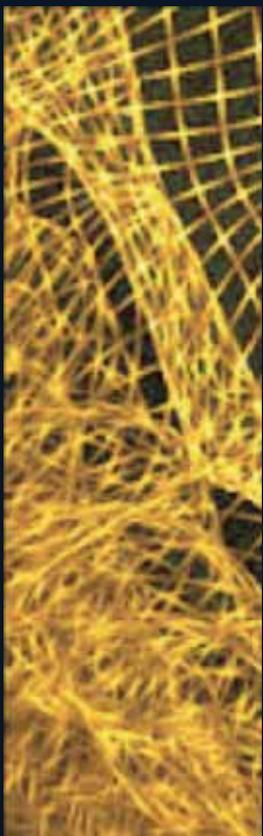


**imdea**  
ciencias sociales



# working papers series

in Economics and Social Sciences

2010/06

## How much competition is a secondary Market?

by Jiawei Chen, Susanna Esteban and Matthew Shum

April 2010

Ctra. Colmenar Viejo km. 14, 28049 Madrid, Spain

<http://www.imdea.org/socialsciences>  
<http://repec.imdea.org>  
[contacto.cienciassociales@imdea.org](mailto:contacto.cienciassociales@imdea.org)

[www.imdea.org](http://www.imdea.org)

# How Much Competition is a Secondary Market?\*

Jiawei Chen  
UC-Irvine

Susanna Esteban  
Universitat Autònoma de Barcelona

Matthew Shum  
Caltech

March 12, 2010

## 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, closing down the secondary market increases (net) profits of new car manufacturers by 39%. This suggests that regulatory changes that lower liquidity in secondary markets may aid manufacturers.

*Keywords:* Secondary Markets, Durable Goods, Oligopoly, Transaction Costs, Automobile Industry, Market Power

---

\*The authors can be contacted by e-mail at [jiaweic@uci.edu](mailto:jiaweic@uci.edu) (Chen), [susanna.esteban@gmail.com](mailto:susanna.esteban@gmail.com) (Esteban) and [mshum@caltech.edu](mailto:mshum@caltech.edu) (Shum). Guofang Huang provided exceptional research assistance. We thank Eiichi Miyagawa, and seminar participants at Arizona, Drexel, National University of Singapore, Stanford GSB, UC Davis, UCSD, Warwick, Wisconsin, IIOC 2007, Econometric Society NAWM 2008, the Industrial Economics workshop at Ente Einaudi (Rome, Italy) and EARIE 2009 for helpful comments. Esteban is also a member of the Barcelona Graduate School of Economics and acknowledges the support of the Spanish Ministry of Education, of the Excellence Project of the Bank of Spain, of the European Commission (EFIGE 225343), of the Barcelona GSE Research Network and of the Generalitat de Catalunya.



# 1 Introduction

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.<sup>1</sup>

Has this dramatic expansion in secondary markets (or “temporary ownership”, to use the colorful terminology above) helped or hurt new good producers? In this paper, we seek to understand how secondary markets affect firms’ behavior and profits by building and calibrating a dynamic equilibrium model of durable goods oligopoly with transaction costs.

The effects of secondary markets must be understood against the backdrop of how durability affects firms’ behavior. Relative to a nondurable goods industry, firms producing durable goods face two additional sources of competition: a contemporaneous, static source and a dynamic one. Opening secondary markets introduces two effects which potentially offset these sources of competition. First, durability causes consumers to purchase the good infrequently, because used goods still yield consumption value. This contracts the demand curve faced by firms, as those consumers who own a used good “stay out” of the market, and reduces the firms’ market power. We call this static source of competition the *substitution problem* faced by durable goods producers.

By permitting resale, secondary markets change how the stock of used goods enters the firms’ residual demand function. Secondary markets allow consumers to return to the primary market, resulting in a more efficient allocation of the existing stock of goods. This is a *sorting* (or *allocative*) *effect* of secondary markets, and it could both exacerbate or offset the substitution problem. If new and used goods are close substitutes in consumption, then firms “lose” the high valuation consumers, resulting in the most detrimental residual demand function for the firms. If, instead, they are imperfect substitutes, resale encourages

---

<sup>1</sup>From Nissanoff (2006).



high-valuation consumers to return to the primary market, because these consumers are least willing to settle for a used good as an alternative to a new one. This offsets the substitution problem, and permits firms to earn higher profits than if secondary markets did not exist. See Anderson and Ginsburgh (1994), Hendel and Lizzeri (1999b), and Porter and Sattler (1999) for more discussion of the allocative role of secondary markets.

Second, durability also introduces a dynamic source of competition for the firm. Durability has forward-looking, competitive effects that are absent in a static model. As pointed out by Coase (1972), durability erodes market power if the firm is unable to commit to low levels of future production (or high prices) and prevent forward-looking consumers from delaying their purchases. This leads to a *credibility problem* for firms: although the firm can avoid these delays by announcing high future prices (or low future levels of output), such announcements are not credible, as consumers anticipate that, once sales are made, the firm will lower prices to raise its profits. Essentially, then, durable goods firms compete with their own “future selves” as they will not wish to implement the “current selves” future plans.

Secondary markets also affect the degree of this forward-looking competition. If the change in the residual demand function due to secondary markets allows firms to exercise more market power, secondary markets carry the indirect benefit of partially alleviating the firms’ competition with their own future selves. If, instead, it results in less market power, the secondary market may exacerbate dynamic competition. We call this forward-looking dynamic effect, which might be beneficial or detrimental, the *indirect commitment effect* of secondary markets. See Liang (1999) for more discussion of the commitment effect of secondary markets.<sup>2</sup>

Therefore, whether secondary markets help or hurt producers is ultimately an empirical question, the answer to which depends on the magnitude of the sorting and indirect commitment effects, all measured relative to the substitution and credibility problems.<sup>3</sup> In turn, these are all functions of the underlying market features, such as product heterogeneity and consumers’ preferences. Our main contribution in this paper is to build a dynamic equilibrium model of a durable-goods industry, which allows us to address the role of secondary markets in oligopolistic industries with a heterogeneous consumer population. In our analysis, transaction costs play a key role in disentangling these various effects. By raising transaction costs, we shut down secondary markets and hone in on the effects of durability

---

<sup>2</sup>In Liang’s model, new and used goods are perfect substitutes so that secondary markets do not have an allocative role.

<sup>3</sup>We introduce the taxonomy of the substitution and credibility problems facing durable goods producers, and of the sorting and indirect commitment effects of secondary markets, mainly for expositional convenience, and it may not correspond strictly to the definitions used in the existing literature.



itself on firms' behavior; in contrast, by decreasing them, we make transactions frictionless and increase the competitive pressure faced by firms from the secondary markets.

To our knowledge, our equilibrium durable goods oligopoly model is the first in which firms face both a substitution and credibility problem, and in which secondary markets have both a sorting and indirect commitment effect. Thus it provides a rich framework in which to analyze the effects of secondary markets. We calibrate our model's parameter values to match aggregate data from the American automobile industry over the 1994–2003 period. To meet the challenge of computing the dynamic equilibrium oligopoly model, we use the MPEC approach (Mathematical Programming with Equilibrium Constraints; see Luo, Pang, and Ralph, 1996), 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. Indeed, we find that closing secondary markets altogether would raise firms' profits (in steady-state) by 39%. Nonetheless, counterfactual simulations show that the secondary market can have a beneficial effect on profits when the consumer population is more heterogeneous in the persistent component, when the new and used cars are less substitutable, and when the market structure is more concentrated. These findings confirm the importance of accounting for all effects when evaluating the competitive implications of secondary markets.

More broadly, our results shed light on whether using regulation to increase or decrease liquidity in secondary markets can aid automobile manufacturers. Our results suggest that policies that *increase* frictions in the secondary market for cars can benefit new car manufacturers. This is a novel policy recommendation for helping the US automobile manufacturers out their current malaise, and goes against the grain of policies aimed at reducing the costs of buying a car.

## 1.1 Existing literature

Understanding the role of secondary markets has been a long-standing question in the literature. The earliest discussions arose in the 1940's, motivated by the *United States vs. Alcoa* monopolization case.<sup>4</sup> One key issue raised in Alcoa's defense was that it faced substantial competition from the used (scrap) aluminum sector. The US Court of Appeals ruled against Alcoa; 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.

---

<sup>4</sup> cf. Areeda and Kaplow (1988, pp. 476ff).





Secondary markets function if transaction costs are sufficiently low, consumers are heterogeneous in their preferences, and car characteristics or consumers' preferences change over time, motivating consumers to frequently re-optimize their car choices.<sup>5</sup> A recent empirical literature has analyzed the demand side problem of forward-looking consumers in markets for durable goods, and allowed 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 (forthcoming), Hartmann (2006), Chevalier and Goolsbee (2009), Carranza (2007), Schiraldi (2006), and Copeland (2006)).<sup>6</sup> Following this literature, our paper assumes that consumers are heterogeneous in both a *vertical (quality)* differentiation dimension, which is persistent over time and causes consumers to sell their low-quality used cars, 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. We show in this paper how the magnitudes of the effects we are quantifying depend on the sources of heterogeneity.

While most of the papers above focus on analyzing consumer demand in durable goods markets, the empirical literature on equilibrium in durable goods markets is smaller.<sup>7</sup> Our paper builds on Esteban and Shum (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. Nair (2007) and Goettler and Gordon (2008) are two other papers which estimate dynamic equilibrium models for (respectively) the video game console and PC microprocessors 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. In contrast, the model in this paper allows for both secondary markets and consumer transactions costs in a dynamic oligopolistic equilibrium framework; to our knowledge, this is new in the literature.

As we remarked above, transaction costs are the fundamental instrument enabling us to isolate the effects of secondary markets from those of durability.<sup>8</sup> A number of existing

---

<sup>5</sup>See Waldman (2003) for an overall review of the durable goods literature.

<sup>6</sup>There has also been a large literature (including Bresnahan (1981), Berry, Levinsohn, and Pakes (1995), Goldberg (1995), Petrin (2002)) which estimates static demand-supply models for the automobile industry, where firms do not internalize the intertemporal linkages between the new and used car markets. In a simulation exercise (Chen, Esteban, and Shum (2008)), we find that ignoring product durability and the intertemporal linkages between primary and secondary markets can result in substantial biases in the estimates of the demand elasticities and markups.

<sup>7</sup>The theoretical literature has also generalized the durable goods problem to an oligopoly, see Gul (1987), Carlton and Gertner (1989), Esteban (2002), Sobel (1984), Bulow (1986), and Driskill (2001).

<sup>8</sup>One alternative—to modify competition in the secondary market by making the good less durable—is not as clean, as it would be conflating the implications of secondary markets with those of durability.

papers have analyzed the effects of transactions costs in secondary markets from both a theoretical and an empirical standpoint. Anderson and Ginsburgh (1994) studied the full commitment problem of the firm, accounting for transaction costs and how these endogenize the secondary market, and show that the secondary market may have mixed effects on durable goods' manufacturers. Similarly, Porter and Sattler (1999) allow for transaction costs in a model of secondary markets and a monopolistic seller that can fully commit, and find evidence that the secondary market plays an allocative role with consumers transacting because of their heterogeneous preference for newness. In both these papers, the assumption that firms can commit effectively eliminates the credibility problem, thus not accounting for the indirect commitment effect of secondary markets.

Stolyarov (2002) builds a model with competitive primary and secondary markets, where consumer are heterogeneous and incur transaction costs when trading in the used car market. He uses this model to explain the pattern of used car holdings and transactions in the US data.<sup>9</sup> Also assuming a competitive primary market, Gavazza and Lizzeri (2009) calibrate a model of secondary markets with heterogeneous consumers and transaction costs to the automobile markets in France, the UK, and the US, and quantify the effects of secondary markets on firms' revenue.

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.<sup>10</sup> Second, we do not allow firms to choose the durability of their products, as has been done in the planned obsolescence literature.<sup>11</sup>

The next section presents the model. Section 3 presents the calibration exercise and the model evaluation at steady state. Section 4 runs counterfactual experiments to address our core question, whether secondary markets aid or hurt durable goods manufacturers. Section 5 concludes.

---

<sup>9</sup>With an approach closer to the macroeconomics literature, Adda and Cooper (2000), Eberly (1994), Attanasio (2000), among others, model consumers as having (S,s) type replacement problem.

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

<sup>11</sup>See, for example, Swan (1972), Bulow (1986), Waldman (1993), Hendel and Lizzeri (1999a) , Waldman (1996), Iizuka (2007), Rust (1985), among many others, as models of endogenous depreciation and model introduction.

## 2 Model

In this section, we describe our model of a durable goods oligopoly with secondary markets. Consumers incur transaction costs when selling used goods in the secondary market and are heterogeneous in their valuations. Time is discrete and firms and consumers are infinitely lived and forward-looking.

There are  $J$  different types of cars, including both new and used, that differ in model and vintage, and are heterogeneous in quality (product characteristics). We index all available car types (new and used) by  $j = 0, 1, \dots, J$ , where  $j = 0$  is the outside option of no car and where the first  $F$  cars, cars  $j = 1, \dots, F$ , with  $F \leq J$ , are new. For each car type  $j$ , we let  $\alpha_j \geq 0$  denote its quality-product characteristics index and normalize  $\alpha_0 = 0$ . We assume, for simplicity, that each firm produces only one car model. Thus, with  $j = 1, \dots, F$ , we index firms as well as the different new car models produced.

We define the depreciation of car models as follows:  $d(j) \in \{0, F + 1, \dots, J\}$  denotes the next period's index of a car type that is currently indexed by  $j$ , with the convention that  $d(0) = 0$  and  $d(j) = 0$  if  $j$  is in its last period of life. Similarly, we let  $a(j) \in \{0, 1, \dots, J\}$  denote the previous period's index of a car type that currently has index  $j$ . Together,  $a(d(j)) = j$ .

In what follows, we describe the model and derive the equilibrium. We first formulate the consumers' and firms' problems in partial equilibrium and then require full equilibrium by clearing all markets and formulating correct expectations on both sides of the market.

### 2.1 Consumer's problem

We first consider the consumers' problem in partial equilibrium, where consumers take current and future prices as given. There is a continuum of consumers with unit mass, with a generic consumer being denoted by  $i$ . Consumers are differentiated in two dimensions. On the one hand, consumers differ in their marginal utility of money,  $\gamma$ , of which there are  $l = 1, \dots, L < \infty$  distinct types in proportions  $\pi_1, \dots, \pi_L$ , with  $\sum_l \pi_l = 1$ . We let  $l_i$  denote  $i$ 's type and  $\gamma_i$  denote his marginal utility of money. On the other hand, consumers are also heterogeneous in their valuation of goods, which is modeled as an i.i.d shock that perturbs each consumer's product choice in every period. We let  $\vec{\epsilon}_{it} \equiv (\epsilon_{i0t}, \epsilon_{i1t}, \dots, \epsilon_{iJt})$  be the vector of idiosyncratic shocks of consumer  $i$  in period  $t$ , where the shocks are i.i.d. across  $(i, j, t)$ . In our specification of the utility function that follows,  $\gamma$  captures vertical differentiation among the new and used cars in the consumers' preferences, while  $\epsilon$  captures



horizontal differentiation.<sup>12</sup>

We let  $r_{it} \in \{0, F + 1, \dots, J\}$  denote the index of the car owned by a consumer  $i$  at the beginning of period  $t$  and  $B_{jt}^l$ , for  $j = F + 1, \dots, J$ , 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.

We let  $p_{jt}$  be the price of good  $j$  in period  $t$ , and  $\vec{p}_t = (p_{0t}, p_{1t}, \dots, p_{Jt})$  be the price vector at time  $t$ . We set  $p_{0t} = 0$  for all  $t$ . If a consumer sells the car she owns, she receives its price, but incurs a transaction cost  $k_j$  for  $j = 0, F + 1, \dots, J$ . We assume the transaction cost is the same for all car models except for car  $j = 0$ , which carries a transaction cost of 0. Accordingly, we let  $k_j = k$  for all  $j > F$  and  $k_0 = 0$ .<sup>13</sup>

Consumer  $i$  derives the following utility flows. In period  $t$ , if she keeps the car she currently owns—car  $r_{it}$ , she gets a one-period utility of

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

If, instead, she sells  $r_{it}$  and purchases  $j$  as a replacement (which can be the outside option  $j = 0$ ), her one-period utility is

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

where  $k_{r_{it}}$  is the transaction cost she incurs when selling  $r_{it}$ . We assume that each  $\epsilon_{ijt}$  is distributed type 1 extreme-value, which leads to a number of convenient closed-form expressions in what follows.<sup>14</sup>

With positive transactions costs, then, the consumer's car choice in period  $t$  depends on both her type (her marginal utility of money), as well as the car she currently owns. In contrast with a model without transaction costs, our consumer is not indifferent between keeping a car and selling/repurchasing it from the secondary market because she incurs transaction costs in the latter.<sup>15</sup>

<sup>12</sup>Our assumptions on heterogeneity can be contrasted with those in Porter and Sattler (1999), Berry and Pakes (2007), and Esteban and Shum (2007), who assume pure vertical differentiation, with the distribution of  $\gamma$  being continuous and uniform, and without any  $\epsilon$  errors. These models are not too convenient for computational reasons because the market shares can be discontinuous functions of the model's parameters.

<sup>13</sup>We assume the magnitude of the consumers' transactions costs is exogenous. Hendel and Lizzeri (1999b) note that producers can effectively "endogenize" transaction costs by limiting the transferability of warranties. However, in the car market, which is the focus of this paper, warranties are fully transferrable.

<sup>14</sup>With this assumption, our consumer demand model resembles the "dynamic logit" specifications of the dynamic discrete-choice models that started with Rust (1987).

<sup>15</sup>Esteban and Shum (2007), for instance, assume no transaction costs and a utility function that is quasi-linear in income. Together, these assumptions imply that the consumers' dynamic optimization problems are equivalent to a sequence of static decision problems with prices that are equal to the implicit rental prices.





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

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

where

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

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

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

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

$$q_j(\vec{p}_t, j', \hat{p}_{t+1}; \gamma_i) = \frac{\exp \left( \alpha_j + \mathbf{1}_{j \neq j'} \cdot \gamma_i \cdot (p_{j't} - p_{jt} - k_{j'}) + \beta \tilde{V}(\hat{p}_{t+1}, d(j); \gamma_i) \right)}{\sum_{h=0}^J \exp \left( \alpha_h + \mathbf{1}_{h \neq j'} \cdot \gamma_i \cdot (p_{j't} - p_{ht} - k_{j'}) + \beta \tilde{V}(\hat{p}_{t+1}, d(h); \gamma_i) \right)}. \quad (3)$$

### 2.1.1 Aggregate Demand Functions

Next, we aggregate up individual consumers' choices to obtain the aggregate quantity demanded for each car model  $j$  in period  $t$ . Let  $\vec{Q}_t^D$  be the vector of new and used car demand by consumer types, with generic element  $Q_{j,t}^l$ , and let the total demand for car type  $j$  be given by

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

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  $j$ ).

Analogously, the supply of used cars in the market is given by

$$Q_{j't}^S = \sum_l \sum_{j:j \neq j'} B_{j't}^l \cdot q_j(\vec{p}_t, j', \hat{p}_{t+1}; \gamma_l), \quad \text{for } j' = F + 1, \dots, J. \quad (5)$$

## 2.2 Firms' problem

We now turn to the firms' problem, which we solve in partial equilibrium by taking as given the inverse demand functions. 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 used car holdings by consumer type,  $\vec{B}_t$ . Then, in every period, firms choose quantities simultaneously to maximize their discounted sum of current and future profits while accounting for the optimality of their future actions.

Our assumption that firms choose quantities is supported by several institutional features of the automobile industry. First, implicit in the Bertrand-price setting game is the assumption that capacities are flexible. In the automobile industry, however, capacities do not appear to be easily adjustable (cf., Bresnahan and Ramey (1994)). Second, it appears to be a common practice 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.

To formulate the problem of the firms, we introduce some notation. We let  $\vec{x}_t = (x_{1t}, \dots, x_{Ft})$  be the vector of production choices by all firms, and let  $\vec{x}_{-jt}$  be the sub-vector containing all elements of  $\vec{x}_t$  excluding  $x_{jt}$ . We also assume the marginal cost of production of each firm  $j = 1, \dots, F$  is constant and equal to  $c_j \geq 0$ .

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  $P_j(\vec{x}_t, \vec{B}_t)$  be the inverse demand function of each firm  $j$ . 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 equilibrium output that is characteristic of durable goods problems. Later, in equilibrium (the next section), we will require that this inverse demand function be consistent with the recursive substitution of the expected future equilibrium behavior.

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' equilibrium production  $\vec{x}_{-jt}^*$ , the maximization problem of each firm  $j = 1, \dots, F$  is a dynamic programming problem with state  $\vec{B}_t$ . Then, a Markov-perfect equilibrium consists of value functions  $W_j(\cdot)$  and decision rules  $G_j(\cdot)$  for all  $j = 1, \dots, F$  such that these



functions satisfy

$$\begin{aligned}
W_j(\vec{B}_t) &= \max_{x_{jt}} \left( P_j((x_{jt}, \vec{x}_{-jt}^*), \vec{B}_t) - c_j \right) x_{jt} + \beta W_j(L((x_{jt}, \vec{x}_{-jt}^*), \vec{B}_t)), & \text{and} \\
x_{jt}^* &= G_j(\vec{B}_t, \vec{x}_{-jt}^*) \equiv G_j(\vec{B}_t).
\end{aligned} \tag{6}$$

Note that, by focusing on a Markov-perfect equilibrium, we require firms' production strategies to be time-consistent—equivalently, that firms cannot commit to production levels in future periods which are sub-optimal once the future period is reached. Because of this, when we compute the Markov-perfect equilibrium for our model, we are accounting for the *indirect* commitment effects of secondary markets.

### 2.3 Equilibrium

To complete the equilibrium definition, we require that the markets for all goods, both new and used, clear, and 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 law-of-motions assumed in the supply-side problem be consistent with those obtained from the demand side. Specifically, in a durable goods model, the inverse demand function depends, as it does in this paper, on future production.<sup>16</sup> In a Markov perfect equilibrium, the firms' future production can be written recursively as a function of the current control and state. Therefore, we require that:

- (i) *primary market clearance*: for each car type  $j = 1, \dots, F$ ,  $G_j(\vec{B}) = Q_j^D$  in the demand equation in (4);
- (ii) *secondary market clearance*: for each car type  $j = F + 1, \dots, J$ ,  $Q_j^D = Q_j^S$  in the used car demand and supply equations in (4) and (5);<sup>17</sup>
- (iii) *consistency of inverse demand functions*:  $\vec{p} = P(\vec{x}, \vec{B})$  solves the system of demand functions in (4) and (5), where the next period's price is given by  $\vec{p}' = P(G(L(\vec{x}, \vec{B})), L(\vec{x}, \vec{B}))$ ;
- (iv) *consistency of law of motion for car holdings vector*: the state variables for the next period ( $\vec{B}'$ ) evolve as

$$\begin{aligned}
B_j^{l'} &= Q_{a(j)}^l & \text{for each used car } j = F + 1, \dots, J, \\
B_0^{l'} &= 1 - \sum_{j=F+1, \dots, J} Q_{a(j)}^l, \\
B_j^{l'} &= 0, & \text{otherwise,}
\end{aligned} \tag{7}$$

<sup>16</sup>Indeed, this future dependence is what yields different solutions for the time consistent and inconsistent problems of the firms.

<sup>17</sup>The distributional assumptions on preference heterogeneity (namely, the  $\epsilon$ 's having support over the entire extended real line) ensure that the secondary market always clears at a positive price and thus, the secondary market is never in excess supply (cf. Chen, Esteban, and Shum (2010, section 2.3)).



and this updating rule equals the law-of-motion  $L(\vec{X}, \vec{B})$  introduced in the previous section.

### 3 Calibration

In order to quantify the effects of secondary markets, we calibrate our model to aggregate data from the US automobile market. As we describe below, some of the parameter values are set a priori based on data or recent empirical studies, while the remaining ones are obtained by finding the parameter values so that, in steady-state, the predicted values of the endogenous variables match the average aggregate values for the US 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 number of used cars in existence was many times larger than that of new cars. This property presents a computational difficulty for our dynamic model. 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—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 (i.e.,  $d(1) = 2$ ), we restrict heterogeneity to make all used cars identical and, instead, assume that in each period a used car dies with probability  $\delta \in (0, 1)$ . Formally, we set<sup>18</sup>

$$d(2) = \begin{cases} 0 & \text{with probability } \delta \text{ ("dies"), and} \\ 2 & \text{with probability } 1 - \delta \text{ ("survives"),} \end{cases}$$

which implies that in the steady state, the average age of existing cars as a function of  $\delta$  is

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

Since the average automobile age in the United States is 9 years (as previously stated), 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  $\gamma$ 's, arise from income differences in the population.

<sup>18</sup>Because  $d(\cdot)$  is now stochastic, the  $a(\cdot)$  mapping is no longer well-defined.



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, this two-vintage, two-type specification model implies that the aggregate state  $\vec{B}_t$  equals  $(B_{2t}^1, B_{2t}^2)$ , where  $B_{2t}^1$  and  $B_{2t}^2$  are the used car stocks owned by the respective consumer types.

On the supply side, we consider an oligopoly consisting of three firms producing homogeneous new cars, corresponding to the Big 3 US 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:  $\alpha_1$ , the new car utility;  $\alpha_2$ , the used car utility;  $\gamma_1$  (resp.  $\gamma_2$ ), 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 squared differences between the model's steady state predictions and the U.S. averages for the fraction of each type of consumers who purchase new and used cars and the new and used vehicle prices. These US averages are obtained from the owned vehicle component of the Consumer Expenditure Survey, for the years 1994–2003. All prices are deflated to 2003 dollars.

Despite having reduced the number of parameter values, having dynamics on both the demand and 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.<sup>19</sup> The MPEC approach is a large-scale 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). 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 dramatically.<sup>20</sup>

### *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. All monetary numbers are reported in \$1,000 in 2003 dollars.

<sup>19</sup>MPEC is an acronym for Mathematical Programming with Equilibrium Constraints, cf. Luo, Pang, and Ralph (1996). These tools were recently advocated by Su and Judd (2008).

<sup>20</sup>Compared to grid search, for example, the MPEC approach cuts the computation time by about 90%.





The calibrated parameter values also show that new cars yield a utility ( $\alpha_1 = 1.75$ ) that is 47% higher than the utility of used cars ( $\alpha_2 = 1.19$ ). The type I consumers have a higher taste for quality and a lower price sensitivity ( $\gamma$ ) equal to 1.63, while the type II consumers have a lower taste for quality and a higher price sensitivity coefficient of 2.30. As reported in Table 3, the steady state is reached when 10.9% of the type I consumers purchase new cars and 17.8% purchase used cars, and 4.5% of the type II consumers purchase new cars and 20.2% purchase used cars. In the steady state, 71% of the type I consumers and 68% of the type II consumers start the next period owning a used car (see Table 4).

These calibrated parameter values satisfy some external validity checks, relative to existing empirical results. The marginal cost parameter is calibrated to equal \$18,400, 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 2000 dollars), which corresponds to \$18,905 in 2003 dollars. Also in the relevant range is the transactions cost parameter  $k$ , which is calibrated to equal \$2,400. Data from the Kelley Blue Book indicates that the difference—which may serve as a proxy for transactions cost—between the trade-in value of a used car (sale price for consumers) and its suggested retail value (buyer’s price) is typically between \$2,000 and \$3,000 in 2007 dollars.

Moreover, Table 4 reports the implied steady-state markup, which is equal to 0.19, or \$4,400 (evaluated at the steady-state new car price of \$22,800). 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 figures remain in the same ballpark as those studies.<sup>21</sup>

Table 4 also contains the consumers’ car ownership transitional probabilities, which show important behavioral differences between the two types of consumers when evaluated at steady state. 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/model in the data.

---

<sup>21</sup>See pg. 882 in Berry, Levinsohn, and Pakes (1995) and note that those were estimated for the 1970’s and 1980’s time period.

## 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 (sorting and indirect commitment) may play.

Our first goal is to understand whether secondary markets aid or harm durable goods manufacturers. To review our discussion from the introduction of the paper, durability presents the producers with two problems, relative to the non-durable case: a substitution and a credibility problem. Active secondary markets allow for a fraction of used cars to be traded, which introduces the sorting and indirect commitment effects, both of which could either hurt or help producers. To determine which signs and magnitudes these effects have and whether these outweigh the substitution and credibility problems, we first consider a set of counterfactual experiments in which we change the transactions cost parameter  $k$  from its calibrated value of \$2,400, and then recompute the steady state holding all other parameters fixed. Graphical evidence is presented in Figures 1, 2 and 3.

The top panel of Table 5 presents the steady-state outcomes for the “baseline” case, where we allow the size of the transactions cost to vary from \$2,400 to \$100,000 (which closes secondary markets) and from \$2,400 to \$0 (which makes them frictionless), while holding all the other parameters fixed at the calibrated values in Table 2. The results indicate that, relative to the baseline case, closing the secondary market raises profits by 39%. This effect is not symmetric, however; we find that making transactions frictionless decreases profits, but only by 1%. These results indicate that, on the whole, more active secondary markets bring a (large) negative sorting effect, and lower their profits.

Furthermore, the effects on new car production and price are presented in Figure 2. There, we see, as we would expect, new car production decreasing as the secondary market becomes more active. The new car price exhibits a milder adjustment (first falling slightly, and then rising slightly).

Finally, in Figure 3, we present evidence on the effects of opening the secondary market on car purchase behavior. The top graph shows that, when moving from a closed to a frictionless secondary market, the (less price-sensitive) type I consumers’ probability of buying a new car increases slightly, from 9.2% to 10.6%, while the (more price-sensitive) type II consumers’ probability drops by more than half, from 8.9% to 4.2%. At the same time, the bottom graph indicates that the difference by types in the fraction of consumers purchasing used cars increases as the secondary market expands, starting from a very small difference when the secondary market is not active.





This differential behavior of the two consumer types highlights the sorting effect of secondary markets, with high-valuation type-I consumers “selecting” disproportionately into the new goods market. Taken together, these results indicate that the vertical component in the consumers’ preference heterogeneity, given by the  $\gamma$ ’s, plays a small role in the behavioral patterns of the different consumer types when secondary markets are non-existent. However, as the secondary market expands, we find that this vertical component explains the different consumption patterns in the primary and secondary markets because of the allocative role of used car markets.

Next, we consider additional sets of counterfactual experiments, designed to highlight scenarios in which secondary markets may play a beneficial role.

### *1. Assessing Consumer Heterogeneity*

We start by analyzing the role of persistent consumer heterogeneity. As just seen, the persistent heterogeneity component plays a significant role when the secondary market is active, allowing the new car producers to raise their profits by, essentially, raising prices to high willingness-to-pay (type I) consumers, who “select” into the primary market by reselling more often their used cars in the secondary market. In the second panel of Table 5, we increase the persistent consumer heterogeneity by decreasing  $\gamma_1$  but increasing  $\gamma_2$  (thus increasing the willingness-to-pay of the high type consumers and decreasing the willingness-to-pay of the low type ones). This magnifies the disproportionate sorting of the more valuable Type I consumers into the primary market, and should lead to higher profits for the firms.

Accordingly, we see that closing secondary markets (relative to our baseline) decreases profits by 36%, while making transactions frictionless increases them by 1%. In contrast, when we eliminate consumer heterogeneity (the bottom panel of Table 5), we find that profits increase by 45% if we shut down the secondary market, and increase by 2% if we make transactions frictionless. Both simulations are in line with our analysis of the beneficial sorting effect of secondary markets if there is sufficient product and consumer heterogeneity.<sup>22</sup>

### *2. Assessing Product Differentiation*

Table 6 contains results from a set of counterfactuals that consider changes in the degree of quality differentiation between new and used cars. As we discussed earlier, secondary markets would hurt the new car producers more if new and used cars were less quality

---

<sup>22</sup>Although Table 5 reports results for three pairs of  $(\gamma_1, \gamma_2)$  values, we have extensively varied these parameters, and our findings are robust. This also applies to Tables 6–8 below.



differentiated. An active secondary market reallocates the stock of used cars efficiently among consumers, reshaping the firms' residual demand curves. This reallocation is especially detrimental to firms when the used goods substitute well with new goods because, in that case, the firm disproportionately “loses” the high-valuation consumers. The bottom two panels from this table confirm this intuition. Throughout, we hold  $\alpha_1$ , the quality of a new car, fixed at the baseline value of 1.75. When we reduce  $\alpha_2$  to 0.60, thus making new and used cars less substitutable, opening the secondary market increases firms' profits by 3%, relative to the calibrated transaction cost. However, when we increase  $\alpha_2$  to 1.50, so that new and used cars are closer in quality, the opening of the secondary market reduces profits by 2%. If, instead, the secondary market is closed down, profits decrease by 2% when  $\alpha_2 = 0.60$  but increase by 46% when  $\alpha_2 = 1.50$ . The differences in these two sets of counterfactuals highlight the inverse relation between the sign of the substitution effect and the substitutability between new and used cars, and whether the sorting effect of secondary markets offsets the inherent substitution problem facing durable goods producers.

### 3. *Assessing Durability*

In a third set of counterfactuals, reported in Table 7, we consider changes in car durability, which we formalize as changes in the value of  $\delta$ , the per-period death probability of a used car. This allows us to zero in on the indirect commitment effect of secondary markets. Namely, enhancing durability has a negative indirect commitment effect, because it allows high valuation consumers to keep their used cars longer, and stay out of the primary market. This reduces the “credibility” of high future prices, and exacerbates the firms' competition with their own future selves. Moreover, increasing durability expands the stock of used cars, which magnifies a negative sorting effect if the goods are close substitutes. Accordingly, the sorting effects of secondary markets are less likely to offset the substitution problem. By both these channels, then, we expect that when cars are more durable, firms prefer a less active secondary market, and vice versa.

The results in the bottom two panels of Table 7 confirm this intuition. In the second panel, durability is increased by reducing the death probability to  $\delta = 0.05$ . In that case, further increasing transaction costs to close down secondary markets increases profits by 113%. However, when durability is reduced by increasing  $\delta$  to 0.25, each firm's profits increase by 5% if transaction costs are reduced to \$0, so the firms would prefer secondary markets to be frictionless.

### 4. *Assessing Market Structure*

In the final set of counterfactuals, reported in Table 8, we consider how the benefits of the secondary market vary depending on market structure, given by the number of primary

market competitors. These counterfactuals are motivated by the existing theoretical literature on secondary markets, which have varied in their assumptions regarding the market structure in the primary market.

The benchmark model in this paper is a dynamic Cournot oligopoly. As in a static Cournot setting, oligopolistic firms overproduce relative to the optimal industry level, because they do not internalize the negative effect that their own increase in output has on other firms' profits. An increase in output implies an increase in the stock of used goods; therefore, the more firms there are, the larger the stock of used goods will be. On the whole, then, the net effect of a less concentrated market structure is similar to that of increasing durability, and we expect the implications for the secondary market to be the same as in the durability counterfactuals described above.

Accordingly, the results in Table 8 show that as the market structure becomes less concentrated, the benefits from closing the secondary market emerge. The first panel shows that closing secondary markets increases profits by 39% in the benchmark case, whereas in a duopoly (the second panel), profits rise by only 18%. If the firm is a monopolist (the third panel), then closing the secondary market, instead, decreases the firm's profits, whereas expanding the secondary market increases its profits.

## 5 Summary and conclusions

To investigate how the tradability of durable goods in secondary markets affects firms' behavior and profits, we develop a rich 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. To our knowledge, our model is the first which simultaneously allows for the substitution and credibility problems related to durability, and the sorting and indirect commitment effects of secondary markets.

In our model, the key element that helps us identify the competitive effect of secondary markets is the transaction cost parameter. Using the calibrated version of the model, we run counterfactuals in which we vary the magnitude of transactions 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, closing the secondary market altogether raises the profits of new car manufacturers by 39%. Thus, to answer the question posed in the title of the paper: used goods trading in secondary markets do compete vigorously with primary markets, to the overall detriment of the 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 to new good producers when (1) consumers are more heterogeneous in their price-sensitivity; (2) new and used cars are more quality-differentiated; (3) cars are less durable; and (4) the primary market is more concentrated. These effects are broadly consistent with the existing theoretical literature on the re-allocative and commitment roles of secondary markets.

More broadly, our results suggest that policies which *increase* frictions in the secondary market for cars can benefit new car manufacturers, which are currently in a malaise. This goes against the grain of policies aimed at reducing the costs of buying a car. Indeed, in Chen, Esteban, and Shum (2010), we show (using a much simpler model than the one analyzed in this paper) that sales tax credits, meant to encourage consumers to buy new cars, could backfire and hurt car producers in the long run. At the least, our analysis suggests that effective policy-making in durable goods industries must pay attention to the dynamic and static competition effects, which are oftentimes countervailing.



## References

- ADDA, J., AND R. COOPER (2000): “Balladurette and Jupette: A Discrete Analysis of Scrapping Subsidies,” *Journal of Political Economy*, 108, 778–806.
- AKERLOF, G. (1970): “The Market for “Lemons”: Quality Uncertainty and the Market Mechanism,” *Quarterly Journal of Economics*, 84, 488–500.
- ANDERSON, S., AND V. GINSBURGH (1994): “Price Discrimination via Second-hand Markets,” *European Economic Review*, 38, 23–44.
- AREEDA, P., AND L. KAPLOW (1988): *Antitrust Analysis: Problems, Text, Cases*. Little, Brown, and Company.
- ATTANASIO, O. (2000): “Consumer Durables and Inertial Behavior: Estimation and Aggregation of (s,S) Rules,” *Review of Economic Studies*, 67, 667–696.
- BERRY, S., J. LEVINSOHN, AND A. PAKES (1995): “Automobile Prices in Market Equilibrium,” *Econometrica*, 63, 841–890.
- BERRY, S., AND A. PAKES (2007): “The Pure Characteristics Demand Model,” *International Economic Review*, 48, 1193–1225.
- BOND, E. (1982): “A Direct Test of the “Lemons” Model: The Market for Used Pickup Trucks,” *American Economic Review*, 72, 836–840.
- BRESNAHAN, T. (1981): “Departures from Marginal Cost Pricing in the American Automobile Industry,” *Journal of Econometrics*, 17, 201–227.
- BRESNAHAN, T., AND V. RAMEY (1994): “Output Fluctuations at the Plant Level,” *Quarterly Journal of Economics*, 108, 593–624.
- BULOW, J. (1986): “An Economic Theory of Planned Obsolescence,” *Quarterly Journal of Economics*, 101, 729–749.
- CARLTON, D., AND R. GERTNER (1989): “Market Power and Mergers in Durable-Good Industries,” *Journal of Law and Economics*, 32, S203–S231.
- CARRANZA, J. E. (2007): “Estimation of Demand for Differentiated Durable Goods,” manuscript, University of Wisconsin.
- CHEN, J., S. ESTEBAN, AND M. SHUM (2008): “Estimation Biases of Omitting Durability,” *Journal of Econometrics*, 147, 247–257.
- (2010): “Do Sales Tax Credits Stimulate the Automobile Market?,” to appear, *International Journal of Industrial Organization*.



- CHEVALIER, J., AND A. GOOLSBEE (2009): “Are Durable Goods Consumers Forward Looking? Evidence from the College Textbook Market,” *Quarterly Journal of Economics*, 124, 1853–1884.
- COASE, R. (1972): “Durability and Monopoly,” *Journal of Law and Economics*, 15, 143–149.
- COPELAND, A. (2006): “Intertemporal Substitution and Automobiles,” mimeo., Bureau of Economic Analysis.
- COPELAND, A., W. DUNN, AND G. HALL (2005): “Prices, Production, and Inventories over the Automotive Model Year,” NBER Working Paper, #11257.
- DRISKILL, R. (2001): “Durable Goods Oligopoly,” *International Journal of Industrial Organization*, 19, 391–413.
- EBERLY, J. (1994): “Adjustment of Consumers’ Durables Stocks: Evidence from Automobile Purchases,” *Journal of Political Economy*, 102, 403–436.
- ERDEM, T., S. IMAI, AND M. KEANE (2003): “Brand and Quantity Choice Dynamics under Price Uncertainty,” *Quantitative Marketing and Economics*, 1, 5–64.
- ESTEBAN, S. (2002): “Equilibrium Dynamics in Semi-Durable Goods Markets,” manuscript, Penn State University.
- ESTEBAN, S., AND M. SHUM (2007): “Durable Goods Oligopoly with Secondary Markets: the Case of Automobiles,” *RAND Journal of Economics*, 38, 332–354.
- GAVAZZA, A., AND A. LIZZERI (2009): “The Effects of Heterogeneity in Secondary Markets: a Comparison of France, UK and US Car Markets,” mimeo., NYU.
- GOETTLER, R., AND B. GORDON (2008): “Durable Goods Oligopoly with Innovation: Theory and Empirics,” manuscript, Carnegie Mellon University.
- GOLDBERG, P. (1995): “Product Differentiation and Oligopoly in International Markets: The Case of the US Automobile Industry,” *Econometrica*, 63, 891–951.
- GORDON, B. (forthcoming): “A Dynamic Model of Consumer Replacement Cycles in the PC Processor Industry,” *Marketing Science*.
- GOWRISANKARAN, G., AND M. RYSMAN (2006): “Dynamics of Consumer Demand for New Durable Goods,” manuscript, Boston University.
- GUL, F. (1987): “Noncooperative Collusion in Durable Goods Oligopoly,” *RAND Journal of Economics*, 18, 248–254.
- HARTMANN, W. (2006): “Intertemporal Effects of Consumption and Their Implications for Demand Elasticity Estimates,” *Quantitative Marketing and Economics*, 4, 325–349.



- HENDEL, I., AND A. LIZZERI (1999a): “Adverse Selection in Durable Goods Markets,” *American Economic Review*, 89, 1097–1115.
- (1999b): “Interfering with Secondary Markets,” *RAND Journal of Economics*, 30, 1–21.
- HENDEL, I., AND A. NEVO (2006a): “Measuring the Implications of Sales and Consumer Inventory Behavior,” *Econometrica*, 74, 1637–1673.
- (2006b): “Sales and Consumer Inventory,” *RAND Journal of Economics*, 37, 543–561.
- IZUKA, T. (2007): “An Empirical Analysis of Planned Obsolescence,” *Journal of Economics and Management Strategy*, 1, 191–226.
- JUDD, K. (1998): *Numerical Methods in Economics*. MIT Press.
- LIANG, M. (1999): “Does a Second-Hand Market Limit a Durable Goods Monopolist’s Market Power?” manuscript, University of Western Ontario.
- LUO, Z., J. PANG, AND D. RALPH (1996): *Mathematical Programs with Equilibrium Constraints*. Cambridge University Press.
- MELNIKOV, O. (2000): “Demand for Differentiated Durable Products: The Case of the U.S. Computer Printer Market,” manuscript, Cornell University.
- MIRANDA, M., AND P. FACKLER (2002): *Applied Computational Economics and Finance*. MIT Press.
- NAIR, H. (2007): “Intertemporal Price Discrimination with Forward-looking Consumers: Application to the US Market for Console Video-Games,” *Quantitative Marketing and Economics*, 5, 239–292.
- NISSANOFF, D. (2006): *Future Shop: How the New Auction Culture will Revolutionize the Way we Buy, Sell, and Get the Things we Really Want*. Penguin Press.
- PETRIN, A. (2002): “Quantifying the Benefits of New Products: the Case of the Minivan,” *Journal of Political Economy*, 110, 705–729.
- PORTER, R., AND P. SATTLER (1999): “Patterns of Trade in the Market for Used Durables: Theory and Evidence,” NBER working paper, #7149.
- RUST, J. (1985): “When is it Optimal to Kill off the Market for Used Durable Goods?,” *Econometrica*, 54, 65–86.
- (1987): “Optimal Replacement of GMC Bus Engines: An Empirical Model of Harold Zurcher,” *Econometrica*, 55, 999–1033.



- SCHIRALDI, P. (2006): “Automobile Replacement: a Dynamic Structural Approach,” mimeo, LSE.
- SOBEL, J. (1984): “The Timing of Sales,” *Review of Economic Studies*, 51, 353–368.
- STOLYAROV, D. (2002): “Turnover of Used Durables in a Stationary Equilibrium: are Older Goods traded More?,” *Journal of Political Economy*, 110, 1390–1413.
- SU, C., AND K. JUDD (2008): “Constrained Optimization Approaches to Estimation of Structural Models,” manuscript, Northwestern University.
- SUSLOW, V. (1986): “Short-Run Supply with Capacity Constraints,” *RAND Journal of Economics*, 17, 389–403.
- SWAN, P. (1972): “Optimum Durability, Second-Hand Markets, and Planned Obsolescence,” *Journal of Political Economy*, 80, 575–585.
- WALDMAN, M. (1993): “A New Perspective on Planned Obsolescence,” *Quarterly Journal of Economics*, 108, 273–283.
- (1996): “Durable Goods Pricing When Quality Matters,” *Journal of Business*, 69, 489–510.
- (2003): “Durable Goods Theory for Real World Markets,” *Journal of Economic Perspectives*, 17, 131–154.





## A 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), 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; see Luo, Pang, and Ralph (1996)) 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 squared 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 SNOPT, a state-of-the-art optimization solver, 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 parameter space that converge 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 case presented in Section 3. Let  $(D_1^{1ss}, D_1^{2ss}, D_2^{1ss}, D_2^{2ss}, p_1^{ss}, p_2^{ss})$  and  $(D_1^{1US}, D_1^{2US}, D_2^{1US}, D_2^{2US}, p_1^{US}, p_2^{US})$  be 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 new car price, and  $p_2$  is used 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  $\theta_2 \equiv (B_2^{1ss}, B_2^{2ss}, D_1^{1ss}, D_1^{2ss}, D_2^{1ss}, D_2^{2ss}, p_1^{ss}, p_2^{ss})$  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  $\theta_3$  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:

$$\begin{aligned} \min_{\theta} \quad & \left( \frac{D_1^{1ss} - D_1^{1US}}{D_1^{1US}} \right)^2 + \left( \frac{D_1^{2ss} - D_1^{2US}}{D_1^{2US}} \right)^2 + \left( \frac{D_2^{1ss} - D_2^{1US}}{D_2^{1US}} \right)^2 + \left( \frac{D_2^{2ss} - D_2^{2US}}{D_2^{2US}} \right)^2 \\ & + \left( \frac{p_1^{ss} - p_1^{US}}{p_1^{US}} \right)^2 + \left( \frac{p_2^{ss} - p_2^{US}}{p_2^{US}} \right)^2 \end{aligned} \quad (8)$$

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

Table 1: Fixed parameters

Discount factor ( $\beta$ )	1/1.04
# of distinct ex-ante consumer types	2
% of type I consumers	50%
% of type II consumers	50%
Probability of used car quantity depreciation ( $\delta$ )	0.11
# of firms	3

Table 2: Calibrated parameters

New car utility ( $\alpha_1$ )	1.75
Used car utility ( $\alpha_2$ )	1.19
Type I consumers' marginal utility of money ( $\gamma_1$ )	1.63
Type II consumers' marginal utility of money ( $\gamma_2$ )	2.30
Marginal cost ( $c$ )	\$18,400
Transaction cost ( $k$ )	\$2,400



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

	Model steady state values	U.S. data averages (1994–2003) <sup>a</sup>
% of Type 1 consumers: <sup>b</sup>		
who purchase new cars	10.9	9.8
who purchase used cars	17.8	18.7
% of Type 2 consumers: <sup>c</sup>		
who purchase new cars	4.5	4.2
who purchase used cars	20.2	18.6
New vehicle price	\$22,800	\$23,000
Used vehicle price	\$8,900	\$9,000

<sup>a</sup> From Consumer Expenditure Survey, owned vehicle module.

<sup>b</sup> Households with above-median income.

<sup>c</sup> Households with below-median income.

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

Firm markup	0.19	
<i>Consumers' transition probabilities <math>P(s_t r_t)</math><sup>a</sup></i>		
	Type I	Type II
$P(1 2)$	0.10	0.04
$P(2 2)$	0.70	0.76
$P(0 2)$	0.20	0.20
$P(1 0)$	0.13	0.06
$P(2 0)$	0.61	0.64
$P(0 0)$	0.26	0.30
% consumers who own a used car	71	68

<sup>a</sup>  $P(s_t|r_t)$  is the probability that a consumer owning car  $r_t$  at the beginning of  $t$  purchases car  $s_t$ .





Table 5: Effects of opening secondary market: More vs. less consumer heterogeneity

Variable	<i>Transactions cost (\$1,000)</i>			
	100	20	2.4	0
BASELINE: $\gamma_1 = 1.63$ , $\gamma_2 = 2.30^a$				
New car production per firm <sup>b</sup>	0.030	0.029	0.026	0.025
Used car transactions	0.00	0.05	0.19	0.22
Used car stock	0.82	0.80	0.70	0.67
New car prices (\$1,000)	23.6	22.9	22.8	22.9
Used car prices (\$1,000)	—	19.9	8.9	7.4
Profits per firm (\$1,000)	0.16	0.13	0.11	0.11
% $\Delta$ vs. calibrated	(+39%)	(+19%)	—	(-1%)
MORE HETEROGENEITY: $\gamma_1 = 1.00$ , $\gamma_2 = 3.00$				
New car production per firm	0.030	0.029	0.026	0.025
Used car transactions	0.00	0.08	0.19	0.22
Used car stock	0.82	0.79	0.71	0.68
New car prices (\$1,000)	22.2	23.6	25.2	25.5
Used car prices (\$1,000)	—	16.3	6.2	4.7
Profits per firm (\$1,000)	0.11	0.15	0.18	0.18
% $\Delta$ vs. calibrated	(-36%)	(-13%)	—	(+1%)
LESS HETEROGENEITY: $\gamma_1 = 2.00$ , $\gamma_2 = 2.00$				
New car production per firm	0.030	0.030	0.025	0.024
Used car transactions	0.00	0.05	0.19	0.22
Used car stock	0.82	0.80	0.69	0.67
New car prices (\$1,000)	23.3	22.9	22.4	22.6
Used car prices (\$1,000)	—	20.5	9.3	7.9
Profits per firm (\$1,000)	0.15	0.13	0.10	0.10
% $\Delta$ vs. calibrated	(+45%)	(+29%)	—	(+2%)

<sup>a</sup> $\gamma_1$  and  $\gamma_2$  are type I and type II consumers' marginal utility of money, respectively.

<sup>b</sup>New car production per firm, used car transactions, and used car stock are all measured against the consumer population, which is normalized to one.

Table 6: Effects of opening secondary market: More vs. less quality differentiation

Variable	<i>Transactions cost (\$1,000)</i>			
	100	20	2.4	0
BASELINE: $\alpha_1 = 1.75$ , $\alpha_2 = 1.19^a$				
New car production per firm <sup>b</sup>	0.030	0.029	0.026	0.025
Used car transactions	0.00	0.05	0.19	0.22
Used car stock	0.82	0.80	0.70	0.67
New car prices (\$1,000)	23.6	22.9	22.8	22.9
Used car prices (\$1,000)	—	19.9	8.9	7.4
Profits per firm (\$1,000)	0.16	0.13	0.11	0.11
% $\Delta$ vs. calibrated	(+39%)	(+19%)	—	(-1%)
MORE DIFFERENTIATION: $\alpha_1 = 1.75$ , $\alpha_2 = 0.60$				
New car production per firm	0.027	0.025	0.022	0.021
Used car transactions	0.00	0.06	0.21	0.24
Used car stock	0.73	0.69	0.60	0.58
New car prices (\$1,000)	21.5	21.6	22.2	22.4
Used car prices (\$1,000)	—	14.9	5.3	4.1
Profits per firm (\$1,000)	0.08	0.08	0.08	0.09
% $\Delta$ vs. calibrated	(-2%)	(-2%)	—	(+3%)
LESS DIFFERENTIATION: $\alpha_1 = 1.75$ , $\alpha_2 = 1.50$				
New car production per firm	0.031	0.030	0.027	0.026
Used car transactions	0.00	0.05	0.17	0.20
Used car stock	0.85	0.82	0.74	0.71
New car prices (\$1,000)	24.5	24.3	23.2	23.3
Used car prices (\$1,000)	—	23.0	10.9	9.3
Profits per firm (\$1,000)	0.19	0.18	0.13	0.13
% $\Delta$ vs. calibrated	(+46%)	(+37%)	—	(-2%)

<sup>a</sup> $\alpha_1$  and  $\alpha_2$  are new car utility and used car utility, respectively.

<sup>b</sup>New car production per firm, used car transactions, and used car stock are all measured against the consumer population, which is normalized to one.





Table 7: Effects of opening secondary market: More vs. less durability

Variable	<i>Transactions cost (\$1,000)</i>			
	100	20	2.4	0
BASELINE: $\delta = 0.11^a$				
New car production per firm <sup>b</sup>	0.030	0.029	0.026	0.025
Used car transactions	0.00	0.05	0.19	0.22
Used car stock	0.82	0.80	0.70	0.67
New car prices (\$1,000)	23.6	22.9	22.8	22.9
Used car prices (\$1,000)	—	19.9	8.9	7.4
Profits per firm (\$1,000)	0.16	0.13	0.11	0.11
% $\Delta$ vs. calibrated	(+39%)	(+19%)	—	(-1%)
MORE DURABILITY: $\delta = 0.05$				
New car production per firm	0.015	0.015	0.013	0.012
Used car transactions	0.00	0.04	0.16	0.20
Used car stock	0.92	0.90	0.76	0.73
New car prices (\$1,000)	25.4	23.4	22.4	22.4
Used car prices (\$1,000)	—	18.4	4.9	3.2
Profits per firm (\$1,000)	0.11	0.07	0.05	0.05
% $\Delta$ vs. calibrated	(+113%)	(+48%)	—	(-4%)
LESS DURABILITY: $\delta = 0.25$				
New car production per firm	0.052	0.051	0.047	0.046
Used car transactions	0.00	0.06	0.22	0.25
Used car stock	0.62	0.61	0.57	0.56
New car prices (\$1,000)	21.9	22.0	23.0	23.3
Used car prices (\$1,000)	—	20.0	11.6	10.5
Profits per firm (\$1,000)	0.18	0.18	0.22	0.23
% $\Delta$ vs. calibrated	(-16%)	(-14%)	—	(+5%)

<sup>a</sup> $\delta$  is the probability of used car quantity depreciation.

<sup>b</sup>New car production per firm, used car transactions, and used car stock are all measured against the consumer population, which is normalized to one.



Table 8: Effects of opening secondary market: Changes in market structure

Variable	<i>Transactions cost (\$1,000)</i>			
	100	20	2.4	0
BASELINE: $N = 3$ (TRIOPOLY)				
New car production per firm <sup>a</sup>	0.030	0.029	0.026	0.025
Used car transactions	0.00	0.05	0.19	0.22
Used car stock	0.82	0.80	0.70	0.67
New car prices (\$1,000)	23.6	22.9	22.8	22.9
Used car prices (\$1,000)	—	19.9	8.9	7.4
Profits per firm (\$1,000)	0.16	0.13	0.11	0.11
% $\Delta$ vs. calibrated	(+39%)	(+19%)	—	(-1%)
DUOPOLY: $N = 2$ (DUOPOLY)				
New car production per firm	0.045	0.044	0.038	0.036
Used car transactions	0.00	0.05	0.19	0.23
Used car volume	0.82	0.79	0.68	0.66
New car prices (\$1,000)	26.2	26.0	26.3	26.6
Used car prices (\$1,000)	—	22.6	12.0	10.8
Profits per firm (\$1,000)	0.35	0.33	0.30	0.30
% $\Delta$ vs. calibrated	(+18%)	(+12%)	—	(0%)
MONOPOLY: $N = 1$ (MONOPOLY)				
New car production per firm	0.081	0.077	0.062	0.059
Used car transactions	0.00	0.06	0.22	0.25
Used car stock	0.73	0.70	0.57	0.54
New car prices (\$1,000)	39.7	40.2	46.4	49.3
Used car prices (\$1,000)	—	34.6	29.9	31.2
Profits per firm (\$1,000)	1.72	1.67	1.74	1.84
% $\Delta$ vs. calibrated	(-1%)	(-4%)	—	(6%)

<sup>a</sup>New car production per firm, used car transactions, and used car stock are all measured against the consumer population, which is normalized to one.

Figure 1: Opening secondary market in the calibrated model: size of secondary market and profits per firm

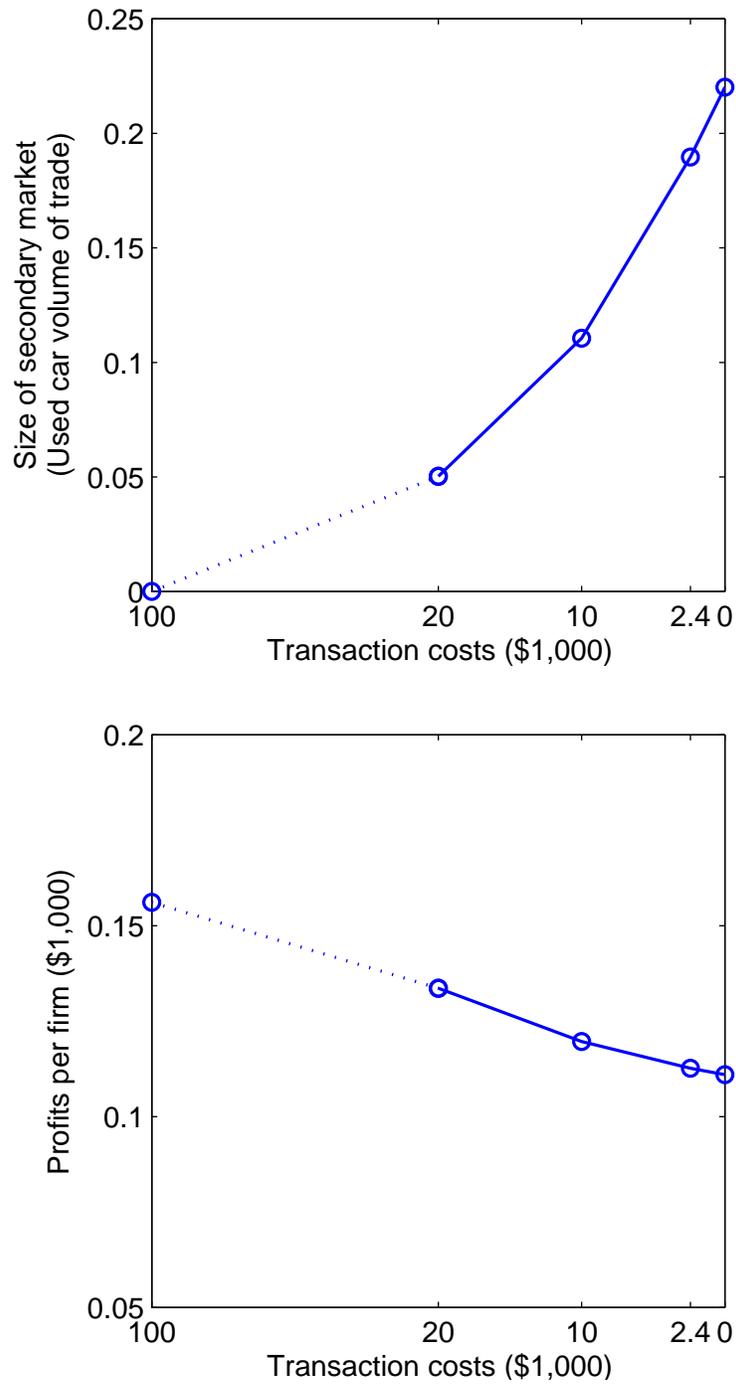


Figure 2: Opening secondary market in the calibrated model: new car production per firm and new car price

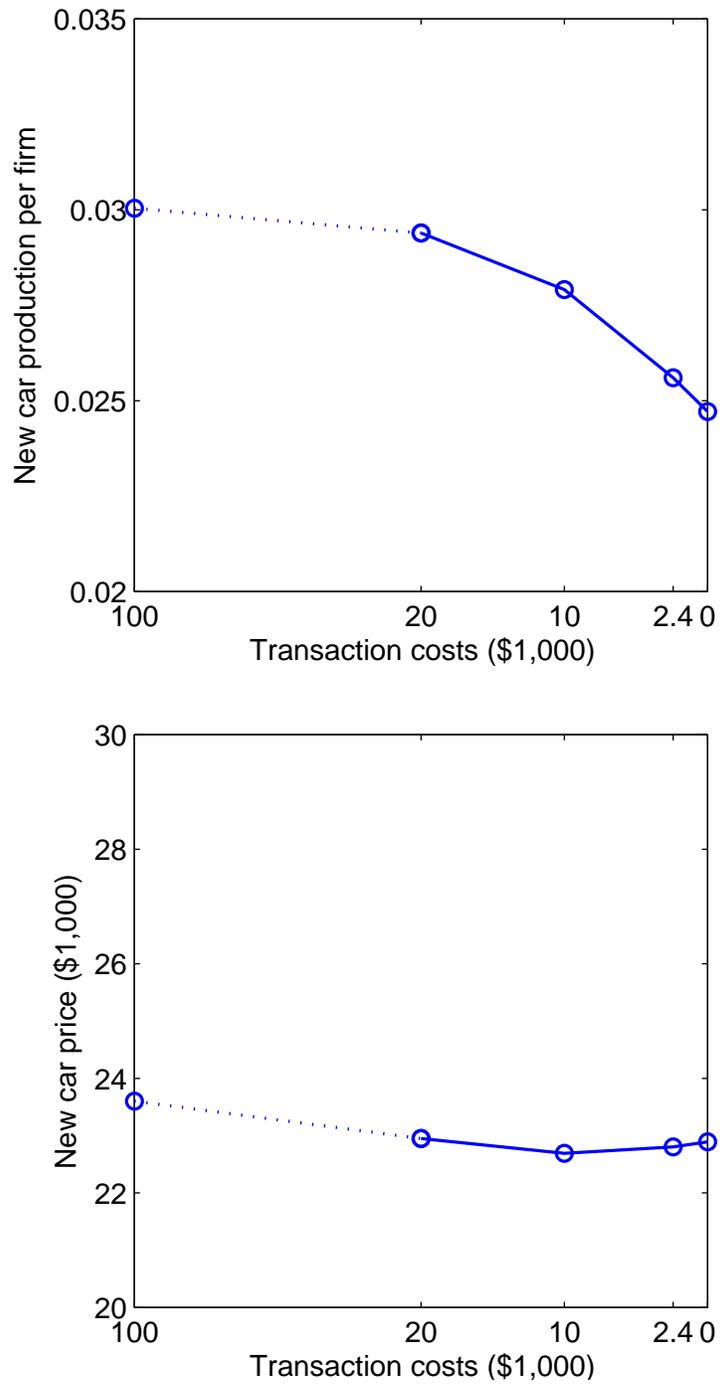


Figure 3: Opening secondary market in the calibrated model: new car and used car purchases by type

