065	Income tax records
σ^2_{eL}	permanent shock variance – low edu	0.056	Income tax records

Table 2: Calibrated Parameter Values

	Descriptions	Value
θ^H	preference for first-hand car – high edu	1.741
θ^L	preference for first-hand car – low edu	1.701
α	utility premium of owning car	-0.153
η	$\text{logit}(\epsilon) \sim \mathcal{N}(\eta, 1)$	1.613

Table 3: Calibration Moments

Moments	High education		Low education	
	Data	Model	Data	Model
Ownership rate				
Age 30˜40	68.6%	69.8%	68.4%	69.2%
Age 41˜60	77.6%	73%	72.4%	71.5%
% buyers who buy new cars				
Age 30˜40	22.8%	20.3%	16.5%	14.9%
Age 41˜60	33.7%	40.2%	26.7%	32.5%
Ownership duration of new cars*	2.5	2.3	2.35	2.33

*As we assume bi-annual vintage, ownership duration is divided by 2.

Table 4: The lemons premium

vintage		0	1	2	3	4	5	6	7
Asymmetric information									
	— Fixed car demand = supply = 20% of population								
1	Dealer price	0.48	0.24	0.21	0.18	0.15	0.12	0.09	0.07
2	Expected car value (owned)	0.48	0.34	0.25	0.2	0.15	0.12	0.09	0.07
3	**Lemons premium**		**-0.1**	**-0.04**	**-0.02**	**0**	**0**	**0**	**0**
4	% of cars being sold		11.1%	38.7%	54.0%	50.1%	45.6%	17.5%	50.3%
5	cumulative %		11.1%	45.5%	74.9%	87.5%	93.2%	94.4%	97.2%
Full information (keep $p^u = 0.48$)									
	— Fixed car demand = 45% > supply = 43% of population								
6	Average Dealer price	0.48	0.34	0.25	0.19	0.14	0.1	0.07	0.06
7	Expected car value (owned)	0.48	0.34	0.26	0.19	0.13	0.09	0.07	0.05
8	% of cars being sold		78.7%	51.1%	43.9%	30.1%	23.2%	18.3%	28.9%
9	cumulative %		78.7%	89.6%	94.2%	95.9%	96.9%	97.4%	98.2%
Full information (allow p^u increases)									
	— Fixed car demand = supply = 39% of population								
10	Average Dealer price	0.53	0.37	0.27	0.21	0.15	0.1	0.08	0.06
11	Expected car value (owned)	0.53	0.38	0.28	0.21	0.15	0.1	0.07	0.05
12	% of cars being sold		75.4%	50.6%	45.3%	30.9%	24.0%	20.3%	29.1%
13	cumulative %		75.4%	87.8%	93.4%	95.4%	96.5%	97.2%	98.0%

Figure 1: Lifetime income, saving, and log consumption profile

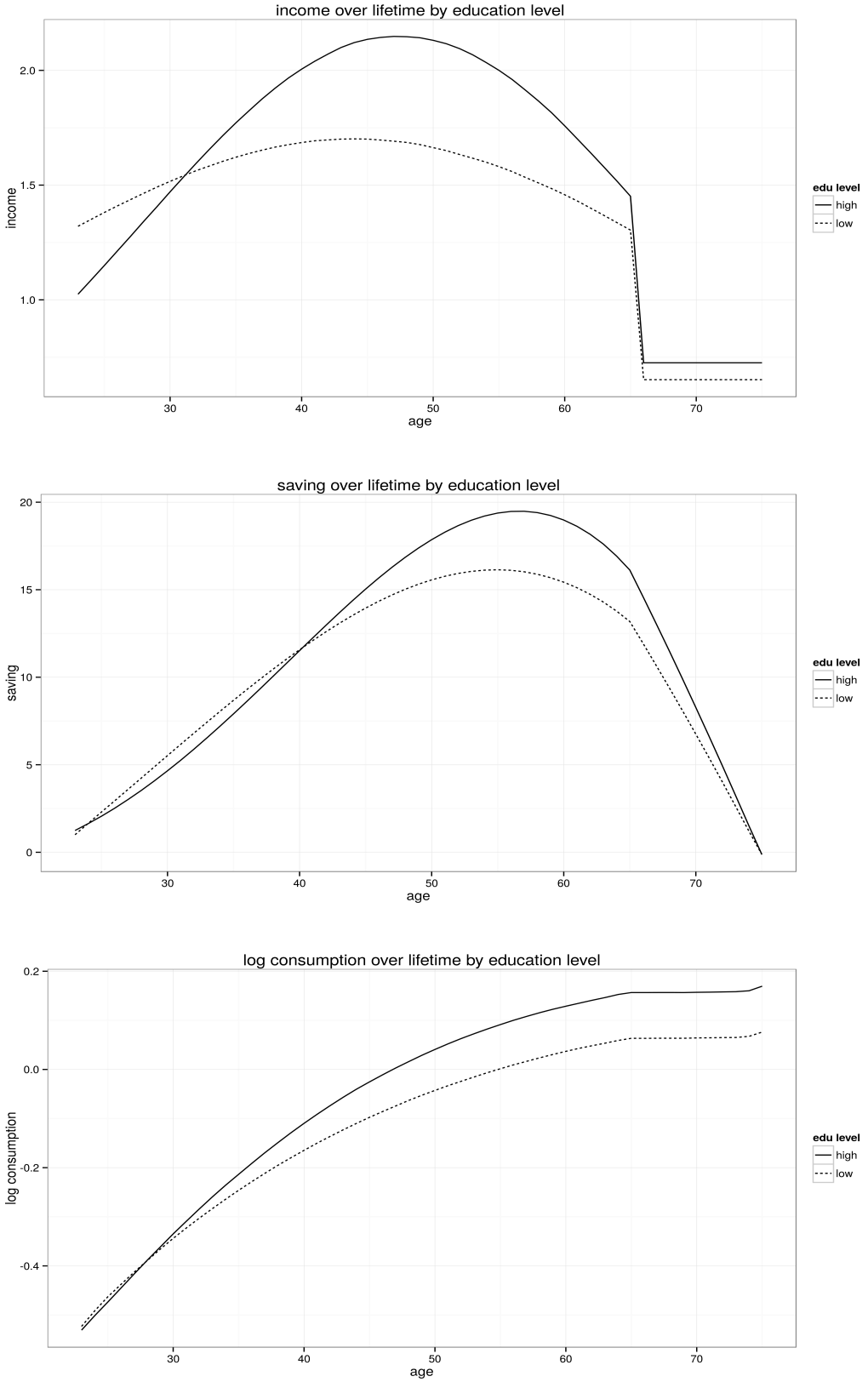
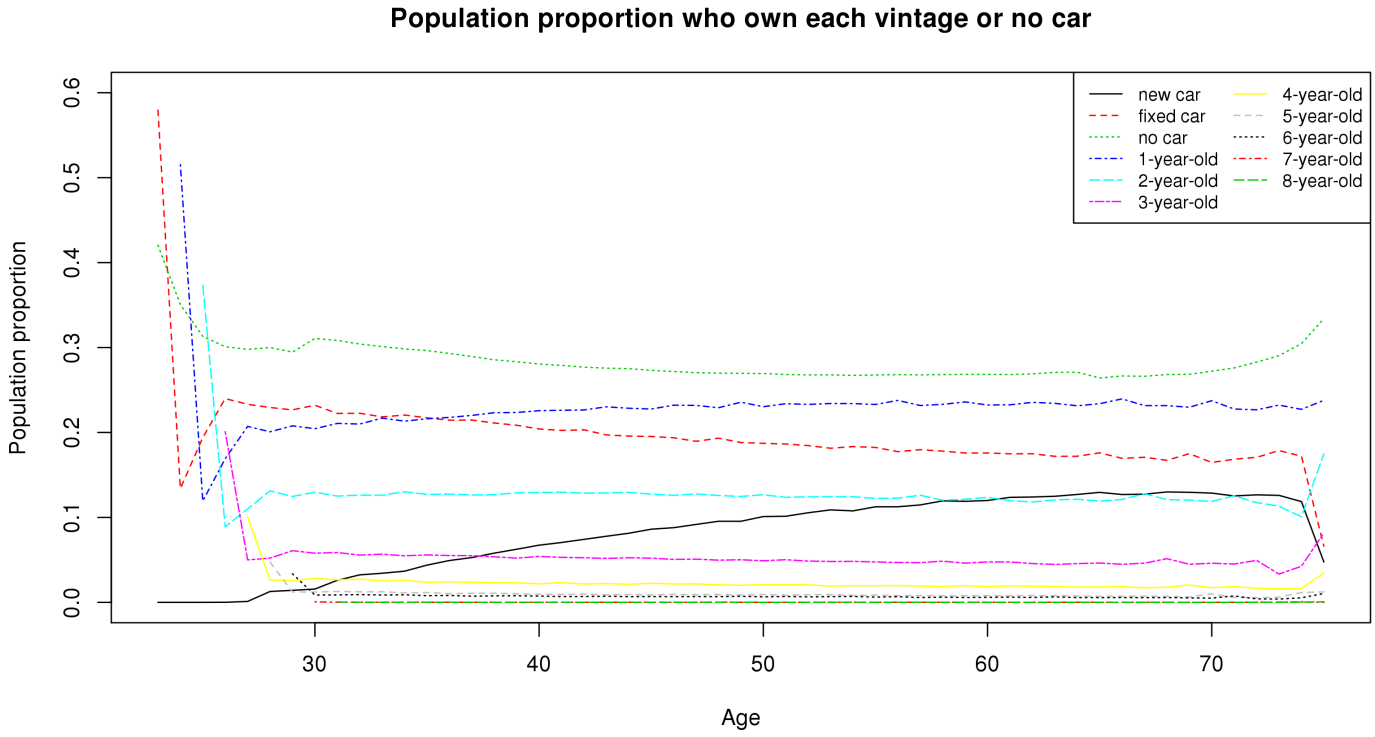


Figure 2: Simulated profiles of ownership and selling



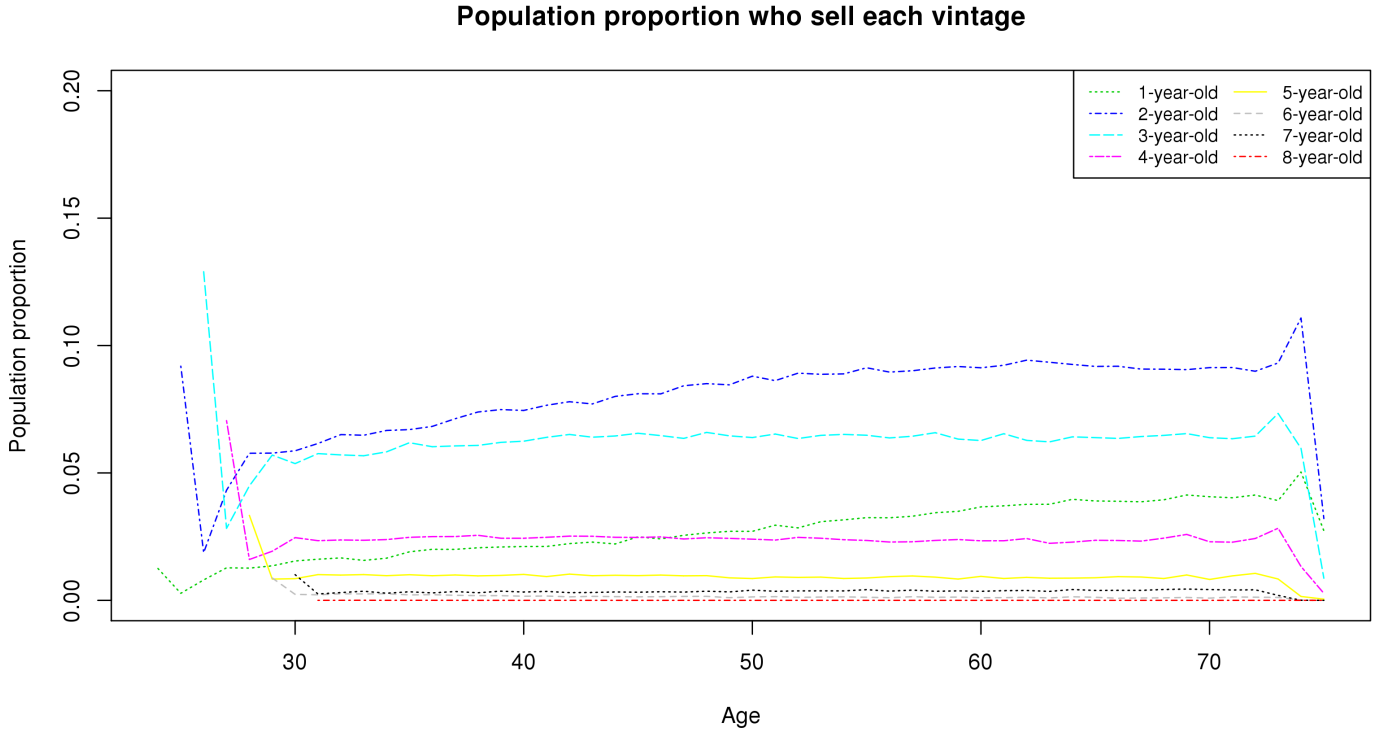
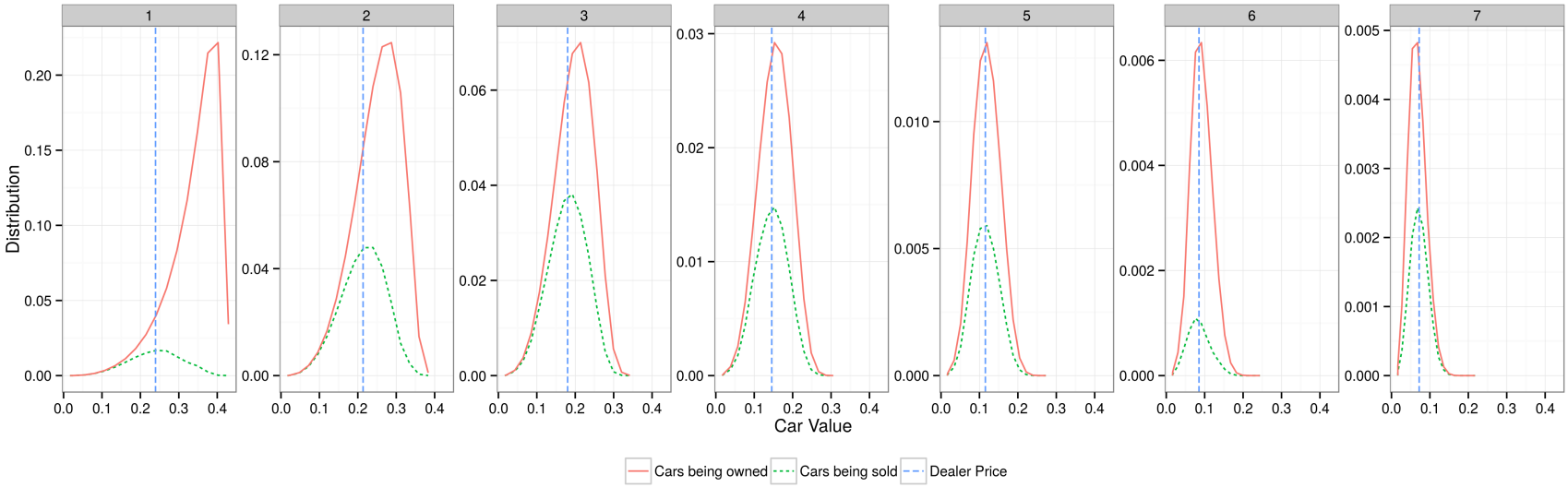


Figure 3: Distribution of Car Value Conditional on being Sold and being Owned by Vintage

(a) Asymmetric Information



(b) Full Information — keep $p^u = 0.48$

