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Durables and Lemons:
Private Information and the Market for Cars*

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Abstract

We specify an equilibrium model of car ownership with private information where individuals sell and purchase new and second-hand cars over their life-cycle. This private information introduces a transaction cost, distorts the market and reduces the value of a car as a savings instrument. We estimate the model using Danish linked registry data on car ownership, income and wealth. The transaction cost, which we term the lemons penalty, is estimated to be 18% of the price in the first year of ownership, declining with the length of ownership. It leads to large reductions in the turnover of cars and in the probability of downgrading in the event of an adverse income shock. The size of the lemons penalty declines when uncertainty in the economy increases, as in recessions: large income shocks induce individuals to sell their cars, even if of good quality, and this reduces the lemons problem.

Keywords: Lemons penalty, car market, income uncertainty, estimated life-cycle equilibrium model

JEL Codes: D15, D82, E21

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1 Introduction

As is the case with many durable goods, car owners know more about their own car quality than buyers: this affects the price that buyers are willing to pay, and in turn the quality of cars that car owners are willing to sell, Akerlof (1970). This private information introduces a transaction cost which is endogenous to the quality of cars that are sold in equilibrium and directly affects the quantity of cars sold and how long cars are owned for. The aim of this paper is to quantify the size of this transaction cost, which we term the lemons penalty, and how this varies with underlying uncertainty in the economy. More generally, the aim is to understand the importance of private information and its role in distorting the durable goods market, changing the volume of transactions and the value of assets, and to show how these distortions affect households.

The lemons penalty reflects the difference between the average quality in the population and the average quality of cars sold, given any observed characteristics. Asymmetric information about the quality of cars means dealers will pay less than the expected value of cars that are owned in the population and this will affect who sells a car. This price discount is the lemons penalty. To quantify the lemons penalty we develop an equilibrium model of the car market, with individuals being life-cycle consumers facing stochastic income and being subject to liquidity constraints. Normally, with such a lemons problem the market for second-hand cars should unravel completely. However, in our equilibrium model the existence of the market is supported because some households are compelled to sell their cars for liquidity purposes, following adverse income shocks. Since these shocks are orthogonal to the unobserved characteristics of the car, the forced sales can be of higher quality, and so the average quality of cars does not collapse. In other words, the average quality of cars in the second-hand market is partly driven by the distribution of the shocks to car quality and partly by the distribution of income shocks themselves.

Beyond understanding the market for durables and characterizing the impact of asymmetric information on prices, this study has direct implications for consumption smoothing and the way the composition of household assets can affect self-insurance: when endogenous transaction costs are high then the use of these durables as assets for consumption smoothing will be restricted and limit the self-insurance capability of households. If the size of the transaction cost varies with underlying uncertainty, then so too may the value of the asset for consumption smoothing. Cars are an important durable to study because they often constitute a large proportion of assets, especially for non-home-owners.

We estimate our model on Danish population register data which includes information about car ownership and we are able to link in dealer resale prices. The key to identification is information on second-hand car sales by duration of ownership. Using the equilibrium model we can then establish the extent of the lemons penalty, by quantifying the average quality in the population and the average quality of cars put on the market.

Asymmetric information may arise in different sides of the car market. However, we assume that dealers have sufficient access to credit or are large enough to have the ability to offer guarantees to buyers of second-hand cars that solves the lemons issue at that part of the second-hand market. Dealers can sell cars of different quality but we assume the presence of guarantees makes this as good as observable. Thus the only point at which asymmetric information is an issue is when private individuals sell to dealers. This market structure also explains why the private-to-private market is limited in Denmark and indeed in our paper we assume this market away.

To define and quantify the lemons penalty, and to understand the distributional implications of the penalty, we specify and estimate a stochastic life-cycle equilibrium model of car ownership, consumption and other asset accumulation. We assume cars depreciate at a stochastic rate, with at least part of this depreciation being private information to the owner. Additionally, we allow for a deterministic depreciation which is known and is the minimum amount of depreciation that can occur. For simplicity, we assume individuals sell cars to car dealers and purchase either new cars or second-hand cars from dealers or choose not to own a car at all. Dealers buy cars from households without knowing their exact quality, fix them and sell them back to households as second-hand cars. In equilibrium, dealers are offered cars that on average are of lower quality than similar cars in the population. Dealers therefore pay a lower price than they would have done if there was no asymmetric information and this difference is the lemons penalty. Crucially for the support of the equilibrium, some people sell their cars due to idiosyncratic shocks to income, rather than due to their cars being of low quality.

For the purposes of quantifying the lemons penalty, we argue that modelling asset accumulation in addition to wealth held in cars is critical. The lemons penalty is an equilibrium concept that depends on the number and type of cars flowing in and out of the car market. The rate at which cars are bought and sold depends on individual access to credit and their ability to accumulate savings to purchase cars. Attanasio et al. (2008) and Alessie et al. (1997) highlight the importance of credit conditions for car demand, and we also document that car transactions are associated with substantial changes in financial asset holdings in our data.[1]

We estimate the model using high quality Danish population-wide administrative register data for the period with complete information about car ownership 1992-2009. The register data is linked to longitudinal income-tax records with information about income and wealth of the owners as well as to information on the second-hand prices for cars. The core data set is the Central Register of Motor

[1]In Figure 8 in Appendix A we document using the administrative data that financial asset holdings change significantly at the time where households buy cars. Including savings in the model is critical, as we can otherwise not match key aspects of the data. Conceptually, this arises because without other means of saving, the purchase of a car must be financed by sacrificing current consumption and this dramatically reduces the flows in and out of the car market. Modelling wealth accumulation complicates the model significantly and makes it difficult to unfold other aspects, such as car type heterogeneity.

Vehicles (CRMV) from which we have data covering the period 1992-2009. This register contains information about the entire population of cars registered with Danish number plates. These are then merged with prices of all new and used cars on the market in the same period and with the individual register data on income, wealth and family characteristics. To the best of our knowledge no other data set collects longitudinal information about cars, income and wealth, and we are going to exploit these unique features of the data to inform the model.

We use a method of simulated moments estimator (McFadden, 1989; Pakes and Pollard, 1989) using data for households where the oldest household member is aged 30-60 in the period 1992 to 2009. Our approach is to choose the parameters to minimize the relative deviations between moments calculated in the data and corresponding simulated moments, where the targeted moments include the ownership rates of cars by age and by education, the fraction of people who buy new cars by age and by education, the fraction of cars sold by ownership duration, average ownership duration of cars, and holdings of financial assets.

The lemons penalty is particularly large early on in ownership. This reflects the difference between the average quality in the population and the average quality of cars sold. We find that a car that has been owned for just 1-year has the biggest lemons penalty when it is sold: 18% of the equilibrium price in the first year of ownership. In the second year the penalty is still substantial: 9% of the equilibrium price in the second year of ownership. Thereafter, the lemons penalty declines quickly as ownership duration increases. The high lemons penalty for cars of short ownership duration suppresses their transactions, and this in turn reinforces the size of the penalty as it is mainly those with particularly low quality cars who will sell. The second-hand car market does not collapse because individuals have different motives for selling their cars: negative income shocks lead some individuals to sell high quality cars despite the lemons penalty they then have to pay. We show that as a result of this mechanism, the lemons penalty tends to be relatively high when overall income risk is low, which is typically the case when the economy is booming, because fewer cars of relatively high quality are put on the market. Conversely, the penalty is low when uncertainty is high. Moreover, these differences in the lemons penalty matter because the presence of the penalty delays replacement substantially and reduces the probability of downgrading in response to an adverse income shock. The final point we stress is that the lemons penalty has distributional consequences: owners of good quality cars lose and owners of 'lemons' benefit because both receive the same price due to the asymmetric information. The information failure leads to imperfect insurance against having a car of low quality, and further, improving information worsens this (imperfect) insurance.

A significant amount of previous papers have modelled households ownership and replacement of cars and recognized that the car replacement decision is associated with transactions costs. Lam (1991), Eberly (1994), Attanasio (2000), Foote, Hurst, and Leahy (2000) present Ss-models of car ownership where exogenous transaction costs create inaction regions, or Ss-bands, within which the household does not upgrade or downgrade the car. Generally, Ss-models are concerned with the consumer decision and do not model the endogenous determination of prices in the second-hand market and hence do not provide an explicit economic explanation of why transaction costs vary as the supply of cars to the secondary market changes. Goldberg (1995) focuses on the market for new cars and consequently is not concerned directly with the pricing in the second-hand market.

This paper connects with the literature emphasizing the interaction between the market for new cars and the used car market. Hendel and Lizzeri (1999) incorporate adverse selection in to a dynamic model and examine the interactions between new and used car markets to show, among other things, that the used car market does not shut down in the presence of adverse selection. A further literature has focused on the effect of policies that can potentially affect the secondary market for cars, such as scrappage subsidies and gasoline prices. Schiraldi (2011) develops and estimates a structural dynamic model of consumer demand for new and used cars and use the estimated model to evaluate the impact of scrappage subsidies. He proposes a strategy for identifying transaction costs, but assumes that the quality of used cars is common knowledge among agents, so that there is no adverse selection problem. Busse et al. (2013) model the effect of changing gasoline prices on equilibrium prices of new and used cars to learn about how consumers trade off capital costs and ongoing user costs of cars, but not how consumers change their valuation of new and used cars. Gavazza et al. (2014) develop an equilibrium model of the primary and secondary market for cars to learn about how differences in the characteristics of these markets can explain observed differences between the US and French car markets. Critical in relation to our study is that Gavazza et al. (2014) assume exogenous transaction costs in the market for used cars and therefore do not model how asymmetric information about the quality of cars in the secondary markets varies endogenously. Adda and Cooper (2000) model demand for new cars and how this interacts with the cost of replacing a used with a new car and use this model to examine the effect of scrappage subsidies in France. They do not model trade in the secondary market for cars and hence ignore the issue of adverse selection in the market for used cars. Finally, Gillingham et al. (2019) develop a dynamic equilibrium model of the car market with multiple types of new and used cars where prices and quantities of used cars are determined endogenously to equate supply and demand for all car types. However, their model includes only exogenous transactions costs and there is not asymmetric information about the quality of cars.

The papers cited are concerned with how primary markets interact with secondary markets and/or how specific policies affecting the second-hand market, such as scrappage subsidies, affect the primary market, but they do not model how the lemons penalty is endogenously determined. In this paper we emphasize how variations in household resources together with the car market determine the prices of second-hand cars and thus how the lemons penalty is determined. The key contribution is to assess the importance of asymmetric information on the car market by developing a quantified dynamic general equilibrium model of the car market. In the model, we explicitly model demand and supply of cars to the secondary market while allowing for asymmetric information about the quality of used cars. The key parameters of the model are estimated using very detailed and high quality data about household income fluctuations and car replacement decisions.

An important characteristic of durable goods is that they have an asset value as well as delivering a flow of consumption services. Consequently durable goods have the potential to act as a savings instrument that can be used to provide self-insurance when faced with adverse income shocks, depending on the cost of liquidation. To take this into account, we explicitly model cars as an asset accumulation device. Our study thus links up to an extensive literature about consumption smoothing and shocks: Deaton (1991), Browning and Crossley (2009), Blundell et al. (2008), Low et al. (2010), and Kaplan and Violante (2014). If there is no private information (generating a transaction cost), then a durable good is like a non-durable good in that there is perfect reversibility. The transaction cost induced by asymmetry introduces an irreversibility that reduces the value of a durable as an asset that can be used to smooth consumption. A key feature of our approach is the recognition that transaction costs are in part endogenous and driven by current economic circumstances. Fluctuations in economic circumstances, such as through recessions, will lead to changes in the lemons penalty: the penalty is smaller when sales are motivated more by a need for liquidity or as a result of shocks to income, as opposed to being motivated by a car being of low quality.

Our estimated model allows us not only to identify the transaction costs but also to quantify the self-insurance value of cars and the extent by which this is reduced by asymmetric information. We use the model to explore the implications of asymmetric information for the extent of downgrading. When information is symmetric, sellers receive a price that reflects the actual quality of cars and therefore owners are willing to sell their car even if it has been bought recently and is of high quality. In this case, owners downgrade in order to liquidate the assets value which can then be used for non-car spending. When there is asymmetric information, car owners are less willing to sell cars that have been bought recently and are of high quality: the offered price does not reflect the true quality of the car but rather reflects the average quality of cars for sale.

The next section presents the model and details about the solution method. Section 3 presents and describes the data. Section 4 outlines the estimation approach. Section 5 presents the results on the lemons penalty; and further, shows how the lemons penalty varies with income uncertainty. Section 6 shows the case of symmetric information. In section 7 we investigate the impact of asymmetric information on the downgrading of cars. Section 8 concludes.

2 Model of the Car Market

The economy is stationary and consists of T overlapping generations. Households are life-cycle expected utility maximizers. They draw utility from cars and from other consumption and they face an exogenous but stochastic stream of income. Their choices are over consumption, car purchase or sale and saving in a liquid asset. All car transactions are mediated by dealers. We denote a period in the life-cycle by t and this should be understood as age. We first describe the nature of cars, then the household problem, and finally equilibrium in the car market.

A period in the model is 1 year. Consumers enter the model at age 21, retire after age 61 and leave the model at age 79. In Denmark, a driving license can be held from age 18 and is valid until death, subject to checks after age 70.

2.1 Cars and Dealers

A car, owned by individual i in period t, has quality q_{it} and ownership duration $z_{it} \in \{0, 1, \ldots, \bar{z}\}$.[2] Quality is one-dimensional and evolves over time, but cars differ in their type. Households can buy any one of three types of car: new, second-hand or bangers. We normalize the quality of second-hand cars sold by dealers to be 1 when they are sold. A banger is a car at the minimum level of quality. We use the term "Regular cars" to describe those bought either as new or as second-hand.

Each period, a regular car receives a persistent and idiosyncratic (for individual i that is) quality shock:

$$q_{it+1} - q^b = d\varepsilon_{it}\left(q_{it} - q^b\right). \tag{1}$$

Quality cannot be lower than the minimum quality q^b, which is the quality of a banger. The term d is the deterministic depreciation factor. The variable $\varepsilon \in [0, 1]$ is the additional stochastic depreciation factor, which is observable only by the owner and follows a beta distribution $\varepsilon \sim \mathcal{B}(\eta_1, \eta_2)$. We contrast our model in Section 6 with the case of symmetric information when all shocks are publicly observed to highlight the implications of asymmetric information. We allow for two further changes to quality: first, a car becomes a banger when it has been owned for more than $\bar{z}$ years, or if it suffers a "banger quality shock', which occurs with probability δ^r. Second, a banger has to be scrapped if it receives a "scrappage quality shock" with probability δ^b. Banger quality is assumed fully observable.

A car can only be bought or sold using a dealer as an intermediary.[3] The only observable characteristic of a used car is how long it has been owned, z, and consequently its price only depends on this characteristic. Thus, a used car of ownership duration z can be sold to a dealer at dealer price p^d_z. This dealer purchase price $\left\{p^d_1, p^d_2, \ldots, p^d_{\bar{z}}\right\}$ is endogenous, and depends on the distribution

[2] We use notation as follows: z or q signify duration of ownership and quality respectively. When we add the subscripts it such as z_{it} we mean the duration of ownership for a car owned by household i in period/age t.

[3] According to bilbasen.dk, the largest second-hand car website in Denmark, 90% of the second-hand car are sold by dealers.

of car quality among private sellers. The price of fixed second-hand cars sold by dealers is p^u. As fixed second-hand cars are of quality 1, p^u can also be thought of as the price for a unit of quality. Consistent with modelling the car market of a small open economy, we assume an internationally set price for new cars p^n, and that the supply of new cars is infinitely elastic. However, the second-hand car market is purely domestic with prices locally determined in relation to the internationally fixed price of new cars.

Dealers are profit-maximizing, but free entry means they make zero profits. A dealer buys a used car from a household and then learns the true quality of that particular car. The dealer fixes the car to have quality 1 (the max) and sells it on as a second-hand car, with ownership duration 0. The average quality of cars of duration z that are sold to dealers is $\bar{q}_z$, which is determined by who chooses to sell cars in equilibrium, and is a function of all prices. On average, to fix a car dealers have to improve the quality from $\bar{q}_z$ to 1 at a cost of $p^u(1-\bar{q}_z)$. The zero profit condition for the dealer trading at a given ownership duration, z, is

$$p^u - \left[p_z^d + p^u(1-\bar{q}_z)\right] = \bar{q}_z p^u - p_z^d = 0 \tag{2}$$

Thus the price paid by a dealer for a car of average quality and ownership duration z is equal to the expected value of the car priced at the resale price.

Our focus is on the lemons penalty that arises because of private information that accumulates during the ownership period, always assuming that at the moment of purchase from the dealer there is no information problem. We therefore simplify the problem and only keep track of the length of ownership and not of the age of the car since it was new. This is based on the assumption that the car-repair by the dealer resets the asymmetric information and the quality of the car sold is fixed to 1. A way to think of this is that the dealer offers a guarantee thus removing any concern of hidden defects.[4] By contrast, the quality of cars that dealers are buying from households is unknown to the dealer.

2.2 Households

A household, i, can own at most one car at a time.[5] Households have education level, e, which is either high or low, according to the education of the household head. The level of education determines both preferences and the income process. Within period t utility function, defined over consumption and cars, is assumed to take the CRRA form:

$$u(c_{it}, \theta_{it}^e, q_{it}) = \frac{\left(c_{it}\left(1+\theta_{it}^e q_{it}\right)^{\alpha_e}\right)^{1-\gamma} - 1}{1-\gamma} \tag{3}$$

[4]Ideally we would have both the age of the car and the duration of ownership as state variables and have prices for cars which depend on both age and ownership duration. This proved computationally infeasible and we focus on the impact of ownership duration, with information asymmetries being reset by dealers. This implies that the number of times a car is sold and its true age is irrelevant in the model.

[5]In our administrative data from Denmark, only 10% of households hold more than one car.

The parameter α_e determines the utility value of owning a car. θ^e_{it} indicates the relative preference between car types

$$\theta^e_{it} = \begin{cases} 0 & \text{if no car} \\ \theta^f_e & \text{if car new when bought} \\ 1 & \text{if car used when bought} \\ \theta^b_e & \text{if banger} \end{cases}$$

The parameter θ^f_e means people may value new cars differently from second-hand cars which have been fixed by dealers, despite the same underlying quality, q. And θ^b_e means people may also value bangers differently.

The household holds liquid assets a_{it} at the beginning of period t. The evolution of the liquid asset is governed by:

$$a_{it+1} = (1+r)\left[a_{it} + y_{it} - c_{it} - B_{it}p_B + S_{it}p_S\right] \tag{4}$$

Where $B_{it} = 1$ if the household buys a car, and $S_{it} = 1$ if the household sells a car. The purchase price, p_B is equal to p^n if it is a new car; p^u if a second-hand car; or p^b if a banger. The selling price depends on ownership duration: $p_S = p^d_z$ if the car has been owned for z periods, and $p_S = p^b$ if it is a banger, independent of ownership duration.

We assume that the maximum amount of borrowing is the sale price of a car that has been owned for an additional year. This allows the use of credit to purchase a car, and the amount of credit is dependent on equilibrium prices. Hence we assume that

$$a_{it+1} \geq -p^d_{z_{it+1}} \tag{5}$$

Cars are a store of credit up to the expected (equilibrium) resale value p^d_z for cars of ownership duration z. Households can access wealth in cars only by selling. If a car randomly turns into a banger (rather than by the gradual process of aging), the owner receives an insurance payment which equals to the collateral value of the car. This is to insure the owner from bankruptcy.

In the standard life-cycle model there is one asset that represents the entire accumulated net wealth of the household. Our model includes a second asset, cars, which is distinct from the liquid asset both because cars generate a flow of utility and because cars are less liquid due to the endogenous transaction costs. This difference in the properties of the assets is introduced in order to capture the effect of illiquid assets on the ability of households to smooth out shocks.

We assume a state pension with a replacement rate of 100 percent. This is higher than the actual replacement rate in Denmark, but it allows us to match observed liquid saving. Moreover, it simplifies the modelling of the life cycle savings motive and allows us to focus on accumulation of assets for precautionary purposes and car buying, which are the critical margins in our application.

Income Households receive an uncertain flow of labour income y_{it} depending on their level of education e:

$$
\begin{aligned}
\ln y_{it} &= b_{e0} + b_{e1}t + b_{e2}t^2 + b_{e3}Z_{it} + r_{it} \\
r_{it} &= v_{it} + \omega_{it} + \nu_{it} \\
v_{it} &= v_{i,t-1} + \epsilon_{it} \\
\omega_{it} &= (1 - U_{it})\, \rho_e \omega_{i,t-1} + U_{it}\kappa_{it}
\end{aligned} \tag{6}
$$

where y_{it} is household disposable income in period t. Z_{it} is a vector of observed household demographic characteristics. r_{it} represents residual log income. There are three error components: v_{it}, ν_{it} and ω_{it}. The first reflects permanent stochastic component to household disposable income; it evolves as a random walk with innovations ϵ_{it} and we view this as the main source of uncertainty. The second component, ν_{it}, represents possibly serially correlated measurement error or transitory shocks. We treat this as measurement error only and this does not affect household behaviour. The third component, ω_{it}, captures the impact of job separation. Specifically, upon job separation household income changes by κ_{it} beyond the permanent shock.[6] Unemployment in Denmark rarely lasts longer than a year; however, it can have lasting effects on household income (see for example Altonji, Smith, and Vidangos, 2013). To capture this we allow the original realization of the shock to persist, with an effect that depreciates at an annual rate ρ_e. U_{it} is a dummy variable equal to one if household i experienced a period of unemployment in year t.

Value Functions and Household Choices

In each period households in the model need to decide how much to consume and how much to save, which is as in the standard life-cycle model, with the difference here that they also need to decide on car ownership. Specifically, a household that does not own a car has to decide whether and what type to buy. Car owners need to decide whether to keep or sell their car, possibly replacing it with a new car, a fixed used car from a dealer or downgrading to a banger. These decisions are made by comparing value functions for each action. Thus, the problem is a mixture of optimization with respect to continuous decisions and discrete choices.

We first define the state variable Ω^s_{it} which defines the position of the household at the start of period t. In all cases the state space includes a_{it} and income y_{it}. For $s = 0$ the household enters the period with no car and for $s = b$ the starting position is a banger. When $s = n$ the individual already owns a car that was new at the time of purchase, while for $s = u$ they own a car originally bought as used. In the latter two cases the state space includes the duration of ownership z_{it} and the current quality q_{it} which results from past depreciation shocks. Quality is normalized to 1 for those buying a car, i.e. when $z_{it} = 0$. We now define

[6] The separation shock κ_{it} can be either positive or negative. A positive value represents job transition and the new job is better paid. A negative value represents an unemployment scarring effect.

$$
V_{it+1}(\Omega^s_{it+1}) = \begin{cases} \max\left[V^0_{it+1}, V^b_{it+1}, V^{n_1}_{it+1}, V^{u_1}_{it+1}\right] & \text{if s= 0, b} \\ \\ \max\left[V^0_{it+1}, V^b_{it+1}, V^{n_1}_{it+1}, V^{n_q}_{it+1}, V^{u_1}_{it+1}\right] & \text{if s= n} \\ \\ \max\left[V^0_{it+1}, V^b_{it+1}, V^{n_1}_{it+1}, V^{u_1}_{it+1}, V^{u_q}_{it+1}\right] & \text{if s= u} \end{cases} \tag{7}
$$

where for clarity we have dropped the dependency of each conditional value function on the state variable Ω^s_{it+1}. The superscripts n_1 and u_1 signifies a purchase of a car (new or used respectively), which by definition always has quality 1; n_q and u_q signifies keeping the existing car with its associated quality q.

Consider first a household who decides not to own a car in period t. This will affect utility in period t and the household will start the next period with no car affecting the relevant state space. The corresponding conditional value function is given by:

$$
V^0_{it}\left(\Omega^s_{it}\right) = \max_{c_{it}} \left\{ \frac{c_{it}^{1-\gamma} - 1}{1-\gamma} + \beta \mathbb{E}_t V_{it+1}(\Omega^0_{it+1}) \right\} \quad \text{for } s = 0, b, n, u
$$

For the household who decides to own a banger in period t, their ownership type at the start of period $t+1$ is given by $\theta^e_{it+1} = \theta^b_e$, but the banger may become scrapped with probability δ^b. z_{it} and q_{it} are not in the state space for banger-owners because the quality is uniform and ownership duration as such does not matter. Thus the corresponding value function becomes

$$
V^b_{it}\left(\Omega^s_{it}\right) = \max_{c_{it}} \left\{ \frac{\left(c_{it}\left(1+\theta^b_e q^b\right)^{\alpha_e}\right)^{1-\gamma} - 1}{1-\gamma} + \beta \mathbb{E}_t \left[\left(1-\delta^b\right) V_{it+1}(\Omega^b_{it+1}) + \delta^b V_{it+1}(\Omega^0_{it+1})\right] \right\}
$$
$$
\text{for } s = 0, b, n, u
$$

A household with a car (used or new) has a conditional value function of:

$$
V^k_{it}\left(\Omega^s_{it}\right) = \max_{c_{it}} \left\{ \frac{\left(c_{it}\left(1+\theta^e_{it} q_{it}\right)^{\alpha_e}\right)^{1-\gamma} - 1}{1-\gamma} + \beta \mathbb{E}_t \left[\left(1-\delta^r\right) V_{it+1}(\Omega^k_{it+1}) + \delta^r V_{it+1}(\Omega^b_{it+1})\right] \right\}
$$
$$
\text{for } k = n,\ u \text{ and } s = 0, b, n, u
$$

In the above δ^r is the probability that the car owned in t becomes a banger at the start of the next period $t+1$. If ownership duration exceeds $\bar{z}$, the car becomes a banger in the following period for sure ($\delta^r = 1$). The utility enjoyed by the car depends on whether it was originally bought as new, in which case $\theta^e_{it} = \theta^f_e$ or was bought used from a dealer $\theta^e_{it} = 1$.

An individual entering the period with any type of car can choose to buy a new or used car, but that purchased car will always have quality fixed to 1. However, if they entered the period with a car which they decide to keep, then their utility will depend on the given quality q_{it}, which is driven by depreciation rather than directly by choice. Thus the available set of choices depends on the state space at the start of the period. The optimal choice is determined by comparing the values in period t.

The relevant expression defining the optimal value function is as in equation (7) but with the timing changed from $t+1$ to t.

2.3 Determining Dealer Purchase Prices: Equilibrium

The market for cars is characterized by the price of new cars (p^n), $\bar{z}$ prices for each ownership duration of a second-hand car ($p_1^d, \ldots, p_{\bar{z}}^d$), the price of bangers (p^b) and the price for used fixed cars purchased by households from the dealer (p^u). Households take these prices as given in making their decisions. We model a stationary economy with equal-sized generations of life-cycle households, where prices are fixed over time and can only change as a result of factors that change the demand for cars and the technology for consumption smoothing, such as welfare policies insuring income or perhaps scrappage subsidies. We now describe how these prices are determined in equilibrium.

The key issue is that of asymmetric information. Car owners receive depreciation shocks which are not observable by the dealers who are potential buyers. We assume that only the ownership duration of the car is observable. Moreover we also assume that the dealer cannot observe characteristics of the household that may be pertinent to the motive for selling the car. Indeed we will assume that only one price is quoted for each car with a particular ownership duration. Given this, the market suffers from adverse selection because at any given price households with cars of lower than expected quality will have an incentive to sell, while those with better than expected quality will not wish to participate in the market. However, the market does not close down because a number of households, who cannot be separately identified, *need* to sell their cars for consumption smoothing purposes due to income shocks.

To determine equilibrium prices we first assume that the price of new cars is exogenous and fixed: Denmark produces no cars and is too small to affect international prices. Implicit in the price of new cars are the (heavy) taxes that Denmark imposes. These then affect the prices of second-hand cars in equilibrium. We use the data directly to determine the price of a banger. Given our definition, a banger can be characterized as having 13% of the quality of a fully fixed car.

In determining the price of cars that dealers are willing to pay, the key component is the average quality of cars of given ownership duration coming to the market

$$\bar{q}_z = \mathbb{E}\left(q_i | z, p^n, p^u, p^b, p_1^d, \ldots, p_{\bar{z}}^d, \text{sale}\right)$$

Because individual quality is private information, dealers will have to offer a pooled price across all qualities given the observable characteristics, which here is just the duration of ownership. This implies some households will be *overpaid*, in the sense that the hidden quality of the car is worse than average and others would be underpaid, making a loss.

In the standard Akerlof (1970) setting, this pooled pricing would lead to the market unravelling since those loosing out would refuse to sell, making the quality pool worse, and thus leading to a decline in the purchase price and so on. However, in our model the existence of the market is supported by two factors. First, there is a utility gain from upgrading. An important reason to sell an old car is to enjoy the higher quality offered by a new one, and quality declines with duration of ownership. Second, some households have to sell because of adverse income shocks. Their need to smooth such shocks leads them to accept losses. It is precisely this mechanism that makes cars an imperfect smoothing tool and defines the transaction costs as endogenous.

To pin down the prices that dealers are willing to pay $\left(p_1^d, \ldots, p_{\bar{z}}^d\right)$, we impose equality between the number of cars purchased (and fixed) and the number of cars sold by the dealer. Underlying this condition is a *no-storage* condition: in our model the dealer does not hoard cars and indeed has no incentive to do so since the economy is stationary.

Finally, note that the information set of the dealer is crucial. Car dealers cannot discriminate between car sellers in terms of the quality of the cars that they bring to the market. In reality car dealers may to some extent be able to discriminate between car sellers and the quality of cars based on observable characteristics, such education or occupation, but we abstract from this.

Defining equilibrium formally (a) All households maximize utility and dealers maximize profit; (b) Dealers do not hold inventories: the number of second-hand cars sold by dealers equals the number of cars they bought from households; (c) Dealers make zero profits; (d) The stock of cars is constant.

3 Data

The empirical analysis is based on Danish administrative data. The core data set is the Central Register of Motor Vehicles (CRMV) from which we have data covering the period 1992-2009. This register contains information about the entire population of cars registered with Danish number plates and holds information about the unique identity of all cars in the form of a serial number, the exact registration and de-registration dates as well as information about the car brand, model and variant. These data are merged with prices of almost any type of new and used car on the market in the same period as is covered by the CRMV. It is possible to follow the price of any given brand-model-variant-vintage combination from when the car is new and until it is eight years old. The price data are collected by the Association of Danish Car Dealers (DAF) based on market analyses and reports from its members and they reflect the price of cars in a "normal condition" depending on the age of the car. Going forward, we will refer to these prices as 'dealer sale prices' and they define the price at which used cars are bought by individuals from the dealer.

The CRMV also contains information about the identity of the owner of any given car at any given point in time, and this information is used for linking the car information to other administrative records of the owner. In particular, we link the CRMV with income tax records and a number of other administrative registers giving longitudinal information about income, wealth, labour market status, education, and family composition of the car owners. In this way we are able to construct a longitudinal data set, where we can follow the population of Danish households in the period 1992-2009 and give a complete description of their income, wealth and car ownership.

The wealth data can be divided into assets and liabilities, which can further be divided into a number of subcategories. Unfortunately, the definitions of these categories are not stable across the observation period. In particular the definitions change almost yearly in the period 1992-1996, but from 1997 the definitions are stable and it is possible to clearly identify financial wealth. Furthermore, the data are longitudinal and this means that we are able to track decisions about the sales and purchases of cars and how these decisions interact with savings decisions. In this way we are able to examine how households use cars as an asset for smoothing adverse income shocks. To the best of our knowledge no other data set collects longitudinal information about cars, income and wealth, and we are going to exploit these unique features of the data to inform the model.

3.1 Statistics on Cars and Households

We consider a 10% extract of the population register and we include an observation only if the oldest person in the household is at least 30 years old and at most 60 years old. To these individuals we add the partner, if there is one, and we summarize all the remaining information at the household level.

Table 1 presents basic summary statistics for two age groups, 30-40 and 41-60.[7] As expected, younger individuals have less accumulated wealth and are thus more likely to find it difficult to smooth out shocks. We group the summary statistics into three parts providing information about car ownership, the financial situation of the household and demographics.

Car ownership is taxed in two ways in Denmark. There is an annual ownership tax and there is a one-time tax associated with purchasing a new car. The latter, called the registration fee, is the most important amounting to up to 180% of the whole sale price thus making Denmark one of the most expensive countries to purchase a new car in. As a consequence 26-32% of the population depending on age does not own a car at any given point in time, (Table 1, column 1 and 3). Another consequence of new cars being expensive is that the average age of the car fleet is eight to nine years.

The average level of disposable income is 309 thousand DKK (1 USD $\approx$6.5 DKK) for the young group and 323 thousand DKK for the middle-aged. A substantial fraction of the population in both age groups hold quite modest amounts of financial assets. This is witnessed by the fact that the median level of financial assets to income is 9 percent for the young group and 15 percent for the 41-60 year old. Table 2 further breaks it down by two education groups, some college and no college, highlighting the skewness in the asset distribution and important differences across education groups.

[7] See Appendix B for the summary statistics for the sample of households who experience job loss.

In fact, around 50 percent of the households in both age groups hold financial assets worth less than one month of disposable income. These low-financial asset households also have little housing equity and are unlikely to be able to use that as a buffer. In contrast 60-67 percent of the households in this group have a car. Consequently, the value of the car stock makes up the over-whelming part of their assets. For the median household in this segment the value of the car makes up 86 percent of their total financial and car assets.

Turning to the group of people holding financial assets amounting to more than one month worth of disposable income the picture looks different. A bigger fraction of the households are car owners and the ownership rate increases with age. The young households have little housing equity, but hold significant amounts of financial assets, so that the car only makes up about 34 percent of the sum of car and financial assets. The middle aged group in this segment has far more housing equity and the car stock only makes up 34 percent of the sum of car and financial assets. In other words, this group appears well-prepared for adverse events.

4 Estimation

The unknown parameters characterising the model are the preference parameters, the income process parameters and the dealer purchase car prices.

There are four types of car prices in the model. The price of a new car, the price of a fixed second-hand car sold by a dealer, the price of a banger, and the prices that dealers pay households for cars of different ownership duration. We observe the list price of new cars and we use the dealer sale prices for used cars to measure the price of fixed second-hand cars. The measurement of these dealer sale prices and the price of bangers is discussed in detail below. The key limitation of the data is that we do not observe dealer purchase car prices, that is transaction prices when dealers buy cars from households. Consequently we cannot rely on observed prices during estimation, and instead, we need to solve for the equilibrium price for cars of different ownership duration simultaneously with estimation of the preference and other parameters.

This feature make estimation computationally demanding. We therefore separate the estimation into two steps: first, we estimate some parameters outside of the model when the process is exogenous to decisions made in the model, as with the income process, and take others directly from the literature. Second, we estimate the remaining parameters by using the Method of Simulated Moments. Within this MSM estimation, we generate the vector of prices that households receive when they sell the cars, which is consistent with equilibrium.

Taking as given the set of pre-estimated parameter values, the algorithm for this MSM estimation proceeds as follows:

Table 1: Summary Statistics

	Full sample			
Age group	30-40		41-60	
	Average	Median	Average	Median
Variable	(1)	(2)	(3)	(4)
Car				
Car owner	0.68	1	0.74	1
Age of car stock, car owner	8.89	9	8.35	8
Owner of regular car, car owner	0.92	1	0.93	1
Owner of banger, car owner	0.17	0	0.16	0
Income/wealth				
Disposable income (1000 DKK)	309	315	323	318
Financial assets / disp. income	0.31	0.09	0.56	0.15
1[financial assets $<$ 1 month disp. income]	0.49	0	0.35	0
Car owner	0.65	1	0.67	1
Car value (1000 DKK), car owner	90	67	96	70
Car value / disp. income, car owner	0.27	0.21	0.28	0.22
Car value / (fin. assets + car value), car owner	0.70	0.86	0.71	0.86
Housing equity to house value (ETV), home owner	0.11	0.00	0.21	0.11
Housing equity to disp. income (ETI), home owner	0.51	0.00	1.02	0.31
1[financial assets $>$ 1 month disp. income]	0.51	1	0.65	1
Car owner	0.72	1	0.77	1
Car value (1000 DKK), car owner	113	87	118	94
Car value / disp. income, car owner	0.34	0.26	0.35	0.28
Car value / (fin. assets + car value), car owner	0.44	0.34	0.39	0.34
Housing equity to house value (ETV), home owner	0.22	0.15	0.44	0.44
Housing equity to disp. income (ETI), home owner	1.11	0.46	2.29	1.55
Demographics				
Age	35	35	50	50
Married/cohabiting	0.71	1	0.75	1
Has children	0.61	1	0.47	0
Homeowner	0.50	1	0.61	1
Some college	0.26	0	0.21	0
Number of observations	1,452,171		2,559,063	
Number of unique households	214,662		267,688	

Notes: A regular car is a car aged less than 15 years. A banger is a car aged more than 15 years. All economic variables are CPI deflated to the level in 2000 and have been censored at 1st and 99th percentile calendar year by calendar year. Car value refers to the value of the stock of cars. Financial assets includes cash in banks, bonds and stocks. ETV and ETI are based on tax assessed house values. Because of changes in the definition of the debt variables these variables can only be calculated for the years 1997-2009. 1 USD $\approx$6.5 DKK

Table 2: Financial assets to disposable income ratio

Age group	30-40				41-60			
Variable	Average	Median	p75	p90	Average	Median	p75	p90
No College	0.28	0.08	0.21	0.59	0.52	0.14	0.47	1.28
Some College	0.41	0.13	0.37	0.91	0.67	0.21	0.66	1.69

1. Make an initial guess of endogenous parameter values.

2. Find a fixed point for the dealer purchase prices p^d_z using the zero-profit condition (equation 2), separately for cars of each ownership duration. This is a fixed point problem: as prices change the average quality $\bar{q}_z$ changes at all ages z.

3. At these equilibrium prices (p^d_z), evaluate the criterion function using simulated and actual moments. This means that, since the dealer price of cars is set at the equilibrium value, we evaluate moments at the prices where the zero inventory condition holds and where the stock of cars is constant.

4. Parameters are updated and the process is repeated from step 2 until convergence.

4.1 Pre-estimated Parameters

The parameter values that are fixed or externally estimated are listed in Table 3. We assume a risk aversion coefficient of 1.43 (see, among others, Blundell et al. 1994).[8] The interest rate measure is the yield of the two-year Danish government bonds adjusted by consumer price index averaged over 1996-2009, which gives a rate of 1.6%. The remaining parameters in Table 3 are now discussed in turn.

Constructing Dealer Car Prices We observe data on the list price of new cars. We also observe dealer sale prices, which we relate directly to the price of fixed second-hand cars. Our concept of a fixed second-hand car is the second-hand car at the maximum quality. Our dealers fix cars they buy from households to achieve this quality and then sell them on. From the data we quantify this price in the following way: we use the median dealer sale price of second-hand cars that are one year old. This determines the price of a fixed second-hand car, which we can compare to the observed price of a new car.[9] We normalize all the prices and income by the price of a fixed second-hand car. This implies that $p^u = 1$ and that the price of a new car in the model is $p^n = 1.14$.

We assume a car can be owned for up to 9 years, i.e. $\bar{z} = 9$. We use the year-to-year depreciation rate in dealer sale prices, which is 11 percent, as the deterministic depreciation rate in the model, i.e. $d = 1 - 0.11 = 0.89$. We think of bangers as old cars which are of minimal quality and so not subject to asymmetric information. To quantify the value of a typical banger we observe that the weighted average of median dealer sale price of cars more than 15 years old is 20 thousand DKK, and we set the banger price in the model to $p^b = \frac{20}{159} = 0.13$. This defines the base quality $q^b = \frac{p^b}{p^u} = 0.13$, implying

[8] We consider alternative values of risk aversion and re-estimate the model with these values. For example, in Appendix D, we report results of the estimation when when the risk aversion parameter is set to be 4. The resulting estimates of the lemons penalty are similar.

[9] The median depreciation rate across one-year-old cars is 12.1 percent. The median book price of a new car in the data is 181 thousand DKK. We therefore set the price of a fixed second-hand car to $181 \times (1 - 0.121) \approx 159$ thousand DKK.

that a banger is worth 13 percent of a fixed second-hand car in terms of quality. We set the annual scrappage rate for for bangers at $\delta^b = 0.073$, which is determined by the scrappage rate for cars more than 15 years old in the data.

Table 3: Parameters estimated outside the model

Parameter	Description	Value	Source
p^n	new car price	$1.14p^u$	DAF Car Data (181 DKK)
p^u	fixed car price	normalized to 1	DAF Car Data (159 DKK)
p^b	banger price	$0.13p^u$	DAF Car Data (20 DKK)
d	deterministic depreciation	0.89	DAF Car Data
δ^b	scrap rate for bangers	0.073	DAF Car Data
r	interest rate	0.016	Bond rate
γ	relative risk aversion	1.43	Blundell et al. (1994)
	Income Process by education group		
	No College		
b_0, b_1, b_2	deterministic age profile	-0.37, 0.031, -0.00071	Tax records
σ^2_{v0}	variance initial perm.	0.179	Tax records
σ^2_{ϵ}	variance perm. shock	0.018	Tax records
δ_u	probability separation	0.037	Income process
κ_1, κ_2	support separation shock	0.107, -0.245	Income process
ρ	persistence separation shock	0.635	Income process
	Some College		
b_0, b_1, b_2	deterministic age profile	-0.53, 0.070, -0.0014	Tax records
σ^2_{v0}	variance initial perm.	0.133	Tax records
σ^2_{ϵ}	variance perm. shock	0.021	Tax records
δ_u	probability separation	0.025	Income process
κ_1, κ_2	support separation shock	0.181, -0.286	Income process
ρ	persistence separation shock	0.734	Income process

Estimation of the Income Process We estimate the parameters of the household income process (6) separately for each education group (some college and no college) using the Danish income tax records in 1992-2009.[10] We define income to be total household disposable income, which includes the effects of taxes and transfers. The sample used for estimation includes those aged 23-60 only, thus avoiding retirement years. Retirement income is assumed riskless.

To estimate the deterministic age profile, we regress log household disposable income on Age_t, Age_t^2

[10] We classify people according to their level of completed education in 2009, the final year in our sample. Education is defined based on the household head.

as well as calendar year dummies and dummy variables for household structure, i.e. dummy for having a partner and five dummies for up to five children.

There are three error components in the residual log income r_{it}: first, v_{it} which is the permanent shock; second, ω_{it} which captures the impact of (exogenous) job separation on wages; and finally measurement error (or transitory shocks) ν_{it}.

Estimation is based on moments for residual income growth, which depending on the case, take the form

$$\triangle r_{it} \equiv g_{it} = \begin{cases} \epsilon_{it} + \triangle\nu_{it} & \text{for those who have not had job separation} \\ \epsilon_{it} + \triangle\nu_{it} + \kappa_{it} & \text{for those employed in } t-1 \text{ and had job separation in } t \\ \epsilon_{it} + \triangle\nu_{it} + \rho_e\kappa_{it} - \kappa_{it} & \text{for those had job separation in } t-1 \text{ and employed in } t \end{cases}$$

recalling that $v_{it} = v_{i,t-1} + \epsilon_{it}$ and $\omega_{it} = (1 - U_{it})\, \rho_e \omega_{i,t-1} + U_{it}\kappa_{it}$.

To estimate the variance of the permanent shock σ_ϵ^2 we use the autocovariance structure of the residual income growth for those who have not had a job separation. It is valid to do this because in our model a job separation represents an exogenous shock to income and hence there is no selection bias. The moments used are as in Meghir and Pistaferri (2004). Given an estimate of σ_ϵ^2 we can then use the autocovariances for individuals with job separations to estimate the remaining parameters of the income process reported in Table 3. Further details of the estimation are in Appendix C.

The estimates of σ_ϵ^2 is 0.018 for the no-college group, and is 0.021 for the some-college group, which by way of comparison are substantially lower than the equivalent numbers in the US. To capture initial dispersion we assume the first draw of the permanent component, v_{i0}, is drawn from a Normal distribution with mean zero and variance $\sigma_{v_0}^2$. The standard deviations are estimated to be 0.2 for the no-college group and 0.15 for the some-college group based on the dispersion of household earnings at age 21.

Assets We do not include housing and pension wealth explicitly in the model in order to avoid excessive computational complexity but allow for one liquid asset (beyond cars). We assume that the replacement rate for retirement income is 100 percent. This effectively implies that asset accumulation in our model is for precautionary purposes only, against adverse wage or unemployment shocks, while at the same time lifetime wealth remains sufficiently high.

Initial conditions We need to specify the initial conditions for financial assets, car ownership and ownership duration. We compute the empirical distribution of the ratio of financial assets to earnings by education group among households aged 20-26 in the Danish administrative data. We set the initial levels of financial assets to earnings to match this distribution, using 10 different values taken from the deciles of the CDF in the data. Initial financial wealth is computed using this ratio and initial earnings estimated above. The initial car ownership position is either that the household does not own a car, or that it owns a regular car with ownership duration $z \in \{1, ..., 9\}$ or that it owns a banger. We compute moments from age 30 by which time the impact of this initial allocation will be diminished.

4.2 Estimated parameter values

We use the Simulated Method of Moments to estimate the remaining parameters using data for households where the household head is aged between 30-60 in the period 1992 to 2009. The standard errors of the structural parameters are computed as in Gourieroux et al. (1993), where the covariance matrix of the data moments is estimated using the block bootstrap.

Table 4: Fitted Moments

Moments		Data	Model
Ownership rate of regular cars			
Some College	Age 30 - 40	64.3%	64.1%
	Age 41 - 60	73.5%	75.3%
No College	Age 30 - 40	62.8%	61.2%
	Age 41 - 60	67.2%	62.2%
Ownership rate of bangers			
Some College	Age 30 - 60	9.9%	8.4%
No College	Age 30 - 60	12.3%	12.5%
% people buy new cars			
Some College	Age 30 - 40	5.0%	3.4%
	Age 41 - 60	6.4%	10.9%
No College	Age 30 - 40	3.9%	2.5%
	Age 41 - 60	5.4%	6.4%
Median financial asset to income at 55		0.209	0.212
Ownership duration of cars		4.63	4.624
% of cars being sold after 1 year		5.6%	1.3%
% of cars being sold after 2 years		24.7%	20.1%
% of cars being sold after 3 years		41.4%	43.2%
% of cars being sold after 4 years		55.6%	65.6%
% of cars being sold after 5 years		66.9%	73.8%
% of cars being sold after 6 years		75.0%	76.7%

Table 4 shows the moments we use and how well the model can fit them. These moments pin down 10 parameters, whose estimates are presented in Table 5 and include:

- Parameters common to both education groups: the discount factor β, the arrival rate of a banger shock δ^r, and the parameters for the distribution of the private depreciation factor $\varepsilon \sim \mathcal{B}(\eta_1, \eta_2)$.

- Parameters that are allowed to differ between education groups: the utility benefit of owning car α_e, the relative preference for cars bought as new θ_e^f, and the relative preference for bangers θ_e^b.

Table 5: Estimated Parameter Values

Description	Param.	Value	s.e.
Common parameters			
Discount factor	β	0.970	0.0001
Private depreciation factor $\varepsilon \sim \mathcal{B}(\eta_1, \eta_2)$	η_1	16.864	0.0983
	η_2	1.925	0.0110
Arrival rate of banger shock	δ^r	0.090	0.0024
Some College			
Preference for new car	θ^f	1.162	0.0009
Preference for banger	θ^b	0.619	0.0052
Utility benefit of owning car	α	0.283	0.0018
No College			
Preference for new car	θ^f	1.162	0.0004
Preference for banger	θ^b	0.600	0.0010
Utility benefit of owning car	α	0.300	0.0005

Based on our estimates the distribution of the private depreciation factor is $\varepsilon \sim \mathcal{B}(16.864, 1.925)$, which implies a mean of 0.9, and a variance of 0.0047. The deterministic depreciation factor $d = 0.89$, and the overall expected depreciation factor $d\mathbb{E}(\varepsilon) = 0.8$ implying the excess quality over and above the basic q^b declines on average at a rate of 20% a year as shown in equation (1).

Given the estimated utility parameters, households have a higher preference for new cars, and a lower preference for bangers. The positive value of α_e implies that cars and consumption are substitutes in utility, in the sense that the cross-partial derivative of utility with respect to c and q is negative. The discount factor $\beta = 0.97$ lies within the range of values commonly assumed in dynamic discrete choice models (e.g. Rust, 1987). Finally, about 9% of cars randomly become bangers each year (over and above those that reach that state deterministically because of age).

5 The Lemons Penalty

Our estimates and the structure of the model implies a lemons penalty, i.e, an endogenous transactions cost. This penalty, together with the deterministic depreciation factor defines the path for how the price changes as the duration of ownership increases. We show implications for the timing and volume of transactions.

Dealers will purchase cars at a price equal to the expected quality of cars that are being sold. Asymmetric information means that the expected quality of cars with a given duration of ownership that are offered to dealers will be lower than the expected quality of cars with that ownership duration that are owned in the population. Dealers will therefore pay less than the expected value of cars that are owned in the population.

To define the lemons penalty we need to consider the expected loss incurred by a randomly chosen individual who sells their car at the going price. Thus the lemons penalty is defined as the difference between the average car value in the population (irrespective of the decision to sell) and the prevailing dealers equilibrium price. As we show below, a high lemons penalty for newly-bought cars implies that households will hold onto good cars, and the average quality of older cars will be better than otherwise.

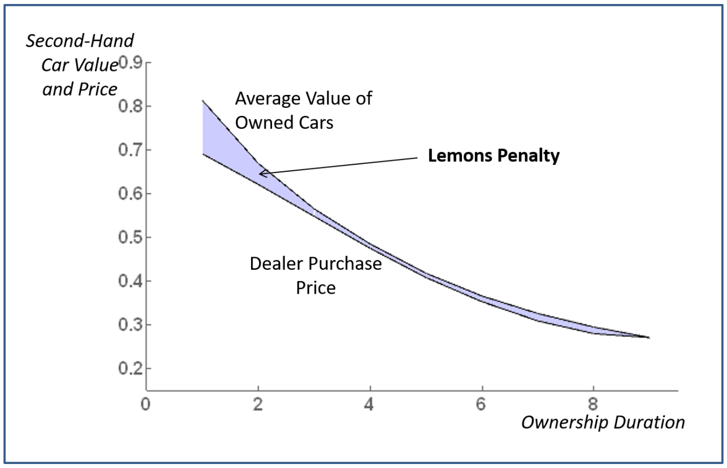
The resulting transaction costs/lemons penalty are shown in Table 6. The first row of Table 6 shows the equilibrium dealer price, which equals the expected value of cars being sold, according to equation (2) and which ensures zero profits. The second row of Table 6 shows the expected value of cars that are owned in the population. The difference between these is the lemons penalty, shown in the third row as a percentage of the equilibrium dealer price. The columns show how the equilibrium price varies with the duration of ownership. This generates a time path for the lemons penalty, which we show explicitly in Figure 1, and which is unobservable in the data. The size of the lemons penalty initially declines markedly with ownership duration but then stabilizes and even increases again. A car that has been owned for just 1-year has the biggest lemons penalty when it is sold: -0.128, which is 18% of the equilibrium dealer price in the first year of ownership. In the second year it is still substantial: -0.053, which is 8% of the equilibrium price in the second year of ownership.

Table 6: Prices and the Lemons Penalty

Ownership years	1	2	3	4	5	6	7	8	9
Dealer price	0.697	0.634	0.558	0.491	0.427	0.371	0.326	0.287	0.286
Expected car value (in population)	0.825	0.687	0.585	0.504	0.439	0.387	0.346	0.313	0.286
Lemons penalty (% of dealer price)	-18%	-8%	-5%	-3%	-3%	-4%	-6%	-8%	0
% of cars being sold	1.3%	20.1%	43.2%	65.6%	73.8%	76.7%	78.3%	78.7%	100%

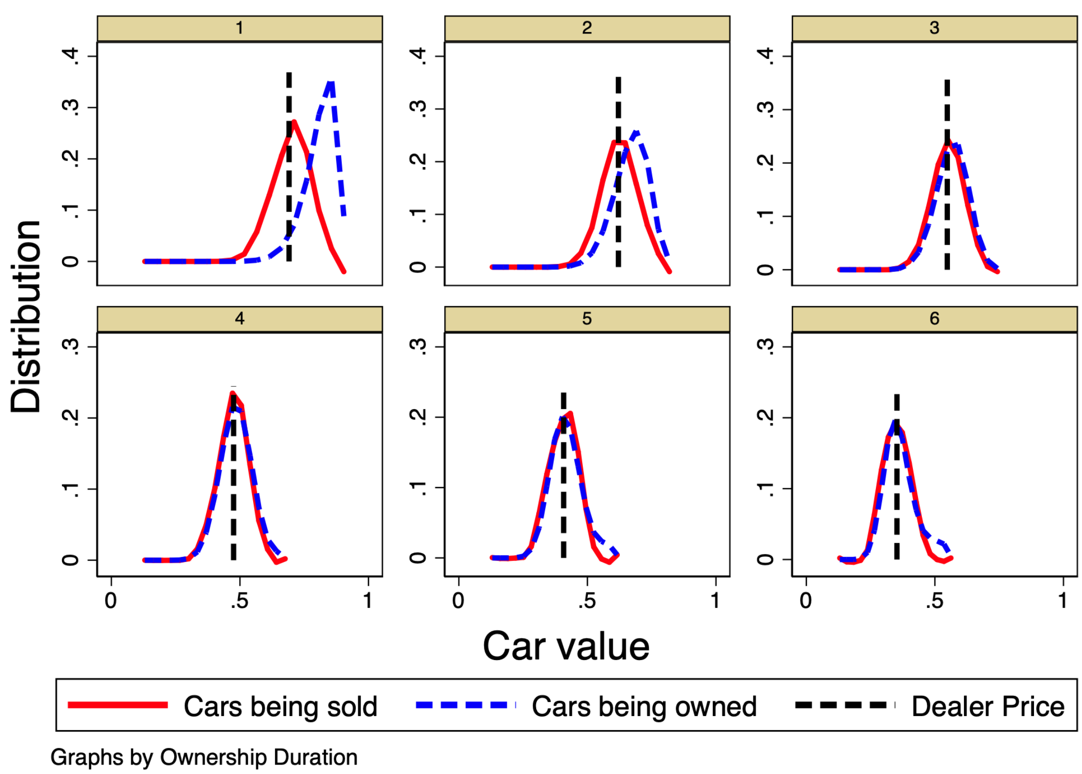
The lemons penalty is of course only a penalty for those who are selling a car with quality better than the average. For some, the asymmetric information means they receive a price for their car greater than the true quality of the car and the “penalty” is not enough of a discount. Asymmetric information

Figure 1: Price Declines by Ownership Duration



Notes: The figure plots the average value of all owned cars and the dealer purchase prices against ownership duration, cf. Table 6 , rows 1-3.

Figure 2: Distribution of Value of Cars Sold and of Cars in the Population by Ownership Duration



leads to distributional consequences as well as efficiency consequences: in terms of efficiency, the penalty captures the transaction cost associated with the lower price when selling a car of average quality; in terms of distribution, there are winners and losers from the lack of information. Figure 2 shows the simulated distribution of quality of cars sold (the solid line) compared to the dealer price (vertical line) and compared to the distribution of cars owned (the dashed line), for different ownership durations. This highlights the low average quality of cars sold, especially for cars with short ownership duration, compared to the distribution in the population. The figure also highlights that some cars are sold when their true quality is above the market price: owners whose cars are on the right of the dealer price make a loss when selling their cars. Nonetheless, some high quality cars are sold, typically when individuals suffer income shocks, or when their owners wish to upgrade relative to the car quality they own.

In Appendix D, we consider various robustness checks on our estimates of the lemons penalty. We re-estimate the model using a higher value for risk aversion, $\gamma = 4$. Changing the value of γ changes some of the estimated parameters, in particular the discount rate, but leads to only a slight reduction in the estimated lemons penalty. We also re-estimate the model allowing for an exogenous transaction cost to assess whether the endogenous nature of the transactions cost is important to matching the data. When we allow for both an exogenous and endogenous transaction cost, the estimated exogenous component is small (0.3% of the dealer purchase price), and the resulting lemons penalty is similar to the baseline estimation without exogenous transaction cost.

5.1 The Lemons Penalty and Income Risk

In our estimated model, the market for second-hand cars does not collapse. This is despite some households selling their cars at a value below that implied by the cars' true quality. One reason the market does not collapse is that households have multiple reasons for selling a car, rather than just it being of low quality. In this subsection, we highlight a key factor in stopping the market collapsing: income shocks. As the variance of income shocks increases, more households will choose to sell their cars, either to downgrade to maintain consumption after a severe negative shock, or to upgrade.

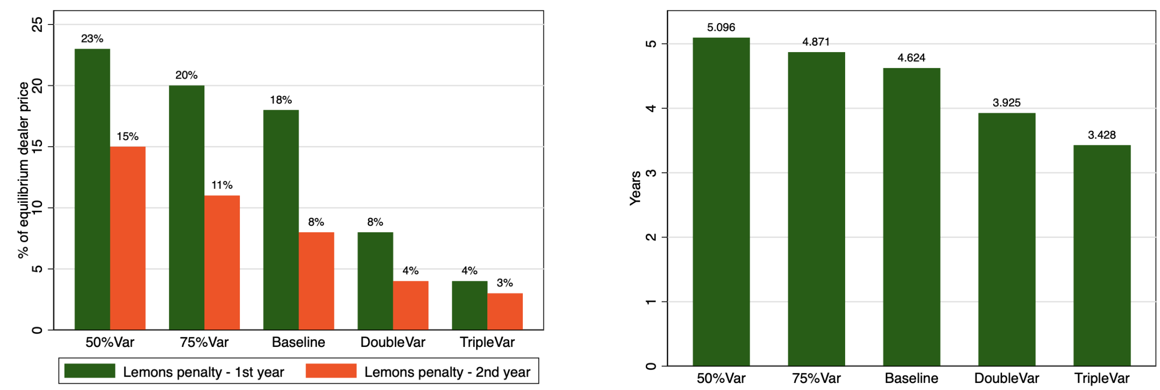
We show in Figure 3 the counter-factual effect of varying the variance of income shocks on the lemons penalty and on ownership duration, fixing all other parameters at their baseline values. We consider changing the variance of permanent shocks to half its estimated value and increasing it to up to three times its estimated value. Panel (a) of Figure 3 reports the lemons penalty in the first and second year of ownership, for the different values of the variance. As the variance of income shocks increases, the size of the lemons penalty falls as more car sales are driven by income shocks rather than quality, with the penalty halving as the variance doubles. Similarly, when the variance is reduced by 50%, the penalty increases substantially.

Corresponding to these changes in equilibrium prices with the variance, panel (b) of Figure 3 shows the effect on the average duration of car ownership. As the variance of income shocks increases, average duration falls, reflecting both the greater need for households to access the asset-value in cars, and also the reduced lemons penalty from selling.

The value of these experiments changing the variance of permanent shocks is that there is now substantial evidence that the variance of permanent income shocks changes over the business cycle. Storesletten et al. (2001) and Blundell et al. (2013), among others, show the variance of income shocks σ_ϵ^2 increases in recessions.[11] Such counter-cyclical movements would lead to the lemons penalty being lower in recessions than in booms.

Figure 3: Change the Variance of Permanent Income Shock

(a) Lemons penalty in the first 2 years of ownership　　(b) Ownership duration of cars



6 Symmetric Information

In our baseline model, the idiosyncratic stochastic shocks affecting car quality are private information. We compare this assumption to the case where all idiosyncratic shocks are fully observable and so information is symmetric.

In the symmetric information model, a household with a car of quality $q_{j,t}$ can sell it at its true value $q_{j,t}p^u$. Compared to the asymmetric information case, good cars can be sold at a better price in the symmetric information case, while bad cars are at a lower price. Since a car can now be sold at its true quality, it is more valuable as a store of value. On the other hand, the price that the household receives will vary with the true quality, rather than being the same regardless of quality, and this introduces more variation into the future value of any car.

[11] Similarly, Guvenen et al. (2014) show that changes in labor income become left skewed in recessions.

In scenario one, we consider symmetric information in an environment when there is no transactions cost, using our baseline parameter values. The absence of the lemons penalty means that cars are much more freely traded and the aggregate demand of fixed cars increases: in any given period, the number of people buying a second-hand car increases from 10% to 29% of the population. This level of trade is much greater than in the data. To match the observed level of trade, in scenario two, we introduce an exogenous transaction cost proportional to the value of the car into the environment with symmetric information. For this scenario, we reestimate the parameters of the model, including the exogenous transaction cost. Table 7 reports the prices and transaction volumes under these two scenarios and compares them to the baseline case with asymmetric information.

Table 7: Asymmetric and Symmetric Information Prices

Ownership years	1	2	3	4	5	6	7	8	9
Asymmetric information									
Dealer price	0.697	0.634	0.558	0.491	0.427	0.371	0.326	0.287	0.286
Expected car value (in population)	0.825	0.687	0.585	0.504	0.439	0.387	0.346	0.313	0.286
Lemons penalty (% of dealer price)	-18%	-8%	-5%	-3%	-3%	-4%	-6%	-8%	0
% of cars being sold	1.3%	20.1%	43.2%	65.6%	73.8%	76.7%	78.3%	78.7%	100%
Symmetric information									
Average Dealer price	0.828	0.700	0.590	0.505	0.424	0.380	0.351	0.334	0.280
Expected car value (in population)	0.825	0.681	0.570	0.485	0.419	0.370	0.332	0.303	0.280
% of cars being sold	77.6%	83.7%	86.0%	88.4%	90.7%	92.1%	93.3%	94.1%	100%
Symmetric information with exogenous transaction cost									
Average Dealer price	0.864	0.754	0.671	0.600	0.530	0.469	0.431	0.397	0.357
Expected car value (in population)	0.871	0.762	0.670	0.592	0.525	0.469	0.426	0.389	0.357
% of cars being sold	3.1%	23.4%	53.3%	66.8%	75.8%	81.6%	84.8%	87.3%	100%

Notes: Asymmetric information: baseline estimation when individual car quality is private information; Symmetric information: simulation results using the baseline parameter values when all shocks on car quality are observable and there is no transactions cost; Symmetric information with exogenous transaction cost: re-estimation of the model with symmetric information and an additional parameter on the exogenous transactions cost.

The 1st and 5th rows of Table 7 report average dealer prices under asymmetric information and under symmetric information without transactions costs. For the asymmetric information case, the average dealer price is the dealer price faced by everyone, whereas with symmetric information the dealer price will vary across cars with the same ownership duration because of quality differences.

The key finding is that the average dealer prices of cars are higher in the symmetric information model than the dealer prices in the asymmetric information model, reflecting higher average quality of cars being sold under symmetric information. The second panel of Table 7 (rows 5 and 6) compares the average dealer prices and the average value of cars in the population that would prevail under symmetric information: these are almost identical. Compared to the asymmetric information case, high quality cars are sold much sooner leading to the average quality being higher and close to the population average.

The symmetric information case in the second panel of Table 7 leads to much faster transactions occurring than under asymmetric information. This fast rate of transactions is at odds with the data, and so we introduce an exogenous transactions cost to the symmetric information case so that we can match the rate of transactions. The transaction cost is introduced for a household selling a car: for a car of value $q_{j,t}p^u$, the household pays a transaction cost $\lambda q_{j,t}p^u$ proportional to the sale price. We estimate the symmetric information model, adding the exogenous transaction cost λ as an additional parameter to estimate. The estimated parameter values and fitted moments are in the column labelled "Sym Cost" of Table 10 and Table 11 in Appendix D. Our estimate of this cost is 4.7%.

The third panel of Table 7 reports the prices and rate of transactions in this case. As in the symmetric information case with no transaction cost, the average dealer price, and hence the average value of cars being sold, is very close to the average value in the population.

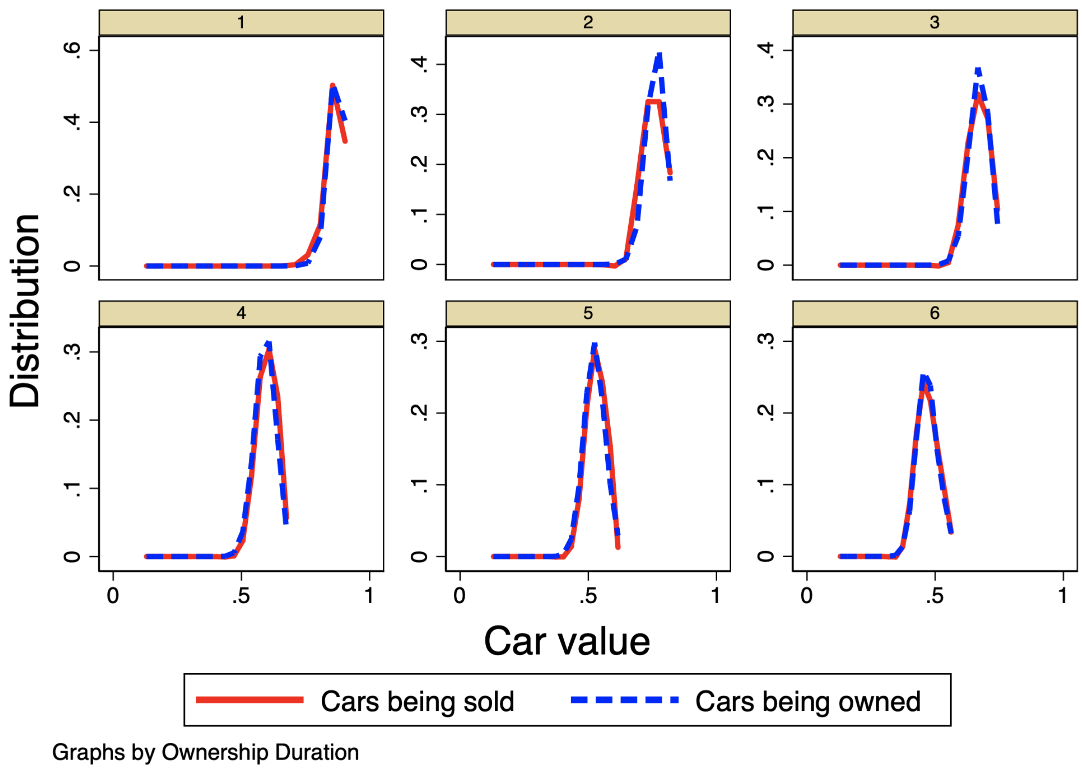
Figure 4 shows the distribution of the value of cars sold and the distribution in the population in the scenario with exogenous transaction costs. Under symmetric information, the quality distribution for cars for sale is almost identical to the distribution for cars in the population. This is in contrast to the distribution under asymmetric information shown in Figure 2 above, where the quality of cars sold is clearly lower than in the population.

The asymmetric information and symmetric information assumptions have different effects on the quality of cars sold, and in turn, this affects the extent to which cars can be used to smooth consumption. In the next section, we show how this propensity to sell cars following negative income shocks is affected by different types of transaction costs.

7 Adverse Income Shocks and Downgrading

One of the implications of the lemons penalty is that the car stock cannot be adjusted easily in response to an income shock. This reduces the value of the asset as a consumption smoothing device, which can have important welfare implications for low income people with low levels of liquid assets and much of their wealth accounted for by their car. In this section we examine how the propensity to downgrade the car stock is affected by asymmetric information. Here we focus on an adverse income event caused by an unemployment shock. We start by examining whether the quantified model is

Figure 4: Distribution of Value of Cars Sold and of Cars Owned: Symmetric Information



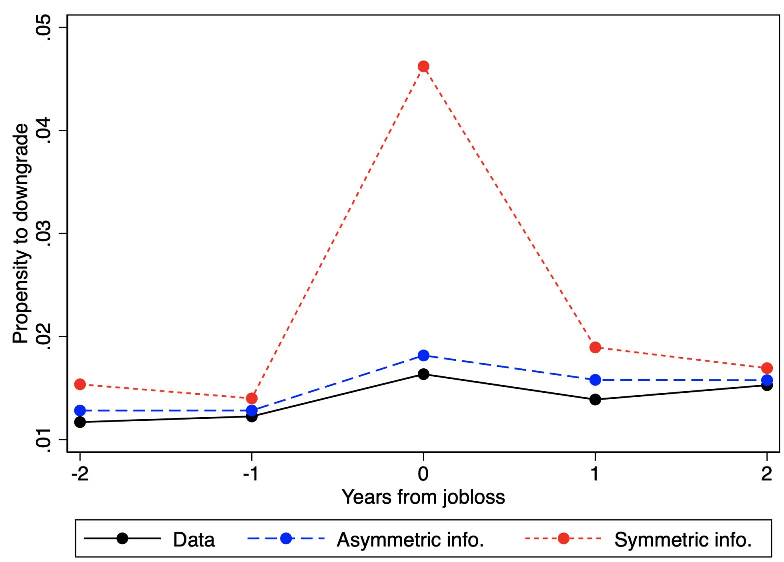
Notes: The figure plots for each level of ownership duration, the distribution of car quality in the population of cars owned and among the sub population of cars that are sold. The transaction cost is proportional to the value of the car.

able to match data on the propensity to downgrade upon job separation. We then compare simulated responses to unemployment events under the assumptions of symmetric and asymmetric information. We focus on the probability of downgrading, i.e. selling a car and either replacing it with a banger or not replacing at all.

7.1 Comparison to the Data

Evidence on how households respond to job loss was not used in the estimation procedure, and it thus provides some useful validation. We focus on the specific sample of job-losers and perform an event study for outcomes around the job loss. The event is defined to be the first job loss observed in the period 1999-2009. We include single adult households and couples.[12] Figure 5 compares the observed downgrading to downgrading in the model following the same job separation shock. Both the amount of downgrading before job loss and the increase in downgrading on job loss are similar between the data and the asymmetric information case.

Figure 5: Downgrading after Job Loss. Data and Model Simulation



Notes: The event graphs are constructed by ordering observations according to the first year in the data period where households experience to be unemployed for at least 2 months on average across the adult household members. Downgrading takes place when a car is sold in period t and the value of the car stock in year t is at most 40% of the value of the car stock in year $t-1$.

[12]For singles we define a job loss to take place if the person has been out of job for a total of at least 60 days during the year. For couples we define the job loss to take place if the total unemployment accumulates to 120 days when summarized for both partners over the year. This is done to obtain shocks that are of comparable magnitude across singles and couples.

7.2 Adverse Income Shocks under Symmetric and Asymmetric Information

For many households, cars are a substantial financial asset. However, the lemons penalty reduces the willingness of households to sell cars of good quality, or even of average quality. This is a transactions cost that reduces the value of holding a car as a way to smooth shocks. When information is symmetric, this transactions cost of selling a car is not present, increasing the value of holding a car as a financial asset. In this section, we compare the responses of households to becoming unemployed when there is asymmetric information to when there is symmetric information.

Figure 5 shows downgrading behaviour following the job separation shock under symmetric information, to compare to the model with asymmetric information and downgrading in the data. The dashed line shows the asymmetric information case, and the dotted line shows the symmetric information case. Downgrading cars to smooth income shocks is substantially greater under symmetric information. The lemons penalty reduces the liquidity of cars and reduces the extent that cars are used as an insurance device against adverse income shocks. This difference in the average downgrading probabilities masks substantial differences in how cars of different ownership duration and of different quality are used.

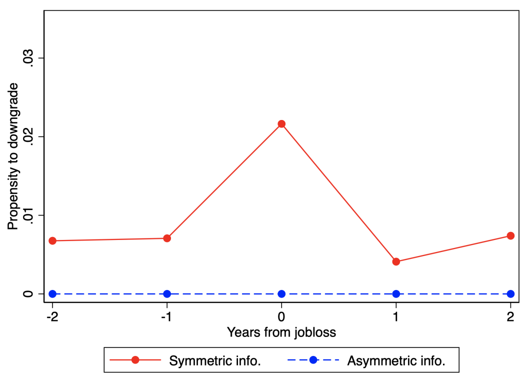
Figure 6 shows how cars of different ownership duration are downgraded. Newly purchased cars are used extensively for consumption smoothing under symmetric information when the cars can be sold for a fair value, but are rarely used when there is a lemons penalty. Under asymmetric information, it is older cars where there is less of a lemons penalty that are sold on job loss.

Even when conditioning on the length of car ownership, there are differences in which cars are being used for smoothing job separation shocks. Figure 7 reports how the probability of downgrading differs by the quality of car. Cars are split into four types, relative to the dealer price: very low quality cars, which have quality less than 90% of the average quality being sold; low quality cars which are between 90% and 100% of average quality; good quality cars which are no more than 10% higher quality than the average; and very good quality which are more than 10% better than average. Figure 7 shows downgrading for asymmetric information on the left-hand side, and symmetric information on the right-hand side. The difference is stark: under asymmetric information, it is the very low quality cars which are being sold to smooth consumption; whereas under symmetric information, it is the very high quality cars which are being sold.

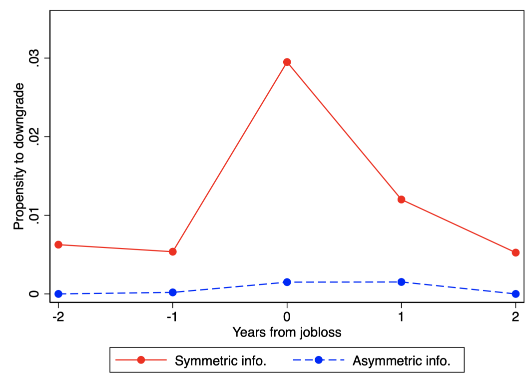
The message from Figure 7 is that the presence of asymmetric information introduces insurance against a car being of low quality: since dealers cannot condition the price on quality because it is unobservable, the owners of bad cars receive a price above the true quality of their car, whereas the owners of good cars receive a price below the true quality. This insurance comes at a price, which is the transactions cost of the lemons penalty, reducing the expected value of the asset.

Figure 6: Simulated Downgrading by Ownership Duration

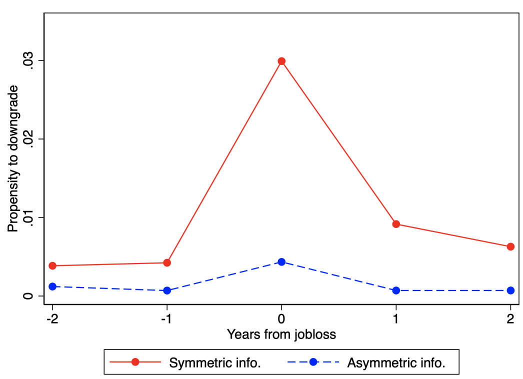
(a) Owned for 1-year



(b) Owned for 2-years



(c) Owned for 3-years



(d) Owned for 4-years

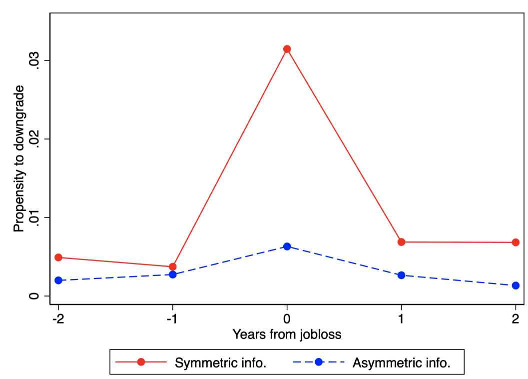
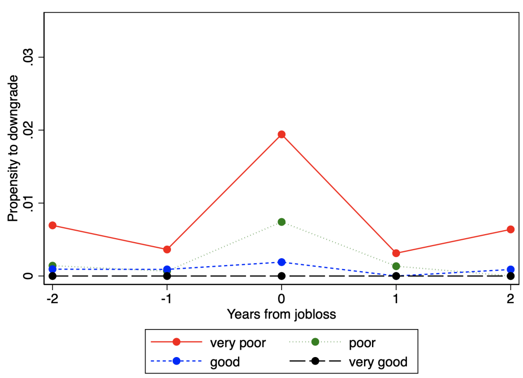
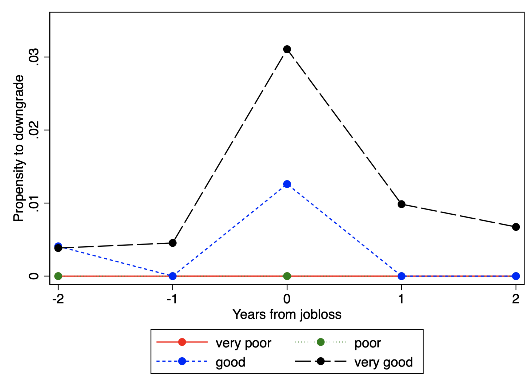


Figure 7: Simulated Downgrading by Car Quality

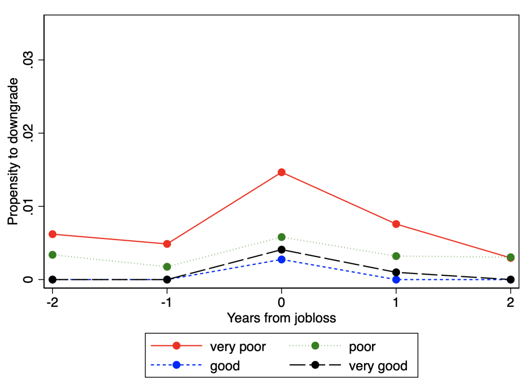
(a) Asymmetric info. (Owned for 3-years)



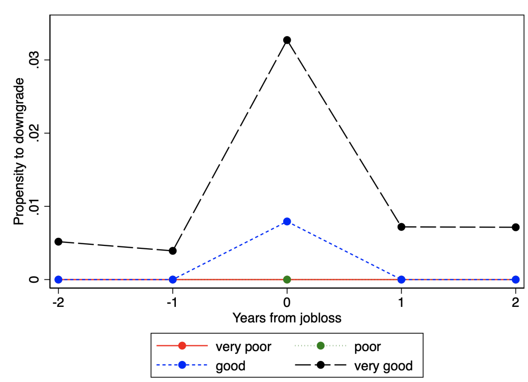
(b) Symmetric info. (Owned for 3-years)



(c) Asymmetric info. (Owned for 4-years)



(d) Symmetric info. (Owned for 4-years)



There are 4 levels of quality: very poor (quality less than 90% of average among owned cars), poor (between 90% and 100%), good (100% to 110%) and very good (over 110% of average).

8 Conclusions

In this paper we assess the importance of the lemons penalty in the car market. The lemons penalty exists when car sellers know more about the quality of the car they are selling than buyers, i.e. when there is asymmetric information about the quality of cars being traded. This type of asymmetric information implies that dealers will pay less than the expected value of cars in the population and this will systematically affect who sells a car such that cars put on the market are, on average, of lower quality than the expected quality in the population of cars. This price discount is the lemons penalty, and it is endogenous to the quality of cars that are sold in equilibrium.

In order to quantify the quality of cars in the population and the quality of cars put on the market we formulate and quantify a stochastic life-cycle equilibrium model of car ownership in which dealers buy old cars from households without the dealers knowing the true quality. Car dealers are offered cars that, on average, are of lower quality than similar cars in the population and so the dealers are will only pay a lower price. Households selling above average quality cars therefore receive a lower payment than what they would have if there was no informational asymmetry about the quality of the car and this difference is the lemons penalty. The supply of cars into the used car market varies as households receive news about their income and this affect the average quality of cars entering the secondary market. This mechanism enables us to study how equilibrium prices and the flow of cars in and out of the market is characterized.

Our results show that the lemons penalty is significant in the first years of car ownership, but that it declines quickly with ownership. We show that the lemons penalty reduces the transaction volume significantly. We further show that the size of the lemons penalty depends on the amount of underlying uncertainty: the greater the variance of shocks to income, the greater the chance that individuals will sell their cars for reasons unrelated to the quality of the car. This means that the average quality of cars sold will be closer to the average in the population.

If there were full information about the quality of cars in the market and in the population, sellers receive a price that reflects the actual quality of cars, i.e. there is no lemons penalty, and therefore owners are more willing to sell their car if it is of high quality. As a consequence, the composition of cars in the market changes, and are on average, of higher quality and cars are traded more frequently.

Full information brings a gain for people with high quality cars, who are then able to get a price that matches its true quality. This is of particular value for owners of cars that have been bought recently and are of high quality: such owners can now better use the car for countering adverse income shocks than in the asymmetric information environment. The effect is opposite for owners of low quality cars: full information brings a lower price and they will be less able to use the car to smooth during times of low income. For this group, asymmetric information has a benefit and introduces insurance against holding a car of low quality. Asymmetric information has distributional consequences as well as efficiency consequences. Further, this insurance comes at a price - the transactions cost induced by the lemons penalty - which we show reduces significantly the expected asset value of a car, and this has a substantial effect on the market for cars. Further, the transaction cost means that lower income individuals, for whom the car makes up a large fraction of their wealth, are prevented from using this asset efficiently for income smoothing.

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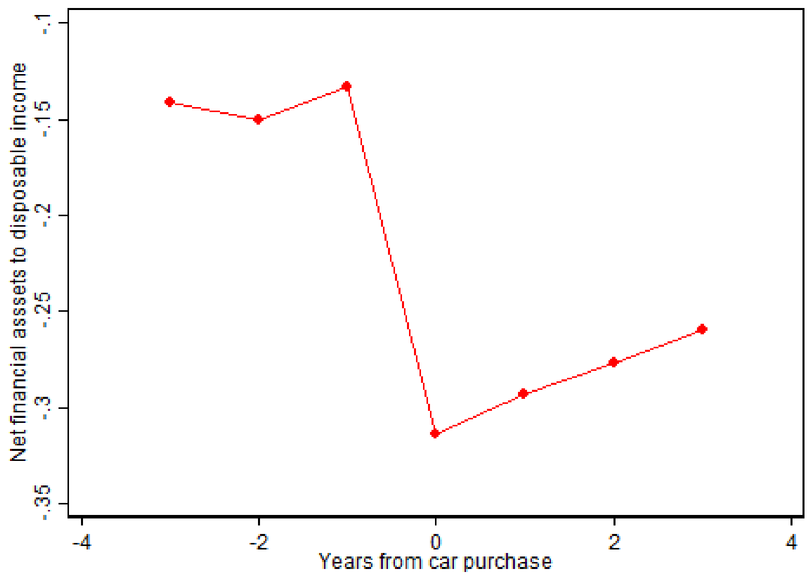
A Financial Assets around Time of Car Purchase

This appendix documents how net financial asset holdings fluctuate around the time when households in the sample buy a car in an event study. Net financial asset include bank deposits, shares, bonds, and non-mortgage debt, and net financial assets are measured relative to average disposable income for the household across the years where the household enters the sample. The event is defined to be the first car purchase observed in the period 1999-2009.

Figure 8: Net Financial Assets Around Time of Car Purchase



B Summary statistics for full sample and for job-loss sample

Table 8 presents summary statistics for the full sample and for the sample of households who experience job loss, splitting by age group.

C Income Process

The estimated unconditional autocovariances up to order three are presented in Table 9 for the two education groups. Second- and higher order autocovariances are statistically significant reflecting some persistence in the transitory component. Their size is however very small.[13]

[13]We have also estimated autocovariances year-by-year. These estimates (not reported) indicated a very stable pattern across the sample period, and we therefore only report the pooled estimates.

Table 8: Summary Statistics

	Full sample				Job loss sample			
Age group	30-40		41-60		30-40		41-60	
Variable	Average (1)	Median (2)	Average (3)	Median (4)	Average (5)	Median (6)	Average (7)	Median (8)
Car								
Car owner	0.68	1	0.74	1	0.66	1	0.69	1
Age of car stock	8.89	9	8.35	8	10	10	9.44	9
Owner of regular car	0.92	1	0.93	1	0.90	1	0.90	1
Owner of banger	0.17	0	0.16	0	0.22	0	0.22	0
Income/wealth								
Disposable income (1000 DKK)	309	315	323	318	260	262	265	264
Financial assets / disp. income	0.31	0.09	0.56	0.15	0.31	0.09	0.57	0.14
1[financial assets < 1 month disp. income]	0.49	0	0.35	0	0.49	0	0.36	0
Car owner	0.65	1	0.67	1	0.62	1	0.62	1
Car value (1000 DKK)	90	67	96	70	90	65	90	65
Car value / disp. income	0.27	0.21	0.28	0.22	0.32	0.24	0.32	0.24
Car value / (fin. assets + car value)	0.70	0.86	0.71	0.86	0.79	0.88	0.78	0.88
Housing equity to house value (ETV)	0.11	0.00	0.21	0.11	0.11	0.00	0.20	0.10
Housing equity to disp. income (ETI)	0.51	0.00	1.02	0.31	0.54	0.00	1.04	0.30
1[financial assets > 1 month disp. income]	0.51	1	0.65	1	0.51	1	0.64	1
Car owner	0.72	1	0.77	1	0.70	1	0.74	1
Car value (1000 DKK)	113	87	118	94	109	80	110	83
Car value / disp. income	0.34	0.26	0.35	0.28	0.37	0.27	0.38	0.29
Car value / (fin. assets + car value)	0.44	0.34	0.39	0.34	0.47	0.34	0.41	0.34
Housing equity to house value (ETV)	0.22	0.15	0.44	0.44	0.22	0.14	0.43	0.41
Housing equity to disp. income (ETI)	1.11	0.46	2.29	1.55	1.14	0.45	2.28	1.52
Demographics								
Age	35	35	50	50	35	35	50	50
Married/cohabiting	0.71	1	0.75	1	0.66	1	0.70	1
Has children	0.61	1	0.47	0	0.62	1	0.45	0
Homeowner	0.50	1	0.61	1	0.52	1	0.62	1
Some college	0.26	0	0.21	0	0.23	0	0.17	0
Number of observations	1,452,171		2,559,063		466,426		678,752	

Notes: A regular car is a car aged less than 15 years. A banger is a car aged more than 15 years. All economic variables are CPI deflated to the level in 2000 and have been censored at 1st and 99th percentile calendar year by calendar year. Car value refers to the value of the stock of cars. Financial assets includes cash in banks, bonds and stocks. ETV and ETI are based on tax assessed house values. Because of changes in the definition of the debt variables these variables can only be calculated for the years 1997-2009. The joblooser sample includes observations for individuals who have been affected by events during the period 1999-2009. An unemployment event is defined to take place if the household is exposed to three months of full time unemployment over the year. For two-adult households it is defined to take place if the couple jointly experience at least six months of unemployment within a calendar year. For confidentiality reasons the medians are calculated as the average of 4 observations around the true median.

Table 9: The autocovariances of residual log income

Order	No college	Some college
0	0.0456 (0.00021)	0.0463 (0.00036)
1	-0.0136 (0.00013)	-0.0128 (0.00023)
2	-0.0017 (0.00008)	-0.0017 (0.00013)
3	-0.0005 (0.00007)	-0.0007 (0.00011)

The variance of the job separation shock σ_κ^2 can be estimated using the residual income growth for those employed in $t-1$ and unemployed in t, $g_{it,eu} = \epsilon_{it} + \triangle\nu_{it} + \kappa_{it}$ based on the expression $\sigma_\kappa^2 = E\left(g_{it,eu}^2\right) - \sigma_\epsilon^2 - 2\sigma_\nu^2$, where the subscript eu denotes "from employment to unemployment." The persistence of the unemployment shock ρ_e is estimated from the variance of residual income growth for those unemployed in $t-1$ and employed in t, $g_{it,ue} = \epsilon_{it} + \triangle\nu_{it} + \rho_e\kappa_{it} - \kappa_{it}$ using the expression $\rho_e^2 = \left[E\left(g_{it,ue}^2\right) - \sigma_\epsilon^2 - 2\sigma_\nu^2 - \sigma_\kappa^2\right]/\sigma_\kappa^2$, where the subscript ue denotes "from unemployment to employment." The estimates of ρ_e is 0.635 for the No College group, and is 0.734 for the Some College group.

For simplicity, we assume κ_{it} follows a discrete two point distribution with support $\{\kappa_{1s}, \kappa_{2s}\}$, each occurs 50% of the time. κ_{1s} is positive, representing job a separation shock that leads to a better new job, and κ_{2s} is negative, representing a serious scarring effect due to unemployment. $\{\kappa_{1s}, \kappa_{2s}\}$ are estimated based on the mean and variance of the residual income growth for those employed in t-1 and unemployed in t using minimum distance methods. The estimates are $\{0.107, -0.245\}$ for the No College group, and is $\{0.181, -0.286\}$ for the Some College group. Finally, we set the probability of job separation δ_u to be 3.7% for the No College group and 2.5% for the Some College group annually.

D Robustness

Here we consider alternative specifications of our model. First, we consider an alternative specification where the risk aversion parameter is set to be 4 instead of 1.43 in the baseline model. The estimated parameter values and fitted moments are in the column labelled "Risk Averse" of Table 10 and Table 11 respectively. When households are more risk-averse, there is an increased incentive to save. To match the data on asset accumulation, this increased risk aversion is offset by a reduced discount rate

(0.84 versus 0.97 in the baseline). The resulting lemons penalty, in the panel labelled "Risk Averse" of Table 12, is estimated to be 16% of the price in the first year of ownership, declining with the length of ownership. The level and path of the lemons penalty is therefore little changed by the re-estimation using greater risk aversion.

In the second experiment, we assume existence of an exogenous proportional transaction cost in the baseline model. The transaction cost is identical for car owners who have owned their cars for the same length of time, and so does not have the distributional implications of the lemons penalty. The purpose of this exercise is to assess the relative importance of the exogenous versus endogenous components of the transactions cost.

We estimate the exogenous transaction cost as an additional parameter within the baseline model. The estimated parameter values and fitted moments are in the column labelled "Asy Cost" of Table 10 and Table 11 respectively. The estimated proportional transaction cost is 0.3%. The corresponding lemons penalty is showed in the panel labelled "Asy Cost" of Table 12: the average loss of a transaction imposed by the lemons penalty is substantially greater than the estimated proportional cost. Indeed, the estimated lemons penalty is little changed by the additional transactions cost parameter.

In the final experiment, we estimate the exogenous transaction cost when information is symmetric: all shocks are publicly observed and sellers receive a price that reflects the actual quality of cars. The estimated parameter values and fitted moments are in the column labelled "Sym Cost" of Table 10 and Table 11 respectively. The estimated proportional transaction cost is 4.7%.

Table 10: Robustness: Estimated Parameter Values

Parameters		Baseline	Risk Averse	Asy Cost	Sym Cost
Common parameters					
Exogenous transaction cost				0.003	0.047
Discount factor	β	0.970	0.843	0.970	0.970
Private depreciation factor	η_1	16.864	15.923	16.856	37.454
	η_2	1.925	1.418	1.922	1.790
Arrival rate of banger shock	δ^r	0.090	0.084	0.090	0.094
Some College					
Preference for new car	θ^f	1.162	1.160	1.161	1.179
Preference for banger	θ^b	0.619	0.873	0.651	0.766
Utility benefit of owning car	α	0.283	0.293	0.287	0.244
No College					
Preference for new car	θ^f	1.162	1.165	1.160	1.198
Preference for banger	θ^b	0.600	0.650	0.594	0.647
Utility benefit of owning car	α	0.300	0.283	0.302	0.235

Table 11: Robustness: Fitted Moments

Moments		Data	Baseline	Risk Averse	Asy Cost	Sym Cost
Ownership rate of regular cars						
Some College	Age 30 - 40	64.3%	64.1%	63.7%	64.4%	63.5%
	Age 41 - 60	73.5%	75.3%	75.3%	75.4%	73.9%
No College	Age 30 - 40	62.8%	61.2%	57.1%	61.4%	51.9%
	Age 41 - 60	67.2%	62.2%	62.0%	62.3%	60.3%
Ownership rate of bangers						
Some College	Age 30 - 60	9.9%	8.4%	7.6%	9.9%	10.0%
No College	Age 30 - 60	12.3%	12.5%	8.7%	12.3%	12.5%
% people buy new cars						
Some College	Age 30 - 40	5.0%	3.4%	3.6%	3.5%	2.8%
	Age 41 - 60	6.4%	10.9%	11.9%	11.1%	9.6%
No College	Age 30 - 40	3.9%	2.5%	2.7%	2.5%	3.4%
	Age 41 - 60	5.4%	6.4%	6.7%	6.4%	6.7%
Median financial asset to income at 55		0.209	0.212	0.212	0.209	0.208
Ownership duration of cars		4.63	4.624	4.626	4.629	4.238
% of cars being sold after 1 year		5.6%	1.3%	1.6%	1.2%	3.1%
% of cars being sold after 2 years		24.7%	20.1%	18.0%	20.2%	23.4%
% of cars being sold after 3 years		41.4%	43.2%	43.8%	43.4%	53.3%
% of cars being sold after 4 year		55.6%	65.6%	63.1%	65.1%	66.8%
% of cars being sold after 5 years		66.9%	73.8%	72.9%	73.5%	75.8%
% of cars being sold after 6 years		75.0%	76.7%	76.6%	76.6%	81.6%

Table 12: Robustness: Prices and the Lemons Penalty

Ownership years	1	2	3	4	5	6	7	8	9
Baseline									
Dealer price	0.697	0.634	0.558	0.491	0.427	0.371	0.326	0.287	0.286
Expected car value (in population)	0.825	0.687	0.585	0.504	0.439	0.387	0.346	0.313	0.286
Lemons penalty (% of dealer price)	-18%	-8%	-5%	-3%	-3%	-4%	-6%	-8%	0
% of cars being sold	1.3%	20.1%	43.2%	65.6%	73.8%	76.7%	78.3%	78.7%	100%
Risk Averse									
Dealer price	0.727	0.660	0.591	0.526	0.466	0.410	0.367	0.331	0.313
Expected car value (in population)	0.842	0.714	0.617	0.539	0.474	0.420	0.376	0.342	0.313
Lemons penalty (% of dealer price)	-16%	-8%	-4%	-2%	-2%	-2%	-2%	-3%	0
% of cars being sold	1.6%	18.0%	43.8%	63.1%	72.9%	76.6%	80.1%	81.4%	100%
Asy Cost									
Dealer price	0.698	0.634	0.558	0.491	0.427	0.371	0.326	0.287	0.286
Expected car value (in population)	0.825	0.687	0.585	0.504	0.439	0.387	0.346	0.313	0.286
Lemons penalty (% of dealer price)	-18%	-8%	-5%	-3%	-3%	-4%	-6%	-9%	0
% of cars being sold	1.2%	20.2%	43.4%	65.1%	73.5%	76.6%	78.3%	78.7%	100%