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Gavazza, Alessandro and Lizzeri, Alessandro and Rokestkiy, Nikita

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Alessandro Gavazza¶ Alessandro Lizzeri§ Nikita Roketskiy‖

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Abstract

We quantitatively investigate the allocative and welfare effects of secondary markets for cars. An important source of gains from trade in these markets is the heterogeneity in the willingness to pay for higher-quality (newer) goods, but transaction costs are an impediment to instantaneous trade. We explore how the income distribution affects this heterogeneity—income is an important determinant of willingness to pay for quality. Calibration of the model successfully matches several aggregate features of the U.S. and French used-car markets. Counterfactual analyses show that transaction costs have a large effect on volume of trade, allocations, and the primary market. Aggregate effects on consumer surplus and welfare are relatively small, but the effect on lower-income households can be large.

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¶Leonard N. Stern School of Business, New York University. 44 West 4th Street, New York, NY 10012. Email: agavazza@stern.nyu.edu.

§Department of Economics, New York University, 19 West 4th Street, New York, NY 10012-1119. Email: alessandro.lizzeri@nyu.edu.

‖Department of Economics, New York University, 19 West 4th Street, New York, NY 10012-1119. Email: nroketskiy@nyu.edu.

1 Introduction

Secondary markets play an important allocative role for some durable goods. For instance, in the U.S., the number of used-car transactions is approximately three times as large as the number of new-car transactions. Furthermore, the dispersion of used-car prices (measured by the coefficient of variation) is approximately five times as large as the dispersion of new-car prices, suggesting that secondary markets play an important role in broadening the spectrum of goods available to consumers.

The amount of activity in secondary markets varies dramatically across goods, with some markets extremely active (e.g., cars, aircraft) and others much less so (e.g., white goods, computers). More surprisingly, the amount of activity also varies substantially across different countries for the same goods. For instance, the American used-car market is much more active than the French market. What forces are responsible for these differences? What are the consequences for prices and allocations, for producers' profits and consumers' welfare? How do these differences in activity affect the extent of variety available to consumers? Can some of the observed differences in the primary markets across goods and countries be due, in part, to the underlying causes of the differences in activity in the secondary markets? These are some of the questions that this paper addresses.[1]

We present a simple model of durable-goods markets to tackle these issues. As in all markets, activity in secondary markets arises because of some gains from trade between counterparties. In the car market, an important source of such gains from trade is heterogeneity in the willingness to pay for quality: high-willingness-to-pay consumers sell used units when they upgrade to a new unit.[2] Transaction costs are an impediment to instantaneous (i.e., 100 percent) trade. The extent of trade depends upon the degree of heterogeneity in preferences. We quantitatively investigate how the income distribution determines this heterogeneity by calibrating our model to match the aggregate volume of trade in the used-car market.[3] Despite its simplicity, the model fits the data very well.

[1] Empirical studies of secondary markets include the following markets: cars (Porter and Sattler, 1999; Adda and Cooper, 2000; Stolyarov, 2002; Esteban and Shum, 2007; Chen, Esteban and Shum, 2011; and Schiraldi, 2011); truck tractors (Bond, 1983); commercial aircraft (Pulvino, 1998; Gavazza, 2011a and 2011b); business aircraft (Gilligan, 2004; Gavazza, 2011c); and capital equipment (Eisfeldt and Rampini, 2009).

[2] There are, of course, other reasons for trade. For instance, the ideal car depends on household size, so changes in the number of children may lead some households to trade in their sedan to purchase a minivan. Such characteristics could, in principle, be added to our model, but we suspect that their overall effect would be small.

[3] It is well established that income is the key determinant of households' vehicles purchases: see, among

We then use the model to perform several counterfactuals with the purpose of understanding the functioning of secondary markets and their impact on the market for new goods. First, we examine the effects of transaction costs by comparing two polar cases with the baseline calibrated model: perfectly functioning secondary markets with zero transaction cost and complete shutdown of secondary markets with prohibitive transaction costs. Naturally, we expect any changes in secondary markets to affect primary markets. Thus, the supply response of new-goods producers is an important element determining the welfare consequences of secondary markets' frictions. We consider two extreme supply scenarios that help highlight how primary markets adjust: 1) a perfectly elastic supply—i.e., the price of new cars does not respond to changes in transaction costs, but the quantity does; and 2) a perfectly inelastic supply—i.e., the quantity of new cars does not respond to changes in transaction costs, but the price does. We believe that these counterfactuals are useful to understand the importance of transaction costs for manufacturers, since they indicate that *either* output *or* prices change when transaction costs change, even in an oligopolistic market for new cars.

Our analysis shows that three key economic forces affect allocations and welfare in our counterfactuals with different transaction costs relative to the baseline case: 1) Increasing (decreasing) transaction costs has the partial-equilibrium direct effect of destroying (freeing) resources, thereby affecting households' willingness to pay because they obtain different net resale prices; 2) lower (higher) transaction costs have the partial-equilibrium indirect effect of allowing a finer (coarser) matching between households' preferences and the quality of their cars; and 3) the previous two forces feed into the general-equilibrium effects of changing new- and used-car prices and/or quantities relative to the baseline case.

Overall, we find that the impact of transaction costs on allocations in the secondary market, as well as in the market for new goods, is large. In contrast, the effects on aggregate welfare are smaller, although the distribution of these effects is uneven, with low-income households suffering large losses from increases in transaction costs. For instance, if transaction costs are large enough to shut down secondary markets, the aggregate consumer-surplus loss equals five to 11 percent of the aggregate baseline consumer surplus (in which transaction costs are calibrated to the data), depending on the elasticity of new-car supply. However,

many others, Aizcorbe and Starr-McCluer (1996), Aizcorbe, Starr and Hickman (2003), Aizcorbe, Bridgman and Nalewaik (2009), and Yurko (2012). Particularly related is the contemporaneous paper by Yurko (2012), which also investigates the role of income heterogeneity in car markets, but does not consider the allocative and welfare effects of secondary markets by performing the counterfactual analyses that we present in Section 5.

households with incomes below the median U.S. income suffer surplus losses larger than 50 percent of their baseline surplus. Aggregate welfare changes are smaller because, due to income heterogeneity, the highest-income households have disproportionate weights in the calculation of aggregate surplus. These households have the smallest surplus loss when transaction costs increase because several margins of adjustment allow them to reduce the effects of transaction costs—for example, they can scrap their cars if resale is prohibitively expensive—and they do not suffer much from the higher costs that accompany such adjustments. However, since transaction costs affect the total quantity of cars by increasing scrappage, low-income households disproportionately suffer from this reduced availability of cars.

These counterfactual analyses also reveal some additional intriguing findings. For example, we find that either new-car output or new-car prices (depending on whether new-car supply is elastic or inelastic) is non-monotonic in transaction costs, with either output or prices going up relative to the baseline case. This non-monotonicity is due to the different quantitative magnitudes of the key economic forces for different levels of transaction costs. When transaction costs are zero, frictionless secondary markets lead to much finer matching of qualities to consumer valuations, thereby raising high-valuation households' willingness to pay for new cars. When supply is perfectly elastic (inelastic), the quantity (price) of new cars produced must increase. Instead, when transaction costs are prohibitive, used-car markets shut down completely, so the only way for households to upgrade quality is to scrap their used units. Indeed, scrappage increases substantially, with cars lasting only two thirds as long as in the baseline scenario. This increased scrappage feeds into a substantially higher demand for new cars and, hence, higher output or price, depending on the elasticity of supply.

We further consider the allocative and welfare effects of a scrappage policy that forces households to scrap their cars earlier than they otherwise would. Scrappage policies have been introduced in a number of countries, and the policy that we consider is closest to the Japanese *shaken* system of tough emission inspections that induces a particularly young fleet of cars in Japan.[4] Specifically, we impose that households have to scrap their cars when they reach $T = 11$ years of age; we choose $T = 11$ since this is approximately the average scrappage age in the counterfactual with prohibitive transaction costs, so this choice facil-

[4]As we explain in Section 5.2, our steady-state model is less well suited to an analysis of temporary policies such as cash for clunkers. See Adda and Cooper (2000) for such an analysis that does not, however, take into account the effects of secondary markets.

itates the comparison between these counterfactuals. However, two substantive differences arise between the case in which the scrappage age is imposed to be $T = 11$ and the case of prohibitive transaction costs in which the *average* scrappage age is endogenously the same. First, secondary markets are active when there is a scrappage policy, but they are not when transaction costs are prohibitive. Second, households' scrappage decisions are heterogeneous when transaction costs are prohibitive, with higher-income households scrapping their cars substantially earlier than lower-income households. Instead, this heterogeneity does not arise under the scrappage policy since all cars have positive net resale values, and, thus, no households scrap them before they reach $T = 11$.

We find that this scrappage policy has minor effects on aggregate welfare relative to the baseline case, especially in the case of elastic supply, although the welfare losses are again large for low-income households. Moreover, we find that welfare is higher with this scrappage policy than with prohibitive transaction costs, further highlighting the welfare gains of resale markets. The reason is that the first effect—i.e., active secondary markets—allows a finer matching of relatively young vintages to high-valuation consumers, whereas the second effect—i.e., heterogeneous scrappage—allows finer control of relatively low-quality cars for low-valuation consumers. The first effect dominates because of supermodularity: More value is created at the top of the quality distribution than is lost at the bottom.

Finally, we explore the quantitative effects of heterogeneity by considering data from another country, France. The income distribution in France is less dispersed than in the U.S., and the model predicts that we should observe less trade in the French used-car market than in the U.S. Indeed, this is also what the data say. The magnitude of the difference is also substantial: The average holding time is approximately 30-percent larger in France than in the U.S. Our model quantitatively matches French aggregate statistics extremely well. Of course, there are many differences between the U.S. and France beyond the differences in the income distribution. However, it is notable that income distribution alone can account for all the differences in the aggregate car-market data on which we focus. Another interesting consequence of lower heterogeneity is that car prices are flatter in France than in the U.S., starting with a lower new-car price and ending with higher used-car prices in France for the oldest vintages.

2 Related Literature

This article contributes to two main strands of the literature. First, the theoretical literature on consumer durable goods has investigated the role of secondary markets in allocating new and used goods (Rust, 1985; Anderson and Ginsburgh, 1994; Waldman 1997, 2003; Hendel and Lizzeri, 1999a,b; Stolyarov, 2002). The first part of our paper is close to Stolyarov (2002), which investigates resale rates across different car vintages. The current paper contributes to this strand of the literature by providing a quantitative analysis of the allocative and welfare effects of secondary markets, and by evaluating policies that affect secondary markets.

Second, a series of papers has analyzed car markets. Many influential papers analyze product differentiation and consumers' choices among new cars (Bresnahan, 1981; Berry, Levinsohn and Pakes, 1995; Goldberg, 1995; Petrin, 2002) or manufacturers' pricing (Verboven, 1996; Goldberg and Verboven, 2001), but they do not consider used goods and secondary markets. Wang (2008) incorporates the durability of the good in consumers' choice of new cars, and Schiraldi (2011) considers new and used cars in consumers' choice sets, but they do not analyze the equilibrium in the market. Eberly (1994) and Attanasio (2000) study households' adjustments of their vehicles' stocks in partial-equilibrium. Hence, relative to all these contributions, our equilibrium model is better suited to address the general-equilibrium effects of heterogeneity and secondary markets, and of policies, such as scrappage policies, that impact durable-goods markets. The closest paper is Chen, Esteban and Shum (2011). The main difference is that they focus on the effects of the secondary market on the primary market: They consider an oligopoly model with forward-looking firms, and they compare the effects of secondary markets both for the case of commitment and for the case in which manufacturers lack commitment. Instead, our main focus is on the allocative and welfare role of secondary markets: We consider a model with richer household heterogeneity and greater vertical variety of used goods.

3 Model

3.1 Assumptions

We modify a model of vertical product differentiation that has become a standard way to model secondary markets (see, for instance, Rust, 1985; Anderson and Ginsburgh, 1994; Hendel and Lizzeri, 1999a and 1999b). Stolyarov (2002) numerically solved such a model to generate some interesting patterns for secondary markets with transaction costs. We extend Stolyarov's analysis to incorporate some features that are important in the data (e.g., multiple cars per household). We then evaluate how this simple model can account for some aggregate features of the data, while abstracting from some important features of car markets, such as horizontal product differentiation.

The first step is to obtain the overall equilibrium in the car market for any given level of new-car output.[5] In every period, a constant (exogenous) flow x of new cars enters the market. We will infer this output from the data and, as will become clear, in our baseline model, it would be equivalent to assume that the unit cost of cars is equal to p_0 and that the car industry is perfectly competitive, so that any quantity of new cars can be supplied at price p_0.

New cars are homogeneous,[6] with quality q_0 and deterministic depreciation: A car of age a is of quality q_a, with $q_a > q_{a+1}$.[7] Each car "lives" until it is (endogenously) scrapped at time T. For expositional simplicity, we describe the case in which, in equilibrium, all agents choose to scrap at the same time T^*. This is the relevant case for our baseline calibration and implies that the steady-state total mass of cars is equal to xT^*.[8]

A majority of U.S. households own more than one car (see Section 4.1). We want the model to capture this feature of the data for two reasons: because, as discussed below, this has consequences for the secondary market; and because we want to contrast the U.S. with France, where the number of cars per household is much lower. Thus, we must allow households to own more than one car. However, this significantly complicates the numerical computation, so we do not allow for more than two cars: In each period, a household has value for, at most, two cars. Each household has a preference parameter θ that determines the flow of utility that the household enjoys from its cars. Specifically, a household with preference θ and with two cars enjoys a per-period flow of utility equal to $\theta q_1 - c$ from its

[5] In our counterfactuals, we consider two opposite scenarios for supply: 1) a perfectly elastic supply, as in a perfectly competitive industry with constant marginal cost equal to p_0; and 2) a perfectly inelastic (per-period) supply equal to x.

[6] We have also considered heterogeneous vertical qualities of new goods, and obtained similar results to those reported in later sections. Clearly, the car market exhibits other features that we abstract from, such as *horizontal* differentiation among car models, as in Berry, Levinsohn, and Pakes (1995). However, the focus of our analysis is on the replacement patterns that emerge from gains from trade due to *vertical* differentiation among different ages of a given car model.

[7] We can also interpret depreciation as the growing distance between older cars and the improving technological frontier of new models (e.g., air bags, electronic stability control, etc.).

[8] Some of our counterfactuals require aggregation of heterogeneous scrappage decisions. This is a straightforward extension that we omit from the main analysis to avoid cumbersome notation.

first (better) car, and $\alpha\theta q_j - c$ from its second car. The parameter $\alpha \in (0,1)$ captures the lower valuation for the second car, and the parameter c is a per-period holding (i.e., maintenance) cost, independent of car quality. The role of the holding cost is to generate a reasonable scrappage age.[9] The preference parameter θ is distributed in the population according to the non-degenerate c.d.f. F, whereas α is the same for all households in the population.[10]

In order for the model to generate interesting implications on trade in the secondary market, and to match relevant features of the data, we must assume some frictions.[11] We assume that there are transaction costs in the secondary market: If a household sells a car of age a, it pays a transaction cost λ_a proportional to the sale price. The level of transaction costs will be a key variable in some of our counterfactuals.

3.2 Household problem

A household chooses how many cars to own and, for each car, which vintage to buy and how long to keep it. We now formally derive the value functions for the household problem. We proceed by separating the problem into two stages. In the first stage, the household decides whether to have zero, one or two cars. In the second stage, the household decides which vintage(s) to own and how long to keep it (them).

The value V^0 of not owning cars is normalized to zero.

Let $V^1(\theta, a)$ be the value of owning one car of age a for a household with valuation θ. In every period, this household considers whether to keep the q_a car or to replace it, taking as given the (endogenous) vector of prices $p = (p_0, .., p_{T-1})$. Thus, the value $V^1(\theta, a)$ is equal to:

$$V^1(\theta, a) = \theta q_a - c + \beta \max \left\{ V^1(\theta, a+1), \max_{a'} V^1(\theta, a') - p_{a'} + (1 - \lambda_{a+1}) p_{a+1} \right\}. \quad (1)$$

[9] In fact, if we allow holding costs to increase with the age of the car, the only relevant ones are those for cars close to scrappage age.

[10] We also allowed α to be heterogeneous across households. Obviously, adding this heterogeneity allows our model to match the data better. However, since our calibration with homogeneous α already matches the data very well (see Table 3), we choose the more parsimonious parametrization.

[11] Two comments on our assumption on transaction costs: 1) Some dependence of transaction costs on prices is realistic. Allowing for a fixed component of transaction costs is straightforward and does not change our qualitative and quantitative results; and 2) the fact that transaction costs are paid by the sellers is immaterial since, as in the analysis of tax incidence, equilibrium allocations are invariant to the "statutory incidence" of transaction costs.

Equation (1) says that the household enjoys a current-period utility flow equal to $\theta q_a - c$ from owning a car of age a. In the following period, the household decides whether to keep it (obtaining a value equal to $V^1(\theta, a+1)$) or sell it to replace it with a newer one, thereby obtaining a value equal to:

$$\max_{a'} V^1(\theta, a') - p_{a'} + (1 - \lambda_a) p_a. \tag{2}$$

As Stolyarov (2002) shows, for each household θ, there is an $a^*(\theta)$ that maximizes equation (2); $a^*(\theta)$ is the vintage that household θ buys whenever it replaces the car. Moreover, since the utility flow $\theta q - c$ is increasing in the quality of the car, and quality depreciates over time, the household θ replaces its car whenever the car reaches age $a^{**}(\theta)$. Such age $a^{**}(\theta)$ satisfies the following two inequalities:

$$\begin{aligned} V^1(\theta, a^{**}) &< V^1(\theta, a^*) - p_{a^*} + (1 - \lambda_{a^{**}}) p_{a^{**}}, \\ V^1(\theta, a^{**} - 1) &> V^1(\theta, a^*) - p_{a^*} + (1 - \lambda_{a^{**}-1}) p_{a^{**}-1}. \end{aligned}$$

The first inequality says that the household prefers to simultaneously sell a vintage-a^{**} car and purchase a vintage-a^* car, rather than to keep the vintage-a^{**} car. The second inequality says that the household prefers to keep a vintage-$a^{**}-1$ car, rather than to sell it and purchase a vintage-a^* car.

The previous arguments imply that it is optimal for a household θ to buy a car of age $a^*(\theta)$ and to keep it until it reaches age $a^{**}(\theta)$, for a total of $n^*(\theta) = a^{**}(\theta) - a^*(\theta)$ periods. It easy to show that $a^*(\theta)$ and $a^{**}(\theta)$ are decreasing in θ—i.e., households with stronger preferences for quality choose newer vintages. Thus, we can write the value function $V^1(\theta, a, n)$ of a household with valuation θ buying a car of quality a and keeping it for n periods as:

$$V^1(\theta, a, n) = \frac{\theta \sum_{i=0}^{n-1} \beta^i q_{a+i} - c \sum_{i=0}^{n-1} \beta^i - p_a + \beta^n (1 - \lambda_{a+n}) p_{a+n}}{1 - \beta^n}.$$

The household's problem is to choose the optimal quality of car q_{a^*} to acquire and the optimal holding time $n^* = a^{**} - a^*$. Hence, the optimal $\{a^*, n^*\}$ solve:

$$\max_{\{a,n\}} V^1(\theta, a, n) = \max_{\{a,n\}} \frac{\theta \sum_{i=0}^{n-1} \beta^i q_{a+i} - c \sum_{i=0}^{n-1} \beta^i - p_a + \beta^n (1 - \lambda_{a+n}) p_{a+n}}{1 - \beta^n}. \tag{3}$$

The value of owning two cars is more complex because a household can choose to follow a separate policy for each of its two cars. However, a household can economize on transaction costs for its second car by keeping the depreciated first unit as a second car. Indeed, this "intra-household trade" is an important feature of households' observed behavior, as we will report in more detail in Section 4.1.[12] To simplify the computation of the household's decision problem, we allow the household to choose only among the following class of policies: The household keeps any car for a total of n periods, but then alternates between acquiring a newer vintage every m and $m-n$ periods. Thus, such a policy combines two cycles. In the first cycle, the household keeps a car as its first car for m periods, and then the car becomes the second car for the remaining $n-m$ periods. In the second cycle, the household keeps a car as its first car for $n-m$ periods, and then the car becomes the second car for the remaining m periods. Obviously, if $n-m=m$, then the household buys a car every $\frac{n}{2}$ periods and keeps it for n periods. This class of (n,m) policies encompasses a large number of possibilities, and it can be shown that, when transaction costs are sufficiently high, the optimal policy belongs to this class.

The value $V^2(\theta,a,n,m)$ of following a (n,m) policy for a household with valuation θ equals:[13]

$$\begin{aligned} &V^2(\theta,a,n,m) = \\ &\frac{\theta\sum_{i=0}^{m-1}\beta^i q_{a+i} + \alpha\theta\sum_{i=m}^{n-1}\beta^i q_{a+i} - c\sum_{i=0}^{n-1}\beta^i - p_a + \beta^n(1-\lambda_{a+n})p_{a+n}}{1-\beta^n} + \\ &\beta^m \frac{\theta\sum_{i=0}^{n-m-1}\beta^i q_{a+i} + \alpha\theta\sum_{i=n-m}^{n-1}\beta^i q_{a+i} - c\sum_{i=0}^{n-1}\beta^i - p_a + \beta^n(1-\lambda_{a+n})p_{a+n}}{1-\beta^n}. \end{aligned} \tag{4}$$

The first term on the right-hand side of equation (4) is the discounted flow of utility provided by a car that is the household's first car for m periods, then is the second car for $n-m$ periods, and then is sold. Similarly, the second term is the discounted flow of utility provided by a car that is the household's first car for $n-m$ periods, then becomes the second car for additional m periods, and then is sold.

Each household θ chooses the optimal number $k^*(\theta)$ of cars to maximize its value function $W(\theta)$, which equals:

$$W(\theta) = \max\left\{V^0, \max_{\{a,n\}} V^1(\theta,a,n), \max_{\{a,n,m\}} V^2(\theta,a,n,m)\right\}. \tag{5}$$

[12] More specifically, this "intra-household" trade accounts for the difference between the fractions of cars traded and the fraction of household trading a car reported in the first and the second lines, respectively, of Table 1.

[13] Equation (4) assumes that for the first m periods, the household has only one car and does not have a second car until it replaces its first car.

Based on households' choices, the steady-state distribution $h_a(\theta)$ of owners of a car of quality q_a is:

$$h_a(\theta) = \begin{cases} \frac{k^*(\theta) f(\theta)}{n^*(\theta)} & \text{if } a^*(\theta) \leq a < a^*(\theta) + n^*(\theta) \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

Finally, the endogenous scrappage age T^* is determined by the following conditions: 1) No household chooses to keep a car of quality q_{T^*}; 2) no household buys a car of quality q_{T^*}; and 3) a car of quality q_{T^*} has a price p_{T^*} equal to zero.

The market equilibrium is defined by standard competitive conditions. Specifically, an equilibrium is a vector of household decision rules $\{k^*(\theta), a^*(\theta), n^*(\theta), m^*(\theta), T^*\}$ and a vector of prices $p = (p_0, .., p_{T^*-1})$ such that: (i) Decision rules are optimal, and (ii) For every vintage a, markets clear:

$$\int h_a(\theta)\, d\theta = x \quad \text{for} \quad a = 0, .., T^* - 1.$$

4 Calibration

4.1 Data

We use data from the *2000 Consumer Expenditure Survey* (CEX), a cross-sectional survey of 7,860 U.S. households. CEX reports detailed information about households' vehicles at the time of the interview, such as the model; the age; whether it is owned or leased; whether it was acquired in the last 12 months; whether it was acquired new or used; and the price paid.[14] CEX also reports households' income, which we will use to capture households' willingness to pay for car quality in our quantitative analysis in Section 4.

Table 1 reports some aggregate statistics on households' car holdings, computed from the CEX, that the quantitative analysis of our model will successfully match. Specifically, the first row reports that, on average, one in every three U.S. households acquired a car in the 12 months prior to the survey interview. The second row reports that one in every 4.5 cars was purchased within the last 12 months. The third row reports that, of all cars traded, approximately one in every four cars was new. The last three rows report the fraction

[14] CEX also reports some information on cars provided by the employers (company cars), but this information is less detailed than information about personal cars. In addition, in some cases, the decision to replace a company car may not be entirely in the hands of the household. For these reasons, we exclude company cars from our analysis.

Table 1: Secondary Market for Cars, U.S.

$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	3.09
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	4.54
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.55
Households with no car	0.13
Households with one car	0.34
Households with more than one car	0.53

Notes: This table provides aggregate statistics of the U.S. car market computed from the *2000 Consumer Expenditure Survey*.

of households with zero, one and more than one car, respectively. The majority of U.S. households hold more than one car.[15] Overall, these patterns indicate that secondary car markets are very active.

4.2 Choice of Parameters

We calibrate the model to investigate whether it can quantitatively replicate the aggregate statistics for the U.S. markets reported in Table 1. We report in Table 2 the numerical values of the parameters that the we use in our calibration, and we describe below how we choose these numerical values, thereby providing intuitive arguments on the "identification" of these parameters. Most parameters map directly into data analogs, whereas we calibrate two parameters—i.e., the car maintenance cost c and the marginal value of the second car α—to match aggregate statistics on trade volume and car holdings.

An important input into our quantitative analysis is the distribution of θ. This is not directly observable. We decided to use the distribution of household gross income as the distribution of θ. This choice can be partially justified theoretically, based on the following remark.

[15]More precisely, 33 percent of households hold two cars; 13.4 percent of households hold three cars; 4.4 percent of household hold four cars; 1.4 percent of households hold five cars; and 0.65 percent of households hold six or more cars. Our model pools all these households into households with two cars.

Table 2: Calibration Parameters

Parameter	μ	σ	β	δ	xT^*	T^*	c	α
Numerical Value	10.06	1.32	.95	.08	1.40	17	278	.25

Notes: This table provides the numerical values of the parameters used in the calibration.

Remark 1 *If consumers have logarithmic utilities in income, and there are no borrowing constraints, then θ is equal to total expenditure on all goods except cars. Thus, the distribution of income is a good approximation for the distribution of θ.*

In order to understand this remark, consider the following static problem: A household of type θ faces a distribution of qualities q available at price $p(q)$, and chooses q to maximize $\theta q - p(q)$. The first-order condition for this problem is:

$$p'(q) = \theta.$$

Now, consider a household with income y and log utility for the outside good. The household solves

$$\max_q \{q + \log(y - p(q))\}.$$

The first-order condition for this problem is:

$$p'(q) = y - p(q).$$

Thus, if we define $\theta \equiv y - p(q)$, our linear model generates the same choices for consumers. In our model, choosing the age and holding time of a car is the same as choosing its quality, with $p(q)$ replaced by the appropriate equivalent rental price (with transaction costs). The distribution of spending on the outside good $y - p(q)$ is our distribution of θ. In our analysis, we use income y directly.[16] Using the CEX, we find that a lognormal distribution with parameters $\mu = 10.06$ and $\sigma = 1.32$ fits the distribution of income well. These parameters match the CEX average household income of $42,100.

We assume that one period in the model is equal to one year, and we set the discount rate $\beta = .95$.

[16] This is a reasonable approximation. Expenditures for Transportation have a weight equal to 17.3 percent in the basket of goods and services that constitutes the Consumer Price Index. New and used motor vehicles have a weight of 6.3 percent. Furthermore, these expenditures have a high correlation with income, so the dispersion of $y - p(q)$ and the dispersion of y are very similar.

We choose the value of the total stock of cars xT^* to match the sum of the fraction of households with one car plus twice the fraction of households with more than one car. Moreover, we choose a value of the per-period holding cost c to match the scrappage age T^* of cars. In Table 1, we report the ratios

$$r_1 = \frac{\textsc{Total stock of cars}}{\textsc{Cars acquired last 12 months}}$$

and

$$r_2 = \frac{\textsc{Cars acquired last 12 months}}{\textsc{New Cars acquired last 12 months}}.$$

In steady state, the total stock of cars is equal to xT^*, and the mass of new cars acquired in every period is equal to the flow of new cars x. Thus, we can calculate T^* as $T^* = r_1 r_2$. The calculations imply that $T^* = 16.61$ for the U.S., which we approximate to the closest integer: $T^* = 17$. We then calibrate the holding cost c to match this scrappage age T^*, and the corresponding value is $c = 278$ dollars.

The average price of a new-car purchase reported in the CEX is \$22,000, and we choose $q_0 = 0.2$ to match this new-car price. We further let $q_a = (1-\delta)^a q_0$, with a value of $\delta = .08$ to match the average annual depreciation of car prices of around 20 percent.[17]

To calculate transaction costs λ_a, we use price data obtained from the Kelley Blue Book for the most popular cars in the U.S.: Toyota Corolla, Toyota Camry, Toyota Previa and Toyota Sienna. As in Porter and Sattler (1999), we estimate transaction costs using the difference between suggested retail and trade-in values. These values evolve from approximately 15 percent for one-year-old cars to more than 50 percent for cars older than ten years of age. We then fit a quadratic polynomial regression in age to these data on transaction costs to smooth them and average them across different cars.[18]

Finally, we calibrate the parameter $\alpha = .25$ to match the aggregate statistics reported in Table 1. The key statistic that pins down the value of α is the number of cars per household.

[17] We also considered values of $\delta = .09$ and $\delta = .07$. The results (available from the authors upon request) are almost identical.

[18] Our estimates of transaction costs do not take into account that transaction costs may be heterogeneous across households. Specifically, for individuals who choose to transact with dealers, the bid-ask spread is a lower bound on their transaction costs. Instead, for households that choose to transact with private parties, the bid-ask spread is likely an upper bound on their transaction costs. Unfortunately, allowing for heterogeneous transaction costs is computationally burdensome.

Table 3: Secondary Markets: Model vs. Data

	Data	Model
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	3.09	2.89
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	4.54	4.60
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.55	3.69
Households with no car	0.13	0.13
Households with one car	0.34	0.34
Households with more than one car	0.53	0.53

Notes: This table reports the moments of the data that the model seeks to match and the corresponding moments computed from the model with the parameters reported in Table 1.

4.3 Computational Algorithm

For any values of the parameters, we take $N = 10,000$ draws of θ from the lognormal income distribution, and we compute the equilibrium using the following steps:

1. We start with a vector of prices $p = (p_0, .., p_{T-1})$.

2. For each household θ, we calculate the optimal $k^*(\theta)$, $a^*(\theta)$, $n^*(\theta)$ and, if $k^*(\theta) = 2$, the optimal $m^*(\theta)$ that maximize equation (3).

3. We calculate the steady-state distribution $h_a(\theta)$ as $\frac{k^*(\theta)}{n^*(\theta)N}$ if $a^*(\theta) \leq a < a^*(\theta)+n^*(\theta)$, and 0 otherwise.

4. We calculate the integral of the steady-state distribution (6) of age a as $\sum_{i=1}^{N} h_a(\theta_i)$.

5. We search for the vector of prices p that minimizes the excess demand of all vintages. More formally, we search for the vector of prices p that minimizes the largest absolute value of excess demand across all vintages $\max\limits_{a\in\{0,...,T^*-1\}} \left\{\left|\sum_{i=1}^{N} h_a(\theta_i) - x\right|\right\}$.

4.4 Results

Table 3 reports the numerical results of the calibration of our model, along with the observed values in the data. (In the analysis in the following sections, we refer to the results of Table

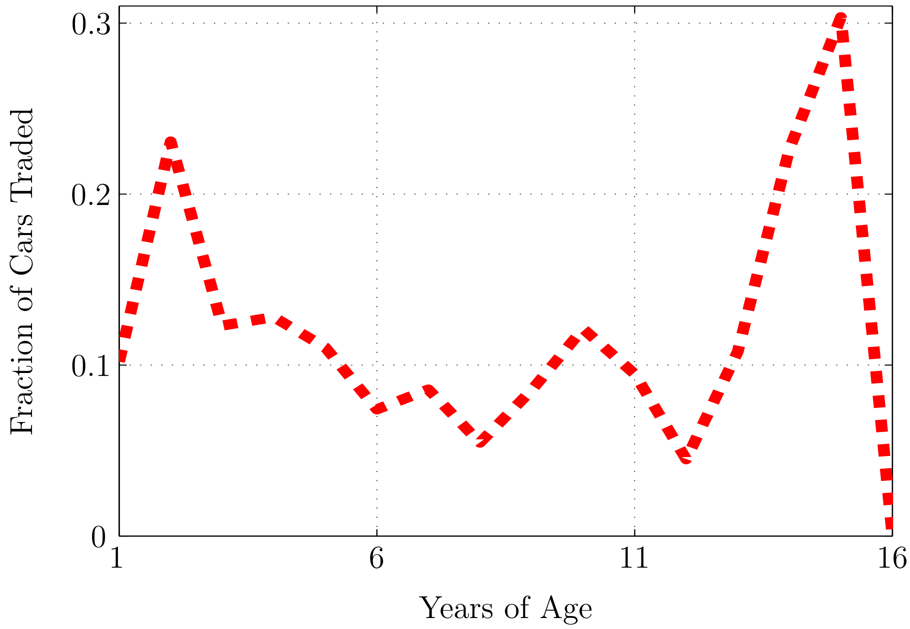

FIG. 1: The figure displays the steady-state fraction of cars traded by vintage.

3 as the "baseline case.") The model is a quantitative success, as it matches the aggregate features of the U.S. car market well. This suggests that, to understand the allocative role of secondary markets, our simple model of vertical differentiation with transaction costs captures the key gains from trade in the used-car market, and, therefore, including additional dimensions of heterogeneity may have limited value.

We discuss below key outcomes of the calibrated model in greater detail

Trade. The model closely matches the statistics on aggregate trade in cars and activity in secondary markets, most notably the fraction of households acquiring a car and the fraction of cars traded.

Figure 1 shows the fractions of used cars traded by age, generated by the model. The plot shows that the relationship between the fraction of used car traded and the age of the car is non-monotonic. These patterns of trade are the focus of Stolyarov (2002). The intuition for the spikes of trade is that, because of transaction costs, only a small fraction of households sells their car after one period, so the resale rates are (locally) increasing when cars are relatively new. Moreover, households are unlikely to purchase old cars that they would scrap after just one period, so the resale rates are (locally) decreasing when cars are old.

Cars per Household. Table 3 shows that the model matches well the fraction of households with no car, one car, and more than one car. The parameter that allows the model to match these statistics is α, the ratio between the value of the second and the first car.

Car Prices. Equilibrium prices decline at a fast rate—approximately 20 percent per year—because of cars' physical depreciation (assumed to be eight percent per year) and because of the equilibrium sorting of consumers across vintages. The reason for this large price decline is that the U.S. income distribution displays wide dispersion, and, thus, the willingness to pay for a marginally better car is high. In Section 5.3, we will see that in France, where the dispersion of the income distribution is lower, the price decline is not as steep.

5 Counterfactual Analyses

We now perform several counterfactuals. Specifically, we analyze the effects of transaction costs by considering two extreme cases: frictionless secondary markets and complete shutdown of secondary markets. By changing the frictions in the secondary market relative to our calibrated baseline, these counterfactuals can help us gain some quantitative insights into the allocative and welfare effects of secondary markets. We then consider the case of scrappage policies that eliminate the availability of older cars. Finally, we delve deeper into the effects of income heterogeneity by calibrating our model to French data.

Naturally, we expect any changes in secondary markets to affect primary markets. Thus, the supply response of new-goods producers is an important element determining the welfare consequences of secondary markets' frictions. We consider two alternative scenarios that help highlight how primary markets adjust. First, we consider the case of perfectly elastic supply—i.e., the price of new cars does not respond to changes in transaction costs, but the quantity does. Second, we consider the case of perfectly inelastic supply—i.e., the quantity of new cars does not respond to changes in transaction costs, but the price does. These two cases can be interpreted as two extremes—of a perfectly competitive industry with constant marginal costs of production, and the other of an industry with binding capacity constraints for all producers. Hence, we wish to emphasize that our counterfactuals consider only short-run effects since the supply-side response to the change in transaction costs is limited. Nonetheless, we believe that these counterfactuals are useful for understanding the importance of transaction costs for manufacturers since they indicate that *either* output *or* prices change when transaction costs change, even in a oligopolistic market for new cars.[19]

In our analysis, we calculate average per-capita flow of consumer surplus as

$$\frac{(1-\beta)\sum_{i=1}^{N} W(\theta_i)}{N}.$$

Moreover, we calculate producers' per-capita flow profits as $(p_0 - mc)\,x$. In the case of a perfectly elastic supply, profits are zero. In the case of an inelastic supply, we impute the marginal cost mc to be equal to the baseline new-car price p_0. Hence, producers' profits are zero in the baseline case, whereas they are equal to $(p_0' - p_0)\,x$ in counterfactual scenarios, where p_0' is the counterfactual new-car price.

The differences in allocations and welfare between our counterfactuals and the baseline case are largely due to three economic effects that we will discuss in more detail for each case.

1. Increasing (decreasing) transaction costs has the partial-equilibrium direct effect of destroying (freeing) resources, thereby affecting households' willingness to pay because they obtain different net resale prices.

2. Lower (higher) transaction costs have the partial-equilibrium indirect effect of allowing a finer (coarser) matching between households' preferences and the quality of their cars.

3. Effects (1) and (2) feed into the general-equilibrium effects of changing new- and used-car prices and/or quantities relative to the baseline case.

5.1 The Effects of Transaction Costs

In this section, we consider the allocative and welfare effects of transaction costs. This is the natural starting point to study the importance of secondary markets. As described in Section 4, in our quantitative analysis, we use transaction costs proportional to prices, calculated by fitting dealer bid-ask spreads. We now consider two extreme counterfactual scenarios: frictionless secondary markets and complete shutdown of secondary markets. These cases correspond to $\lambda_a = 0$ and $\lambda_a = 1$ for all a, respectively.

[19] Our counterfactual analyses do not consider how changes in secondary markets affect the quality of new cars produced. We focus on a single quality of new cars to simplify the way secondary markets expand the array of goods available to consumers, but the forces we discuss still hold when new cars of different qualities are available. Our model can be extended to accommodate multiple qualities on the primary market, along with different durabilities across cars.

5.1.1 Frictionless Resale Markets

When transaction costs are zero—i.e., $\lambda_a = 0$ for all a—the households' maximization problem is equivalent to a static one. Households hold the same car vintage/quality over time by trading in their depreciated units every period. Of course, households differ in the vintage they hold. The equilibrium displays perfect matching between households' preferences (either θ or $\alpha\theta$) and the qualities of the cars chosen in every period. Market clearing requires that either:

1. All households have at least one car, and the highest-income households own two cars. In this case, there is a threshold value θ' that satisfies $X = F(\theta') + 2(1 - F(\theta')) = 2 - F(\theta')$—i.e., all households with income below θ' own one car (the term $F(\theta')$), and all households with income above θ' own two cars (the term $2(1 - F(\theta'))$); or

2. there are households with zero, one, and two cars. In this case, there are thresholds θ'' and θ''' that satisfy $X = 1 - F(\theta'') + 2(1 - F(\theta'''))$ and $\theta'' = \alpha\theta'''$—i.e., all households with income above θ'' own one car (the term $1 - F(\theta'')$), all households with income above θ''' own two cars (the term $2(1 - F(\theta'''))$), and the lowest willingness-to-pay of one- and two-car households is the same.

Case 2 is the empirically relevant one.

Table 4 reports the quantitative results with counterfactual zero transaction costs for the cases of a perfectly elastic supply of new cars—i.e., the price p_0 of new cars is the same as in our baseline case in Section 4—and for the case of a perfectly inelastic supply of new cars—i.e., the quantity x of new cars is the same as in the baseline case in Section 4. Overall, the quantitative effects are similar in these two supply scenarios.

Quantity of cars. Table 4 reports that new-car output increases in the case of elastic supply relative to the baseline case. The reason is that the reduction in transaction costs and the finer matching of qualities to households' valuations combine to raise high-valuation households' willingness to pay. Since prices are kept at the same level by the adjustment of (perfectly elastic) supply, the number of new cars demanded increases. In contrast, by definition, new-car output is unchanged in the case of inelastic supply.

When new-car supply is elastic, the scrappage age decreases slightly relative to the baseline case. The reason is the following. If the scrappage age does not decrease, the increase in the supply of new cars leads to an increase in the total stock of cars. Hence, the marginal

Table 4: Allocative and Welfare Effects of Secondary Markets, No Transaction Costs

	Baseline	Elastic Supply	Inelastic Supply
$\frac{\text{New Cars}}{\text{New Cars, Baseline Case}}$	1	1.05	1
$\frac{\text{Price of a New Car}}{\text{Price of a New Car, Baseline Case}}$	1	1	1.05
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	2.89	1	1
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	4.60	1	1
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.69	16.2	17
Households with no cars	0.13	0.13	0.13
Households with one car	0.34	0.34	0.34
Households with two cars	0.53	0.53	0.53
$\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}$	1	1.04	1.03
$\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	1.11	1.08
$\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	1.12	1.08
$\frac{\text{Welfare}}{\text{Welfare, Baseline case}}$	1	1.04	1.04
$\frac{\text{Transaction Costs}}{\text{Consumer Surplus}}$	0.02	NA	NA

Notes: This table reports statistics on allocations and welfare computed from the model with no transaction costs (i.e., $\lambda_a = 0$) and with an elastic or inelastic supply of new cars, respectively. $\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ and $\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ are computed using only households with cars in the baseline case.

owner of a car would have a lower valuation (either θ or $\alpha\theta$) than in the baseline case. However, taking into account that the holding cost c is such that the marginal owner for the baseline case has zero utility, the reduction in marginal valuation implies that the marginal owner's net utility flow in the new scenario has to be negative, which is a contradiction. The reduction in scrappage age implies that some low-valuation consumers scrap their cars at the earlier age of $T = 16$. In contrast, when new-car supply is inelastic, the scrappage age is the same as in the baseline case. The reason is that the total stock of cars does not change, and, therefore, the optimal scrapping age does not change either since net prices (i.e., net of transaction costs) are positive in both cases. Overall, the total stock of cars is the same in both supply scenarios as in the baseline case.

Prices. New-car prices are obviously unchanged when the supply of new cars is elastic, whereas new-car prices increase when the supply of new cars is inelastic. This increase is the mirror image of the increase in output discussed above for the case of elastic supply. First, the absence of transaction costs allows higher-valuation households to capture the full resale value of cars, thereby increasing their willingness to pay. Second, the absence of transaction costs allows a finer matching between household preferences and cars. In particular, higher-income households own better cars, thereby increasing their willingness to pay.

Interestingly, in both new-car supply scenarios, prices of older cars (i.e., older than the median/average car) decline relative to the baseline case—on average, by 9.8 percent when supply is elastic and by 8.6 percent when supply is inelastic. The intuition for the decrease is consistent with the new-car price increase and arises from the balancing of two contrasting effects. First, as cars age, the expected number of future trades is smaller. Hence, while the elimination of transaction costs raises households' willingness to pay, this effect is smaller for older goods than for newer goods. Second, the finer matching allowed by frictionless trade implies that, relative to the baseline case, lower-valuation households own older cars. Overall, the second negative effect dominates the first positive (but small) one for older goods, thereby depressing their prices. When the supply of cars is elastic, there is an additional effect coming from the higher new-car output. Since only some of the oldest cars are scrapped when transaction costs are zero, the stock of cars of all vintages $a < T$ is higher too. Thus, since the equilibrium displays perfect matching between households' preferences and the quality of their cars, the valuation (either θ or $\alpha\theta$) of the owner of each vintage $a < T$ has to drop to equate supply and demand.

Trade. The effect of removing transaction costs on the volume of trade is dramatic, but perhaps unsurprising. When transaction costs are zero, all cars trade in every period, so the volume of trade is equal to 100 percent. This explains the third, fourth and fifth rows of Table 4.

Cars per Household. The distribution of the number of cars per household is exactly the same in the counterfactual scenarios as in the baseline case. This holds in our model as long as there is trade in the oldest vintage. To understand the reason for this feature, note that the price of the oldest vintage must be zero because the identity of the last vintage is determined by lowest-valuation used-car owner's indifference between owning a car of that vintage or scrapping it—thereby not owning any car and enjoying a utility flow of zero. Hence, the scrappage age is determined by the equality of the utility flow for the last vintage (either $\theta'' q_T$ or $\alpha\theta''' q_T$) and the holding cost c of the lowest-valuation used-car owner (either θ'' or $\alpha\theta'''$). Since the utility flow is higher with younger vintages, the previous arguments imply that to figure out whether a household with valuation θ owns a car, it is enough to determine if its utility flow for the last vintage (either θq_T or $\alpha\theta q_T$) exceeds the holding cost c. Since the total stock of cars is the same in the counterfactual scenarios as in the baseline scenarios, it must also be the case that the marginal θ (and $\alpha\theta$) owning a unit is the same, implying that the distribution of cars per household is also the same.

Welfare. The three economic effects of removing transaction costs—i.e., the direct one of freeing resources, the indirect effect of allowing a finer matching between preferences and vintages, and the general-equilibrium effect on prices—have a contrasting impact on consumer surplus and on overall welfare relative to the baseline case. Specifically, when there are no transaction costs, the first two effects increase consumer surplus and welfare relative to the baseline case. Instead, the general-equilibrium effect on prices—lower on old cars and higher on new cars when the supply is inelastic—has a heterogeneous impact on individual households' surplus, depending on their income, and a negative impact on aggregate consumer surplus, but a positive impact on producers' profits when supply is inelastic.

Figure 2 displays the ratio between consumer surplus in the counterfactual case of zero transaction costs and consumer surplus in the baseline case for all households that acquire a car, ranked by the percentile of their income, for the two scenarios of elastic and inelastic supply. Overall, Figure 2 shows that surplus is higher when transaction costs are zero for

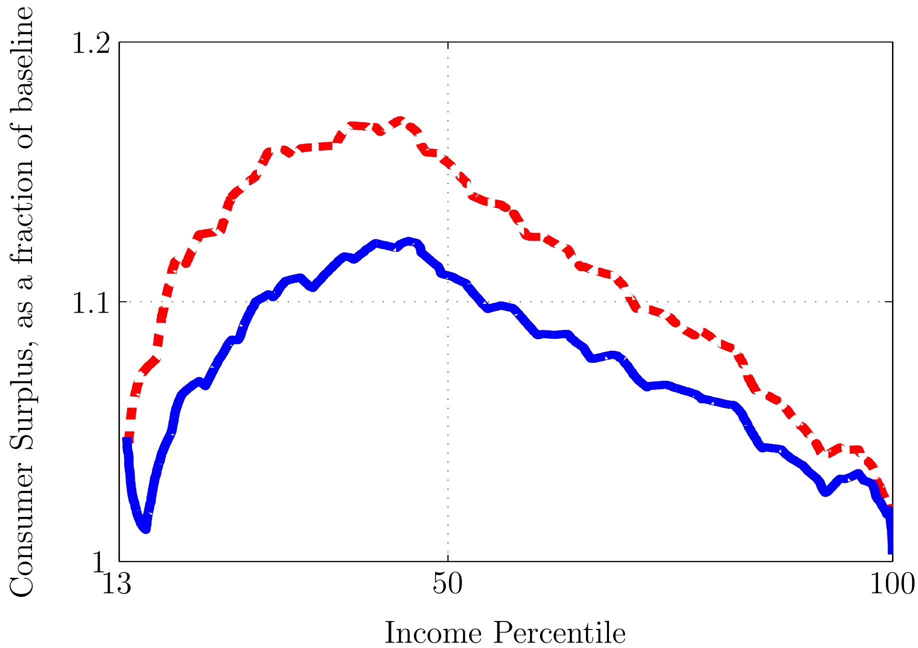

FIG. 2: The figure displays counterfactual consumer surplus with no transaction costs relative to baseline consumer surplus by income percentile, elastic new-car supply (dashed line) and inelastic new-car supply (solid line). Consumer surplus is calculated as the value function $W(\theta)$.

all households, indicating that the first two effects dominate even the effect of higher new-car prices due to an inelastic new-car supply. Moreover, interestingly, these surplus ratios are non-monotonic in income. The reason is that, when there are no transaction costs, households trade cars every period. Instead, in the baseline model, households' car-trading decisions trade off the loss in consumer surplus due to coarser matching with the loss due to transaction costs. In equilibrium, surplus losses are decreasing in the (equilibrium) frequency of trade. Figure 1 shows that the volume of trade is non-monotonic: highest for young and old cars, lowest for middle-aged cars. Because of households' sorting into different vintages based on their income, Figure 1 implies that households with high or low income trade their cars more frequently than middle-income households, thus explaining why middle-income households gain the most when transaction costs vanish. Overall, the average and median percentage surplus gains from having frictionless resale markets equal eight to 11 and eight to 12 percent of the baseline surplus, respectively, depending on the elasticity of the new-car supply.

Table 4 reports that, when secondary markets are frictionless, total consumer surplus increases by three or four percent, corresponding to 363 or 490 dollars per household per year, relative to the baseline case, depending on the new-car supply. Table 4 further reports that the increase in aggregate consumer surplus is smaller than the increase for most households (as displayed in Figure 1); this is because the highest-income households have disproportionate weights in the calculation of aggregate consumer surplus due to the large income inequality in the U.S., and these households receive the smallest gains.

When supply is elastic, producers' profits are zero and, thus, welfare increases by four percent. When supply is inelastic, producers' profits increase relative to the baseline case since new-car prices are higher. Overall, removing transaction costs increases welfare by four percent in the case of inelastic new-car supply, as well. Almost all of this increase is due to the increase in consumer surplus.

The magnitudes reported in Table 4 allow us to quantify the three economic effects of removing transaction costs. The last row of Table 4 reports that the direct effect of transaction costs equals two percent of consumer surplus in the baseline case. Since the total effect of removing transaction costs on consumer surplus when new-car supply is elastic equals four percent of consumer surplus, the indirect effect through a finer matching between preferences and vintages is of the same order of magnitude as the direct effect of transaction costs—equal to approximately two percent of consumer surplus (and welfare). Instead, the difference between aggregate welfare and consumer surplus when new-car supply is inelastic suggests that the general-equilibrium effect on new-car prices—or, alternatively, supply distortions—is approximately equal to one percent of welfare, a smaller magnitude than that of the other two effects of transaction costs.

5.1.2 No Resale Markets

When transaction costs are prohibitive (i.e., $\lambda_a = 1$), households optimally purchase only new cars, and their key choice is how long to keep them before scrapping and replacing them. In equilibrium, each household has an optimal scrappage age $T(\theta)$, with households with higher valuation θ scrapping their cars earlier, thereby holding, on average, younger vintages.

Table 5 reports the quantitative results with counterfactual prohibitive transaction costs for the case of a perfectly elastic supply of new cars—i.e., the price p_0 of new cars is the same as in our baseline case in Section 4—and for the case of a perfectly inelastic supply of new cars—i.e., the quantity x of new cars is the same as in the baseline case in Section 4. Overall, as in the previous analysis of no transaction costs, the quantitative effects are

Table 5: Allocative and Welfare Effects of Secondary Markets, Prohibitive Transaction Costs

	Baseline	Elastic Supply	Inelastic Supply
$\frac{\text{New Cars}}{\text{New Cars, Baseline Case}}$	1	1.21	1
$\frac{\text{Price of a New Car}}{\text{Price of a New Car, Baseline Case}}$	1	1	1.25
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	2.89	5.99	6.48
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	4.60	9.97	10.62
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.69	1	1
Households with no cars	0.13	0.41	0.47
Households with one car	0.34	0.20	0.19
Households with two cars	0.53	0.40	0.34
$\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}$	1	0.95	0.89
$\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.55	0.43
$\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.71	0.49
$\frac{\text{Welfare}}{\text{Welfare, Baseline case}}$	1	0.95	0.94
$\frac{\text{Transaction Costs}}{\text{Consumer Surplus}}$	0.02	NA	NA

Notes: This table reports statistics on allocations and welfare computed from the model with prohibitive transaction costs (i.e., $\lambda_a = 1$) and with an elastic or inelastic supply of new cars, respectively. $\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ and $\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ are computed using only households with cars in the baseline case.

similar in the two supply scenarios.

Quantity of cars. Table 5 reports that, when new-car supply is elastic, new-car output increases by 21 percent relative to the baseline case. Note that this implies that output is non-monotonic in transaction costs since Table 4 shows that new-car output is also larger when there are no transaction costs relative to the baseline case. However, different forces affect output in the two extreme counterfactual scenarios. The reason for the large increase when transaction costs are prohibitive is that scrappage increases dramatically. This is because the secondary-market shutdown implies that the only way for households to upgrade their quality is to scrap their current cars. From the numbers reported in Table 5, it can be verified that, on average, scrappage occurs at approximately age 11, as compared to age 17 in the baseline case.[20] The comparison between the elastic and inelastic cases indicates that, on average, households scrap cars slightly later in the case of inelastic supply. The reason is that, with inelastic supply, new-car output does not increase to partially compensate for earlier scrappage, leading to a higher new-car price and dampening the incentive to scrap early. Overall, the total stock of cars decreases substantially relative to the baseline case, in particular in the case of inelastic supply.

Prices. Table 5 reports that, when new-car supply is inelastic, new-car prices increase by 25 percent relative to the baseline case. This is a mirror image of the increase in output in the case of a perfectly elastic supply. More precisely, prices of new cars increase relative to the baseline case because the demand for new cars increases. Since households scrap their cars earlier than in the baseline case—the mean scrappage age is 10.63 and the median is 11—the demand for new cars increases, and so does their price.

Trade. The effect of prohibitive transaction costs on the volume of trade is, again, unsurprising. When transaction costs are prohibitive, the volume of trade in used cars is zero. This, along with the change in the stock of cars, explains rows 4 and 5.

Cars per Household. Overall, the inability to resell cars reduces the stock of cars relative to the baseline case. Thus, the fraction of households with no cars increases and the fraction of households with cars decreases relative to the baseline case. However, a natural question arises: Since transaction costs are prohibitive, why do some households choose to

[20]The median age of scrappage is nine because the distribution of scrappage ages is asymmetric, with many households scrapping their cars when it is 17.

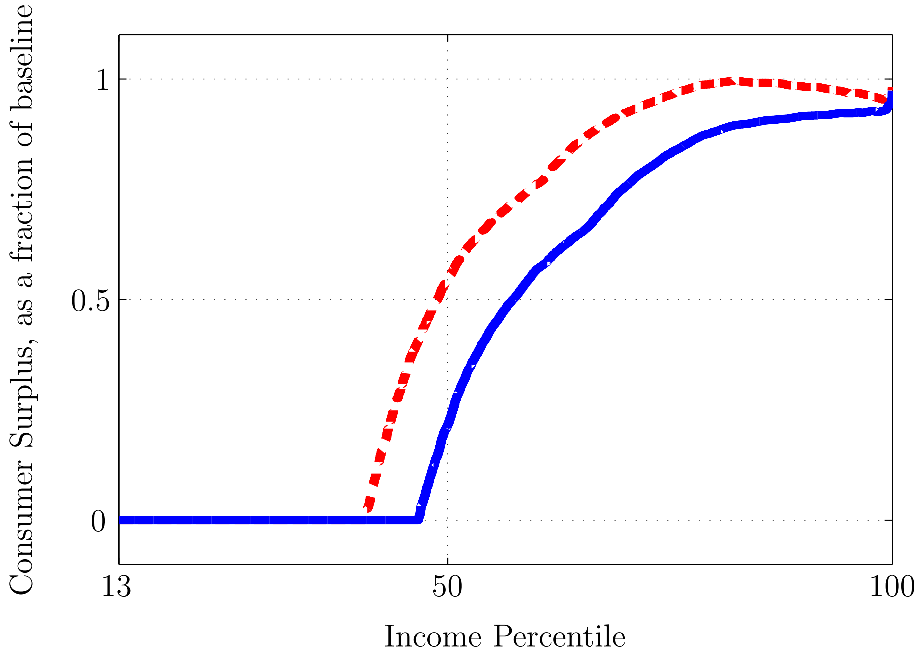

FIG. 3: The figure displays counterfactual consumer surplus with prohibitive transaction costs relative to baseline consumer surplus by income percentile, elastic new-car supply (dashed line) and inelastic new-car supply (solid line). Consumer surplus is calculated as the value function $W(\theta)$.

have only one car—i.e., why do they scrap the car rather than keeping it as a second car? The reason is that households keep cars as second cars (rather than scrapping them) as long as they provide positive utility flows. Since households keep their first cars until they are quite old, these cars are, on average, of low quality. Hence, some households would have negative net utility flow from these cars (i.e., negative $\alpha\theta q - c$) and, thus, would prefer to scrap them.

Welfare. Figure 3 displays the ratio between consumer surplus with prohibitive transaction costs and consumer surplus in the baseline case for all households that acquire a car in the baseline case, ranked by the percentile of their income, for the two scenarios of elastic and inelastic supply. The figure confirms that surplus is higher for all households when new-car supply is more elastic. The figure also shows that households at the bottom of the income distribution suffer the largest surplus loss relative to the baseline case because the lower stock of cars imply that these households do not own a car. Indeed, the surplus losses are quite dramatic for households with income below the median of the distribution:

The average and the median percentage losses equal 45-57 percent and 29-51 percent of the baseline surplus, respectively, depending on the elasticity of the new-car supply. Overall, Table 5 reports that, relative to the baseline case, aggregate consumer surplus drops by only five percent when supply is elastic and by eleven percent when supply is inelastic, corresponding to 571 or 1197 dollars per household per year, respectively. Table 5 reports that the drop in aggregate consumer surplus is smaller than the drop for most households because the highest-income households have disproportionate weights in the calculation of aggregate surplus, and Figure 3 shows that these households have the smallest surplus loss.

When new-car supply is inelastic, producers' profits increase substantially since new-car prices increase by 25 percent, as indicated in the first row of Table 5. Overall, the decrease of consumer welfare due to higher new-car prices is approximately equivalent to the increase in producer profits. Thus, the magnitude of the aggregate decrease in welfare due to prohibitive transaction costs relative to the baseline case is similar—five or six percent—in both supply scenarios.

5.2 Scrappage Policies

In this section, we investigate how scrappage policies affect equilibrium allocations and welfare. This analysis can be useful in understanding the effects of policies that have been implemented in some countries. For example, Japan has a thorough inspection registration system (called *Shaken*), with strict emission standards that induce households to scrap their cars earlier than households in other countries do (Clerides, 2008).

We consider the following policy: All cars are scrapped when they reach $T = 11$. We chose $T = 11$ because this is the approximate average scrappage age in the counterfactual with prohibitive transaction costs examined in Section 5.1.2. However, two substantive differences arise between the case in which the scrappage age is imposed to be $T = 11$ and the previous case of prohibitive transaction costs in which the *average* scrappage age is endogenously the same. First, the level of transaction costs is different. Specifically, we consider the effects of the scrappage policy with the same level of transaction costs as in the baseline case (i.e., 15 percent of p_1, increasing to approximately 50 percent of p_{10}; see Section 4.2). Therefore, secondary markets are active in the case of a scrappage policy. Second, households' scrappage decisions are heterogeneous when transaction costs are prohibitive, with higher-income households scrapping their cars substantially earlier than lower-income households. However, this heterogeneity does not arise under the policy studied in this section since all cars have positive net resale values and, thus, no households scrap them before they reach $T = 11$. As in previous analyses, we evaluate steady-state allocations and welfare. Hence, our analysis complements the evaluation of *temporary* scrappage subsidies that affect the intertemporal incentives to scrap cars, generating a one-off change in the cross-sectional distribution of car vintages (Adda and Cooper, 2000; Copeland and Kahn, 2011; Miravete and Moral, 2011). These papers study models that do not allow for active secondary markets.

Table 6 reports the effects of these counterfactual scrappage policies on allocations and welfare in the two scenarios of elastic and inelastic supply, respectively. Overall, as in previous counterfactual analyses, the quantitative effects are similar in these two supply scenarios.

Quantity of Cars. Table 6 reports that, when the new-car supply is elastic, new-car output increases by 13 percent relative to the baseline case. However, the total stock of cars decreases by 27 percent relative to the baseline case, as the new-car increase does not compensate for the decrease in the scrappage age relative to the baseline case. When the new-car supply is inelastic, the total stock of cars decreases by 36 percent relative to the baseline case.

Prices. Figure 4 displays the effect of the scrappage policy on car prices relative to the prices in the baseline case. The dashed line refers to elastic supply and the solid line to inelastic supply. Two contrasting effects are at work. First, the scrappage policy reduces the total stock of cars, thereby raising the valuation of marginal buyers of all vintages and, thus, increasing prices. Second, the scrappage policy decreases cars' "lifetime," thereby decreasing the resale value of cars—of older vintages, in particular—and, thus, their prices. Figure 4 shows that the first effect quantitatively dominates. Interestingly, intermediate vintages experience the highest increase in prices relative to the baseline case. Intuitively, these are the vintages that have more substitutes since they are in the middle of the vertical distribution of qualities. Thus, the scarcity of cars relative to the benchmark case increases the prices of these vintages relatively more. Finally, prices of older vintages drop rapidly. This is again intuitive since the scrappage policy reduces the useful lifespan of cars.

Trade. In both supply scenarios, since cars last fewer years, primary markets become more important, and the volume of trade in secondary markets relative to primary markets

Table 6: Allocative and Welfare Effects of Scrappage Policies

	Baseline	Elastic Supply	Inelastic Supply
$\frac{\text{New Cars}}{\text{New Cars, Baseline Case}}$	1	1.13	1
$\frac{\text{Price of a New Car}}{\text{Price of a New Car, Baseline Case}}$	1	1	1.19
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	2.89	3.59	3.83
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	4.60	5.28	5.51
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.69	2.08	2.00
Households with no cars	0.13	0.32	0.38
Households with one car	0.34	0.34	0.33
Households with two cars	0.53	0.34	0.29
$\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}$	1	0.99	0.94
$\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.65	0.52
$\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.86	0.68
$\frac{\text{Welfare}}{\text{Welfare, Baseline case}}$	1	0.99	0.97

Notes: This table reports statistics on car allocations computed from the equilibrium of the model with a policy that imposes scrappage of all cars older than 11 years of age. $\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ and $\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ are computed using only households with cars in the baseline case.

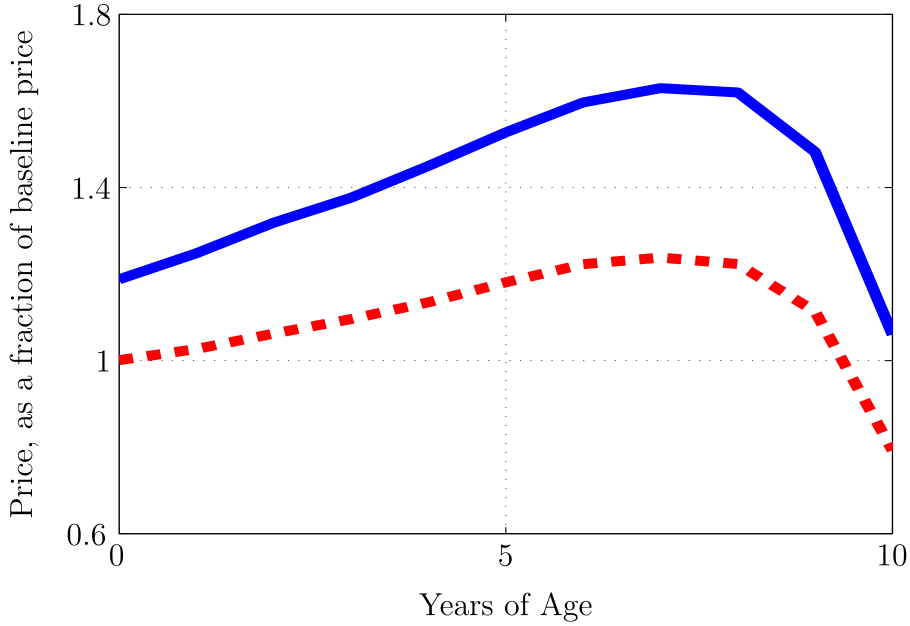

FIG. 4: The figure displays counterfactual car prices relative to baseline car prices when new-car supply is elastic (dashed line) and inelastic (solid line).

is lower than in the baseline case. Overall, the number of transactions in used goods is approximately twice the number of transactions in new goods in both supply scenarios.

Cars per Household. Table 6 shows that the smaller stock of cars, due to the shorter lifespan of cars, increases the fraction of people without cars relative to the baseline case. All of this reduction in the stock of cars comes at the expense of the fraction of households with two cars. The reason is that households' willingness to pay for their second car $\alpha\theta$ is, on average, low since α is low. Since the scrappage policy eliminates older cars and increases the prices of younger cars, second cars are too expensive relative to households' willingness to pay for them. Moreover, this effect is even stronger when the new-car supply is inelastic since, Figure 4 showed, prices increase more in that case. Thus, the decrease in the fraction of households with two cars is larger when the new-car supply is inelastic.

Welfare. Figure 5 displays the ratio between consumer surplus with the scrappage policy and consumer surplus in the baseline case for households that acquire a car in the baseline case, ranked by the percentile of their income, for the two scenarios of elastic and inelastic supply. The figure confirms that households at the bottom of the income

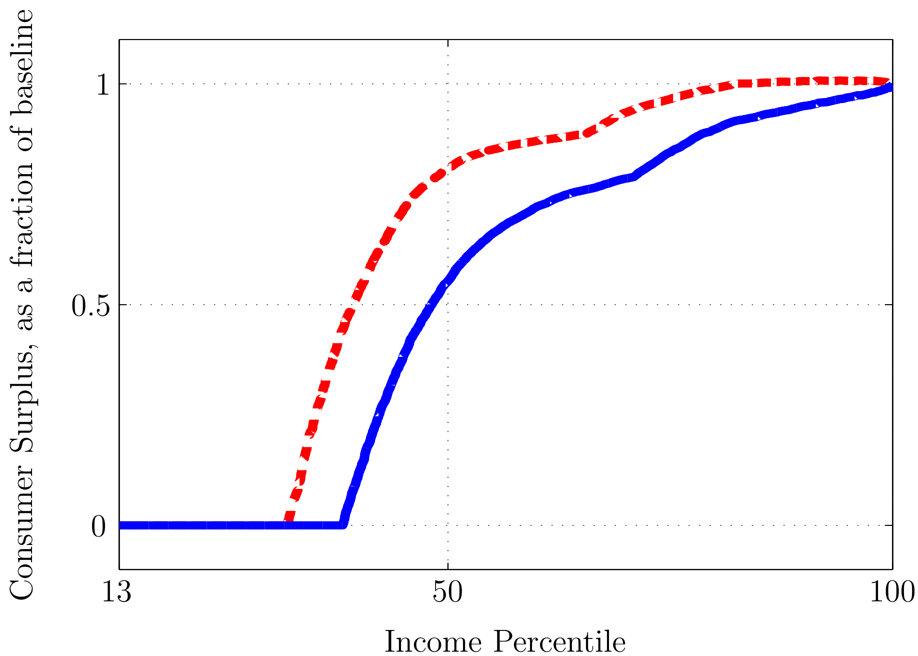

FIG. 5: The figure displays counterfactual consumer surplus with the scrappage policy relative to baseline consumer surplus by income percentile, elastic new-car supply (dashed line) and inelastic new-car supply (solid line). Consumer surplus is calculated as the value function $W(\theta)$.

distribution suffer the largest surplus decrease relative to the baseline case because the lower stock of cars imply that these households do not own a car. The average and median percentage surplus losses equal 35 to 48 percent and 14 to 32 percent of the baseline surplus, respectively, depending on the elasticity of the new-car supply. However, Table 6 reports that the magnitude of the aggregate welfare effects is substantially smaller: It equals either one or six percent, corresponding to 168 or 691 dollars per household per year, depending on the elasticity of the new-car supply. The reason for the small aggregate loss relative to the large loss for many households displayed in Figure 5 is that the highest-income households suffer the smallest losses, and these households have the largest weight in the aggregation of consumer surplus.

Two contrasting effects help explain the difference in consumer surplus between the scrappage policies, reported in Table 6, and the case of prohibitive transaction costs, reported in Table 5. First, secondary markets are active in the case of the scrappage policy, but not when transactions costs are prohibitive, thereby allowing households to sell their depreciated cars at positive net prices. This effect leads to higher consumer surplus in the case of the scrappage policy relative to the case of prohibitive transaction costs. Second, consumers can choose when to scrap their cars when transaction costs are prohibitive, but not with the scrappage policy, thereby allowing consumers to keep cars older than $T = 11$. This effect leads to higher consumer surplus in the case of prohibitive transaction costs relative to the case of the scrappage policy. Overall, a comparison between Tables 5 and 6 indicates that the first effect quantitatively dominates. The reason is that the first effect allows for a finer matching of relatively young vintages to high-valuation consumers, whereas the second effect allows for finer control of relatively low-quality cars for low-valuation consumers. The first effect dominates because of supermodularity: More value is created at the top than is lost at the bottom.

Table 6 further shows that these scrappage policies generate a redistribution of welfare from consumers to producers when supply is inelastic, consistent with the finding of Table 5. In particular, consumer surplus is lower with this scrappage policy because transaction costs are infinite for the oldest vintages. In contrast, producers' profits increase since new-car prices increase. The overall effect of the policy is to decrease welfare, although, again, the quantitative effect is only between one and three percent, depending on the elasticity of the new-car supply.[21]

5.3 The Effect of Heterogeneity: A Comparison with France

As we highlighted throughout our analysis, gains from trade in secondary markets for many durable goods arise from heterogeneous valuations for quality. In our quantitative analysis, we used household income to proxy for households' valuation θ. In this section, we calibrate our model using France's income distribution to investigate the model's quantitative performance on data from a different country.[22] This analysis also allows us to examine how income heterogeneity affects the allocative role of secondary markets and used-car prices.[23]

[21]Note that the positive effect of the scrappage policy on profits, while true for our calibration, is not a general feature of the model, since durability is exogenous. Thus, it could be the case that a reduction in durability, as in the scrappage policy, could hurt the producers.

[22]We also investigated the performance of our model on U.K. data. The model matches qualitative features of the U.K. car market well, and its quantitative performance is reasonably good. Details are available from the authors upon request.

[23]We have also investigated the relationship between income heterogeneity and trade in secondary markets across U.S. States. Specifically, using data from the Consumer Expenditure Survey, we find that the fraction of U.S. cars traded is greater in U.S. States with greater income dispersion. Moreover, using data from the County Business Patterns, we find that Metropolitan Statistical Areas with greater income dispersion have more used-car dealers, but not other retail trades, such as more supermarkets or hardware stores. These

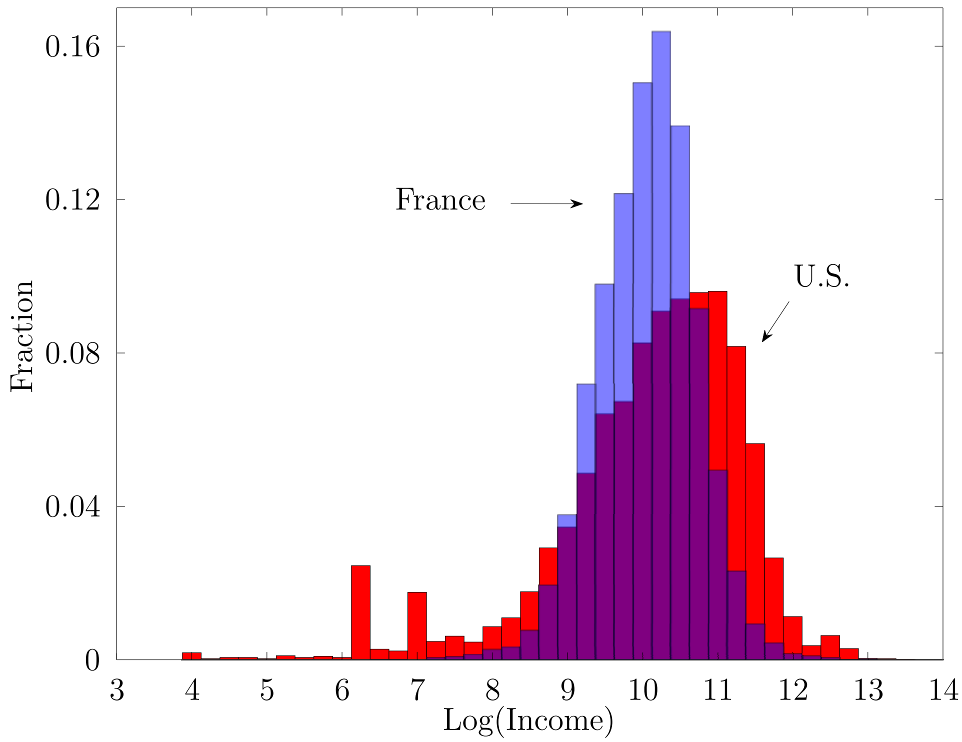

FIG. 6: Histogram of (log) income distribution in France and in the U.S in the year 2000. Income is in Euros for France and in Dollars for the U.S. The average exchange rate during the year 2000 was 1 U.S. Dollar = 1.085 Euro.

To this end, we use the *2000-2001 Enquête Budget des Familles*, a cross-sectional survey of 10,305 French households. The survey is similar to the U.S. Consumer Expenditure Survey. Most notably, it reports households' income, along with the number of vehicles that each household uses at the time of the interview. For up to two vehicles per household, it reports information about each vehicle, such as whether it was acquired in the previous 12 months and whether it was acquired new or used.

From the *Budget des Familles*, we recover the French income distribution. Figure 6 plots its histogram along with the histogram of the U.S. income distributions, showing that income heterogeneity is substantially lower in France than in the U.S. Figure 6 also shows that the French income distribution is very well approximated by a lognormal distribution, and we estimate its parameters as $\mu_{FR} = 10.062$ and $\sigma_{FR} = .650$. Moreover, column (1) of Table 7 reports some aggregate statistics on French households' car holdings calculated from

results are available from the authors upon request.

Table 7: Secondary Markets: Model vs. Data, France

	Data (1)	Model (2)	Model (3)
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	4.39	4.88	4.29
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	5.82	6.31	6.08
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	2.98	2.70	2.80
Households with no cars	0.17	0.08	0.17
Households with one car	0.48	0.65	0.48
Households with two cars	0.35	0.27	0.35

Notes: Column (1) provides aggregate statistics of the French car market computed from the *2000-2001 Budget des familles*. Columns (2) and (3) reports the results of the calibration of the model for different parameter values; see text for more details.

the *Budget des Familles*. The first row reports that, on average, only one out of every 4.5 households acquired a car in France within the last year (the ratio is equal to three in the U.S.; see Table 1). The second row reports that one out of every six cars was traded during the year 2000 (one out of every 4.5 cars in the U.S.). The third row reports that, of all cars traded, approximately one in three cars was new (one in four in the U.S.). Overall, these aggregate statistics show that secondary markets for cars are substantially less active in France than in the U.S., indicating that our model linking the dispersion of income distribution with the volume of trade is qualitatively consistent with these cross-market differences. The last three rows of Table 7 report the distribution of cars per household, documenting another important difference with the U.S.: The average number of cars per household is 19-percent higher in the U.S. than in France.

Table 7 reports the results of two calibrations of our model. For expositional purposes, the calibration reported in column (2) uses exactly the same parameters used in the U.S. baseline calibration, with the only exception of the distribution of θ, for which we use the French income distribution. In the calibration reported in column (3), we further allow the parameters α and c to be specific to France, and we choose them to match the French aggregate statistics of column (1) as closely as possible. (More precisely, for any α, there is

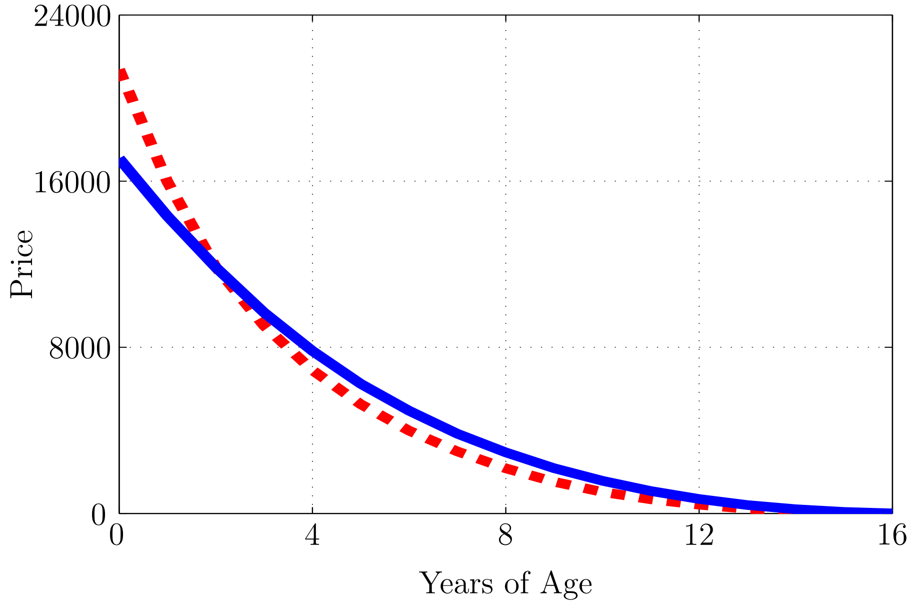

FIG. 7: The figure displays car prices in the U.S. (dashed line) and in France (solid line). Prices are in U.S. dollars. French prices are converted into U.S. dollars using the average exchange rate during the year 2000: 1 U.S. Dollar = 1.085 Euro.

a unique c that equates the aggregate demand of cars with the aggregate supply xT.) The calibrated value of α is equal to .40, and the implied value of c is 651 dollars. The value of α is greater in France than in the U.S. because the total stock of cars is lower in France, implying that households with two cars must value their second car relative to their first car more in France than in the U.S.

Columns (2) and (3) in Table 7 confirm that our model is a quantitative success. More specifically, column (2) shows that the income distribution allows the model to match closely the volume of trade in secondary markets in France. Moreover, allowing for a country-specific parameter α also allows the model to match the distribution of car holdings perfectly.

The model also generates interesting general-equilibrium patterns on the relative decline of car prices between the two countries. This is displayed in Figure 7. New-car prices are higher in the U.S. than in France. However, prices decline at a faster rate in the U.S. than in France. Thus, old-car prices in France are higher than in the U.S. The intuition for these patterns is that France's less-dispersed income distribution flattens the depreciation of prices, as the willingness to pay—i.e., income—for a marginally better car is lower when the income distribution is less dispersed.[24]

6 Conclusions

Secondary markets play a potentially important role in determining the set of durable goods available to consumers and how different segments of the income distribution benefit from such goods. We set up a model to understand the allocative and welfare effects of secondary markets. Our analysis highlights that durable goods offer many different margins of adjustments to consumers: which vintage to buy, how long to keep it, whether to sell it or scrap it. These many margins of adjustments imply that any change in secondary markets—because of changes in transaction costs over time or because of policies that directly affect them, such as scrappage policies—has potentially large effects on the volume of trade and allocations, but smaller effects on consumers' surplus and welfare.

The ideas presented in this paper are potentially useful in understanding allocations and welfare in several durable-goods markets. An important question, left for future research, is how manufacturers' choice of varieties offered on the primary market respond to changes in secondary markets.

[24] Thus, our model provides a potential explanation for cross-country difference in car prices, as reported by Verboven (1996) and Goldberg and Verboven (2001, 2005).

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