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A Quantitative Analysis of the Used-Car Market*

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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. 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-valuation households can be large.

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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.[1]

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., household appliances, 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.[2]

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.[3] Transaction costs are an impediment to instantaneous (i.e., 100 percent) trade.[4] The extent of trade depends on the degree of heterogeneity in preferences. We quantitatively investigate how the distribution of non-durable consumption contributes to this heterogeneity by calibrating our model to match the aggregate volume of trade in the used-car market. Despite its simplicity, the model fits the data very well.

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[1]The coefficient of variation is calculated from the National Automobile Dealers Association (NADA) Car Price Guide.

[2]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, 2013; and Schiraldi, 2011); truck tractors (Bond, 1983); commercial aircraft (Pulvino, 1998; Gavazza, 2011a and 2011b); business aircraft (Gilligan, 2004; Gavazza, 2013); and capital equipment (Eisfeldt and Rampini, 2009).

[3]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. We could, in principle, add such characteristics to our model.

[4]Jovanovic (1998 and 2009) considers frictionless reassignment in a vintage model.

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 costs 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.[5]

Three key economic forces affect allocations and welfare in our counterfactuals with different transaction costs relative to the baseline case: 1) Higher (lower) transaction costs have 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 two previous 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 both the secondary market and in the market for new goods is large. In contrast, the effects on aggregate welfare are small, although the distribution of these effects is uneven, with low-valuation 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 two to six 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, some households with preferences below the median suffer surplus losses larger than 50 percent of their baseline surplus. Aggregate welfare changes are smaller because, due to heterogeneity, the highest-valuation households have disproportionate weights in the calculation of aggre-

[5] Most of our analysis focuses on a single quality of new cars to simplify the way in which secondary markets expand the array of goods available to consumers, but we also consider how the forces that we discuss operate when new cars of different qualities are available (see Section 5.1.2).

gate 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 lower the total quantity of cars by increasing scrappage, low-preference 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 households' 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. When transaction costs are prohibitive, however, 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.[6] Specifically, we impose that households have to scrap their cars when they reach the (approximate) scrappage age that keeps the total stock of cars equal to the stock in the counterfactual with prohibitive transaction costs, so this choice facilitates the comparison between these counterfactuals. However, two substantive differences arise between these two counterfactuals. 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-valuation households scrapping their cars substantially earlier than lower-valuation households. However, this heterogeneity does not arise under the scrappage policy since all cars have positive net resale

[6] 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.

values, and, thus, no households scrap them before they reach the imposed scrappage age.

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-valuation 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 distribution of non-durable consumption 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. market. Indeed, this is also what the data say. The magnitude of the difference is also substantial: The average holding time is approximately 30-percent longer in France than in the U.S. Our model quantitatively matches French aggregate statistics fairly well. Of course, there are many differences between the U.S. and France beyond the differences in the distribution of non-durable consumption. However, it is notable that the model can account for 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. We contribute 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 analyzes 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 neither analyzes 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 papers to ours are Chen, Esteban and Shum (2013) and Yurko (2012). The main difference with Chen, Esteban and Shum (2013) 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. Similarly, the contemporaneous paper by Yurko (2012) investigates the role of heterogeneity in car markets, but does not consider the allocative and welfare effects of secondary markets, as we do by performing the counterfactual analyses in Section 5.[7]

3 Model

3.1 Assumptions

We modify a model of vertical product differentiation, which 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 and obtained some interesting patterns for secondary markets with transaction costs. We extend Stolyarov's analysis to incorporate some features that are important in the data, such as multiple cars per household and the combination of exogenous and endogenous scrappage. 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 equilibrium in the car market for any given level of new-car output. In every period, a constant (exogenous) flow x of new cars enters the market. We

[7]Yurko's (2012) model also assumes an exogenous functional form for prices, whereas we impose no restrictions on prices.

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.[8]

New cars are homogeneous,[9] with quality q_0, and depreciate over time: A car of age a is of quality q_a, with $q_a > q_{a+1}$.[10] In each period, each car "dies" with exogenous probability γ, independent of the age of the car; we interpret this exogenous "death" as the result of accidents or other events that induce households to scrap their cars. All "surviving" cars are (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, as this is the relevant case for our baseline calibration.[11] The steady-state total mass of cars X is equal to $X = \sum_{t=0}^{T} x\,(1-\gamma)^t = x\frac{1-(1-\gamma)^{T+1}}{\gamma}$.

A majority of U.S. households own more than one car (see Section 4.1). We need the model to capture this feature of the data for two reasons: first, because, there are more cars than households, so assuming unit demand would not be consistent with secondary-market activity (we discuss this in more detail later); and, second, because we want to contrast the U.S. with France, where the number of cars per household is lower. However, allowing households to hold more than one car significantly complicates the numerical computation, so we do not allow for more than two cars. Specifically, we assume that each household has a preference parameter θ that determines the flow of utility that the household enjoys from its cars. A household with preference θ and with two cars of vintages a and b enjoys a per-period flow of utility equal to $\theta \max\{q_a, q_b\} - c$ from its first (better) car, and $\alpha\theta \min\{q_a, q_b\} - c$ from its second (worse) 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.[12] The preference parameter θ is distributed in the population according to the non-degenerate c.d.f.

[8] In our counterfactuals, we consider two 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.

[9] We consider heterogeneous vertical qualities of new goods in Section 5.1.2. Clearly, the car market exhibits 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.

[10] 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.).

[11] 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.

[12] For scrappage decisions the only relevant holding costs are those for cars close to the scrappage age.

F, whereas α is distributed in the population according to the non-degenerate c.d.f. G. We assume that for each household θ and α are independent and do not change over time.[13]

In order for the model to generate interesting implications for trade in the secondary market, and to match relevant features of the data, we introduce some frictions. 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.[14] 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. Let $V_{\theta,\alpha}(a,b)$ be the value function of a household with preferences (θ,α) that, in the current period, is enjoying cars of vintage a and b, respectively. $V_{\theta,\alpha}(a,b)$ satisfies:

$$\begin{aligned}
V_{\theta,\alpha}(a,b) = {} & \theta\max\{q_a,q_b\} + \alpha\theta\min\{q_a,q_b\} - c\mathbb{I}\{a<T+1\} - c\mathbb{I}\{b<T+1\} \\
& + \beta(1-\gamma)^2 \max_{a',b'} \left(V_{\theta,\alpha}(a',b') - p_{a'} + p_{a+1}\left(1-\lambda_{a+1}\mathbb{I}\{a'\neq a+1\}\right)\right. \\
& \left. - p_{b'} + p_{b+1}\left(1-\lambda_{b+1}\mathbb{I}\{b'\neq b+1\}\right)\right) \\
& + \beta(1-\gamma)\gamma \max_{a',b'} \left(V_{\theta,\alpha}(a',b') - p_{a'} + p_{a+1}\left(1-\lambda_{a+1}\mathbb{I}\{a'\neq a+1\}\right) - p_{b'}\right) \\
& + \beta(1-\gamma)\gamma \max_{a',b'} \left(V_{\theta,\alpha}(a',b') - p_{a'} - p_{b'} + p_{b+1}\left(1-\lambda_{b+1}\mathbb{I}\{b'\neq b+1\}\right)\right) \\
& + \beta\gamma^2 \max_{a',b'} \left(V_{\theta,\alpha}(a',b') - p_{a'} - p_{b'}\right),
\end{aligned} \tag{1}$$

where we let $q_x \equiv 0$ and $p_x \equiv 0$ for $x > T$ mean having no car, and β is the discount factor common to all households.

Equation (1) says that the household enjoys the current-period utility flows $\theta\max\{q_a,q_b\}-c$ and $\alpha\theta\min\{q_a,q_b\}-c$ from their youngest and oldest car, respectively; recall that, if they own no car (car q_{T+1} in our notation), then this flow utility is zero. In the next period, one of four possible events may happen to a household:

[13] We considered temporary shocks to preferences but in our computation these shocks were of negligible importance for our calibration.

[14] The fact that transaction costs are paid by the sellers is immaterial: just like for taxation, equilibrium allocations are invariant to the "statutory incidence" of transaction costs. Some dependence of transaction costs on prices is realistic and allowing for a fixed component of transaction costs does not change our qualitative and quantitative results. It is also possible to interpret the transaction cost as a reduced form of adverse selection. This would give an additional reason why the percentage transaction cost would rise with the vintage of the good since uncertainty over the quality of cars is likely to rise with the age of the car.

1. With probability $(1-\gamma)^2$, all its cars are still "alive," and the household chooses between replacing any car or keeping it. If the household chooses to replace the depreciated vintage-$(a+1)$ car with a different vintage-a' car, it pays the price $p_{a'}$ and receives the price p_{a+1} net of the transaction costs $\lambda_{a+1}p_{a+1}$. If the household chooses not to replace the car, it enjoys a car of vintage $a'=a+1$, thereby avoiding any transaction costs.

2. With probability $(1-\gamma)\gamma$, the household exogenously scraps its vintage-b car. It then chooses which vintage b' to acquire to replace the scrapped car and chooses whether to replace the depreciated vintage-$(a+1)$ car with a different vintage-a' car.

3. With probability $(1-\gamma)\gamma$, the household exogenously scraps its vintage-a car. It then chooses which vintage a' to acquire to replace the scrapped car and chooses whether to replace the depreciated vintage-$(b+1)$ car with a different vintage-b' car.

4. With probability γ^2, the household exogenously scraps both its cars and then chooses which vintages a' and b' to purchase, if any.

At the beginning of each period, given preferences (θ,α) and currently-owned vintages a and b, households choose policies $a^*(\theta,\alpha,a,b)$ and $b^*(\theta,\alpha,a,b)$ to maximize

$$V_{\theta,\alpha}(a',b') - p_{a'} + p_a\left(1-\lambda_a\mathbb{I}\{a'\neq a\}\right) - p_{b'} + p_b\left(1-\lambda_b\mathbb{I}\{b'\neq b\}\right).$$

Moreover, the endogenous scrappage age T is determined by the following conditions: i) No household chooses to keep a car of quality q_T; ii) no household buys a car of quality q_T; and iii) a car of quality q_T has a price p_T equal to zero.

Let $h(a,b|\theta,\alpha)$ be the stationary distribution of holdings of cars of vintages a and b, respectively, for a household with preferences θ and α. This distribution $h(a,b|\theta,\alpha)$ is constructed recursively as:

$$\begin{aligned} h\left(a',b'|\theta,\alpha\right) = & \sum_{a=0}^{T+1}\sum_{b=0}^{T+1}(1-\gamma)^2\,\mathbb{I}\{a^*(\theta,\alpha,a+1,b+1)=a', b^*(\theta,\alpha,a+1,b+1)=b'\}h(a,b|\theta,\alpha) + \\ & \sum_{a=0}^{T+1}\sum_{b=0}^{T+1}(1-\gamma)\gamma\mathbb{I}\{a^*(\theta,\alpha,a+1,T+1)=a', b^*(\theta,\alpha,a+1,T+1)=b'\}h(a,b|\theta,\alpha) + \\ & \sum_{a=0}^{T+1}\sum_{b=0}^{T+1}(1-\gamma)\gamma\mathbb{I}\{a^*(\theta,\alpha,T+1,b+1)=a', b^*(\theta,\alpha,T+1,b+1)=b'\}h(a,b|\theta,\alpha) + \\ & \sum_{a=0}^{T+1}\sum_{b=0}^{T+1}\gamma^2\mathbb{I}\{a^*(\theta,\alpha,T+1,T+1)=a', b^*(\theta,\alpha,T+1,T+1)=b'\}h(a,b|\theta,\alpha). \end{aligned} \tag{2}$$

Equation (2) says that a household with preferences θ and α and cars of vintages a and b faces the random exogenous scrappage of their cars. With probability $(1-\gamma)^2$, these cars do not "die" but are one year older, and the household chooses which vintages a' and b' to drive in the current period. Similarly, with probability $(1-\gamma)\gamma$, one car dies—thereby becoming a car of vintage $T+1$—and the other car is one year older. The other events have similar explanations.

Integrating over households' preferences yields the stationary distribution $Q(a', b')$ over holdings of cars of vintages a' and b':

$$Q(a', b') = \int_0^1 \int_0^\infty h(a', b'|\theta, \alpha)\, dF(\theta)\, dG(\alpha). \tag{3}$$

Market equilibrium is defined by standard competitive conditions. Specifically, an equilibrium is a vector of households' policies $a^*(\theta, \alpha, a, b)$ and $b^*(\theta, \alpha, a, b)$ and a vector of prices $p = (p_0, .., p_{T-1})$ such that: (i) decision rules are optimal, and (ii) for every vintage t, households' car holdings $\sum_{b=0}^{T} Q(t, b) + \sum_{a=0}^{T} Q(a, t)$ equal the stock $x(1-\gamma)^t$ of this vintage.

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. The 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.[15] The CEX also reports households' income and consumption for different categories of goods. We aggregate consumption goods to construct households' non-durable consumption following Krueger and Perri (2006), and we will use it to capture households' willingness to pay for car quality in our quantitative analysis.

Table 1 reports some aggregate statistics on households' car holdings, computed from the CEX. The quantitative analysis of our model will aim to match these moments. 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. Overall, these patterns indicate that

[15] The 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 in the hands of the household. For these reasons, we exclude company cars from our analysis, but it is possible that some households use their cars for business purposes.

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
Correlation(log(Non-Durables), Age of Young Car)	−0.30
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.*

secondary car markets are very active. The fourth row reports that, on aggregate, households' non-durable consumption predicts households' car holdings, but heterogeneity in households' preferences plays an important role in determining their car holdings. The last three rows report the fraction of households with zero, one and more than one car, respectively. The majority of U.S. households hold more than one car.[16]

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. Most parameters are taken directly from the data, while some are calibrated to match some important features of the CEX data. We report in Table 2 the numerical values of the parameters that 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.

We assume that one period equals one year, and we set the discount rate $\beta = .95$.

One important input into our quantitative analysis is the distribution F of the marginal valuation for quality θ, which is not directly observable. The following theoretical argument is one way to understand our choice of the empirical counterpart of θ. It is natural to think that θ is (inversely) related to the marginal utility of the outside good (non-durable consumption

[16] 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		β	μ_y	σ_y	μ_ϵ	σ_ϵ	$E(\alpha)$	$St.Dev.(\alpha)$
Value		0.95	9.49	0.63	0	1.16	0.2362	0.0748
Parameter	X	x	γ	T	c	δ	q_0	λ_a
Value	1.40	0.0869	0.02	20	1,350	0.0236	0.78	0.15 - 0.50

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

in our setting, see Tirole, 1988, chapter 2). If we assume that households have logarithmic utilities, then this inverse marginal utility is equal to non durable consumption. We also allow for an idiosyncratic component in the valuation for quality. Guided in part by this reasoning, we let $\theta = y\epsilon$, where y is household non-durable consumption and ϵ is a parameter that is a household-specific preference component uncorrelated with y.[17] Using the CEX, we find that a lognormal distribution with parameters $\mu_y = 9.49$ and $\sigma_y = 0.63$ fits the distribution of non-durable consumption almost perfectly. We further let ϵ have a lognormal distribution, imposing $\mu_\epsilon = 0$ (this is just a normalization) and calibrating the parameter σ_ϵ. The parameter σ_ϵ affects several statistics in the calibration, but the correlation between the log of households' non-durable consumption and the age of their youngest car is particularly informative about this parameter σ_ϵ. The calibrated value is $\sigma_\epsilon = 1.16$.

We let the distribution G of α be a Beta distribution. We calibrate the two parameters of the Beta distribution to match the aggregate statistics reported in Table 1. We obtain the best fit of the data with a mean α equal to 0.2362 and a standard deviation of α equal to 0.0748. The key statistic that pins down the mean value of α is the number of cars per household, whereas the standard deviation of α has a broader effect on all statistics.

We set the total stock of cars $X = 1.40$ to match the sum of the fraction of households with one car plus twice the fraction of households with more than one car. We obtain the empirical analog of the ratio of the stock to the flow $\frac{X}{x}$ in the model from the product of the ratios $\frac{\text{Total stock of cars}}{\text{Cars acquired last 12 months}}$ and $\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$ reported in Table 1. This operation yields $\frac{X}{x} = 16.11$, thus implying that the value of x equals 0.0869. We set the "exogenous scrappage" $\gamma = 0.02$ by calculating in the CEX the average fraction of vintage-a to vintage-$(a+1)$ cars for all cars less than 15 years old.[18]

[17] Most previous empirical papers (see Section 2) on the auto market show that several observable households' characteristics (income, household size, age etc.) affect car choices. In the Online Appendix, we show how our framework allows us to capture households' heterogeneity in a similar way to those related papers.

[18] The exogenous scrappage rate $\gamma = 0.02$ is lower than in Cohen and Greenspan (1999) for the years 1970-

Furthermore, from the equality of the total stock of cars $X = x\frac{1-(1-\gamma)^{T+1}}{\gamma}$, we obtain an endogenous scrappage age $T = 20$.[19]

We set $c = \$1,350$ by computing the per-car annual average expenditure on car maintenance, insurance and gasoline in the CEX.[20] We then set q_T to match the scrappage age $T = 20$ corresponding to this value of c, given that the marginal consumer of this car must receive zero flow utility. We further let $q_a = (1-\delta)^a q_0$, with a value of $\delta = 0.0236$ to match the average annual depreciation of car prices of around 20 percent. We then choose $q_0 = 0.78$ to match the average price of \$22,000 of a new-car purchase reported in the CEX.

To calculate transaction costs λ_a, we use price data obtained from the Kelley Blue Book for some of the most popular cars in the U.S.: Toyota Corolla, Toyota Camry, and Toyota Previa/Sienna. As in Porter and Sattler (1999), we estimate transaction costs using the difference between suggested retail and trade-in values. These values increase from approximately 15 percent for one-year-old cars to more than 50 percent for cars more than ten years old.[21] We then fit a quadratic polynomial regression in age to these data on transaction costs to smooth them and average them across different cars.[22]

4.3 Computational Algorithm

For each value of the parameters, we take $N = 1,500$ draws θ_i and α_i $i = 1, ..., N$ from their distributions F and G, 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, α), we calculate optimal policies $a'(\theta, \alpha, a, b)$ and $b'(\theta, \alpha, a, b)$.
3. We calculate the stationary distribution $h(a, b|\theta, \alpha)$.

1996. This is consistent with the persistent improvement in car durability and reliability over time that Cohen and Greenspan already observed in their sample period.

[19] The scrappage rate of cars older than 15 years increases substantially in the CEX. We view our choices of scrappage rates for cars of age $a < T$ and of age T as reasonable approximations of a scrappage process that increases more gradually over the age of the car.

[20] This number is stable across vintages, so we use a constant number to simplify computations.

[21] Transaction costs are increasing in the age of the car in percentage terms. However, because car prices are declining in the age of the car, the dollar value of transaction costs is non-monotonic in the age of the car, declining for cars older than three years.

[22] 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	3.21
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	4.54	5.08
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.55	3.27
Correlation(log(Non-Durables), Age of Young Car)	−0.30	−0.23
Households with no car	0.13	0.13
Households with one car	0.34	0.35
Households with more than one car	0.53	0.52

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. We calculate the stationary distribution $Q(a,b)$ of age a as $\sum_{i=1}^{N} h(a,b|\theta_i,\alpha_i)$.

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:[23]

$$\min_{p} \max_{t\in\{0,\ldots,T\}} \left\{ \left| \sum_{b=0}^{T} Q(t,b) + \sum_{a=0}^{T} Q(a,t) - x(1-\gamma)^{t} \right| \right\}.$$

We choose the parameters that minimize the maximum absolute value of the percentage differences between the empirical and the theoretical moments reported in Table 1 (of course, the last line is redundant, so the objective function does not include it).

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 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, for the purposes of understanding aggregate features of the allocative role of secondary markets, our simple model of vertical differentiation with transaction costs captures key aspects of the gains from trade in the used-car market.

We now discuss in more detail some key outcomes of the calibrated model.

[23] We stop searching for prices when this absolute value is less than $\frac{1}{N}$.

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, although it slightly underpredicts them (by less than ten percent, at most).

Household Car Holdings. Table 3 shows that the model matches the fraction of households with no car, one car, and more than one car very well. The parameter that allows the model to match these statistics is α, the ratio between the preference for the second and for the first car. Moreover, the model matches the correlation between households' non-durable consumption and the of age of their youngest car reasonably well. The unobserved heterogeneity parameter ϵ governs this correlation.

Car Prices. The fast decline of equilibrium prices—approximately 20 percent per year—is the joint outcome of cars' physical depreciation (captured by the parameters γ, δ and T) and the equilibrium sorting of consumers across vintages. The reason for this large price decline is that the U.S. distribution of preferences displays wide dispersion, and, thus, the willingness to pay for a marginally better car is high. In Section 6, we will see that in France, where the dispersion of the distribution of preferences 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.

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—a perfectly competitive industry with constant marginal costs of production versus an industry with binding capacity constraints for all producers. We wish to emphasize that our counterfactuals do not include some additional long-run effects, such as the change in the durability of cars; see the Conclusions for additional discussions. 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.

In our analysis, we compare consumer surplus across the different counterfactuals by averaging the value functions $V_{\theta,\alpha}(a,b)$ over the stationary distribution $h(a,b|\theta,\alpha)$:

$$\sum_{a=0}^{T+1}\sum_{b=0}^{T+1}\int_0^1\int_0^\infty V_{\theta,\alpha}(a,b)\,h(a,b|\theta,\alpha)\,dF(\theta)\,dG(\alpha)\,.$$

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. In our quantitative analysis in Section 4, we used 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.

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-valuation households own two cars. In this case, there is a threshold value $(\alpha\theta)'$ that satisfies $X = 1 + 1 - M\left((\alpha\theta)'\right) = 2 - M\left((\alpha\theta)'\right)$, where households' preferences $\alpha\theta$ have c.d.f. $M(z) = \int_0^z m(x)\,dx$ and p.d.f. $m(x) = \int_0^{+\infty} g\left(\frac{x}{\theta}\right) f(\theta) \frac{1}{\theta} d\theta$. Hence, all households own one car (the term 1), and all households with valuation above $(\alpha\theta)'$ own two cars (the term $1 - M\left((\alpha\theta)'\right)$); or

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

Case 2 is the empirically relevant one, as 13 percent of households have no cars.

Table 4 reports the quantitative results for the scenario of zero 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, 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 as follows. If the scrappage age did not decrease, the increase in the supply of new cars would lead to an increase in the total stock of cars. Hence, the marginal owner of a car would have a lower valuation (either θ or $\alpha\theta$) than in the baseline case. However,

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	1.074
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	3.21	1	1
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	5.08	1	1
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.27	16.64	16.64
Correlation(log(Non-Durables), Age of Young Car)	−0.23	−0.25	−0.23
Households with no cars	0.13	0.13	0.13
Households with one car	0.35	0.35	0.35
Households with two cars	0.52	0.52	0.52
$\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}$	1	1.016	1.008
$\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	1.024	1.008
$\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	1.026	1.010
$\frac{\text{Welfare}}{\text{Welfare, Baseline case}}$	1	1.016	1.015
$\frac{\text{Transaction Costs}}{\text{Consumer Surplus}}$	0.008	0	0

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.

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 $T = 19$ rather than at $T = 20$.

In contrast, when new-car supply is inelastic, the endogenous scrappage age is the same as in the baseline case—i.e., $T = 20$. 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 they 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-valuation 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 average car) decline relative to the baseline case—on average, by approximately 13 percent when supply is elastic and by approximately two 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 and fourth rows of Table 4. While cars are endogenously scrapped at $T = 20$, the exogenous scrappage γ implies that the ratio of the stock of cars to the flow of new cars equals 16.64, lower than T. This explains the fifth row of Table 4.

Household Car Holdings. 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 the lowest-valuation used-car owner's indifference between owning a car of that vintage or scrapping it—thus 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 $\alpha\theta$) that owns a unit is the same, implying that the distribution of cars per household is also the same.

Removing transaction costs increases the absolute value of the correlation between (the log of) households' non-durable consumption and the age of their youngest car, as displayed in the sixth row of Table 4. The magnitude of this increase is small, suggesting that transaction costs have little effect on the sorting between cars and households in the baseline case.

Welfare. The three economic effects of removing transaction costs discussed above—i.e., the direct effect 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. However, 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 preferences, and a negative impact on aggregate consumer surplus; but the general-equilibrium effect a positive impact on producers'

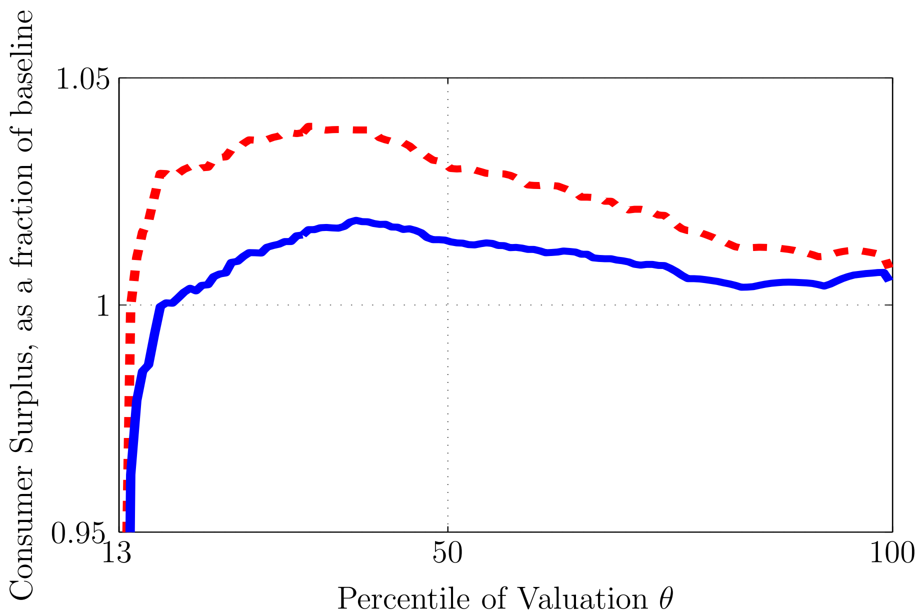

FIG. 1: The figure displays counterfactual consumer surplus with no transaction costs relative to baseline consumer surplus by percentile of valuation θ, elastic new-car supply (dashed line) and inelastic new-car supply (solid line). Consumer surplus is calculated as the average value function before purchasing any car: $\int_0^1 V_{\theta,\alpha}(T+1, T+1)\, dG(\alpha)$.

profits when supply is inelastic.

Figure 1 displays the ratio between consumer surplus in the counterfactual case of zero transaction costs and in the baseline case for all households that acquire a car, ranked by the percentile of their preference θ, for the two scenarios of elastic and inelastic supply. Overall, Figure 1 shows that, for almost all households, surplus is higher when transaction costs are zero, indicating that the first two effects dominate. Interestingly, the ratios are non-monotonic in θ. Households at the bottom of the distribution are marginal car consumers—i.e., they own the worst cars. Prices of these cars adjust to any change in transaction costs to leave surplus close to zero. Inframarginal households receive a positive surplus gain because price adjustment cannot fully extract the surplus change. However, while these gains are monotonic in the preference θ, they have a vanishing percentage effect on the welfare of the highest-preference households. Overall, the average and median percentage surplus gains from having frictionless resale markets equal 0.8 to 2.4 and one to 2.6 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 1.5 percent or 0.8 percent relative to the baseline case, depending on the elasticity of new-car supply. These correspond to \$383 or \$217 per year for households with at least one car. 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-valuation households have disproportionate weights in the calculation of aggregate consumer surplus due to the large preference inequality in the U.S., and these households receive the smallest gains.

When supply is elastic, producers' profits are zero, and, thus, overall welfare increases by the same amount as consumer surplus—i.e., by 1.5 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 1.47 percent in the case of inelastic new-car supply, as well. More than half 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 0.8 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 1.5 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. 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 quite small in this case.

5.1.2 No Resale Markets

When transaction costs are prohibitive (i.e., $\lambda_a = 1$ for all a), households 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 overall aggregate welfare effects are mostly similar in the two supply scenarios.

Quantity of cars. Table 5 reports that, when new-car supply is elastic, new-car output increases by 23 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

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	1.23	1
$\frac{\text{Price of a New Car}}{\text{Price of a New Car, Baseline Case}}$	1	1	1.41
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	3.21	7.05	7.95
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	5.08	11.36	12.58
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.27	1	1
CORRELATION(LOG(NON-DURABLES), AGE OF YOUNG CAR)	−0.23	−0.14	−0.15
HOUSEHOLDS WITH NO CARS	0.13	0.27	0.32
HOUSEHOLDS WITH ONE CAR	0.35	0.28	0.28
HOUSEHOLDS WITH TWO CARS	0.52	0.45	0.40
$\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}$	1	0.98	0.94
$\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.71	0.61
$\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.91	0.79
$\frac{\text{Welfare}}{\text{Welfare, Baseline case}}$	1	0.98	0.97
$\frac{\text{Transaction Costs}}{\text{Consumer Surplus}}$	0.008	*N.A.*	*N.A.*

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.

affect output in the two extreme counterfactual scenarios. The reason for the large increase when transaction costs are prohibitive is that scrappage increases substantially. This occurs 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 $T = 14$ in the case of inelastic supply and at approximately $T = 13$ in the case of elastic supply, as compared to $T = 20$ in the baseline case. Thus, the comparison between the elastic and inelastic cases indicates that, on average, households scrap cars slightly earlier in the case of elastic 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 41 percent relative to the baseline case. This is a mirror image of the increase in output in the case of a perfectly elastic supply: 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 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 the fourth and fifth rows.

Household Car Holdings. 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 two cars decreases relative to the baseline case. However, a natural question arises: Since transaction costs are prohibitive, why do some households choose to have only one car—i.e., why do they scrap a car rather than keeping it as a second car? Clearly, at scrappage time, the car satisfies $\theta q - c \geq 0$, and for most households this inequality holds strictly. However, households keep their first cars until they are quite old; therefore, these cars are, on average, of low quality, implying that a typical case involves $\alpha\theta q - c < 0$. Therefore, it is better to scrap relatively old cars than to keep them as second cars, even though they would give positive utility flows if held as first cars.

Moreover, prohibitive transaction costs decrease the absolute value of the correlation between (the log of) households' non-durable consumption and the age of their youngest car, as reported in the sixth row of Table 5. The magnitude of this decrease is sizable, suggesting that

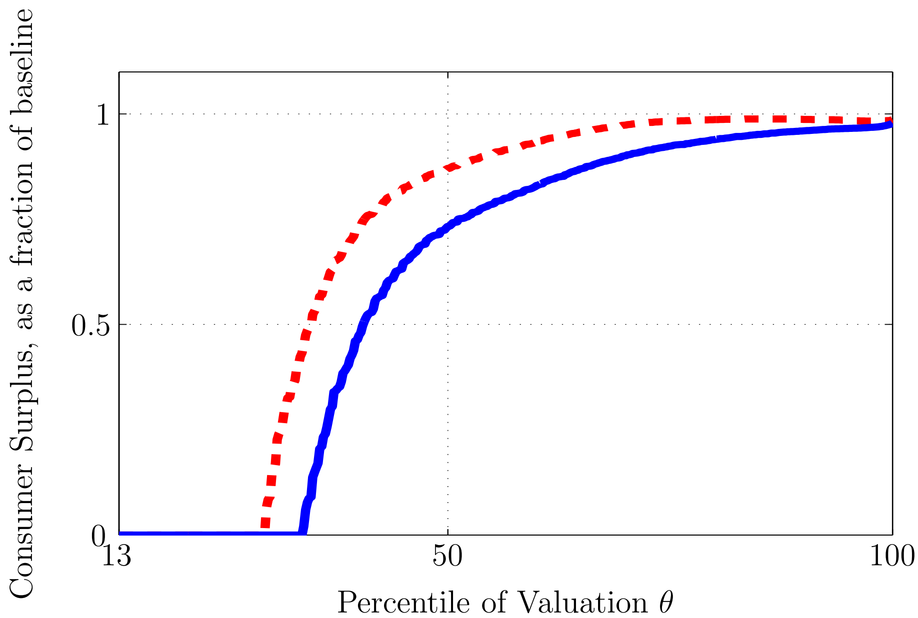

FIG. 2: The figure displays counterfactual consumer surplus with prohibitive transaction costs relative to baseline consumer surplus by percentile of valuation θ, elastic new-car supply (dashed line) and inelastic new-car supply (solid line). Consumer surplus is calculated as the average value function before purchasing any car: $\int_0^1 V_{\theta,\alpha}(T+1, T+1)\, dG(\alpha)$.

the inability to resell cars has a non-trivial effect on the sorting between cars and households and, thus, on their surplus.

Welfare. Figure 2 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 valuation θ, 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 valuation distribution suffer the largest surplus loss relative to the baseline case because the lower stock of cars implies that these households do not own a car. Indeed, the surplus losses are quite dramatic for households with valuation below the median of the distribution: The average and the median percentage losses equal 29-39 percent and 9-21 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 two percent when supply is elastic and by six percent when supply is inelastic, corresponding to $505 or $1,513 per year, respectively, for households with cars in the baseline case. Table 5 reports that the drop in aggregate consumer surplus is smaller than the drop for most households because the highest-preference households have disproportionate weights in the calculation of aggregate surplus. Figure 2 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 41 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—two or three percent—in the two supply scenarios.

Multiple qualities. One limitation of the previous analysis is that we have not allowed a plausible supply-side response: if used cars are not available, manufacturers have an incentive to provide lower-quality new cars. We can extend the model to allow for this possibility by assuming that there is a competitive (i.e., infinitely elastic) supply of lower-quality cars. Specifically, in the Appendix we report in detail on the case in which manufacturers supply new cars of two qualities: a car of quality q_0 (i.e., the same car supplied in the benchmark case) and a car of quality equal to q_5 (i.e., a car whose quality equals a five-year old car of the benchmark case). We set the price of the car of quality q_5 to its price in the benchmark case: $\$7,465$. Thus, the price is well below that of any new car in the U.S. market.

This counterfactual delivers four main results. First, the output of the high-quality new good falls as households with intermediate preferences substitute towards the cheaper, low-quality good. However, total new car output rises significantly relative to the case of a single new car. Second, the aggregate welfare loss from prohibitive transaction costs are even smaller than in the case with a single new car, since households have an additional margin of adjustment. Third, the distribution of the welfare losses are qualitatively similar to those displayed in Figure 2 for the case of a single quality of new cars: consumers at the bottom of the distribution suffer the most, because low-quality new goods are still too expensive for these consumers relative to very old used goods. Fourth, households in the middle of the preference distribution now suffer smaller losses, because the low-quality new goods allow them to obtain qualities that are closer to their target qualities of the benchmark case.

Overall, this counterfactual suggests that a richer expansion of the set of new goods implies a reduction of the aggregate welfare losses relative to the case of a single new car, especially for middle-preference households.

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 the (approximate) scrappage age that keeps the total stock of cars equal to the stock in the counterfactual with prohibitive transaction costs examined in Section 5.1.2—i.e., $T = 15$ in the case of inelastic supply and $T = 13$ in the case of elastic supply. However, two substantive differences arise between these two counterfactuals. 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-valuation households scrapping their cars earlier than lower-valuation 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. 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, 2013; 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 22 percent relative to the baseline case. However, relative to the baseline case, the total stock of cars decreases by 16 percent, as the new-car increase does not compensate for the decrease in the scrappage age. When the new-car supply is inelastic, the total stock of cars decreases by 23 percent relative to the baseline case.

Prices. Figure 3 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

Table 6: Allocative and Welfare Effects of Scrappage Policies

	Baseline	Elastic Supply	Inelastic Supply
$\frac{\text{New Cars}}{\text{New Cars, Baseline Case}}$	1	1.22	1
$\frac{\text{Price of a New Car}}{\text{Price of a New Car, Baseline Case}}$	1	1	1.47
$\frac{\text{Households with at least one car}}{\text{Households that acquired a car in the last 12 months}}$	3.21	4.01	4.90
$\frac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	5.08	6.23	7.51
$\frac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	3.27	1.98	1.74
Correlation(Log(Non-Durables), Age of Young Car)	−0.23	−0.21	−0.21
Households with no cars	0.13	0.25	0.30
Households with one car	0.35	0.33	0.32
Households with two cars	0.52	0.42	0.38
$\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}$	1	0.99	0.95
$\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.76	0.63
$\text{Median}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$	1	0.92	0.79
$\frac{\text{Welfare}}{\text{Welfare, Baseline case}}$	1	0.99	0.98

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 14 years of age in the case of inelastic supply and 13 years of age in the case of elastic supply. $\text{Mean}\left(\frac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline case}}\right)$ 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.

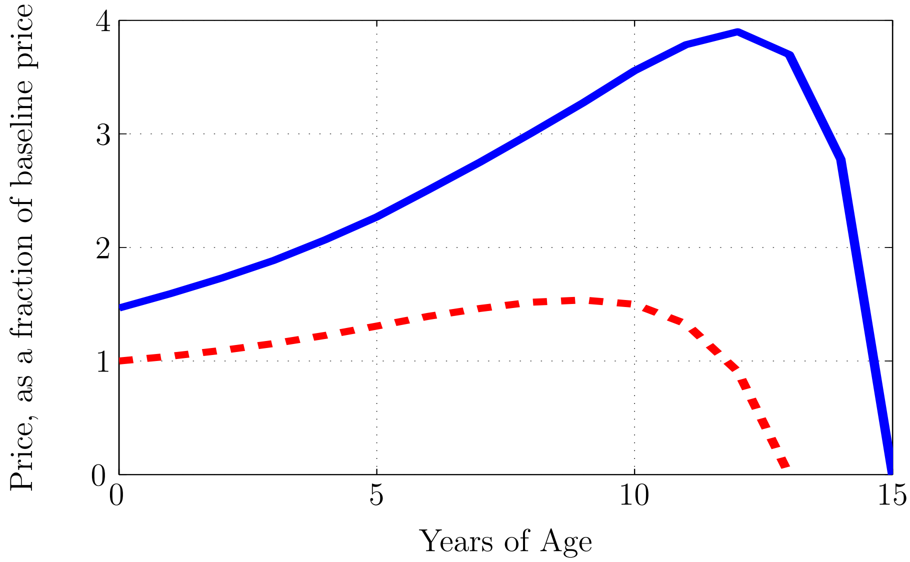

Fig. 3: The figure displays counterfactual car prices relative to baseline car prices when new-car supply is elastic (dashed line) and inelastic (solid line).

value of cars—of older vintages, in particular—and, thus, their prices. Figure 3 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 is lower than in the baseline case. Overall, the number of transactions in used goods is now slightly lower than the number of transactions in new goods in both supply scenarios.

Household Car Holdings. 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

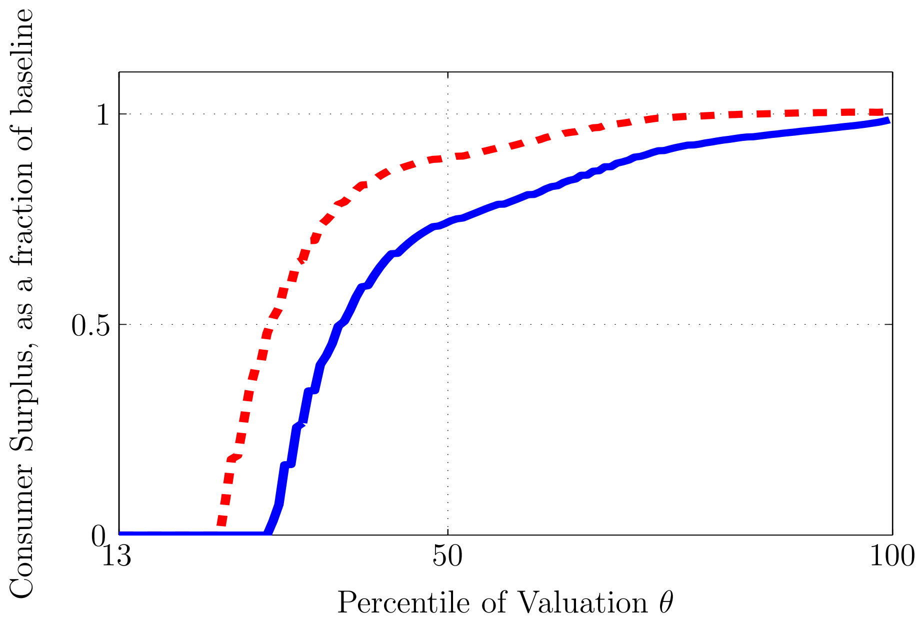

FIG. 4: The figure displays counterfactual consumer surplus with the scrappage policy relative to baseline consumer surplus by percentile of valuation θ, elastic new-car supply (dashed line) and inelastic new-car supply (solid line). Consumer surplus is calculated as the average value function before purchasing any car: $\int_0^1 V_{\theta,\alpha}(T+1, T+1)\, dG(\alpha)$.

since, as Figure 3 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.

Furthermore, these scrappage policies decrease the absolute value of the correlation between the log of households' non-durable consumption and the age of their youngest car, as reported in the sixth row of Table 6. The magnitude of this decrease is smaller than that reported in Table 5, suggesting that scrappage policies have a smaller effect than prohibitive transaction costs on the sorting between cars and households.

Welfare. Figure 4 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 valuation θ, for the two scenarios of elastic and inelastic supply. The figure confirms that households at the bottom of the valuation distribution suffer the largest surplus decrease relative to the baseline case because the lower stock of cars implies that these households do not own a car. The average and median percentage surplus losses equal 24 to 37 percent and 8 to 21 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 effects on consumer surplus is substantially smaller: either one or five percent, depending on the elasticity of the new-car supply, corresponding to \$246 or \$1,230 per year for households with cars in the baseline case. The reason for the small aggregate loss relative to the large loss for many households displayed in Figure 4 is that the highest-valuation households suffer the smallest losses, and they have the largest weight in the aggregate consumer surplus.

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 in Table 5. 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 two percent, depending on the elasticity of the new-car supply.[24]

Two contrasting effects help explain the difference in welfare 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 welfare in the case of the scrappage policy relative to the case of prohibitive transaction costs. Second, households can choose when to scrap their cars when transaction costs are prohibitive, but not with the scrappage policy, thereby allowing households to keep cars older than T. This effect leads to higher welfare 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.

6 The Effect of Heterogeneity: A Comparison with France

As we highlight throughout our analysis, gains from trade in secondary markets for many durable goods arise from heterogeneous valuations for quality. In our quantitative analysis, a key input into a household's valuation for quality θ is non-durable consumption. In this section, we calibrate our model using France's distribution of non-durable consumption to investigate the quantitative performance of the model on data from a different country. This analysis also allows us to examine how preference heterogeneity affects the allocative role of secondary markets and used-car prices.

[24] The positive effect of the scrappage policy on profits may not be a general feature of the model. Because durability is exogenous, a reduction in durability, as in the scrappage policy, could hurt producers.

Table 7: Non-Durable Consumption, U.S. vs. France

	United States	France
Mean(Non-Durable Consumption)	16111.05	15079.37
St. Dev.(Non-Durable Consumption)	11826.26	9916.07

Notes: Values 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.

To this end, we use the *2000-2001 Enquête Budget des Familles*, a cross-sectional survey of 10,305 French households that is similar to the U.S. Consumer Expenditure Survey. Most notably, it reports households' income and consumption for different categories of goods. We aggregate goods to construct households' non-durable consumption following as closely as possible the aggregation we performed on the U.S. CEX. Moreover, the *Budget des Familles* reports the number of vehicles that each household uses at the time of the interview, and, 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.

Table 7 reports the mean and the standard deviation of non-durable consumption in the United States and in France, showing that heterogeneity is lower in France than in the U.S. The French distribution of non-durable consumption is very well approximated by a lognormal distribution with parameters $\mu_{FR} = 9.42$ and $\sigma_{FR} = 0.64$. Moreover, Table 8 reports some aggregate statistics on French households' car holdings calculated from 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 preferences with the volume of trade is qualitatively consistent with these cross-market differences. The last three rows of Table 8 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.

In keeping with the spirit of the quantitative exercise, we perform a "constrained" calibration of the model for France. In particular, we use French-specific parameters governing households' preferences over cars, the total stock of cars, and cars' holding costs, whereas we keep the characteristics of cars—i.e., depreciation and exogenous scrappage—the same as

Table 8: Secondary Markets: Model vs. Data, France

	Data	Model
Households with at least one car / Households that acquired a car in the last 12 months	4.39	3.79
Total stock of cars / Cars acquired in the last 12 months	5.82	5.21
Cars acquired in the last 12 months / New Cars acquired in the last 12 months	2.98	3.19
Correlation(log(Non-Durables), Age of Young Car)	−0.27	−0.35
Households with no cars	0.17	0.15
Households with one car	0.48	0.53
Households with two cars	0.35	0.32

Notes: This table reports the moments of the data computed from the *2000-2001 Budget des Familles* that the model seeks to match and the corresponding moments computed from the model; see text for more details.

those that we used in the calibration for the U.S.. More precisely, we let the product distribution of the valuation $\theta = y\epsilon$ be given by the lognormal distribution of French households' non-durable consumption y (parametrized as described above) and by a lognormal distribution of the unobserved heterogeneity ϵ. This unobservable heterogeneity captures some of the preference-based differences between the U.S. and France that we do not explicitly model. Of course, there are potentially other differences between the U.S. and French car market. However, we believe that it is useful to investigate how far our fairly parsimonious model can go in matching the data. As for the U.S. calibration, we impose $\mu_\epsilon = 0$ and we calibrate the parameter σ_ϵ by matching the correlation between the log of households' non-durable consumption and the age of their youngest car, yielding $\sigma_\epsilon = 0.87$. We further allow the distribution G of α to be a Beta distribution with parameters specific to France. We choose these parameters to match the French aggregate statistics of the first column. The calibrated value of the mean of α equals .16 and the standard deviation of α equals 0. This implies that the dispersion of the preference parameters ϵ and α are lower in France than in the U.S.. Moreover, we allow the holding costs c to be specific to France and the calibrated value of c is 1,884 dollars.[25]

[25] Since the distribution of q, the exogenous scrappage parameter γ and the scrappage age T are the same in the U.S. and French calibration, we need the holding cost c to be country-specific to equate the total stock of cars to the total demand of cars. The *Budget des Familles* reports that the annual average household expenditure on maintenance, insurance and gasoline equals \$1,708 per car. This is higher than in the U.S., as we find in the calibrations.

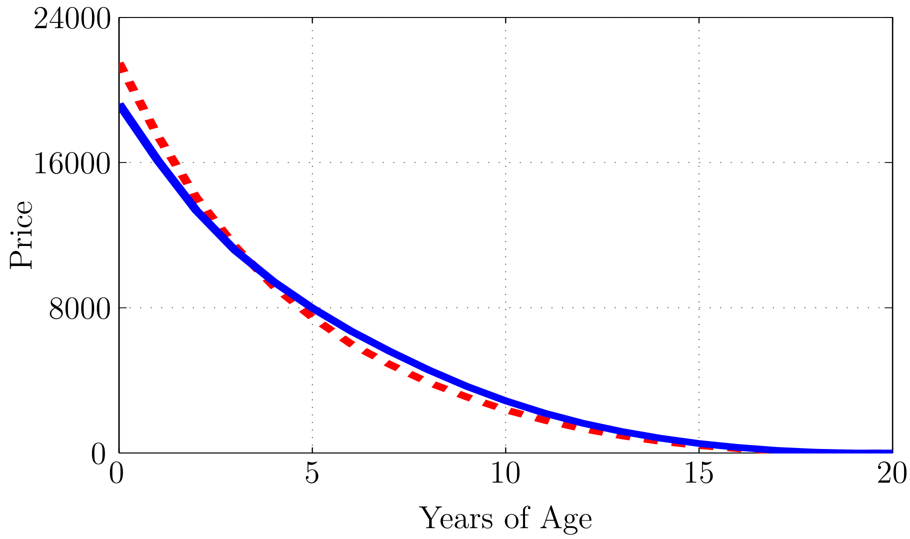

FIG. 5: The figure displays car prices in the U.S. (dashed line) and in France (solid line). Prices are in U.S. dollars. French prices are converted into U.S. dollars using the average exchange rate during the year 2000: 1 U.S. Dollar = 1.085 Euro.

The second column of Table 8 reports the results of the calibration. Table 8 confirms that our model is a quantitative success despite the constraint on the calibration. More specifically, it shows that the valuation distribution allows the model to match the volume of trade in secondary markets in France fairly well, along with the correlation between households' non-durable consumption and the vintage of their youngest car. Moreover, allowing for a country-specific distribution of α allows the model to match the distribution of car holdings well.[26]

The model also generates interesting general-equilibrium patterns on the relative decline of car prices between the two countries; Figure 5 displays them. New-car prices are higher in the U.S. than in France, as they are in the data: the calibration delivers a new-car price in France approximately 10-percent lower than that in the U.S.[27] However, the model-generated prices decline at a faster rate in the U.S. than in France. Thus, old-car prices (i.e., cars older than 4 years) are higher in France than in the U.S. The intuition for these patterns is that France's less-dispersed preference distribution flattens the depreciation of prices, as the willingness to pay for a marginally better car is lower when the preference distribution is less dispersed.

[26]The match between the model and the data becomes almost perfect if we allow the quality distribution q to be specific to France (i.e., with $q_0 = 0.69$ and $\delta = 0.015$).

[27]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).

7 Conclusions

Secondary markets play a potentially important role in determining the set of durable goods available to consumers and how different households with heterogeneous preferences 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.

There are several possible interesting extensions of our analysis. First, it would be useful to allow for endogenous durability. This would have very little effect in the counterfactual of eliminating transaction costs because the endogenous scrappage age is very similar to that in the baseline case. However, the effects could be substantial in the counterfactuals with prohibitive transaction costs and with the scrappage policy because the scrappage age in these counterfactuals is significantly lower than that in the baseline case. This would give manufacturers an incentive to reduce their investments in durability so that cars would depreciate faster. Calculating the welfare consequences of accounting for endogenous durability requires a measure of the cost savings that come from such a reduction in durability. However, even without such a measure, we can conclude that the change in durability will be beneficial in the case of perfectly elastic supply because the cost savings will be passed along to consumers; this allows the industry to adjust by better tailoring the design of the goods to the needs of consumers. Moreover, there will be a larger output response in these counterfactuals because the reduced durability will lower the cost of production. Second, it would be useful to understand in more detail the effects of variety of cars in the primary market. This would potentially improve our understanding of the effect of secondary markets on the primary market. Finally, we believe that an extension of our framework may be useful in studying the effects of alternative emissions policies: if the emissions of new vehicles are decreasing over time, durability affects aggregate emissions. One could study the relative impact of a policy that accelerates the technological improvement in emissions compared to a policy that encourages scrappage of old, more highly polluting, vehicles.

TABLE 9: Allocative and Welfare Effects of Secondary Markets, Prohibitive Transaction Costs, Elastic Supply of New Cars of Two Qualities

	Two Qualities of New Cars
$\dfrac{\text{New Cars of Quality } q_0}{\text{New Cars, Baseline Case}}$	0.83
$\dfrac{\text{New Cars of Quality } q_5}{\text{Cars of Quality } q_5\text{, Baseline Case}}$	0.78
$\dfrac{\text{Total New Cars}}{\text{New Cars, Baseline Case}}$	1.53
$\dfrac{\text{HHs with at least one car}}{\text{HHs that acquired a car in the last 12 months}}$	6.24
$\dfrac{\text{Total stock of cars}}{\text{Cars acquired in the last 12 months}}$	10.11
$\dfrac{\text{Cars acquired in the last 12 months}}{\text{New Cars acquired in the last 12 months}}$	1
$\dfrac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline}}$	0.99
$\text{Mean}\left(\dfrac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline}}\right)$	0.86
$\text{Median}\left(\dfrac{\text{Consumer Surplus}}{\text{Consumer Surplus, Baseline}}\right)$	0.98
$\dfrac{\text{Welfare}}{\text{Welfare, Baseline case}}$	0.99

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

APPENDIX

In this Appendix, we report in more detail on the counterfactual case with multiple qualities of new cars that we mention in Section 5.1.2. Specifically, we assume that manufacturers supply competitively new cars of two qualities: a car of quality q_0 (i.e., the same car supplied in the benchmark case) and a car of quality equal to q_5 (i.e., a car whose quality equals a five-year old car of the benchmark case). The prices of these cars are equal to their prices in the benchmark case: the high-quality car price is $\$21,487$, and the low-quality car price is $\$7,465$ (note that this price is significantly below that of any new car in the U.S. market).

Table 9 reports the quantitative results of this counterfactual case with prohibitive trans-

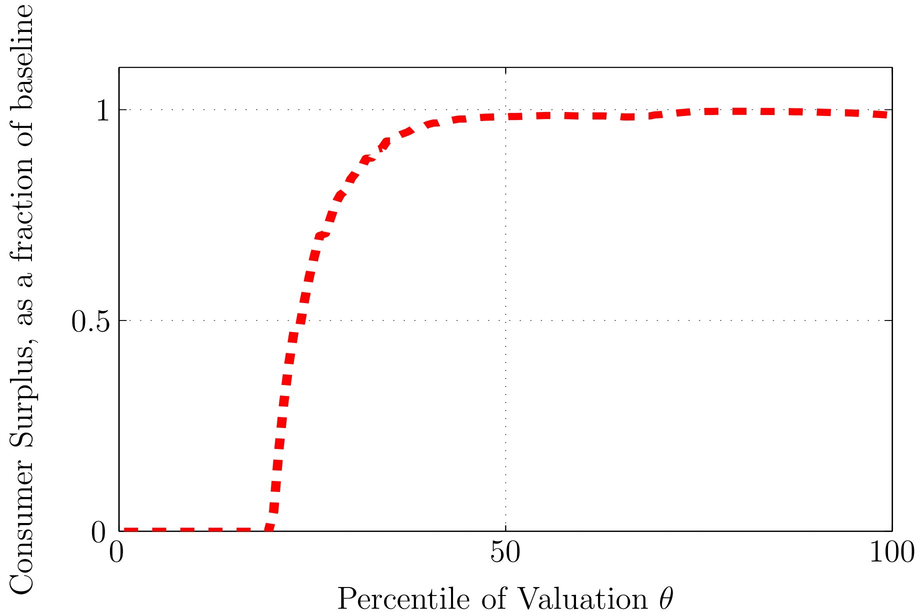

FIG. 6: The figure displays counterfactual consumer surplus with prohibitive transaction costs relative to baseline consumer surplus by percentile of valuation θ, elastic supply of new cars of two qualities. Consumer surplus is calculated as the average value function before purchasing any car: $\int_0^1 V_{\theta,\alpha}(T+1, T+1)\, dG(\alpha)$.

action costs and an infinitely elastic supply of new cars of two qualities. The top rows of the table indicate that the output of the high-quality new good falls, whereas the cheaper, low-quality good captures approximately 45 percent of total new-car sales, as households with intermediate preferences substitute towards it. Overall, total new car output rises by 53 percent relative to the baseline case, and by 25 percent relative to the analogous counterfactual with a single new car (Table 5). The bottom rows of the table confirm that the aggregate welfare losses from prohibitive transaction costs are small. They are even smaller than in the case with a single new car, since the low-quality new car provide households with an additional margin of adjustment. Figure 6 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 valuation θ, for this case of elastic supply of two new cars. The figure shows that households with intermediate preferences suffer very small losses, because the lower-quality new goods allow these households to obtain qualities that are closer to their target qualities of the benchmark case. However, households at the bottom of the distribution still suffer large welfare losses, because low-quality new goods are still too expensive for these consumers relative to very old used goods.

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Online Appendix

In this Appendix, we show how to bridge the gap between the way we model consumer heterogeneity and the way that previous empirical work on the auto market was capturing it. Specifically, we let the heterogeneity of households' preferences be given by $\theta = y\epsilon$, where y is household non-durable consumption and ϵ is a parameter that is a household-specific preference component uncorrelated with y. From $\log\theta = \log y + \log\epsilon$, we can estimate the weights β on observable demographic characteristics X from the regression

$$\log y = \beta X + \eta. \tag{4}$$

Thus, we can write

$$\log\theta = \beta X + \omega$$

with $\omega = \eta + \log\epsilon$ is the unobservable component of "our" preferences and βX is the observable component.

Moreover, we let households' preferences for their second car be given by $\alpha\theta$, with $\alpha \leq 1$. Hence, we can extend the previous procedure to obtain

$$\log\alpha + \log\theta = \log\alpha + \beta X + \omega.$$

In the paper, we assume that α is an unobservable component, distributed in the population according to a Beta distribution on $[0, 1]$ with parameters that we calibrate (Section 4.2).

Alternatively, we can directly assume that preferences θ are composed by an observable component ϕX and an observable part χ:

$$\log\theta = \phi X + \chi. \tag{5}$$

In our model, a households hold at least one car if its preference parameter θ exceeds a fixed threshold. Denoting this constant threshold by θ^*, we obtain that:

$$\begin{aligned}\Pr(\text{household has at least one car}) &= \Pr(\theta > \theta^*) = \Pr(\log\theta > \log\theta^*) \\ &= \Pr(\phi X + \chi - \log\theta^* > 0).\end{aligned}$$

Thus, by assuming that the distribution of χ is a normal distribution, we can obtain an estimate of the weights ϕ normalized by the standard deviation σ_χ of χ by estimating a probit regression.

Similarly, we could further decompose $\log\alpha$ into an observable and an unobservable part

$$\log\alpha = \mu X + \nu.$$

Hence, we obtain

$$\log\alpha + \log\theta = \mu X + \nu + \phi X + \chi = \pi X + \zeta \tag{6}$$

where the weights $\pi = (\mu + \phi)$ are the sum of the weights of the observable demographic characteristics X of θ and of α, and $\zeta = (\nu + \chi)$ is the sum of the unobservable components of θ and of α. In our model, households hold more than one car only if their preferences $\alpha\theta$ exceed a fixed threshold. Denoting this constant threshold by $(\alpha\theta)^*$, we obtain that:

$$\begin{aligned}\Pr(\text{household has more than one car}) &= \Pr\left(\alpha\theta > (\alpha\theta)^*\right) = \Pr\left(\log\alpha + \log\theta > \log(\alpha\theta)^*\right) \\ &= \Pr\left(\pi X + \zeta - \log(\alpha\theta)^* > 0\right).\end{aligned}$$

Thus, by approximating the distribution of ζ with a normal distribution, we can obtain an estimate of the weights π normalized by the standard deviation σ_ζ of ζ by estimating a probit regression.

Table 10 presents estimates of the coefficients β of equation (4), of the coefficients $\frac{\phi}{\sigma_\chi}$ of equation (5), and of the coefficients $\frac{\pi}{\sigma_\zeta}$ of equation (6). Columns (1)-(3) use CEX data to estimate β, $\frac{\phi}{\sigma_\chi}$ and $\frac{\pi}{\sigma_\zeta}$, respectively, for the U.S.; columns (4)-(6) use the *Budget des Familles* to estimate β, $\frac{\phi}{\sigma_\chi}$ and $\frac{\pi}{\sigma_\zeta}$, respectively, for France.

Interestingly, the signs of the coefficients are the same in all specifications and, most notably, in the two countries. Moreover, the magnitudes of several coefficients in columns (1) and (4) are fairly similar. The ratios of coefficients in columns (2) and (5), and (3) and (6), are quite comparable, as well.

Finally, we can recover the parameters σ_χ and σ_ζ for each country by matching the overall variances of θ and of $\alpha\theta$ that we obtained in our calibration. More specifically, the calibration for the U.S. yields

$$var(\log\theta) = var(\log y) + var(\log\epsilon) = .63^2 + 1.16^2 = 1.7425.$$

The probit in column (2) yields

$$var\left(\frac{\log\theta}{\sigma_\chi}\right) = \frac{1}{\sigma_\chi^2}var(\log\theta) = var\left(\frac{\phi X}{\sigma_\chi}\right) + var\left(\frac{\chi}{\sigma_\chi}\right) = .73^2 + 1 = 1.5387.$$

Thus, we obtain $\sigma_\chi = 1.064$ for the U.S. Similarly, the calibration for the U.S. further yields:

$$var(\log\alpha) + var(\log\theta) = .1126 + 1.7425 = 1.8551.$$

The probit in column (3) yields

$$var\left(\frac{\log\alpha + \log\theta}{\sigma_\zeta}\right) = \frac{1}{\sigma_\zeta^2}\left(var(\log\alpha) + var(\log\theta)\right) = var\left(\frac{\pi X}{\sigma_\zeta}\right) + var\left(\frac{\zeta}{\sigma_\zeta}\right) = .840^2 + 1 = 1.7056.$$

Table 10: The Role of Demographic Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)
Age of HoH	.02020	.04170	.06065	.01298	.06527	.07087
	(.00257)	(.00741)	(.00644)	(.00173)	(.00618)	(.00664)
Age of HoH Squared	−.00015	−.00036	−.00053	−.00013	−.00071	−.00075
	(.00002)	(.00007)	(.00006)	(.00002)	(.00005)	(.00006)
Family Size	.14192	.15661	.29717	.11328	.02554	.11701
	(.00517)	(.02299)	(.01721)	(.00412)	(.02102)	(.01309)
Log(Household Income)	.25593	.33555	.37009	.56052	.74048	.84257
	(.01312)	(.02901)	(.03172)	(.01026)	(.04093)	(.03285)
Female of HoH	−.02282	−.22848	−.37675	−.07692	−.79305	−.88508
	(.01315)	(.04821)	(.03713)	(.01212)	(.04025)	(.05229)
Years of Education of HoH	.03464	.07730	.02623	.00852	.03988	.02170
	(.00232)	(.00799)	(.00658)	(.00122)	(.00528)	(.00442)
White HoH	.12881	.66808	.42870	N/A	N/A	N/A
	(.01737)	(.05588)	(.05252)			
Rural Household	.03027	.37252	.48267	.02924	.68264	.50767
	(.02018)	(.10007)	(.06722)	(.00912)	(.04819)	(.03360)
Dummies for Geography	Yes	Yes	Yes	N/A	N/A	N/A
R^2	.465			.594		
log-Likelihood		$-1,705.26$	$-3,136.32$		$-3,180.94$	$-4,837.81$
# Obs.	5,886	5,886	5,886	10,305	10,305	10,305

Notes: Columns (1) and (4) report OLS estimates of the coefficients β in equation (4); the dependent variable is the log of the household's non-durable consumption. Columns (2) and (5) report maximum likelihood estimates of the coefficients $\frac{\phi}{\sigma_\chi}$ in equation (5); the dependent variable is an indicator for whether the household holds at least one car. Columns (3) and (6) report maximum likelihood estimates of the coefficients $\frac{\pi}{\sigma_\varsigma}$ in equation (6); the dependent variable is an indicator for whether the household holds more than one car. Columns (1)-(3) use CEX data for the U.S.; columns (4)-(6) use the Budget des Familles for France. HoH means head of household. N/A means that the variable is not reported in the dataset.

Thus, we obtain $\sigma_\zeta = 1.042$ for the U.S.

Similar calculations yield $\sigma_\chi = .791$ and $\sigma_\zeta = .746$ for France.

Interestingly, this procedure delivers that unobservable heterogeneity plays a larger role in the U.S. than in France, as we found in our calibrations of Sections 4 and 6, respectively.