How Much Competition is a Secondary Market?

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Abstract

Do active secondary markets aid or harm durable goods manufacturers? We build a dynamic equilibrium model of durable goods oligopoly, with consumers who incur lumpy costs when transacting in the secondary market, and calibrate it to U.S. automobile industry data. By varying transaction costs, we obtain a direct measure of the competitive pressure that secondary markets create on durable goods manufacturers. For our calibrated parameter values, opening the secondary market decreases the profits of the new car manufacturers by 42%. Additional counterfactuals show, however, that secondary markets can be beneficial when firms are able to commit to future production levels and when the primary market is more concentrated.

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In recent years, the rapid rise of Internet retailing has jump-started a multitude of markets for a wide spectrum of used goods: virtually everything is resold on the Internet, from animals to toys to books, plants, clothing, appliances; even automobiles and housing units. One market observer notes:

> This evolution is beginning to redefine socially accepted norms for consumer buying and selling behavior. Specifically, we are beginning to embrace the notion of temporary ownership. We will soon live in a world where the norm is to sell our designer shoes after wearing them twice, where Verizon will automatically send us the newest, best, most high tech mobile phone every six months, and where we'll lease our Rolex watches instead of buying them. The "informed consumer" will soon choose the brand of her next handbag based on how much it will likely fetch on eBay next year—which corresponds to how much it will really cost her to own it up until then.[1]

Has this dramatic expansion in secondary markets (or "temporary ownership", to use the colorful terminology above) helped or hurt new good producers? In determining the gains from secondary markets, there are various countervailing effects (as we describe in the next section). Therefore, whether secondary markets help or hurt producers is ultimately an empirical question, the answer to which depends ultimately on the underlying market features, such as product heterogeneity and consumers' preferences. Our main contribution in this paper is to build and calibrate a dynamic equilibrium model of a durable-goods industry, which allows us to address the role that secondary markets play in oligopolistic industries with a heterogeneous consumer population and product depreciation.

In our analysis, transaction costs play a key role in disentangling the effect that secondary markets play. By raising transaction costs, we close down secondary markets to hone in on the effects of durability itself on firms' behavior. In contrast, by decreasing transaction costs, we make transactions frictionless and increase the competitive pressure faced by firms from secondary markets.[2]

[1] From Nissanoff (2006).

[2] Anderson and Ginsburgh (1994) and Porter and Sattler (1999) also use this approach. More details on how our paper differs will follow.

To our knowledge, our model is the first that analyzes the durable goods oligopoly model in a Markov-perfect equilibrium framework whilst allowing for realistic *inertial* behavior (or "hysteresis") on the consumer-side due to transaction costs. We calibrate our model's parameter values to match aggregate data from the US automobile industry in 1994–2003. To meet the challenge of computing the dynamic equilibrium oligopoly model, we use the MPEC approach (Mathematical Programming with Equilibrium Constraints), recently advocated by Su and Judd (2008).

Using the calibrated parameter values, we show that more active secondary markets lead to lower profits for producers, so that the negative effects of secondary markets appear to outweigh the benefits. We find that opening the secondary market from closed to frictionless lowers firms' profits (in the steady state) by 42%. Nonetheless, counterfactual simulations show that opening the secondary market is more beneficial (less detrimental) to producers when (1) firms can commit to future production plans; (2) used cars are less inferior to new cars; (3) cars are less durable; (4) the time-varying component of consumers' preferences become less prominent; or (5) the primary market is more concentrated. These findings confirm the importance of accounting for all effects when evaluating the competitive implications of secondary markets.

The next section describes the various effects that opening secondary markets may have on durable goods producers' profits, and summarizes the relevant literature. Section 2 presents the model. Section 3 presents the calibration exercise and the model evaluation at the steady state. Section 4 runs counterfactual experiments to address our core question, whether secondary markets aid or hurt durable goods manufacturers. Section 5 concludes.

1 Opening secondary markets: A taxonomy of effects

In durable goods markets, consumers typically do not desire to hold onto the same good until it dies; rather, they wish to re-optimize their choices depending on the product's depreciation and their own preferences, which may change over time. Absent secondary markets, consumers can only re-optimize by scrapping the used good they own, hence forfeiting any *residual value* the good may still have. Such a drastic step naturally predisposes consumers to inertial behavior: consumers typically hold on to the depreciated good rather than scrap it.

Opening secondary markets modifies the consumers' calculus in several ways. Re-optimizing consumers no longer need to forfeit the residual value from the used good they own when they re-optimize; instead, they can sell it at the going resale price. At the same time, when re-optimizing, consumers have a wider set of options available to them, being able to purchase used goods of other vintages. How do these changes introduced by secondary markets affect profits of the new goods' producers?

Multiple effects are at play here. First, there is a *substitution* effect, as an active secondary market forces firms to vie for the attention of the re-optimizing consumers, who can now decide whether to buy a new or used good. Even without secondary markets, durability by itself implies an "indirect" substitution effect: consumers owning used goods are more likely to stay away from the primary market, shrinking the demand for new goods and thus creating indirect competition between the firms' new production and the used goods stock. However, by allowing used goods to be traded without frictions, opening the secondary market magnifies the substitution possibilities between new and used goods, which negatively affects firms' profits.

Second, secondary markets play an *allocative* role by segmenting heterogeneous consumers into different markets by vintage. This allows firms to achieve indirect price discrimination. Since consumers no longer need to forfeit the residual value of their asset if they re-optimize, the high valuation types can return to the primary market more often, increasing the firms' revenues. As with the substitution effect, a sorting effect exists even in the absence of the secondary market, but it is more limited: while low-type consumers are forced to keep their used goods, high-types are more willing to scrap their used goods in order to return to the primary market. However, this shortens the lifespan of the good, decreasing its asset value. In contrast, an active secondary market triggers a more efficient allocation of goods among consumers, creating a positive effect on firms' profits.

Lastly, secondary markets also affect the inherent *dynamic competition* between the durable goods manufacturers producing new goods today and their "future-selves", who face competition from the stock of used goods in the future. Without secondary markets, Coase (1972) famously pointed out that time-consistent firms will be hurt by their inability to commit to high future prices, as savvy consumers will postpone their purchases in anticipation of future price drops, forcing earlier decreases in prices. Opening secondary markets modifies but does not eliminate this problem: now savvy consumers may anticipate future drops in the resale prices of used cars, which deters them from paying too much for new cars today and forces the firm to reduce prices. Thus, the dynamic effects of opening the secondary market on firms' profits are ambiguous and interact with the substitution and sorting effects.[3]

Related literature. Understanding whether secondary markets hurt manufacturers is a long-standing question in the literature. The earliest discussions were motivated by the *United States vs. Alcoa* (1945) monopolization case, which Alcoa lost on appeal.[4] One key issue raised in Alcoa's defense was that it faced substantial competition from the used (scrap) aluminum sector. Decades later, Suslow (1986) confirmed, using estimates from a structural model, that Alcoa did indeed retain substantial market power despite the competition from the recyclable aluminum sector.

Anderson and Ginsburgh (1994), Hendel and Lizzeri (1999b), and Porter and Sattler (1999) investigated whether firms would benefit from closing secondary markets, showing that these markets increase allocative efficiency. In their models, consumers are heterogeneous in the persistent component of their valuation of the good, the good depreciates, and firms can

[3]See Liang (1999) for more discussion of the dynamic competition implications of having active secondary markets.

[4]cf. Areeda and Kaplow (1988, pp. 476ff).

fully commit to future prices. In this setting, Anderson and Ginsburgh (1994) and Hendel and Lizzeri (1999b) derive the allocative benefits of secondary markets, showing that the firms can benefit from indirect price discrimination when the secondary markets are active. Porter and Sattler (1999) also provide empirical evidence supporting the allocative role that secondary markets play. More recently, Johnson (2010) extends this framework to allow consumers' preferences to change over time, and finds that a two-period full-commitment monopolist may prefer to close down the secondary market.[5]

There is a vast literature addressing various questions that concern markets of durable goods. Close to our work, and in particular to our modeling of consumers' preferences, are the empirical papers analyzing the demand-side problem of forward-looking consumers in markets for durable goods, allowing for persistent and stochastic components to the consumers' valuations (see Erdem, Imai, and Keane (2003), Hendel and Nevo (2006a), (2006b), Melnikov (2000), Gowrisankaran and Rysman (2006), Gordon (2009), Hartmann (2006), Chevalier and Goolsbee (2009), Carranza (2007), Schiraldi (2006), and Copeland (2006)).[6] Following this literature, we assume that consumers are heterogeneous in both a *vertical (quality)* differentiation dimension, which is persistent over time, and also a *horizontal* differentiation dimension, which changes over time and causes consumers to re-optimize their car choices due to stochastic changes in their car needs.

There is also a much smaller empirical literature on durable-goods markets that accounts for firms' dynamic decision problems in such markets.[7] Our paper builds on Esteban and Shum

[5]In Johnson (2010), a monopolist may prefer to close down the secondary market because doing so enables a different form of indirect price discrimination: consumers who obtain a low realization of their willingness to pay keep the goods even though the firm would never sell to them. Such an effect is also present in our model.

[6]There has also been a large literature (including Bresnahan (1981), Berry, Levinsohn, and Pakes (1995), Goldberg (1995), Petrin (2002)) addressing various issues concerning the automobile industry. These papers estimate static demand-supply models for the automobile industry, where the firms do not internalize the intertemporal linkages between the new and used car markets.

[7]While the theoretical literature on durable goods has traditionally focused on monopoly, the literature has also generalized to oligopoly. For example, Bulow (1986) analyzes the incentives of monopolists and oligopolists regarding planned obsolescence of durable goods, Gul (1987) studies noncooperative collusion in durable goods oligopoly, Carlton and Gertner (1989) examine the effects of mergers in durable goods industries, and Esteban (2002) investigates the equilibrium dynamics in semi-durable goods markets using both a monopoly model and an oligopoly model. Related to these studies, in this paper we assume a triopoly

(2007), who analyzed a durable-goods oligopoly model with secondary markets. However, that paper made the restrictive assumptions of no transaction costs and limited product and consumer valuation heterogeneity to obtain a tractable linear-quadratic specification.[8] Nair (2007) and Goettler and Gordon (2008) are two other papers that estimate dynamic equilibrium models for (respectively) the video game console industry and the PC micro-processors industry. In these two papers, both consumers and firms are forward-looking and solve dynamic programming problems, but there is no secondary market for used goods.

Lastly, since part of our paper seeks to understand the inertia in consumers' car choices from one period to the next, our paper also relates to the studies that model consumers as having (S,s) type replacement problems, such as Eberly (1994), Adda and Cooper (2000), and Attanasio (2000).[9] Particularly related is Stolyarov (2002), which seeks to explain the pattern of used car holdings and trade. With this focus, he builds a model with competitive primary and secondary markets, in which consumer are heterogeneous and replace their goods infrequently due to transaction costs in the used car market. Gavazza and Lizzeri (2009) calibrate a model of secondary markets with heterogeneous consumers, transaction costs, and exogenous new good supply to automobile markets. They find that such a model does remarkably well in matching several aggregate features of the U.S. market.

We end this section by noting some limitations of our analysis. First, we abstract away from asymmetric information between buyers and sellers which, as is well-known (Akerlof (1970)), can cause adverse selection in secondary markets.[10] Second, we do not allow firms to choose the durability of their products, as has been done in the planned obsolescence

in the baseline calibration and also consider a duopoly and a monopoly in the counterfactual exercises. Therefore, our approach allows us to investigate how the primary market structure affects the role of the secondary market.

[8] J. Chen, S. Esteban, and M. Shum ((2008), (2010)) assume logit demand without persistent heterogeneity, but retain the assumption of no transaction costs. The former quantifies the biases in neglecting supply-side dynamics while the latter studies the effects of tax rates reform on durable-goods manufacturers.

[9] For example, Attanasio (2000) estimates the parameters of the (S,s) rule for automobile expenditure using microeconomic data, and finds that idiosyncratic shocks can play an important role in shaping the dynamic properties of the aggregate time series. Similarly, in our paper consumers' idiosyncratic shocks play an important role in determining the market outcome.

[10] The subsequent empirical and theoretical literature in this area is very large; see Bond (1982) and Hendel and Lizzeri (1999a) for representative papers.

literature.[11]

2 Model

Next, we build a model of a durable goods oligopoly with secondary markets. Consumers incur transaction costs when selling used goods in the secondary market and have heterogeneous valuations. Time is discrete and firms and consumers are infinitely lived, forward-looking, and time consistent. For convenience, and foreshadowing our empirical application, we refer to the good as a "car" for the remainder of the paper.

There are J vintages of cars, including both new and used. Cars of different vintages are heterogeneous in their characteristics, while all cars of the same vintage are homogeneous. We index the car vintages by $j = 0, 1, \ldots, J$, where $j = 0$ is the outside option of no car, $j = 1$ is the new car, and cars $j = 2, \ldots, J$ are the used cars ordered by their vintage, from newer to older. Accordingly, we let $d(j)$ denote the next period's vintage of a car that is currently vintage j, with $d(j) = j + 1$, for $j = 1, \ldots, J - 1$, and define $d(J) = 0$ and $d(0) = 0$. Lastly, for each car type, we let $\alpha_j \geq 0$ denote its product-characteristics index and normalize $\alpha_0 = 0$.

In what follows, we describe the model and derive the equilibrium. We first formulate the consumers' and firms' problems in partial equilibrium. Subsequently, we impose equilibrium by clearing all markets and formulating correct expectations by consumers and firms.

2.1 Consumers' problem

In partial equilibrium, consumers take current and future prices as given. There is a continuum of consumers with unit mass, with generic consumer i. Consumers are differentiated in two dimensions. On the one hand, consumers differ in their marginal utility of money, γ, of

[11] See Swan (1972), Bulow (1986), Hendel and Lizzeri (1999a) , Iizuka (2007), M. Waldman (1993), (1996), among many others, for models of endogenous depreciation.

which there are $l = 1, \ldots, L < \infty$ distinct types in proportions $\pi_1, \ldots, \pi_L$, with $\sum_l \pi_l = 1$. We let l_i denote i's type and γ_i denote his marginal utility of money; this is unchanging across time periods and represents a persistent component of preference heterogeneity across consumers. In addition, consumers also experience preference shocks which vary period-by-period. We let $\vec{\epsilon}_{it} \equiv (\epsilon_{i0t}, \epsilon_{i1t}, \ldots, \epsilon_{iJt})$ be the vector of preference shocks of consumer i in period t, where the shocks are i.i.d. across (i, j, t).[12] In our specification of the utility function that follows, γ captures vertical differentiation among the new and used cars in the consumers' preferences, while the preference shocks ϵ allow for horizontal differentiation which varies over time.

We let $r_{it} \in \{0, 2, \ldots, J\}$ denote the index of the car owned by a consumer i at the beginning of period t and B^l_{jt}, for $j = 2, \ldots, J$, denote the measure of consumers in the population who are type l and own a used car j at the beginning of period t. Accordingly, $\vec{B}_t$ is the vector of used car holdings by consumer types.

Consumers make decisions considering current and expected future prices as well as the transaction costs they incur. Because of the latter, the consumers are not indifferent between keeping their car and selling-then-repurchasing the same car from the secondary market because they incur a transaction cost using the latter strategy. As a result, each consumer's choice depends both on her own type as well as on the car vintage she owns.[13] We let p_{jt} be the price of car j in period t and $\vec{p}_t = (p_{0t}, p_{1t}, \ldots, p_{Jt})$ be the corresponding price vector. We set $p_{0t} = 0$ for all t. The consumer incurs a transaction cost k_j, for $j = 0, 2, \ldots, J$, when selling car vintage j. We assume the transaction cost is the same for all cars except for $j = 0$, which carries a transaction cost of 0. Accordingly, we define $k_j = k$ for all $j > 1$ and $k_0 = 0$.[14]

[12] In particular, because all cars of the same vintage are homogeneous, the preference shock ϵ_{ijt}, for consumer i, is the same for all cars of a given vintage j (even when these cars are produced by different firms).

[13] Esteban and Shum (2007), for instance, assume no transaction costs and, as in this paper, a utility function that is quasi-linear in income. Without transaction costs, the consumers' dynamic optimization problems are equivalent to a sequence of static decision problems with prices that are equal to the implicit rental prices.

[14] We assume the magnitude of the consumers' transaction costs is exogenous. Hendel and Lizzeri (1999b)

Consumer i derives the following utility flows in period t. If she keeps her car—car r_{it}—she derives utility of

$$\alpha_{r_{it}} + \epsilon_{ir_{it}t}.$$

If she sells it and purchases j as a replacement (which can be the outside option $j = 0$), her utility is

$$\alpha_j + \gamma_i \cdot (p_{r_{it}t} - k_{r_{it}} - p_{jt}) + \epsilon_{ijt},$$

where $k_{r_{it}}$ is the transaction cost in selling r_{it}, as defined above.[15] Finally, if she scraps her car and buys j as a replacement, she obtains utility of

$$\alpha_j - \gamma_i p_{jt} + \epsilon_{ijt}.$$

When comparing the utility flows, the consumer only sells her used car if $p_{r_{it}t} \geq k_{r_{it}}$, which makes the transaction cost a price floor in the secondary market.[16] We can express compactly consumer i's utility flow in t as

$$u(s_{it}, \vec{p}_t, r_{it}, \epsilon_{it}; \gamma_i) = \underbrace{\alpha_{s_{it}} + \mathbf{1}_{s_{it} \neq r_{it}} \cdot \gamma_i \cdot (\max\{p_{r_{it}t} - k_{r_{it}}, 0\} - p_{s_{it}t})}_{\equiv \tilde{u}(s_{it}, \vec{p}_t, r_{it}; \gamma_i)} + \epsilon_{is_{it}t}.$$

We assume each preference shock ϵ_{ijt} is distributed type 1 extreme-value, which leads to a number of convenient closed-form expressions in what follows.[17]

We can next derive the dynamic maximization problem of each consumer i. For now, we assume consumers take all prices—current and future—as given. Later, in the definition

note that the producers can effectively "endogenize" transaction costs by limiting the transferability of warranties. However, in the car market, which is the focus of this paper, currently warranties are fully transferrable.

[15] This lump-sum specification of transaction costs is motivated by numbers in the Kelley Blue Book; there, we find that the implied transaction cost (measured as the difference between the trade-in value and the suggested retail price) seems largely constant, even for cars of very different valuations and quality classes. Nevertheless, for completeness, we also present calibration results from a specification where transaction costs are proportional to the car price in Section 3.1 of the Online Appendix; the results are qualitatively the same as and quantitatively very similar to those from our baseline specification below.

[16] In our model, consumers cannot store a car without consuming it; that is, only a single car can be owned and this must be consumed. A hybrid model that allows consumers to hold on to a used car, without scrapping it, and yet purchase another car for consumption, would significantly complicate the dynamic behavior of consumers and firms.

[17] With this assumption, our consumer demand model resembles the "dynamic logit" specifications of the dynamic discrete-choice models that started with Rust (1987).

of equilibrium, prices will be recovered from consumers having rational expectations over the firms' future behavior. We let $s_{it} \in \{0, \ldots, J\}$ denote i's consumption choice in t, and (r_{it}, ϵ_{it}) denote the state variables that affect this choice. Then, using $\hat{\vec{p}}_t$ to denote the vector of prices from t onwards, we write the Bellman equation for consumer i's dynamic decision problem as

$$V(\hat{\vec{p}}_t, r_{it}, \vec{\epsilon}_t; \gamma_i) = \max_{s_{it}} \left[u(s_{it}, \vec{p}_t, r_{it}, \epsilon_{it}; \gamma_i) + \beta \tilde{V} \left(\hat{\vec{p}}_{t+1}, d(s_{it}); \gamma_i \right) \right], \tag{1}$$

where $\beta \in (0, 1)$ is the discount factor, common to consumers and firms, and

$$\begin{aligned} \tilde{V}(\hat{\vec{p}}_t, r_{it}; \gamma_i) &\equiv E_{\vec{\epsilon}} V(\hat{\vec{p}}_t, r_{it}, \vec{\epsilon}_t; \gamma_i) \\ &= \log \left\{ \sum_{j=0}^{J} \exp \left(\tilde{u}(j, \vec{p}_t, r_{it}; \gamma_i) + \beta \tilde{V}(\hat{\vec{p}}_{t+1}, d(j); \gamma_i) \right) \right\} \end{aligned} \tag{2}$$

is the expected value function before consumer i's shock is observed (with the latter substitution following from the assumption that the ϵ's are extreme-valued). Accordingly, the choice probability of product j by consumer i who owns a car j' and is of type l takes the multinomial logit form

$$q_j(\vec{p}_t, j', \hat{\vec{p}}_{t+1}; \gamma_l) = \frac{\exp \left(\tilde{u}(j, \vec{p}_t, j'; \gamma_l) + \beta \tilde{V}(\hat{\vec{p}}_{t+1}, d(j); \gamma_l) \right)}{\sum_{h=0}^{J} \exp \left(\tilde{u}(h, \vec{p}_t, j'; \gamma_l) + \beta \tilde{V}(\hat{\vec{p}}_{t+1}, d(h); \gamma_l) \right)}. \tag{3}$$

Remark: *Persistent versus time-varying preference heterogeneity.* Our consumers have both persistent and time-varying components to their preference heterogeneity (measured by, respectively, their γ_i's and the ϵ_{ijt}'s). These two types of heterogeneity have distinctive implications for the profitability of opening the secondary market.

When the time-varying component of preference heterogeneity becomes relatively more important, the distinction between high- vs. low-type consumers becomes more blurred. Accordingly, the sorting benefits of opening the secondary market decrease, and the substitution effects take precedence, so that firms are hurt more when the secondary market opens. When preferences are primarily persistent, however, the sorting benefit increases and the overall effect of opening the secondary market on firms' profits may be reversed.

Thus a model without (with only) time-varying preference heterogeneity may overstate (understate) the benefits to firms from opening the secondary market. ■

2.1.1 Aggregate Demand Functions

We next aggregate up the choices for all consumers to obtain the aggregate quantity demanded for each car vintage j in period t. We let $\vec{Q}_t^D$ be the vector of new and used car demand by consumer types, with generic element Q_{jt}^{Dl}. The total demand for car vintage j is given by

$$Q_{jt}^D \equiv \sum_l Q_{jt}^{Dl} = \sum_l \sum_{j',j'\neq j} B_{j't}^l \cdot q_j(\vec{p}_t, j', \hat{\vec{p}}_{t+1}; \gamma_l), \quad \text{for } j = 1, \ldots, J. \tag{4}$$

By construction, if j is a used car, its demand excludes those consumers who keep their current car (i.e. the second summation above does not include $j' = j$).

Analogously, the supply of used cars in the market, for $j' = 2, \ldots, J$, is given by

$$Q_{j't}^S = \begin{cases} \sum_l \sum_{j,j\neq j'} B_{j't}^l \cdot q_j(\vec{p}_t, j', \hat{\vec{p}}_{t+1}; \gamma_l) & \text{if } p_{j't} \geq k, \\ 0 & \text{otherwise.} \end{cases} \tag{5}$$

2.2 Firms' problem

We now turn to the problem of the firms, which, initially, we solve in partial equilibrium by taking as given the inverse demand functions and the law-of-motion determining the next period's consumers' vehicle holdings. We restrict the firms' strategies to be Markov, requiring that the firms' production choices be only functions of the payoff relevant state, which, in our setting, is the vector of used car holdings by consumer types, $\vec{B}_t$. Then, in every period, firms choose quantities simultaneously to maximize their discounted sum of current and future profits while accounting for the optimality of the future actions.

Our assumption that firms choose quantities is supported by several institutional features of the automobile industry. Capacities do not appear to be easily adjustable in the automobile industry (cf., Bresnahan and Ramey (1994)), which contradicts the implicit assumption of flexible capacities underlying the Bertrand-price setting game. Moreover, it appears common for car manufacturers to adjust prices to clear inventories by offering rebates or other forms of price discounts towards the end of each model-calendar year.

There are N firms producing homogeneous new cars. Let $\vec{x}_t = (x_{1t}, \ldots, x_{Nt})$ be the vector of production choices by all firms, and let $\vec{x}_{-nt}$ be the sub-vector containing all elements of $\vec{x}_t$ excluding x_{nt}, for $n = 1, \ldots, N$. We also assume the marginal cost of production is constant and equal to $c \geq 0$ for all firms.

We let $\vec{B}_{t+1} = L(\vec{x}_t, \vec{B}_t)$ be the law-of-motion of the car holdings' vector, and let $P(\vec{x}_t, \vec{B}_t)$ be the inverse demand function of new cars. For the time being, in partial equilibrium, we exogenously assume the inverse demand function is only a function of the control and state, simplifying the dependence on future output that is characteristic of durable goods problems. In the next section, we show that this inverse demand function is consistent with the recursive substitution of the expected future equilibrium behavior, which, in a Markov perfect equilibrium, is a function of the current control and state.[18]

Given the inverse demand functions $P(\vec{x}_t, \vec{B}_t)$, the law-of-motion $L(\vec{x}_t, \vec{B}_t)$, and the rival firms' production $\vec{x}_{-nt}$, the maximization problem of each firm is a dynamic programming problem with state $\vec{B}_t$. Let x^*_{nt} denote the firm's equilibrium production. Then, a Markov-perfect equilibrium consists of value functions $W_n(\cdot)$ and decision rules $G_n(\cdot)$ such that, for all $n = 1, \ldots, N$,

$$\begin{aligned} W_n(\vec{B}_t) &= \max_{x_{nt}} \left(P((x_{nt}, \vec{x}^*_{-nt}), \vec{B}_t) - c\right) x_{nt} + \beta W_n(L((x_{nt}, \vec{x}^*_{-nt}), \vec{B}_t)), \qquad \text{and} \\ x^*_{nt} &= G_n(\vec{B}_t, \vec{x}^*_{-nt}) \equiv G_n(\vec{B}_t). \end{aligned} \tag{6}$$

<u>Remark:</u> *Time consistent versus time inconsistent (full-commitment) solution.* By focusing on a Markov-perfect equilibrium, we require firms' production strategies to be time-consistent—equivalently, we require that firms cannot commit to future production levels

[18]Indeed, this future dependence is what yields different solutions to the time consistent and inconsistent problems of the firms.

that are sub-optimal once the future period is reached. This assumption will be relaxed in our counterfactual simulations below.

In the time-inconsistent solution, firms choose once and for all their future production plans and credibly commit to not revising their choices. This eliminates the dynamic competition of the firms with their "future selves"; therefore, the dynamic competition effect disappears and the effects of opening the secondary market on the firms' profits are determined solely by the substitution and sorting effects. Obviously, durable-goods manufacturers earn higher profits when they are able to commit; the reduction in profits in moving from the full-commitment scenario to the no-commitment scenario provides, therefore, a good measure of the magnitude of the dynamic effect. ■

2.3 Equilibrium

To complete the equilibrium definition, we require that the markets for all goods, both new and used, clear, that the prices assumed in the demand-side problem be consistent with those obtained from the supply side, and that the inverse demand functions and laws-of-motion assumed in the supply-side problem be consistent with those obtained from the demand side. Therefore, we require:

(i) *Primary market clearance:* For the new car vintage, $\sum_{n=1,\ldots,N} G_n(\vec{B}) = Q_1^D$, as defined in the demand equation in (4).

(ii) *Secondary market clearance/free disposal:* For every used car vintage $j = 2, \ldots, J$, $Q_j^D = Q_j^S$ if $p_j > k$, where Q_j^D and Q_j^S are defined in the used car demand and supply equations (4) and (5), respectively. If $p_j = k$, i.e., if the price floor k binds, then $Q_j^S \geq Q_j^D$, and the measure of used cars scrapped is $Q_j^S - Q_j^D$.[19]

(iii) *Consistency of inverse demand functions:* $\vec{p} = P(\vec{x}, \vec{B})$ satisfies the aggregate demand and supply equations in (4) and (5), where the next period's price is given by

[19]When $p_j = k$, an owner of used car j is indifferent between selling her used car and scrapping it. Therefore, in the model we do not need a rationing rule that specifies, when the quantity supplied is greater than the quantity demanded, which of the suppliers sell their used cars and which scrap their used cars.

$\vec{p}' = P(G(L(\vec{x}, \vec{B})), L(\vec{x}, \vec{B}))$.

(iv) *Consistency of law of motion for car holdings vector:* The vector of car holdings evolves as:

$$
\begin{aligned}
&(B_1^l)' = 0,\\
&(B_2^l)' = Q_1^{Dl},\\
&(B_j^l)' = Q_{j-1}^{Dl} + B_{j-1}^l \cdot q_{j-1}(\vec{p}, j-1, \vec{p}'; \gamma_l), \qquad \text{for } j = 3, \ldots, J, \qquad \text{and}\\
&(B_0^l)' = 1 - \sum_{j=1}^{J} (B_j^l)',
\end{aligned}
\tag{7}
$$

where $Q_\cdot^{Dl}$ is defined in the demand equations (4), $B_{j-1}^l \cdot q_{j-1}(\vec{p}, j-1, \vec{p}'; \gamma_l)$, $j = 3, \ldots, J$, is the measure of type l consumers who keep their used car $j-1$, and the probability $q_\cdot(\vec{p}, \cdot, \vec{p}'; \gamma)$ is defined in equation (3). We also require that the updating rule equal the law-of-motion $L(\vec{X}, \vec{B})$ introduced in the firm's problem.

3 Calibration

In order to quantify the effects of secondary markets, we calibrate our model to aggregate data from the U.S. automobile market. As we describe below, some of the parameter values are set *a priori* based on data or recent empirical studies, while others are obtained by finding parameter values such that, in the steady state, the predicted values of the endogenous variables match the average aggregate values for the U.S. automobile market during the years 1994–2003.

According to the 2001 National Household Travel Survey (NHTS), the average age of cars in the U.S. was 9 years. Therefore, at any point in time, the size of the used car stock was many times that of new cars. This property presents a difficulty for our calibration: if we model cars as living for many periods, the state space becomes very large, and the heavy computational burden makes the calibration exercise infeasible; on the other hand, if we model cars as living for fewer periods, the stock of used cars is only a few times that of new cars, which is vastly different from reality.

To overcome this difficulty, we take a cue from Swan (1972) and assume that the life of a car consists of 2 stages (vintages)—new and used—and that used cars die stochastically as time passes. In particular, while we continue to assume that, after one period, new cars depreciate into used cars with probability one, we make all used cars identical and assume that, in each period, a used car dies with probability $\delta \in (0,1)$. This implies that, in the steady state, the average age of existing cars is

$$\phi(\delta) = \frac{1 \cdot 1 + 2 \cdot 1 + 3 \cdot (1-\delta) + 4 \cdot (1-\delta)^2 + ...}{1 + 1 + (1-\delta) + (1-\delta)^2 + ...}.$$

Since, as previously stated, the average automobile age in the United States is 9 years, we solve $\phi(\delta) = 9$ to obtain $\delta = 0.11$, which we fix in our computations.

Table 1 summarizes all the parameters that we fix in the calibration exercise. The model's persistent heterogeneity parameters, the γ's, arise from income differences in the population. To keep our study tractable, we approximate the income distribution with two consumer types ($L = 2$), which we label as types I and II, and let each type represent half of the consumer population. Empirically, these types are identified as those with above- and below-median income. Then, the car holdings' vector in this two-vintage, two-type specification of the model has two elements, B_2^1 and B_2^2, which are the used car stocks held by each of the two consumer types.

On the supply side, we consider an oligopoly of three firms producing homogeneous new cars, corresponding to the Big 3 U.S. automobile producers (General Motors, Ford and Chrysler). As is common in the literature, we assume the interest rate to be 4%, which corresponds to a discount factor of $\beta = 1/1.04$.

The remaining model parameters are calibrated; these are: α_1, the new car product-characteristics index; α_2, the used car product-characteristics index; γ_1 (resp. γ_2), the type I (resp. II) consumers' marginal utility of money; c, the marginal cost of production (identical for all firms); and k, the transaction cost parameter. We obtain these values by minimizing the sum of the squared percentage differences between the model's steady-state predictions and the U.S. averages for the following variables: (i) the fraction of above-median income ("Type I") and below-median ("Type II") consumers who purchase new and used cars; (ii) the new and used vehicle prices; and (iii) the firms' markup (the difference between the new vehicle price and the marginal cost, divided by the new vehicle price). For (i) and (ii), the U.S. averages are calculated from the owned vehicle component of the Consumer Expenditure Survey for the years 1994–2003, while (iii) is calculated from the annual reports of the Big 3 U.S. automobile producers. All prices are converted to dollars in the year 2003.

Despite having reduced the number of parameters, having dynamics on both the demand and the supply sides of the market imposes a heavy computational burden for the calibration exercise. We overcome this hurdle by taking an MPEC approach to calibration. The MPEC approach is a constrained optimization approach to fitting equilibrium models, with constraints that are given by the equilibrium conditions of the consumers' and producers' dynamic optimization problems (more details are contained in the Appendix).[20] In our calibration exercise, the main advantage of the MPEC approach is to avoid computing the dynamic equilibrium of the model for every candidate set of parameter values, except for the final set. As a result, we reduce the computational burden and associated computing time considerably.

3.1 Calibration results

Table 2 presents the values of the free parameters that yield the best fit, and Table 3 the corresponding simulated steady-state values with the calibrated parameters alongside the U.S. averages. Table 4 reports steady-state results at the calibrated parameter values. Throughout the paper, all monetary numbers are reported in $10,000 in the year 2003.

Table 2 shows that the product-characteristics index of new cars ($\alpha_1 = 1.7$) is 91% higher

[20]See also Luo, Pang, and Ralph (1996) for additional details.

than that of used cars ($\alpha_2 = 0.89$). The type I consumers have a lower price sensitivity (γ) equal to 1.71 (i.e., a higher taste for quality), while the type II consumers have a higher price sensitivity coefficient of 2.3 (a lower taste for quality). Thus, given our calibrated parameter values, gains from trade occur due to the depreciation of the product (both because of the decrease in the product-characteristics index and because of the product's stochastic death) and the heterogeneity in the consumers' valuation of the goods, in both the persistent and the time-varying terms.

The marginal cost parameter is calibrated to equal 1.91 ($19,100), which appears to be in the correct range. Copeland, Dunn, and Hall (2005, pg. 28), for example, reports a lower bound on marginal costs of $17,693 (in the year 2000), which corresponds to $18,905 in the year 2003.

Lastly, the transaction cost parameter k is shown to be calibrated to equal 0.4, corresponding to $4,000. This is roughly consistent with data from the Kelley Blue Book, which indicates that the difference between the trade-in value of a used car (seller's price for consumers) and its suggested retail value (buyer's price)—which may serve as a proxy for transaction cost—is typically in the $3,000-$4,000 range.

Table 3 reports that in the steady state, in every period, 9.7% of the type I consumers purchase new cars and 17.8% purchase used cars, while 4.2% of the type II consumers purchase new cars and 19.3% purchase used cars. Thus, type I consumers participate more in the primary market than type II consumers do and also own a larger fraction of the total car fleet. The used car price, which equals 0.9, is greater than the transaction cost, which equals 0.4, indicating that used cars are not being scrapped in equilibrium. On the other hand, used cars are cheaper than the calibrated marginal cost of production (1.91); at these values, the secondary market allows the firm to obtain some indirect rents from consumers who, otherwise, the firm would not be willing to sell to in the primary market.

Lastly, this table also reports the markup, which equals 0.17. While our model has a stripped-down specification of consumer heterogeneity relative to other empirical studies of the automobile market (e.g., Goldberg (1995), Berry, Levinsohn, and Pakes (1995)), our markup figure remains in the same ballpark.[21]

Table 4 provides a further characterization of the behavior of the different consumer types. It reports that, in the steady state, 67% of the type I consumers and 64% of the type II ones start next period owning a used car. It also contains the consumers' car ownership transitional probabilities, showing that, unconditionally, the high type consumers (type I) are more likely to purchase new cars, while the low type consumers are more likely to hold on to their used cars, which is consistent with the observed sorting of the population by income and car vintage in the data.

4 Counterfactual experiments: Do secondary markets help or hurt new car producers?

The purpose of our counterfactual experiments is to identify when and how secondary markets may be beneficial to durable goods manufacturers and the role that the different effects may play. In these experiments, we change the transaction cost parameter k and recompute the steady state, holding all the other parameters fixed.

The top panel of Table 5 presents these "baseline" counterfactual steady-state outcomes, where we allow the size of the transaction cost to vary between 8 (which closes the secondary market) and 0 (which makes the secondary market frictionless), while holding all the other parameters fixed at the calibrated values reported in Table 2. In this table, as well as in all subsequent tables, new car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one. For expositional convenience, we only report percentage changes in profits from $k = 8$ to $k = 0$.

[21] For example, Berry, Levinsohn, and Pakes (1995, pg. 882) report markups (in 1990) ranging from 0.155 to 0.328, with an average of 0.239.

Relative to $k = 8$, opening the secondary market to $k = 0$ lowers profits by 42%, suggesting that the negative substitution effect outweighs other effects and pointing towards the time-varying component in consumers' preferences playing an important role in explaining new car demand. The magnitude of the substitution effect is also apparent in the halving in output that results from the opening of the secondary market. At the same time, we observe a mild increase in the new car's price accompanied by, not surprisingly, a significant increase in consumers' surplus, from 0.35 to 0.62. Used car scrappage also decreases, suggesting that, with secondary markets, vehicles have a longer lifespan; this translates into an increased residual value of the asset which, all else equal, raises the new goods' price.

Figures 1 and 2 give more details on the effects of opening the secondary market, by plotting the behavior of the two types of consumers. Figure 1 plots new car purchases by consumer type as the secondary market is gradually opened, for $k = 8, 7, ..., 2, 1, 0.4, 0$. The figure shows that fewer consumers buy new cars as the secondary market is opened up. In addition, type I consumers, being the high-valuation type, consistently buy more new cars than type II consumers. Figure 2 plots used car purchases by consumer type as k is decreased from 8 to 0. It shows that the percentage of each type of consumers who buy used cars increases as k decreases, rising from virtually zero at $k \geq 4$ to 22% for type I and 25% for type II at $k = 0$.

Next, we consider additional sets of counterfactual experiments, to better understand the interaction of the different effects—substitution, sorting and dynamic— and how these depend on the underlying parameter and distributional assumptions. In these counterfactuals, multiple effects are at play and we highlight the first-order effects when comparing opened and closed secondary markets.

4.1 Assessing substitution, sorting and dynamic effects: Full-commitment counterfactual

First, we zero in on the magnitude of the substitution vs. sorting effects. To do so, we compute the full-commitment equilibrium of our model for our calibrated parameter values. In this setting, the dynamic effect disappears, because firms no longer compete with their future selves; hence, the changes in profits from opening secondary markets are completely determined by the substitution and sorting effects.

Table 5 reports the results. The second panel of this table shows how, with commitment, opening the secondary market from $k = 8$ to $k = 0$ increases firms' profits by 36%, so the firms prefer an active secondary market. This result implies that, at the calibrated parameter values, the (positive) sorting effect outweighs the (negative) substitution effect.

On the other hand, we have already seen how, in the benchmark scenario when firms are unable to commit, they would be better off when the secondary market is closed (the first panel). The change in the desirability of the secondary market when commitment is eliminated manifests the importance of "Coasian" dynamics: for our calibrated parameter values, when firms cannot commit, opening the secondary market exacerbates the dynamic competition between firms and their "future selves."[22]

4.2 Assessing product characteristics

In our framework, the characteristics of the product are given by its quality (both new and used) and by its durability. We next analyze their role in determining firms' loss from opening secondary markets, starting with the quality.

Quality differentiation. Intuitively, when secondary markets are closed, increasing the quality differentiation by lowering the quality of used goods relative to new goods lowers the cost

[22]We thank a referee for a useful comment on this issue.

of re-optimization (which involves scrapping used goods); this, in turn, induces high-type consumers to return to the primary market more often. On the other hand, early scrappage shortens the expected lifespan of the vehicle and this is discounted in the price of the new asset and the firm's revenues.

This intuition is borne out in the results. In the second panel of Table 6, we increase the quality differential by lowering the quality of a used car α_2 from the calibrated value of 0.89 to 0.7. In this case, opening secondary markets, from $k = 8$ to $k = 0$, decreases profits by 53%, larger than the 42% decrease in the baseline results. Comparing the first and the second panels, lowering α_2 from 0.89 to 0.7 increases used car scrappage and decreases new goods prices, which is consistent with the decreased asset value interpretation given above. The third panel of Table 6 illustrates the counterpart, reducing the quality differential between new and used cars by increasing α_2 to 1.1. We see that in this case an active secondary market becomes less detrimental. From $k = 8$ to $k = 0$, firms' profits decrease by only 33%.[23]

Durability. We next modify the durability of the product. Increased durability leads to a larger stock of used goods against which the firms compete, which exacerbates the negative substitution effect of secondary markets and reduces profits for the firms. Table 7 contains results from counterfactuals where we vary δ, the per-period death probability of a used car. The results in the bottom two panels of Table 7 show that opening secondary markets hurts firms more severely as the product becomes more durable. In the second panel, durability is increased by reducing the death probability to $\delta = 0.05$. In that case, decreasing transaction costs from 8 to 0 reduces profits by 74%. In contrast, when durability is reduced by increasing δ to 0.25, each firm's profits actually increase by 10% if transaction costs are reduced from 8 to 0, so the firms would prefer secondary markets to be frictionless.

We were unable to accommodate endogenous durability choices in the context of our already

[23] Although Table 6 only reports results for three pairs of (α_1, α_2) values, we have extensively varied these parameters, and our findings are robust. This also applies to the other tables in this counterfactuals section.

complicated model. While the counterfactuals we conducted are not equivalent to modeling endogenous durability, they shed some light on the problem of planned obsolescence. Using Table 7 and comparing all profits for all values of k, we observe that making cars less durable (by increasing δ) increases firms' profits, and the magnitude of the increase is larger if the secondary market is more active.[24] For example, increasing δ from 0.11 (the baseline value) to 0.25 increases the firms' profits by 18% when the secondary market is shut down ($k = 8$), but it increases the firms' profits by a much more substantial 121% when the secondary market is frictionless ($k = 0$). These results suggest that when the secondary market becomes more active, firms have a stronger incentive to make their cars less durable.[25]

4.3 Assessing consumer heterogeneity

We next analyze the role that the consumers' time-varying preference shocks (ϵ_{ijt}) play by modifying the variance of their distribution, with a larger variance implying a more prominent role for the time-varying component of preferences—more volatile preferences, in short. The first panel of Table 8 reports results for the baseline case, in which the scale parameter of the type I extreme value distribution for ϵ_{ijt} is normalized to 1 and hence $Var(\epsilon_{ijt}) = \pi^2/6$.[26] In the second panel, the variance is doubled, and in the third panel, the variance is halved (the mean is normalized to 0 throughout).

We find that as the variance of ϵ_{ijt} is increased, opening the secondary market hurts the firms more. In fact, Table 8 reports that from $k = 8$ to $k = 0$, firms' profits decrease by 42% at the baseline variance, compared to a much larger 61% at the doubled variance and a much smaller 24% at the halved variance. This is consistent with the implications of persistent vs. time-varying heterogeneity which we discussed in our earlier remark; essentially, when only the time-varying heterogeneity is present, the sorting benefits of opening secondary markets become much reduced, and the detrimental substitution effects of sec-

[24] We have also computed profits for all the (δ, k) combinations with $\delta \in \{0.05, 0.11, 0.15, 0.2, 0.25\}$ and $k \in \{0, 0.4, 1, 2, 3, 4, 8\}$, and these findings are robust.

[25] We thank a referee for a useful comment on this issue.

[26] See Section 2.10.4 in Anderson, de Palma, and Thisse (1992).

ondary markets dominate. At the same time, an increase in the variance also triggers a significant increase in used car scrappage.

To examine the role of persistent vs. time-varying preference heterogeneity further, we consider (in the Online Appendix) two additional sets of counterfactuals. First, we vary consumers' persistent heterogeneity by changing the γ's (reported in Table A7 of the Online Appendix). Consistent with the intuition above, a smaller persistent heterogeneity (which implies a more prominent role for the time-varying heterogeneity) leads to a larger decrease in profits from opening the secondary market, whereas a larger persistent heterogeneity leads to a smaller decrease in profits.

Second, we strengthen the persistent component of heterogeneity by allowing the α parameters to vary across consumer types. Specifically, suppose type I consumers are "new car lovers" whose valuation of a car quickly drops when the car gets older ($\alpha_{1,I} >> \alpha_{2,I}$), while Type II consumers are "used car lovers" who only care about whether a car runs well and whose valuation of a car does not drop much when the car gets older ($\alpha_{1,II} \approx \alpha_{2,II}$). In this case, the secondary market plays a more active sorting role; correspondingly, we find (see Table A8 of the Online Appendix) that opening the secondary market becomes less detrimental to new car producers.[27]

4.4 Assessing market structure

We next consider the interaction between opening the secondary market and the market structure (i.e., the number of primary market competitors). As in a static Cournot setting, our oligopolistic firms overproduce relative to the optimal industry level, because they do not internalize the negative externality that their own output creates on other firms' profits; the Cournot externality worsens as the number of firms increases. This resulting increase in aggregate output also implies an increase in the stock of used goods, which exacerbates the negative substitution effect of opening secondary markets.

[27]We thank a referee for a useful comment on this issue.

The results in Table 9 are in line with this intuition, showing that, as the market structure becomes less concentrated, opening the secondary market decreases firms' profits by a larger amount. The first panel shows that opening secondary markets from closed to frictionless decreases profits by 42% in the baseline case, whereas in a duopoly (the second panel), profits decrease by only 23%. If the firm is a monopolist (the third panel), however, opening the secondary market *increases* its profits by 15%; therefore, when the oligopolistic externality is eliminated, a monopolist would prefer frictionless secondary markets.

4.5 Additional counterfactuals

In the Online Appendix, we report, together with the counterfactuals on persistent heterogeneity discussed above, two additional counterfactuals as robustness checks. First, we consider an alternative specification in which the transaction cost in the secondary market is proportional to the used car price rather than fixed. The results are remarkably similar to those in the baseline specification.

Second, we enhance the accounting of persistent heterogeneity of consumer types by approximating the income distribution by three, not two, types. The results show that our main findings are robust as firms prefer to close secondary markets; nonetheless, the magnitude of the firms' loss due to the secondary market is smaller, which suggests that having approximated the distribution with two types may have understated the positive sorting role that secondary markets play.

5 Summary and conclusions

To investigate how the tradability of durable goods in secondary markets affects firms' behavior and profits, we develop a dynamic equilibrium model of durable goods oligopoly, in which consumers face lumpy costs of transacting in the secondary markets and respond by buying and selling infrequently. Both sides of the market—firms and consumers—are forward-looking. We calibrate the model to match aggregate data from the American automobile industry and obtain a good fit.

In our model, the key element that helps us isolate the effects of secondary markets on durable-goods manufacturers is the transaction cost parameter. Using the calibrated version of the model, we run counterfactuals in which we vary the magnitude of transaction costs, to measure the effects of the secondary market on firms. On the whole, the negative effects of secondary markets dominate: at the preferred parameter values, opening the secondary market from closed to frictionless lowers the profits of the new car manufacturers by 42%. Thus, to answer the question posed in the title of the paper: used goods traded in secondary markets harm new good producers.

Additional counterfactuals highlight scenarios in which secondary markets could be beneficial to firms. We find that opening the secondary market by reducing the transaction costs is more beneficial (less detrimental) to new goods producers when (1) firms can commit to future production plans; (2) used cars are less inferior to new cars; (3) cars are less durable; (4) the time-varying component of consumers' preferences become less prominent; or (5) the primary market is more concentrated. These effects are broadly consistent with the existing theoretical literature on the re-allocative roles of secondary markets.

We close with the caveat that we have had to make many simplifying assumptions in this paper to facilitate its computation, and abstract away from a number of important features of the car market. Heterogeneity among car characteristics and consumer preferences is limited, only allowing for two different car qualities (new and used) in the calibration. The durability of cars is exogenously given rather than chosen by firms. Automobile manufacturers must sell their cars rather than lease them.[28] At the same time, consumers are restricted to own (at most) one car, are infinitely-lived and there is no entry or exit of consumers.[29] For these reasons, our results should be interpreted with some caution. Nevertheless, one

[28]Table 2 of Aizcorbe, Starr, and Hickman (2003) indicates that between 4.5% and 6.4% of households leased automobiles during our sample period.

[29]While this seems innocuous for the car market, it may not be appropriate for, say, the stroller market, where consumers enter (resp. exit) when their children are born (resp. grow up).

general lesson we learn from our analysis is that effective policy-making in durable goods industries must pay attention to both the dynamic and static effects on both sides of the market, which are oftentimes countervailing.

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Table 1. Fixed parameters

Discount factor (β)	1/1.04
# of distinct persistent consumer types (L)	2
% of type I consumers	50%
% of type II consumers	50%
Probability of used car quantity depreciation (δ)	0.11
# of firms (N)	3

Table 2. Calibrated parameters[a]

New car product-characteristics index (α_1)	1.70
Used car product-characteristics index (α_2)	0.89
Type I consumers' marginal utility of money (γ_1)	1.71
Type II consumers' marginal utility of money (γ_2)	2.30
Marginal cost (c), $10,000	1.91
Transaction cost (k), $10,000	0.40

[a] Throughout the paper, all monetary numbers are reported in $10,000 in the year 2003.

Table 3. Steady-state values at calibrated parameters and U.S. data averages

	Model steady-state values	U.S. data averages (1994-2003)[a]
% of Type 1 consumers:[b]		
who purchase new cars	9.7	9.8
who purchase used cars	17.8	18.7
% of Type 2 consumers:[c]		
who purchase new cars	4.2	4.2
who purchase used cars	19.3	18.6
New vehicle price ($10,000)	2.3	2.3
Used vehicle price ($10,000)	0.9	0.9
Firms' markup	0.17	0.17

[a] Calculated from Consumer Expenditure Survey and annual reports of the Big 3 U.S. automobile producers.
[b] Households with above-median income.
[c] Households with below-median income.

Table 4. Steady-state results, at calibrated parameter values

Consumers' transition probabilities $P(s_t\|r_t)$[a]		
	Type I	Type II
P(1|2)	0.08	0.03
P(2|2)[b]	0.69	0.75
P(0|2)	0.22	0.22
P(1|0)	0.13	0.06
P(2|0)	0.53	0.54
P(0|0)	0.34	0.40
% consumers who own a used car	67	64

[a] $P(s_t|r_t)$ is the probability that a consumer who owns r_t at the beginning of t chooses s_t.
[b] In the model, all used cars are identical. Therefore, no consumers sell their current used car and buy a different used car in the same period, and P(2|2) in the table corresponds to consumers who keep their current used car. In the U.S. data averages, 5.7% of type I consumers and 4.6% of type II consumers sell their current used car and buy a different used car in the same year.

Table 5. No commitment vs. perfect commitment

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: no commitment				
New car production per firm[a]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[b]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[d]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[c]
Perfect commitment				
New car production per firm[a]	0.039	0.032	0.021	0.018
Used car transactions	0.00	0.05	0.21	0.25
New car price ($10,000)	2.52	2.27	3.52	3.72
Used car price ($10,000)[b]	8.00	2.00	2.01	1.90
Used car scrappage	0.04	0.02	0.00	0.00
Consumer surplus ($10,000)[d]	0.31	0.37	0.46	0.52
Profits per firm ($10,000)	0.024	0.011	0.033	0.033 (+36%)[c]

[a] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.

[b] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.

[c] Percentage change in profits from k = 8 to k = 0.

[d] Consumers' utilities are converted to monetary terms using their respective γ's.

Table 6. Effects of closing secondary market: Assessing quality differentiation

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: α_1 = 1.70, α_2 = 0.89[a]				
New car production per firm[b]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[c]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[d]
More differentiation: α_1 = 1.70, α_2 = 0.7				
New car production per firm[b]	0.048	0.040	0.019	0.017
Used car transactions	0.00	0.04	0.20	0.25
New car price ($10,000)	2.21	2.16	2.27	2.31
Used car price ($10,000)[c]	8.00	2.00	0.69	0.42
Used car scrappage	0.08	0.05	0.00	0.00
Consumer surplus ($10,000)[e]	0.28	0.31	0.48	0.57
Profits per firm ($10,000)	0.014	0.010	0.007	0.007 (-53%)[d]
Less differentiation: α_1 = 1.70, α_2 = 1.1				
New car production per firm[b]	0.042	0.032	0.025	0.024
Used car transactions	0.00	0.04	0.18	0.23
New car price ($10,000)	2.29	2.28	2.33	2.35
Used car price ($10,000)[c]	8.00	2.07	1.06	0.83
Used car scrappage	0.04	0.00	0.00	0.00
Consumer surplus ($10,000)[e]	0.42	0.45	0.60	0.68
Profits per firm ($10,000)	0.016	0.012	0.011	0.011 (-33%)[d]

[a] α_1 and α_2 are new car and used car product-characteristics indexes, respectively.
[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.
[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.
[d] Percentage change in profits from k = 8 to k = 0.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table 7. Effects of closing secondary market: Assessing durability

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: δ = 0.11[a]				
New car production per firm[b]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[c]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[d]
More durability: δ = 0.05				
New car production per firm[b]	0.030	0.025	0.014	0.010
Used car transactions	0.00	0.03	0.16	0.22
New car price ($10,000)	2.31	2.21	2.21	2.21
Used car price ($10,000)[c]	8.00	2.00	0.60	0.17
Used car scrappage	0.05	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.41	0.43	0.56	0.64
Profits per firm ($10,000)	0.012	0.007	0.004	0.003 (-74%)[d]
Less durability: δ = 0.25				
New car production per firm[b]	0.061	0.051	0.043	0.043
Used car transactions	0.00	0.05	0.20	0.25
New car price ($10,000)	2.20	2.18	2.32	2.36
Used car price ($10,000)[c]	8.00	2.00	1.16	1.00
Used car scrappage	0.07	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.25	0.28	0.46	0.54
Profits per firm ($10,000)	0.018	0.014	0.017	0.019 (+10%)[d]

[a] δ is the probability of used car depreciation.
[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.
[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.
[d] Percentage change in profits from *k* = 8 to *k* = 0.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table 8. Effects of closing secondary market: Assessing variance of taste shocks

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: Var(ε) = $\pi^2/6$[a]				
New car production per firm[b]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[c]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[d]
Larger variance: Var(ε) = $2*\pi^2/6$				
New car production per firm[b]	0.059	0.047	0.026	0.023
Used car transactions	0.00	0.06	0.20	0.24
New car price ($10,000)	2.33	2.24	2.29	2.33
Used car price ($10,000)[c]	8.00	2.00	0.58	0.32
Used car scrappage	0.11	0.08	0.00	0.00
Consumer surplus ($10,000)[e]	0.44	0.51	0.71	0.80
Profits per firm ($10,000)	0.025	0.015	0.010	0.010 (-61%)[d]
Smaller variance: Var(ε) = $1/2*\pi^2/6$				
New car production per firm[b]	0.035	0.031	0.026	0.024
Used car transactions	0.00	0.02	0.16	0.23
New car price ($10,000)	2.19	2.19	2.20	2.22
Used car price ($10,000)[c]	8.00	2.10	1.15	0.91
Used car scrappage	0.02	0.00	0.00	0.00
Consumer surplus ($10,000)[e]	0.31	0.32	0.43	0.50
Profits per firm ($10,000)	0.010	0.009	0.008	0.008 (-24%)[d]

[a] ε is a consumer's idiosyncratic taste shock.
[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.
[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.
[d] Percentage change in profits from $k = 8$ to $k = 0$.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table 9. Effects of closing secondary market: Assessing market structure

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: *N* = 3[a]				
New car production per firm[b]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[c]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[d]
Duopoly: *N* = 2				
New car production per firm[b]	0.061	0.043	0.035	0.032
Used car transactions	0.00	0.05	0.19	0.24
New car price ($10,000)	2.46	2.48	2.61	2.71
Used car price ($10,000)[c]	8.00	2.07	1.20	1.01
Used car scrappage	0.04	0.00	0.00	0.00
Consumer surplus ($10,000)[e]	0.32	0.35	0.51	0.59
Profits per firm ($10,000)	0.033	0.024	0.025	0.026 (-23%)[d]
Monopoly: *N* = 1				
New car production per firm[b]	0.084	0.069	0.058	0.055
Used car transactions	0.00	0.06	0.20	0.25
New car price ($10,000)	3.42	3.59	4.16	4.59
Used car price ($10,000)[c]	8.00	2.94	2.57	2.75
Used car scrappage	0.01	0.00	0.00	0.00
Consumer surplus ($10,000)[e]	0.21	0.26	0.40	0.46
Profits per firm ($10,000)	0.128	0.116	0.131	0.147 (+15%)[d]

[a] *N* is the number of firms.
[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.
[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.
[d] Percentage change in profits from *k* = 8 to *k* = 0.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Figure 1. Opening secondary market in the calibrated model:
New car purchases by consumer type

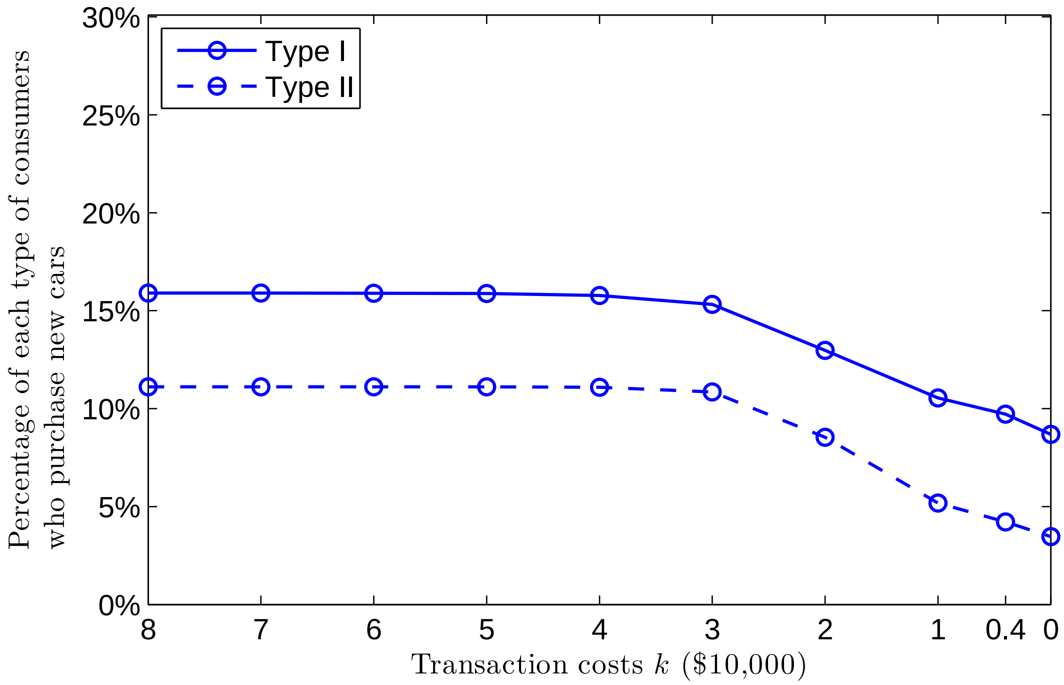
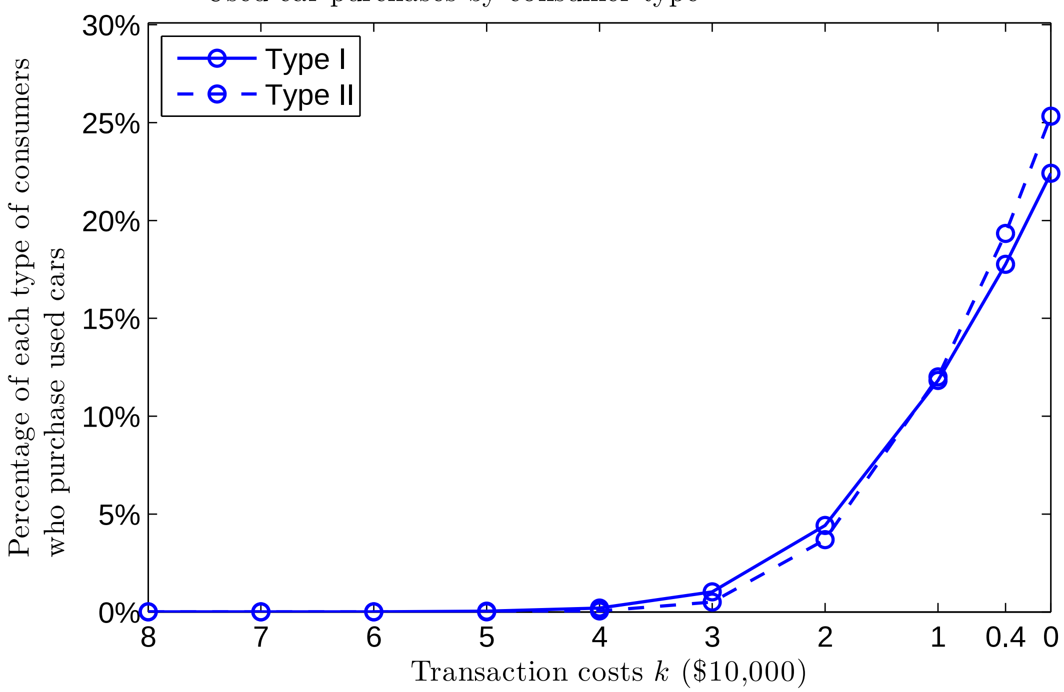


Figure 2. Opening secondary market in the calibrated model:
Used car purchases by consumer type



How Much Competition is a Secondary Market? – Online Appendixes (Not for Publication)

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1 The MPEC approach to calibration

In calibrating the model, some of the parameter values are chosen based on data or recent empirical studies (summarized in Table 1 of the paper), and the remaining are obtained by finding the parameterization that best matches the steady state in the model to the average values in the American automobile industry over the 1994–2003 period. For the latter, we use the MPEC (Mathematical Programming with Equilibrium Constraints) approach, recently advocated by Su and Judd (2008).

In the MPEC approach, we formulate the calibration as a constrained optimization problem, in which the objective is to minimize the sum of the squared percentage differences between the model's steady-state values and the U.S. averages, and the constraints come from the equilibrium conditions and the steady-state conditions. We then submit the problem to solvers SNOPT and KNITRO using the TOMLAB optimization environment. An important feature of this approach is that it does not require the constraints to be exactly satisfied during the optimization process; instead, it generates a sequence of points in the

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parameter space that converges to a point that satisfies both the constraints and the optimality conditions. Consequently, the only equilibrium that needs to be solved exactly is the one associated with the final calibrated values of parameters. This feature results in significant reduction in computation time compared to a grid search, which requires solving the equilibrium exactly at each grid point.

Consider the two-vintage, two-type specification presented in the main text. Let (D_1^{1ss}, D_1^{2ss}, D_2^{1ss}, D_2^{2ss}, p_1^{ss}, p_2^{ss}, η^{ss}) and (D_1^{1US}, D_1^{2US}, D_2^{1US}, D_2^{2US}, p_1^{US}, p_2^{US}, η^{US}) denote the model steady state and the U.S. averages, respectively, where D_j^l is the percentage of type l consumers who purchase car j, for $l = 1, 2$ and $j = 1, 2$, p_1 is the new car price, p_2 is the used car price, and η is the firms' markup (the difference between the new car price and the marginal cost, divided by the new car price). In the calibration, the set of fixed parameters are $(N, \beta, \pi_1, \pi_2, \delta) = (3, 1/1.04, 0.5, 0.5, 0.11)$. Let $\theta_1 \equiv (\alpha_1, \alpha_2, \gamma_1, \gamma_2, c, k)$ denote the set of free parameters that we want to calibrate using the MPEC approach. Let $\theta_2 \equiv$ (B_2^{1ss}, B_2^{2ss}, D_1^{1ss}, D_1^{2ss}, D_2^{1ss}, D_2^{2ss}, p_1^{ss}, p_2^{ss}, η^{ss}) denote the steady-state values. We use the collocation method and approximate the equilibrium policy and value functions using tensor product bases of univariate Chebyshev polynomials (Judd (1998); Miranda and Fackler (2002)). Let θ_3 denote the coefficients in the Chebyshev polynomial approximation of the equilibrium functions. Finally, let $\theta \equiv (\theta_1, \theta_2, \theta_3)$. The calibration solves the following constrained minimization problem:

$$\begin{aligned}\min_\theta \quad & \left(\frac{D_1^{1ss} - D_1^{1US}}{D_1^{1US}}\right)^2 + \left(\frac{D_1^{2ss} - D_1^{2US}}{D_1^{2US}}\right)^2 + \left(\frac{D_2^{1ss} - D_2^{1US}}{D_2^{1US}}\right)^2 + \left(\frac{D_2^{2ss} - D_2^{2US}}{D_2^{2US}}\right)^2 \\ & + \left(\frac{p_1^{ss} - p_1^{US}}{p_1^{US}}\right)^2 + \left(\frac{p_2^{ss} - p_2^{US}}{p_2^{US}}\right)^2 + \left(\frac{\eta^{ss} - \eta^{US}}{\eta^{US}}\right)^2,\end{aligned}$$

subject to the equilibrium conditions specified in the Model section (Section 2), as well as the steady-state conditions $\vec{B}^{ss} = L(G(\vec{B}^{ss}), \vec{B}^{ss})$, where $\vec{B}^{ss} = (B_2^{1ss}, B_2^{2ss})$.

2 Equilibrium policy and value functions

Figures A1 and A2 present more details about the equilibrium in the calibrated parameterization. Figure A1 plots the firms' policy (production) function, and Figure A2 plots the firms' value function; both are functions of the aggregate state, (B_2^1, B_2^2). When there are more used cars available, the demand for new cars is reduced, hence we expect firms to choose lower production levels and earn smaller profits. Accordingly, Figure A1 shows that a firm's production level generally decreases in both B_2^1 and B_2^2. A firm produces 0.116 at state $(0, 0)$. The production drops to 0.040 at $(0.5, 0)$ and 0.043 at $(0, 0.5)$. If the state is $(0.5, 0.5)$, the production further drops to 0.013. Similarly, Figure A2 shows that a firm's value generally decreases in both B_2^1 and B_2^2. A firm has a value of 0.339 at state $(0, 0)$. The value drops to 0.252 at $(0.5, 0)$ and 0.253 at $(0, 0.5)$. If the state is $(0.5, 0.5)$, the value further drops to 0.220.

3 Alternative specifications and robustness checks

In this Appendix, we consider some alternative specifications and robustness checks of the baseline model presented in the main text.

3.1 Proportional transaction costs

Here we consider an alternative specification, in which the transaction cost in the secondary market is proportional to the used car price rather than being fixed. The proportional transaction cost is calibrated to be 43% of the used car price (Table A1), and the steady-state values at the calibrated parameterization fit the U.S. data averages well (Table A2). Similar to the finding in the baseline specification, we find that opening the secondary market by decreasing k from 99.99% to 0% decreases firms' profits by 43% (Table A3), so firms would prefer the secondary market to be inactive.

3.2 Three types of consumers

We enhance the ability of the model to capture the persistent heterogeneity of consumers by approximating the income distribution by three, not two, types. That is, we let the population of consumers be equally divided into three different groups and then recalibrate the model to find the free parameter values that yield the best fit. The calibrated parameter values, as well as the steady-state values and data averages, are reported in Tables A4 and A5, respectively. By better capturing persistent heterogeneity, our model can better approximate the sorting effect that secondary markets play. Table A6 reports the counterfactuals of varying transaction costs to open secondary markets, showing that the firm's profits decrease by 37% if the secondary markets are opened from $k = 8$ to $k = 0$. The magnitude of the decrease is smaller, however, than the one obtained when the population is only approximated with two consumer types (which corresponds to a 42% decrease in profits). These results highlight the implication of having to simplify the distribution of types to keep the state space tractable, which may be an undervaluation of the sorting benefit of the secondary market.

3.3 Persistent heterogeneity

The allocative gains of secondary markets depend positively on the underlying persistent heterogeneity in the population of consumers as they enhance the sorting gains from segmenting the heterogeneous consumers. Table A7 reports a set of counterfactuals in which we vary consumers' persistent heterogeneity by changing the γ's. The findings corroborate our intuition. In the second panel of Table A7, we increase the persistent consumer heterogeneity by holding γ_1 fixed at the calibrated value of 1.71 and increasing γ_2 from the calibrated value of 2.3 to 3, thus decreasing the willingness-to-pay of the low-valuation consumers. We see that opening secondary markets (by reducing k from 8 to 0) decreases profits by only 25%, which is much smaller than the 42% decrease in the baseline case. In contrast, when we eliminate persistent consumer heterogeneity by setting both γ_1 and γ_2

equal at 1.71 (the third panel of Table A7), we find that profits decrease by a larger 55% if we open the secondary market.

3.4 Increased market segmentation: "new car lovers" and "used car lovers"

In the baseline specification described in the main text, the two types of consumers face the same α_1 and α_2 (per-period utilities of new and used cars), and type I has a lower γ (marginal utility of money) than type II. Therefore, type I consumers receive higher values from both new and used cars (in monetary terms, converted from utilities using γ) than type II consumers.

Here we consider an alternative specification of the per-period utilities of new and used cars. Suppose type I consumers are new car lovers whose valuation of a car quickly drops when the car gets older. In contrast, type II consumers are used car lovers whose valuation does not drop substantially over time because they only care about whether their car runs well. To model such preferences, we increase $\alpha_{2,II}$, the per-period utility of used cars for type II consumers, from 0.89 to 1.6, while holding the other utilities ($\alpha_{1,I}$, $\alpha_{1,II}$, and $\alpha_{2,I}$, defined analogously) fixed at their baseline values, 1.7, 1.7, and 0.89, respectively. In this specification, for type I consumers, a car's utility drops by 48% from 1.7 to 0.89 when it changes from new to old, whereas for type II consumers, the utility drops by only 6% from 1.7 to 1.6. Moreover, when the γ's are taken into account, type I consumers get a higher value from a new car than type II consumers ($\alpha_{1,I}/\gamma_1 = 0.99$ for type I, compared to $\alpha_{1,II}/\gamma_2 = 0.74$ for type II), whereas type II consumers get a higher value from a used car than type I consumers ($\alpha_{2,II}/\gamma_2 = 0.70$ for type II, compared to $\alpha_{2,I}/\gamma_1 = 0.52$ for type I). In this case, because the two types of consumers have more divergent tastes, the secondary market is expected to play a more active sorting role and be more beneficial (or less detrimental) to new car producers.

The second panel in Table A8 reports the results for this alternative specification. Opening the secondary market (from $k = 8$ to $k = 0$) decreases firms' profits by 35%, which is smaller than the 42% decrease in the original specification (reported in the first panel). This result shows that the secondary market is less detrimental to the firms in the alternative specification, consistent with the intuition above. In the third panel in Table A8, we consider an opposite scenario, in which $\alpha_{2,II}$ is decreased to 0.6. In this case, opening the secondary market decreases firms' profits by a larger percentage, 47%.

References

Judd, K. (1998): *Numerical Methods in Economics.* MIT Press.

Miranda, M., and P. Fackler (2002): *Applied Computational Economics and Finance.* MIT Press.

Su, C., and K. Judd (2008): "Constrained Optimization Approaches to Estimation of Structural Models," manuscript, Northwestern University.

Table A1. Calibrated parameters: Proportional transaction costs

New car product-characteristics index (α_1)	1.84
Used car product-characteristics index (α_2)	0.87
Type I consumers' marginal utility of money (γ_1)	1.83
Type II consumers' marginal utility of money (γ_2)	2.42
Marginal cost (*c*), $10,000	1.90
Transaction cost (*k* : % of used car price)[a]	43%

[a] Transaction cost at the steady state is equivalent to 0.39 ($3,900).

Table A2. Steady-state values at calibrated parameters and U.S. data averages: Proportional transaction costs

	Model steady-state values	U.S. data averages (1994-2003)[a]
% of Type 1 consumers:[b]		
who purchase new cars	9.7	9.8
who purchase used cars	17.8	18.7
% of Type 2 consumers:[c]		
who purchase new cars	4.2	4.2
who purchase used cars	19.3	18.6
New vehicle price ($10,000)	2.3	2.3
Used vehicle price ($10,000)	0.9	0.9
Firms' markup	0.17	0.17

[a] Calculated from Consumer Expenditure Survey and annual reports of the Big 3 U.S. automobile producers.
[b] Households with above-median income.
[c] Households with below-median income.

Table A3. Closing secondary market: Proportional transaction costs

Variable	Transaction cost *k* (% of used car price)			
	99.99%	95%	43%	0%
Transaction costs are proportional to the used car price				
New car production per firm[a]	0.044	0.027	0.023	0.021
Used car transactions	0.00	0.08	0.19	0.24
New car price ($10,000)	2.22	2.27	2.29	2.29
Used car price ($10,000)[b]	17.78	1.54	0.90	0.62
Used car scrappage	0.00	0.00	0.00	0.00
Consumer surplus ($10,000)[d]	0.31	0.36	0.49	0.57
Profits per firm ($10,000)	0.014	0.010	0.009	0.008 (-43%)[c]

[a] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.

[b] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.

[c] Percentage change in profits from k = 99.99% to k = 0%.

[d] Consumers' utilities are converted to monetary terms using their respective γ's.

Table A4. Calibrated parameters: Three types of consumers

New car product-characteristics index (α_1)	1.65
Used car product-characteristics index (α_2)	0.78
Type I consumers' marginal utility of money (γ_1)	1.68
Type II consumers' marginal utility of money (γ_2)	2.01
Type III consumers' marginal utility of money (γ_3)	2.42
Marginal cost (c), $10,000	1.90
Transaction cost (k), $10,000	0.44

Table A5. Steady-state values at calibrated parameters and U.S. data averages: Three types of consumers

	Model steady-state values	U.S. data averages (1994-2003)[a]
% of Type 1 consumers:[b]		
who purchase new cars	10.3	10.4
who purchase used cars	17.5	17.9
% of Type 2 consumers:[c]		
who purchase new cars	6.5	6.6
who purchase used cars	18.6	21.1
% of Type 3 consumers:[d]		
who purchase new cars	3.6	3.6
who purchase used cars	19.2	17.4
New vehicle price ($10,000)	2.3	2.3
Used vehicle price ($10,000)	0.9	0.9
Firms' markup	0.17	0.17

[a] Calculated from Consumer Expenditure Survey and annual reports of the Big 3 U.S. automobile producers.
[b] Households with income above 67th percentile.
[c] Households with income between 33rd and 67th percentiles.
[d] Households with income below 33rd percentile.

Table A6. Closing secondary market: Three types of consumers

Variable	Transaction cost *k* ($10,000)			
	8	2	0.44	0
Three types of consumers, $\gamma_1 = 1.68$, $\gamma_2 = 2.01$, $\gamma_3 = 2.42$[a]				
New car production per firm[b]	0.046	0.038	0.023	0.021
Used car transactions	0.00	0.04	0.18	0.24
New car price ($10,000)	2.21	2.14	2.29	2.32
Used car price ($10,000)[c]	8.00	2.00	0.91	0.65
Used car scrappage	0.06	0.04	0.00	0.00
Consumer surplus ($10,000)[e]	0.30	0.33	0.48	0.57
Profits per firm ($10,000)	0.014	0.009	0.009	0.009 (-37%)[d]

[a] γ_1, γ_2, and γ_3 are type I, type II, and type III consumers' marginal utility of money, respectively.
[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.
[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.
[d] Percentage change in profits from $k = 8$ to $k = 0$.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table A7. Effects of closing secondary market: Assessing persistent consumer heterogeneity

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: γ_1 = 1.71, γ_2 = 2.30[a]				
New car production per firm[b]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[c]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[d]
More heterogeneity: γ_1 = 1.71, γ_2 = 3				
New car production per firm[b]	0.042	0.033	0.024	0.021
Used car transactions	0.00	0.04	0.18	0.24
New car price ($10,000)	2.18	2.14	2.27	2.31
Used car price ($10,000)[c]	8.00	2.00	1.01	0.76
Used car scrappage	0.05	0.02	0.00	0.00
Consumer surplus ($10,000)[e]	0.30	0.32	0.47	0.55
Profits per firm ($10,000)	0.011	0.008	0.009	0.009 (-25%)[d]
Less heterogeneity: γ_1 = 1.71, γ_2 = 1.71				
New car production per firm[b]	0.051	0.043	0.023	0.020
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.30	2.19	2.33	2.36
Used car price ($10,000)[c]	8.00	2.00	0.72	0.43
Used car scrappage	0.08	0.05	0.00	0.00
Consumer surplus ($10,000)[e]	0.43	0.48	0.64	0.73
Profits per firm ($10,000)	0.020	0.012	0.010	0.009 (-55%)[d]

[a] γ_1 and γ_2 are type I and type II consumers' marginal utility of money, respectively.
[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.
[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.
[d] Percentage change in profits from *k* = 8 to *k* = 0.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table A8. Changing α_2 for type II consumers

Variable	Transaction cost *k* ($10,000)			
	8	2	0.4	0
Baseline: $\alpha_{2,II}$ = 0.89[a]				
New car production per firm[b]	0.045	0.036	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.24	2.17	2.30	2.33
Used car price ($10,000)[c]	8.00	2.00	0.91	0.64
Used car scrappage	0.06	0.03	0.00	0.00
Consumer surplus ($10,000)[e]	0.35	0.38	0.53	0.62
Profits per firm ($10,000)	0.015	0.009	0.009	0.009 (-42%)[d]
$\alpha_{2,II}$ = 1.6				
New car production per firm[b]	0.042	0.032	0.026	0.025
Used car transactions	0.00	0.05	0.17	0.22
New car price ($10,000)	2.33	2.31	2.36	2.38
Used car price ($10,000)[c]	8.00	2.10	1.11	0.87
Used car scrappage	0.04	0.00	0.00	0.00
Consumer surplus ($10,000)[e]	0.46	0.50	0.65	0.72
Profits per firm ($10,000)	0.018	0.013	0.012	0.012 (-35%)[d]
$\alpha_{2,II}$ = 0.6				
New car production per firm[b]	0.046	0.039	0.021	0.018
Used car transactions	0.00	0.04	0.19	0.25
New car price ($10,000)	2.20	2.15	2.27	2.31
Used car price ($10,000)[c]	8.00	2.00	0.76	0.50
Used car scrappage	0.07	0.04	0.00	0.00
Consumer surplus ($10,000)[e]	0.31	0.34	0.50	0.59
Profits per firm ($10,000)	0.014	0.009	0.007	0.007 (-47%)[d]

[a] $\alpha_{2,II}$ is the used car product-characteristics index for type II consumers. $\alpha_{1,I}$, $\alpha_{1,II}$, and $\alpha_{2,I}$ are defined analogously and are fixed at their baseline values, 1.70, 1.70, and 0.89, respectively.

[b] New car production per firm, used car transactions, and used car scrappage are all measured against the consumer population, which is normalized to one.

[c] Because of the type I extreme value distribution of ε, there is a positive, though small, measure of buyers of used cars even at a very high used car price.

[d] Percentage change in profits from k = 8 to k = 0.

[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Figure A1. Firms' policy (production) function

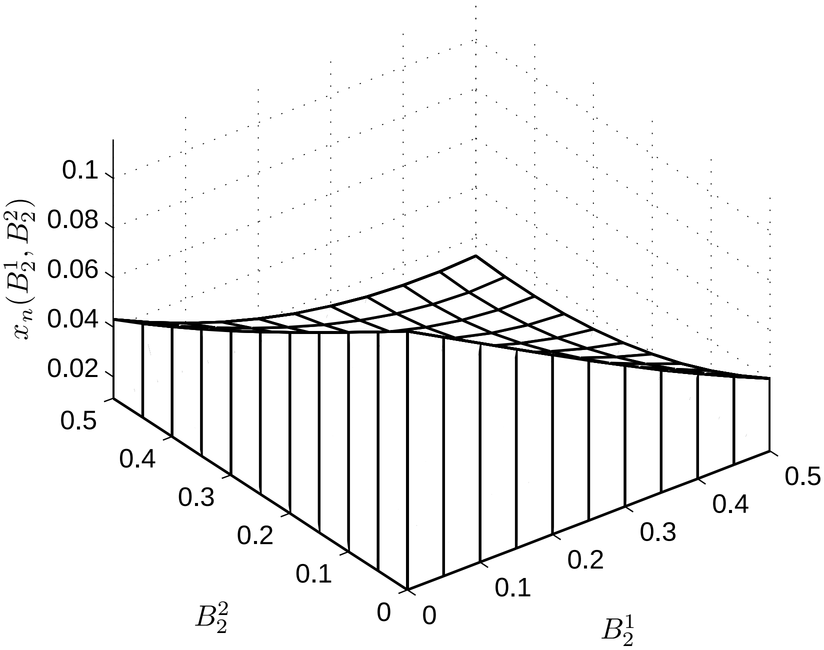

Figure A2. Firms' value function