When do Secondary Markets Harm Firms? – Online Appendixes (Not for Publication)

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I 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 derive from the equilibrium and 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

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optimization process; instead, it generates a sequence of points in the 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 $\theta_2 \equiv (B_2^{1ss}, B_2^{2ss}, D_1^{1ss}, D_1^{2ss}, D_2^{1ss}, D_2^{2ss}, p_1^{ss}, p_2^{ss}, \eta^{ss})$ 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:

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

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

II Equilibrium policy and value functions

Figures A1 and A2 present some 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.

III Opening the secondary market in the baseline specification

In the baseline counterfactuals, we open the secondary market by lowering the transaction cost k from 8 to 0. Figure A3 reports the effects of opening the secondary market, by plotting the behavior of the two types of consumers as the secondary market becomes more active. Panel 1 plots new car purchases by consumer type as the secondary market is gradually opened, for $k = 8, 7, \ldots, 2, 1, 0.44, 0$. The figure shows that fewer consumers buy new cars as the secondary market is opened up. In addition, type 1 consumers, being the high-valuation type, consistently buy more new cars than type 2 consumers. Panel 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 23% for type 1 and 26% for type 2 at $k = 0$. Finally, Panel 3 shows that as the secondary market is opened up, the percentage of each type of consumers who own (new or used) cars drops; such a decrease is driven by the firms' lower production of new cars as the secondary market becomes more active. Throughout, a larger percentage of type 1 consumers own cars, compared to type 2 consumers.

IV Details on the full commitment problem

We consider the full commitment problem in which each firm, $j = 1, \ldots, N$, chooses, once and for all, the sequence of production $\{x_t\}_{t=1}^{\infty}$ that maximizes its discounted profits given rival's choices $\{\vec{x}_{-nt}\}_{t=1}^{\infty}$ and the initial state $\vec{B}_{t=1}$. We look for a solution in which each firm commits to a constant sequence of output and the industry state remains constant. Hence, we are solving directly for a constant output solution for the full commitment problem, rather than looking for the steady state of the optimal full commitment output sequence.[1]

Let x^* denote the firms' constant production in a symmetric equilibrium in our full commitment problem,[2] and let $\vec{B}^* = (B_2^{1*}, B_2^{2*})$ denote the absorbing state (the state that the industry will never leave once it enters) when each firm commits to producing x^* in every period. We solve for x^* which satisfies a necessary condition that a firm does not find it profitable to deviate in its choice for the initial period; that is, from a firm's perspective, if (1) all rival firms in the initial period and in all future periods, and this firm itself in all future periods, are committed to producing x^*, (2) consumers correctly anticipate such production paths, and (3) the industry state in the initial period is $\vec{B}^*$, then it is this firm's optimal choice, in terms of maximizing the sum of discounted profits, to produce x^* in the initial period, taking into account how this choice affects prices in other periods.

[1]The reason is that solving for the optimal full commitment output sequence is computationally infeasible in our nonlinear dynamic oligopoly settings, due to the infinite dimensionality of the problem. The previous literature on computing full commitment solutions (eg. Ljungqvist and Sargent (2004), Söderlind (1999)) has restricted attention to simpler linear-quadratic models with only a single decision-maker.

[2]Symmetry, per se, is not imposed when solving for each individual firm's optimal choices, though we focus attention on equilibria involving identical production levels for the firms.

The details of the iterative algorithm to solve for x^* and $\vec{B}^*$ are as follows. Let $t = 1$ be the initial period. Let x denote the quantity that every firm commits to producing in every period, let $NPV_{t=2}(\vec{B})$ denote a firm's NPV at $t = 2$ (i.e., the sum of the firm's profits at $t = 2, 3, 4, \ldots$, all discounted to $t = 2$) as a function of the state, and let $\tilde{V}(\vec{B})$ denote a consumer's expected value function. In each iteration, given x^{in}, $NPV^{in}_{t=2}$, and $\tilde{V}^{in}$ (the inputs), we compute x^{out}, $NPV^{out}_{t=2}$, and $\tilde{V}^{out}$ (the outputs). First, compute $NPV^{out}_{t=2}$ and $\tilde{V}^{out}$ assuming every firm commits to producing x^{in} at $t = 2, 3, 4, \ldots$[3] Next, solve for the absorbing state $\vec{B}^a$ assuming every firm commits to producing x^{in} in every period. Then, assuming that the state at $t = 1$ is $\vec{B}^a$, and that from a firm's perspective, all rival firms at $t = 1, 2, 3, \ldots$ and this firm itself at $t = 2, 3, 4, \ldots$ are committed to producing x^{in}, we obtain x^{out} by solving for this firm's $t = 1$ production that maximizes its NPV at $t = 1$.[4][5] Update x^{in}, $NPV^{in}_{t=2}$, and $\tilde{V}^{in}$ with x^{out}, $NPV^{out}_{t=2}$, and $\tilde{V}^{out}$, and iterate until convergence, that is, iterate until the relative difference between the inputs and the outputs is below a pre-specified precision level. When the algorithm converges, we obtain x^* and $\vec{B}^*$ as the x^{out} and $\vec{B}^a$ produced in the last iteration.

V 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. These results are also briefly summarized in Section IV.E of the main text.

[3] A policy function describes a firm's choice as a function of the state. In a full commitment scenario, each firm commits to a sequence of quantities for all periods—independent of the state. Hence in this case there is no policy function per se. However, in the special case in which a firm commits to a constant production sequence, which we consider here, it is as if the firm has a flat "policy function".

[4] The firm's NPV at $t = 1$ equals its profits at $t = 1$ plus $\beta \times NPV_{t=2}(\vec{B}_{t=2})$. Note that $\vec{B}_{t=2}$ also depends on the firm's $t = 1$ production.

[5] Note that here we solve the optimization problem from a single firm's perspective (taking its rivals' behavior as given) rather than the joint (industry) profit maximization problem, hence the solution differs from the full-commitment collusive outcome.

A Broad range of parameter values

Although in Tables 6 and 8 we only report results for three values of $Var(\epsilon)$ and three values of δ, respectively, we have extensively varied the parameter values, and our findings are robust. Figure A4 presents the changes in the steady-state market outcome (quantities, prices, scrappage, consumers who own no cars, consumer surplus, and firm profits) as we let δ take on increasing values in $\{0.05, 0.11, 0.15, 0.25, \ldots, 0.95\}$. The figure shows that the main patterns we observe from Table 8 are robust for a wide range of δ values, even at extreme values such as when δ is close to 1. In particular, we see that as we successively increase δ, the change in profits from $k = 8$ to $k = 0$ gradually increases and reverses sign, from negative at $\delta = 0.05$ to positive at $\delta = 0.95$. Similarly, Figure A5 presents the changes in the steady-state market outcome as we let $Var(\epsilon)$ take on increasing values in $\{1, 2, \ldots, 10\} \times 1/8 \times \pi^2/6$, and shows that the main patterns we observe from Table 6 are robust. In particular, we see that as we successively increase $Var(\epsilon)$, the change in profits from $k = 8$ to $k = 0$ generally becomes more negative.

B 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 46% 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 100% to 0% decreases firms' profits by 35% (Table A3), so firms would prefer the secondary market to be inactive.

C 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 allocative 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 33% if the secondary markets are opened from $k = 8$ to $k = 0$. The magnitude of the decrease is slightly smaller, however, than the one obtained when the population is only approximated with two consumer types (which corresponds to a 35% decrease in profits). These results show the implication of having to simplify the distribution of types to keep the state space tractable, which may be an undervaluation of the allocative benefits of the secondary market.

D Persistent heterogeneity

The allocative gains of secondary markets depend positively on the underlying persistent heterogeneity in the population of consumers as they enhance the allocative gains from segmenting the heterogeneous consumers. At the same time, as we discussed in the main text, changes in the persistence of consumer preferences affect the magnitude of substitution possibilities even when the secondary market is closed, and thus affect the gains from closing the secondary market. 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 first panel of Table A7, we eliminate persistent consumer heterogeneity by setting both γ_1 and γ_2 equal at 1.7. We see that opening secondary markets (by reducing k from 8 to 0) decreases profits by a 43%, which is larger than the 35% decrease in the baseline case. In contrast, when we increase the persistent consumer heterogeneity by holding γ_1 fixed at the calibrated value of 1.7 and increasing γ_2 from the calibrated value of 2.28 to 3 (the third panel of Table A7), we find that profits decrease by a smaller 23% if we open the secondary market. That is, with more heterogeneity, the gains from opening the secondary market increase.

E 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 1 has a lower γ (marginal utility of money) than type 2. Therefore, type 1 consumers receive higher values from both new and used cars (in monetary terms, converted from utilities using γ) than type 2 consumers.

Here we consider an alternative specification of the per-period utilities of new and used cars by making them consumer type dependent. Suppose type 1 consumers are new car lovers whose valuation of a car quickly drops when the car gets older. In contrast, type 2 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 $\alpha_{2,2}$, the per-period utility of used cars for type II consumers, from 0.8 to 1.4, while holding the other utilities ($\alpha_{1,1}$, $\alpha_{1,2}$, and $\alpha_{2,1}$, defined analogously) fixed at their baseline values, 1.67, 1.67, and 0.8, respectively. In this specification, for type 1 consumers, a car's utility drops by 52% from 1.67 to 0.8 when it changes from new to old, whereas for type II consumers, the utility drops by only 16% from 1.67 to 1.4. Moreover, when the γ's are taken into account, type 1 consumers get a higher value from a new car than type 2 consumers ($\alpha_{1,1}/\gamma_1 = 0.98$ for type 1, compared to $\alpha_{1,2}/\gamma_2 = 0.73$ for type 2), whereas type 2 consumers get a higher value from a used car than type 1 consumers ($\alpha_{2,2}/\gamma_2 = 0.61$ for type 2, compared to $\alpha_{2,1}/\gamma_1 = 0.47$ for type 1). In this case, on the one hand, because the two types of consumers have more divergent tastes, the secondary market is expected to play a more active allocative role and be more beneficial (or less detrimental) to new car producers. On the other hand, since the quality differential between new cars and used cars becomes smaller for half of the consumers, the negative substitution effect of the secondary market is expected to strengthen, creating a larger positive effect from closing the secondary market. The overall effect is thus ambiguous.

The third 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 34%, which is slightly smaller than the 35% decrease in the original specification (reported in the second panel). This result shows that comparing the alternative specification to the baseline, overall the increase in the allocative benefits slightly outweighs the increase in the substitution effect. In the first panel in Table A8, we consider an opposite scenario, in which $\alpha_{2,2}$ is decreased to 0.4. In this case, opening the secondary market decreases firms' profits by a larger percentage, 39%.

F Monopoly

We replicate our main counterfactual experiments for the case of a monopolist. The counterparts are Table A9 for the full commitment counterfactual in the second panel of Table 5, Table A10 for the durability counterfactual in Table 8, and Table A11 for the time-varying variance counterfactual in Table 6.

Consistent with the findings from the corresponding tables in the paper, Tables A9-A11 show that firms' ability to commit, less product durability, or smaller variance of taste shocks makes secondary markets more beneficial (less harmful) to the firms. These results show that the general findings that we obtain from the oligopoly baseline carry over to the case with monopoly, suggesting robustness of our findings.

G Leasing equilibrium

Here we consider the case in which firms lease, instead of sell, new and used cars. In this setting, consumers are static; firms are also static as long as each firm leases no more than x_n/δ used cars, where x_n is the new car production by firm n in each period, and δ is the death rate of used cars.

We solve a static problem in which firm n's objective is $\max_{\{x_n,y_n\}}(p_1 - c)x_n + (p_2 - k)y_n$, where y_n is the quantity of used cars leased by firm n, c is new cars' (constant) marginal costs, k is used cars' "transaction costs" (the costs of servicing a used vehicle for one year of use), and p_1 and p_2 (new and used leasing prices, respectively) depend on $(x_n, y_n, x_{-n}, y_{-n})$ according to the market-clearing conditions based on consumers' static logit choice probabilities. We solve for a symmetric Nash equilibrium (x^*, y^*), then verify if the condition $y^* \leq x^*/\delta$ is met. The results are presented in Table A12. Using the calibrated parametrization from the baseline, we find that each firm indeed leases fewer than x^*/δ used cars and scraps the balance.

In some specifications, lease contracts may be the mechanism to implement the full commitment solution as the solution to these two problems may be the same. However, as shown in Hendel and Lizzeri (1999), the problems of a firm that leases durable goods and a time inconsistent firm that sells them may not have the same solutions since, in the former, the firm has one more degree of freedom: by recovering the ownership of used cars, the firm can scrap part of the stock if doing so increases its profits. As shown in the leasing equilibrium results, the firm effectively uses scrappage to control the stock, obtaining an additional significant gain in profits. Furthermore, comparing the leasing equilibrium to the baseline (sales without commitment), we find that the leasing equilibrium results in lower new car production, more consumers who own no cars, lower consumer surplus, and much higher profits for the firms.

H Matching non-ownership moments

Here we conduct an alternative calibration which tries to also match the non-ownership moments. In the baseline of the paper, we fix δ at 0.11 to match the observed expected lifetime of a vehicle. In this new calibration, we take an alternative approach and fix δ at 0.095 to match the observed aggregate non-ownership: $\delta = 0.095$ satisfies non-ownership = 1-D_1-D_1/δ (where D_1 is the measure of consumers who purchase new cars), using U.S. data averages. In the new calibration, we add two extra moments to match: percentage of Type 1 consumers who do not own cars, and percentage of Type 2 consumers who do not own cars. Table A13 reports the calibrated parameter values and Table A14 the steady-state values at the calibrated parameters together with the U.S. data averages. As shown in the latter table, the main trade-off is given by the (slightly) worse fit in the fraction of each consumer type owning a used car. Table A15 reports the main counterfactual experiment for the new calibrated parameter values. Although there are small quantitative differences, the findings are consistent with our previous results. If before profits decrease by 35% (0.005 in absolute value) when opening secondary markets, now they decrease by 40% (0.006).

VI Non-monotonicity in results as transaction costs increase

In some of the counterfactual results, we see that firms' profits and new car price can be non-monotonic as we increase the transaction cost k from 0 to 8. The reason for such non-monotonicity lies in the fact that there are countervailing forces at play, and so the relationship between an outcome variable (such as profits or prices) and the transaction cost depends on the net effect of the countervailing forces and hence can change signs as we move to different ranges of k.

An illustration of such non-monotonicity is given by Figure A6, which shows profit per firm for all the (δ, k) combinations with $\delta \in 0.05, 0.07, \ldots, 0.25$ and $k \in 0, 0.5, \ldots, 8$. The figure shows that for low levels of k (roughly, $k < 1.5$), profit per firm increases with k

if δ is small, but decreases with k if δ is large. As a result, for large δ, we observe non-monotonicity in profit as we increase k. Such non-monotonicity conforms to our intuitions and suggests that the countervailing forces need to be taken into consideration in order to correctly understand how transaction costs affect the market outcome.

VII Volatility in new car price vs. in used car price

In some of the counterfactual results, such as those reported on Tables 6 and 8, we see that as we vary the key parameters (such as $Var(\epsilon)$ or δ), used car prices at $k = 0$ are highly volatile across the three specifications, whereas new car prices at $k = 0$ are relatively stable. The reason is that when there is a triopoly, firms' markups are constrained by the oligopolistic competition among firms, so new car prices are relatively stable across the specifications, leaving used car prices to change substantially to adjust for the changes in the parameter values.[6] In contrast, when there is monopoly, we see that the changes in new car prices become more significant while changes in used car prices become less significant.

Table A16 reports such comparisons for the counterfactuals involving varying δ and $Var(\epsilon)$, respectively. The top panel shows that when we increase δ from 0.05 to 0.25, in the case with a triopoly, at $k = 0$ new car price changes by 9%, whereas used car price changes by a much larger 614%. In contrast, in the case with a monopoly, at $k = 0$ new car price changes by -23%, whereas used car price changes by -24%, so the volatility in new car price is roughly the same as that in used car price.

Similarly, the bottom panel shows that when we increase $Var(\epsilon)$ from $3/4 \times \pi^2/6$ to $5/4 \times \pi^2/6$, at $k = 0$ new car price changes by 6%, whereas used car price changes by a larger percentage at -17%. In contrast, in the case with a monopoly, at $k = 0$ new car price changes by 13%, whereas used car price changes by a smaller 9%. These comparisons are

[6] In the primary market, firm are strategic players. When there is more than one firm, the firms compete against each other, which constrains their markups.

consistent with our intuitions that the concentration in the primary market affects the relative volatility of new car price and used car price.

References

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Table A1. Calibrated parameters: Proportional transaction costs

New car product-characteristics index (α_1)	1.80
Used car product-characteristics index (α_2)	0.81
Type 1 consumers' marginal utility of money (γ_1)	1.80
Type 2 consumers' marginal utility of money (γ_2)	2.38
Marginal cost (c), $10,000	1.90
Transaction cost (k : % of used car price)[a]	46%

[a] Transaction cost at the steady state is equivalent to 0.42 ($4,200).

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	9.69	9.8
who purchase used cars	17.77	18.7
% of Type 2 consumers:[c]		
who purchase new cars	4.20	4.2
who purchase used cars	19.32	18.6
New vehicle price ($10,000)	2.30	2.3
Used vehicle price ($10,000)	0.90	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. Opening secondary market: Proportional transaction costs

Variable	Transaction cost k (% of used car price)*			
	100%	95%	46%	0%
Transaction costs are proportional to the used car price				
New car production per firm[a]	0.046	0.026	0.023	0.021
Used car transactions	0.00	0.08	0.19	0.24
New car price ($10,000)	2.21	2.28	2.30	2.32
Used car price ($10,000)[b]	--	1.48	0.90	0.68
Transaction cost ($10,000)	--	1.41	0.42	0.00
Used car scrappage	0.06	0.00	0.00	0.00
Consumers who own no cars	0.19	0.22	0.30	0.35
Consumer surplus ($10,000)[d]	0.30	0.35	0.48	0.57
Profits per firm ($10,000)	0.014	0.010	0.009	0.009 (-0.005, -35%)[c]

* The calibrated transaction cost is k = 46%.

[a] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars are all measured against the consumer population, which is normalized to one.

[b] When k = 100%, used car price is numerically indeterminate.

[c] First number in parenthesis: change in profits from k = 100% to k = 0%; second number in parenthesis: percentage change in profits from k = 100% 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)	1.63
Used car product-characteristics index (α_2)	0.73
Type 1 consumers' marginal utility of money (γ_1)	1.66
Type 2 consumers' marginal utility of money (γ_2)	1.99
Type 3 consumers' marginal utility of money (γ_3)	2.40
Marginal cost (c), $10,000	1.90
Transaction cost (k), $10,000	0.46

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	10.31	10.4
who purchase used cars	17.49	17.9
% of Type 2 consumers:[c]		
who purchase new cars	6.52	6.6
who purchase used cars	18.59	21.1
% of Type 3 consumers:[d]		
who purchase new cars	3.60	3.6
who purchase used cars	19.16	17.4
New vehicle price ($10,000)	2.29	2.3
Used vehicle price ($10,000)	0.90	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. Opening secondary market: Three types of consumers

Variable	Transaction cost k ($10,000)*			
	8	2	0.46	0
Three types of consumers, $\gamma_1 = 1.66$, $\gamma_2 = 1.99$, $\gamma_3 = 2.40$[a]				
New car production per firm[b]	0.047	0.039	0.023	0.021
Used car transactions	0.00	0.04	0.18	0.24
New car price ($10,000)	2.20	2.14	2.29	2.34
Used car price ($10,000)[c]	8.00	2.00	0.90	0.68
Used car scrappage	0.07	0.04	0.00	0.00
Consumers who own no cars	0.22	0.22	0.31	0.36
Consumer surplus ($10,000)[e]	0.29	0.32	0.47	0.56
Profits per firm ($10,000)	0.014	0.010	0.009	0.009 (-0.005, -33%)[d]

* The calibrated transaction cost is $k = 0.46$.
[a] γ_1, γ_2, and γ_3 are type 1, type 2, and type 3 consumers' marginal utility of money, respectively.
[b] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from $k = 8$ to $k = 0$; second number in parenthesis: 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 opening secondary market: Assessing persistent consumer heterogeneity

Variable	Transaction cost *k* ($10,000)*			
	8	2	0.44	0
Less heterogeneity: γ_1 = 1.7, γ_2 = 1.7[a]				
New car production per firm[b]	0.053	0.045	0.023	0.022
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.28	2.19	2.36	2.43
Used car price ($10,000)[c]	8.00	2.00	0.76	0.57
Used car scrappage	0.09	0.06	0.00	0.00
Consumers who own no cars	0.19	0.19	0.30	0.35
Consumer surplus ($10,000)[e]	0.40	0.45	0.61	0.70
Profits per firm ($10,000)	0.020	0.013	0.011	0.011 (-0.009, -43%)[d]
Baseline: γ_1 = 1.7, γ_2 = 2.28				
New car production per firm[b]	0.046	0.038	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.22	2.16	2.30	2.35
Used car price ($10,000)[c]	8.00	2.00	0.90	0.69
Used car scrappage	0.07	0.04	0.00	0.00
Consumers who own no cars	0.20	0.20	0.30	0.35
Consumer surplus ($10,000)[e]	0.32	0.35	0.50	0.60
Profits per firm ($10,000)	0.015	0.010	0.009	0.010 (-0.005, -35%)[d]
More heterogeneity: γ_1 = 1.7, γ_2 = 3				
New car production per firm[b]	0.043	0.035	0.023	0.021
Used car transactions	0.00	0.03	0.18	0.24
New car price ($10,000)	2.17	2.13	2.26	2.31
Used car price ($10,000)[c]	8.00	2.00	0.99	0.76
Used car scrappage	0.06	0.03	0.00	0.00
Consumers who own no cars	0.23	0.22	0.31	0.36
Consumer surplus ($10,000)[e]	0.27	0.30	0.44	0.53
Profits per firm ($10,000)	0.011	0.008	0.008	0.009 (-0.003, -23%)[d]

* The calibrated transaction cost is k = 0.44.

[a] γ_1 and γ_2 are type 1 and type 2 consumers' marginal utility of money, respectively.

[b] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from k = 8 to k = 0; second number in parenthesis: 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 2 consumers

Variable	Transaction cost *k* ($10,000)*			
	8	2	0.44	0
$\alpha_{2,2}$ = 0.4[a]				
New car production per firm[b]	0.047	0.041	0.021	0.020
Used car transactions	0.00	0.03	0.19	0.25
New car price ($10,000)	2.18	2.14	2.24	2.31
Used car price ($10,000)[c]	8.00	2.00	0.76	0.58
Used car scrappage	0.08	0.06	0.00	0.00
Consumers who own no cars	0.31	0.30	0.36	0.39
Consumer surplus ($10,000)[e]	0.27	0.30	0.46	0.55
Profits per firm ($10,000)	0.013	0.010	0.007	0.008 (-0.005, -39%)[d]
Baseline: $\alpha_{2,2}$ = 0.8				
New car production per firm[b]	0.046	0.038	0.023	0.021
Used car transactions	0.00	0.04	0.19	0.24
New car price ($10,000)	2.22	2.16	2.30	2.35
Used car price ($10,000)[c]	8.00	2.00	0.90	0.69
Used car scrappage	0.07	0.04	0.00	0.00
Consumers who own no cars	0.20	0.20	0.30	0.35
Consumer surplus ($10,000)[e]	0.32	0.35	0.50	0.60
Profits per firm ($10,000)	0.015	0.010	0.009	0.010 (-0.005, -35%)[d]
$\alpha_{2,2}$ = 1.4				
New car production per firm[b]	0.044	0.032	0.025	0.024
Used car transactions	0.00	0.05	0.17	0.22
New car price ($10,000)	2.29	2.26	2.34	2.37
Used car price ($10,000)[c]	8.00	2.00	1.06	0.81
Used car scrappage	0.05	0.01	0.00	0.00
Consumers who own no cars	0.13	0.13	0.23	0.28
Consumer surplus ($10,000)[e]	0.41	0.45	0.60	0.68
Profits per firm ($10,000)	0.017	0.011	0.011	0.011 (-0.006, -34%)[d]

* The calibrated transaction cost is k = 0.44.
[a] $\alpha_{2,2}$ is the used car product-characteristics index for type 2 consumers. $\alpha_{1,1}$, $\alpha_{1,2}$, and $\alpha_{2,1}$ are defined analogously and are fixed at their baseline values, 1.67, 1.67, and 0.80, respectively.
[b] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from k = 8 to k = 0; second number in parenthesis: percentage change in profits from k = 8 to k = 0.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table A9. No commitment vs. full commitment, with monopoly

Variable	Transaction cost k ($10,000)*			
	8	2	0.44	0
No commitment				
New car production per firm[a]	0.085	0.066	0.057	0.053
Used car transactions	0.00	0.06	0.20	0.25
New car price ($10,000)	3.31	3.50	4.07	4.54
Used car price ($10,000)[b]	8.00	2.80	2.46	2.65
Used car scrappage	0.02	0.00	0.00	0.00
Consumers who own no cars	0.29	0.33	0.43	0.46
Consumer surplus ($10,000)[d]	0.20	0.24	0.38	0.45
Profits per firm ($10,000)	0.120	0.106	0.123	0.141 (+0.021, +18%)[c]
Full commitment				
New car production per firm[a]	0.079	0.061	0.050	0.045
Used car transactions	0.00	0.06	0.19	0.24
New car price ($10,000)	3.50	3.84	4.76	5.80
Used car price ($10,000)[b]	8.00	3.07	3.06	3.79
Used car scrappage	0.01	0.00	0.00	0.00
Consumers who own no cars	0.32	0.38	0.49	0.55
Consumer surplus ($10,000)[d]	0.18	0.21	0.33	0.38
Profits per firm ($10,000)	0.127	0.118	0.143	0.174 (+0.048, +38%)[c]

* The calibrated transaction cost is k = 0.44.

[a] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from k = 8 to k = 0; second number in parenthesis: percentage change in profits from k = 8 to k = 0.

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

Table A10. Opening secondary market: Assessing durability, with monopoly

Variable	Transaction cost *k* ($10,000)*			
	8	2	0.44	0
More durability: δ = 0.05[a]				
New car production per firm[b]	0.045	0.038	0.031	0.028
Used car transactions	0.00	0.05	0.19	0.25
New car price ($10,000)	4.14	4.23	4.61	5.09
Used car price ($10,000)[c]	8.01	3.35	2.72	2.92
Used car scrappage	0.00	0.00	0.00	0.00
Consumers who own no cars	0.13	0.21	0.36	0.41
Consumer surplus ($10,000)[e]	0.26	0.30	0.44	0.51
Profits per firm ($10,000)	0.101	0.088	0.083	0.090 (-0.011, -11%)[d]
Baseline: δ = 0.11				
New car production per firm[b]	0.085	0.066	0.057	0.053
Used car transactions	0.00	0.06	0.20	0.25
New car price ($10,000)	3.31	3.50	4.07	4.54
Used car price ($10,000)[c]	8.00	2.80	2.46	2.65
Used car scrappage	0.02	0.00	0.00	0.00
Consumers who own no cars	0.29	0.33	0.43	0.46
Consumer surplus ($10,000)[e]	0.20	0.24	0.38	0.45
Profits per firm ($10,000)	0.120	0.106	0.123	0.141 (+0.021, +18%)[d]
Less durability: δ = 0.25				
New car production per firm[b]	0.117	0.088	0.089	0.089
Used car transactions	0.00	0.06	0.18	0.23
New car price ($10,000)	2.83	3.04	3.58	3.93
Used car price ($10,000)[c]	8.00	2.42	2.13	2.23
Used car scrappage	0.03	0.00	0.00	0.00
Consumers who own no cars	0.55	0.56	0.56	0.55
Consumer surplus ($10,000)[e]	0.13	0.16	0.29	0.34
Profits per firm ($10,000)	0.108	0.099	0.148	0.181 (+0.073, +68%)[d]

* The calibrated transaction cost is k = 0.44.

[a] δ is the probability of used car depreciation.

[b] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from k = 8 to k = 0; second number in parenthesis: percentage change in profits from k = 8 to k = 0.

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

Table A11. Opening secondary market: Assessing variance of taste shocks, with monopoly

Variable	Transaction cost *k* ($10,000)*			
	8	2	0.44	0
Smaller variance: Var(ε) = 3/4*π^2/6[a]				
New car production per firm[b]	0.082	0.070	0.059	0.055
Used car transactions	0.00	0.05	0.19	0.25
New car price ($10,000)	3.22	3.33	3.80	4.25
Used car price ($10,000)[c]	8.00	2.80	2.36	2.53
Used car scrappage	0.01	0.00	0.00	0.00
Consumers who own no cars	0.27	0.30	0.41	0.45
Consumer surplus ($10,000)[e]	0.19	0.22	0.34	0.40
Profits per firm ($10,000)	0.108	0.100	0.111	0.128 (+0.020, +19%)[d]
Baseline: Var(ε) = π^2/6				
New car production per firm[b]	0.085	0.066	0.057	0.053
Used car transactions	0.00	0.06	0.20	0.25
New car price ($10,000)	3.31	3.50	4.07	4.54
Used car price ($10,000)[c]	8.00	2.80	2.46	2.65
Used car scrappage	0.02	0.00	0.00	0.00
Consumers who own no cars	0.29	0.33	0.43	0.46
Consumer surplus ($10,000)[e]	0.20	0.24	0.38	0.45
Profits per firm ($10,000)	0.120	0.106	0.123	0.141 (+0.021, +18%)[d]
Larger variance: Var(ε) = 5/4*π^2/6				
New car production per firm[b]	0.090	0.064	0.055	0.053
Used car transactions	0.00	0.07	0.20	0.25
New car price ($10,000)	3.37	3.65	4.31	4.80
Used car price ($10,000)[c]	8.00	2.81	2.55	2.77
Used car scrappage	0.02	0.00	0.00	0.00
Consumers who own no cars	0.31	0.35	0.44	0.47
Consumer surplus ($10,000)[e]	0.21	0.26	0.41	0.48
Profits per firm ($10,000)	0.132	0.112	0.133	0.152 (+0.020, +15%)[d]

* The calibrated transaction cost is k = 0.44.
[a] ε is a consumer's idiosyncratic taste shock.
[b] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from k = 8 to k = 0; second number in parenthesis: percentage change in profits from k = 8 to k = 0.
[e] Consumers' utilities are converted to monetary terms using their respective γ's.

Table A12. Baseline vs. leasing equilibrium

Baseline: Transaction cost of a used car = 0.44 (×$10,000)	
New car production per firm[a]	0.023
Used car transactions	0.19
New car price ($10,000)	2.30
Used car price ($10,000)	0.90
Used car scrappage by consumers	0.00
Consumers who own no cars	0.30
Consumer surplus ($10,000)[b]	0.50
Profits per firm ($10,000)	0.009
Leasing equilibrium: Cost of servicing a used car for one year = 0.44 (×$10,000)	
New car lease per firm[a]	0.016
Implicit capitalized price for a new car	6.97
Used car lease per firm	0.11
Implicit capitalized price for a used car	4.97
New car price ($10,000)	2.20
Used car price ($10,000)	0.72
Used car scrappage by firms	0.03
Consumers who own no cars	0.62
Consumer surplus ($10,000)[b]	0.26
Profits per firm ($10,000)	0.035

[a] New/used car production per firm, new/used car lease per firm, used car scrappage, and consumers who own no cars are all measured against the consumer population, which is normalized to one.
[b] Consumers' utilities are converted to monetary terms using their respective γ's.

Table A13. Calibrated parameters: Matching non-ownership moments[a]

New car product-characteristics index (α_1)	2.29
Used car product-characteristics index (α_2)	1.18
Type 1 consumers' marginal utility of money (γ_1)	1.89
Type 2 consumers' marginal utility of money (γ_2)	2.49
Marginal cost (c), $10,000	1.90
Transaction cost (k), $10,000	0.46

[a] δ, the probability of used car depreciation, is fixed at 0.095 to match the observed aggregate non-ownership: $\delta = 0.095$ satisfies non-ownership = $1 - D_1 - D_1/\delta$ (where D_1 is the measure of consumers who purchase new cars), using U.S. data averages.

Table A14. Steady-state values at calibrated parameters and U.S. data averages: Matching non-ownership moments

	Model steady-state values	U.S. data averages (1994-2003)[a]
% of Type 1 consumers:[b]		
who purchase new cars	9.98	9.8
who purchase used cars	14.57	18.7
who do not own cars	18.69	13.4
% of Type 2 consumers:[c]		
who purchase new cars	4.20	4.2
who purchase used cars	15.81	18.6
who do not own cars	18.87	26.0
New vehicle price ($10,000)	2.27	2.3
Used vehicle price ($10,000)	0.91	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 A15. Opening secondary market: Matching non-ownership moments

Variable	Transaction cost k ($10,000)*			
	8	2	0.46	0
New car production per firm[a]	0.040	0.033	0.024	0.022
Used car transactions	0.00	0.03	0.15	0.22
New car price ($10,000)	2.27	2.24	2.27	2.31
Used car price ($10,000)[b]	8.00	2.00	0.91	0.62
Used car scrappage	0.04	0.02	0.00	0.00
Consumers who own no cars	0.09	0.10	0.19	0.25
Consumer surplus ($10,000)[d]	0.44	0.46	0.58	0.66
Profits per firm ($10,000)	0.015	0.011	0.009	0.009 (-0.006, -40%)[c]

* The calibrated transaction cost is k = 0.46.

[a] New car production per firm, used car transactions, used car scrappage, and consumers who own no cars 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] First number in parenthesis: change in profits from k = 8 to k = 0; second number in parenthesis: percentage change in profits from k = 8 to k = 0.

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

Table A16. New car price and used car price at *k* = 0: Triopoly vs. monopoly

	Triopoly	Monopoly
Counterfactuals: Durability. Prices at *k* = 0:		
New car price ($10,000) when δ = 0.05	2.15	5.09
New car price ($10,000) when δ = 0.25	2.36	3.93
Percentage change in new car price from δ = 0.05 to δ = 0.25	9%	-23%
Used car price ($10,000) when δ = 0.05	0.14	2.92
Used car price ($10,000) when δ = 0.25	0.97	2.23
Percentage change in used car price from δ = 0.05 to δ = 0.25	614%	-24%
Counterfactuals: Variance of taste shocks. Prices at *k* = 0:		
New car price ($10,000) when Var(ε) = $3/4*\pi^2/6$	2.28	4.25
New car price ($10,000) when Var(ε) = $5/4*\pi^2/6$	2.42	4.80
Percentage change in new car price from Var(ε) = $3/4*\pi^2/6$ to Var(ε) = $5/4*\pi^2/6$	6%	13%
Used car price ($10,000) when Var(ε) = $3/4*\pi^2/6$	0.76	2.53
Used car price ($10,000) when Var(ε) = $5/4*\pi^2/6$	0.63	2.77
Percentage change in used car price from Var(ε) = $3/4*\pi^2/6$ to Var(ε) = $5/4*\pi^2/6$	-17%	9%

Figure A1. Firms' policy (production) function

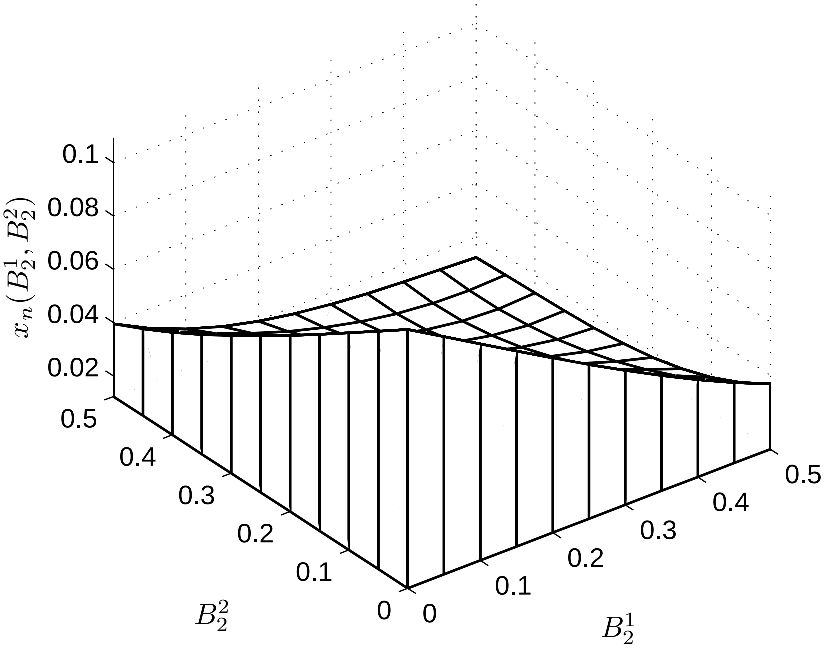
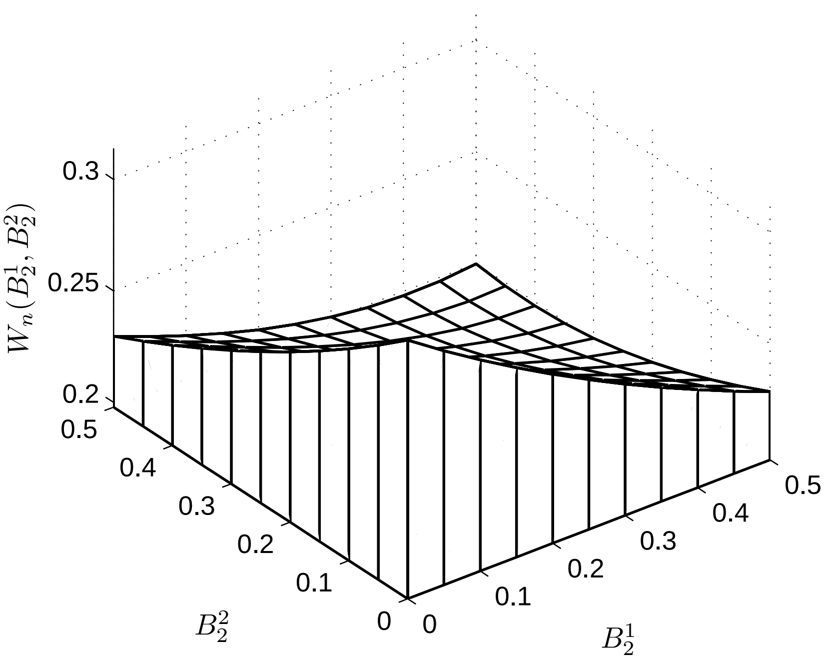


Figure A2. Firms' value function



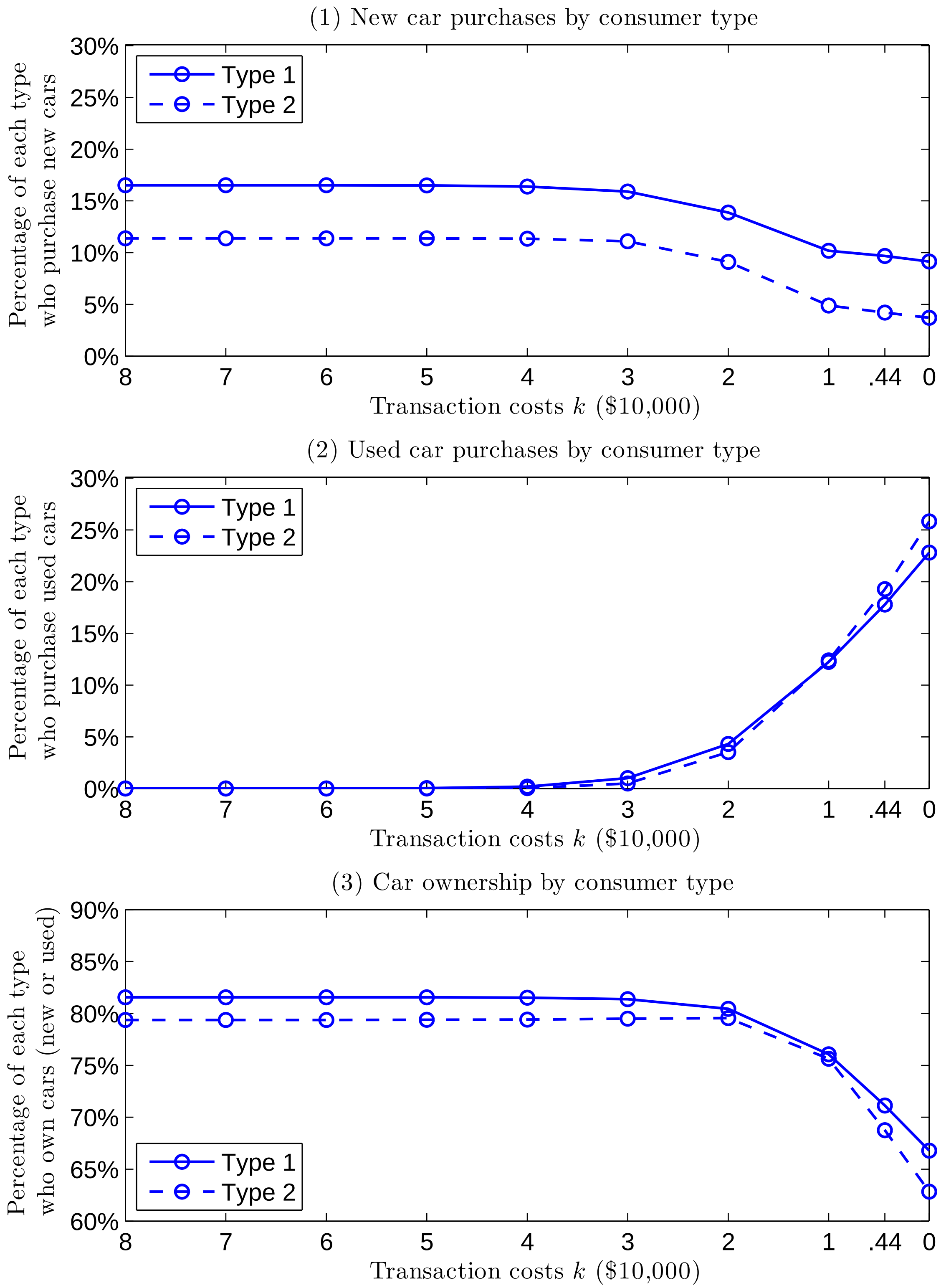


Figure A3. Opening secondary market in the calibrated model:
Car purchases and car ownership by consumer type.
Each type corresponds to 50% of the population.

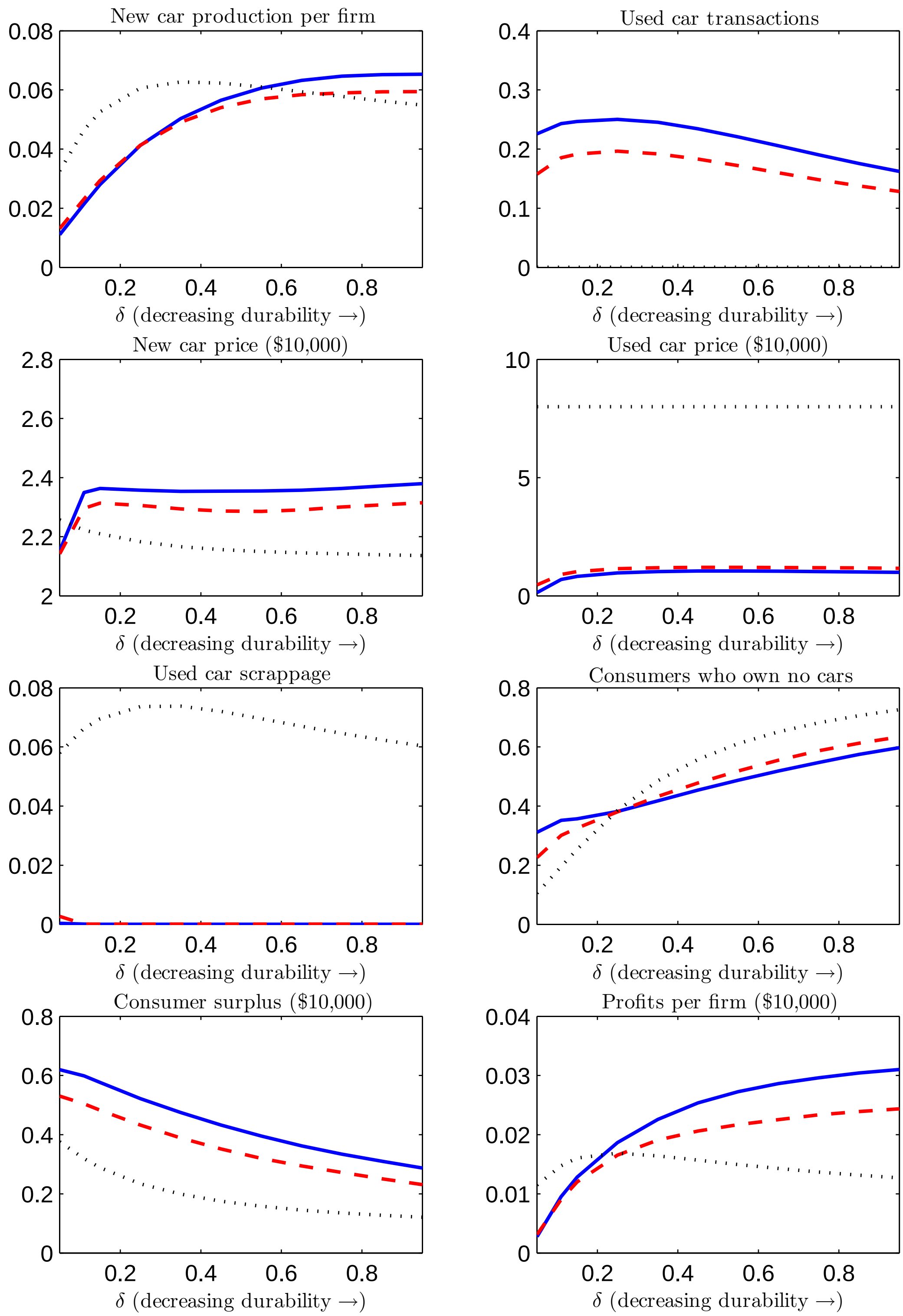


Figure A4. Assessing durability. $\delta = 0.05, 0.11, 0.15, 0.25, ..., 0.95$
Solid lines: frictionless secondary market ($k = 0$). Dashed lines: calibrated secondary market ($k = 0.44$). Dotted lines: closed secondary market ($k = 8$).

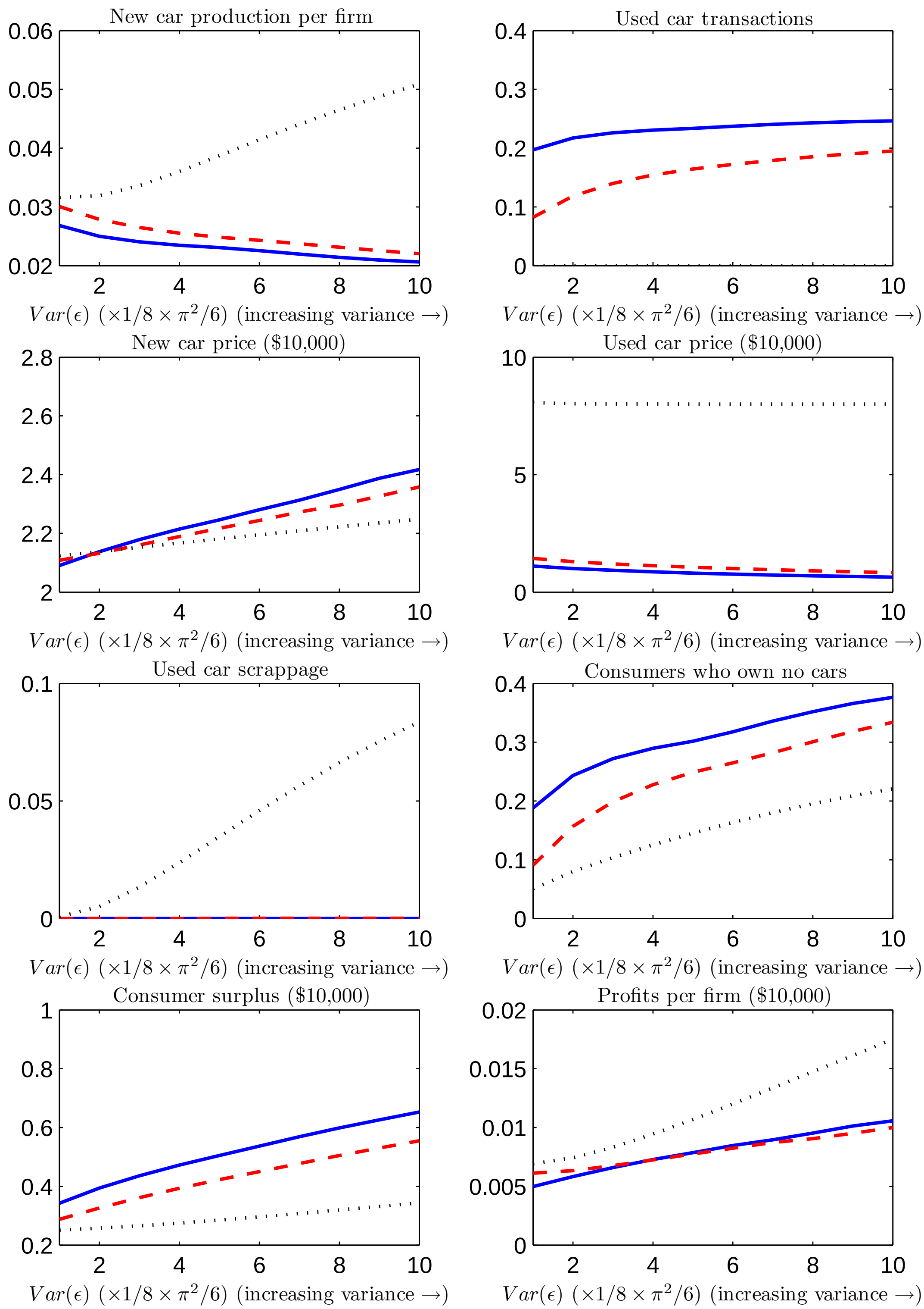


Figure A5. Assessing variance of taste shocks. $Var(\epsilon) = 1, 2, ..., 10$ $(\times 1/8 \times \pi^2/6)$ Solid lines: frictionless secondary market ($k = 0$). Dashed lines: calibrated secondary market ($k = 0.44$). Dotted lines: closed secondary market ($k = 8$).

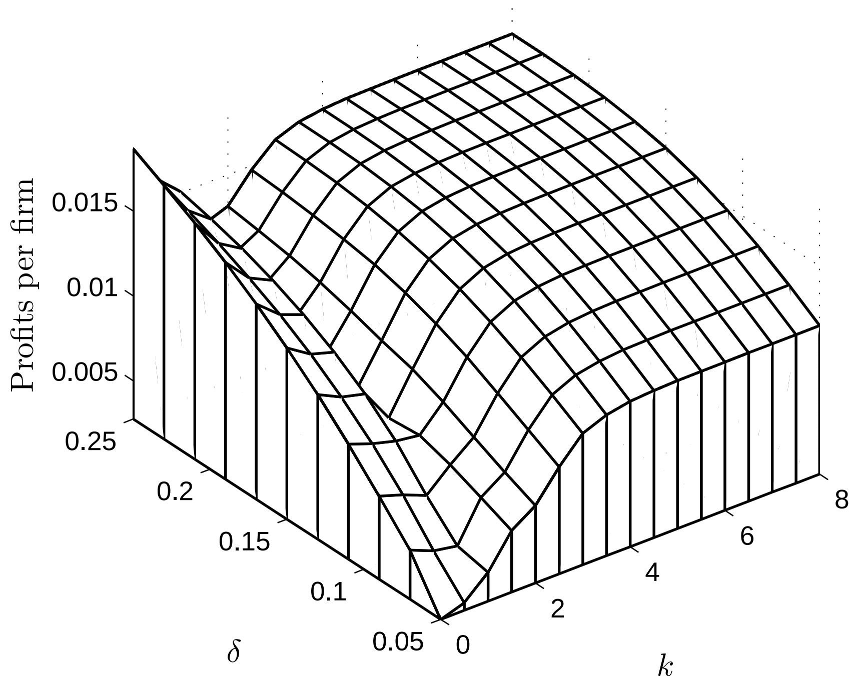


Figure A6: Profits per firm for different combinations of (δ,k).