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Electronic Companion—"An Empirical Analysis of Scarcity Strategies in the Automobile Industry" by Subramanian Balachander, Yan Liu, and Axel Stock, *Management Science*, DOI 10.1287/mnsc.1090.1056.

APPENDIX A

In order to extend the analysis of DeGraba's (1995) two-period model to the post-introductory stage, we consider a similar two-period model for the post-introductory stage with the exception that consumers know their valuations (are fully informed of the product) in period 1 of this post-introductory stage. Thus, we can imagine that these two periods of the post-introductory stage begin at the end of period 2 in DeGraba's model with a new set of consumers who have entered the market. We use the same notation as in DeGraba (1995): there are n consumers, h of whom are of a high type with a high valuation V_H for the product, while the remaining n-h consumers are of a low type with a low valuation V_L ($V_H > V_L$) for the product, and M being the marginal cost of the product to the firm. As in DeGraba, consumers and the firm have a discount factor of 1. Finally, we assume that the firm can produce any desired quantity every period. In the remainder of the discussion, any reference to a particular period pertains to the post-introductory stage unless explicitly mentioned otherwise. Then, under the conditions that support a buying frenzy equilibrium accompanied by rationing (Proposition 1 of DeGraba (1995)), Proposition A.1 below derives the sub-game perfect equilibrium.

<u>Proposition A.1</u>: Assume that condition (1) in DeGraba (1995) applies so that [1]

$$n(V_L - M) > h(V_H - M) \qquad \text{(A.1)}$$

Then, in the unique subgame perfect equilibrium, consumers of both types buy in the first period if and only if the price $P_1 \leq V_L$. Moreover, in this equilibrium, the firm charges V_L in the first period and all consumers buy and exit the market.

<u>Proof</u>: Consider first the second-period equilibrium if all consumers have delayed purchase. Then, because of (A.1), the firm prices at V_L and produces enough to sell to all consumers. If only high or low consumers remain in the second period, the firm's price will be V_H and V_L respectively. Now consider the first-period equilibrium. The only price that consumers of both types will be willing to pay to buy in this period is V_L. This is trivially true for low consumers. Suppose, to the contrary, that high consumers are

[1] See footnote 8 in DeGraba (1995).

willing to buy at a price P_1 in the first period such that $V_L < P_1 \leq V_H$. Then, a high consumer can deviate and derive a higher surplus by delaying purchase. Thus, it is an equilibrium strategy for both types of consumers to be willing to pay no more than V_L in the first period. It is also an equilibrium strategy for the firm to charge V_L in the first period and sell to all consumers.[2] *Q. E. D.*

The above proposition shows that the unique equilibrium in the post-introductory stage of DeGraba's model involves the firm charging a price of V_L in the first period of the post-introductory stage and all consumers purchasing (cf. the market-clearing equilibrium in DeGraba (1995)). More importantly, the proposition shows that both high and low types are willing to pay no more than V_L in period 1 of the post-introductory stage of the game. In contrast, they are both willing to pay $(h/n)V_H + (n\text{-}h)V_L/n > V_L$ in period 1 of the introductory stage when there is scarcity and when they do not know their valuations for the product. This establishes hypothesis H_{2b}. The intuition for why high types are willing to pay lower than their valuations (V_H) in the post-introductory stage is their realization that the firm makes more money by selling to all consumers at V_L than by selling only to the high consumers at V_H. Thus, the high types can successfully resist any attempt to skim them with a higher price by delaying purchase.

[2] Note that producing less than h in order to credibly suggest that the second-period price will be V_H is not profitable for the firm because of condition (A.1) - see also footnote 8, p. 335 in DeGraba on this point.

APPENDIX B

In this section we demonstrate the basis of our specification of the pricing equation (equation (13) in the paper) using the concept of virtual marginal cost to account for signaling. We do so using the following steps. First, we show that the signaling price for a high quality product is distorted upwards from its full information level when the marginal cost for a high-quality product is greater than that of a low-quality product. Second, we demonstrate that the best-response price for a high-quality product under full information is increasing in its cost. Taken together, these two results establish that any signaling price can be expressed as the best-response price under full information plus a virtual marginal cost, as specified in equation (13) in the paper.

Assume that consumers are uncertain about the quality of a new car model *j* and believe it can be either high (*H*) (or low (*L*) – we refer to these two quality possibilities as "types" for the new car model. We assume that consumers' prior beliefs are that the probability of the car model's quality being high is ρ. Denote the firm's profit in the introductory period of a new car model *j* as $\Pi(p_j^i, \pi_j^i, q_b, q_a, p_{j-})$, where q_b and q_a are respectively the perceived and true quality of the car model, p_j^i and π_j^i are the introductory price and probability of availability (inversely related to scarcity) respectively of the new model, and p_{j-} is the vector of prices of other models sold by the firm in the introductory period. Note that q_b indicates consumers' posterior beliefs after they observe some signal from the firm such as the price and scarcity of the new car model. Thus, $\Pi(p_j^i, \pi_j^i, H, L, p_{j-})$ would indicate the profit of car model *j* with a true quality of *L* when consumers believe its quality to be *H*. In the rest of the presentation, for simplicity, we omit the reference to p_{j-} in the notation for the firm's profit.

Let p_{jH}^{i*} and p_{jL}^{i*} denote respectively the optimal (best-response) introductory prices for the high and low type of new car model *j* under full information, i.e. when consumers know the true quality of the car model. Note also that under full information, there is no need for the firm to artificially induce scarcity (see also Stock and Balachander 2005). Thus, the optimal prices under full information are the best-response prices given by equation (10) in the paper. Then, with π_j^i = 1, $\Pi(p_{jH}^{i*}$, 1, H, H) and $\Pi(p_{jL}^{i*}$,1, L, L) would represent respectively the optimal (best-response) profits for the high- and low-quality types of car models under full information.

In a separating equilibrium, the high-quality and low-quality types of new car model j choose different strategies (prices and scarcity levels) and are thus distinguished by consumers when they observe the introductory strategy of the new car model. Since a low-quality car model's type is thus revealed to consumers in a separating equilibrium, its equilibrium introductory price is the full-information price of p_{jL}^{i*} with no scarcity. Let p_{jH}^i and π_j^i be the introductory price and availability of the high-quality type in the separating equilibrium. A necessary condition for the separating equilibrium is that the low-quality type does not gain by deviating and adopting the strategy of the high-quality type. Thus, we have

$$\Pi(p_{jH}^i, \pi_{jH}^i, H, L) \leq \Pi(p_{jL}^{i*}, 1, L, L) \tag{A.1}$$

The expression on the left-hand side of the above equation is the profit to the low-quality type from adopting the high-quality type's strategy and thus pretending to be a high-quality car model. The expression on the right-hand side of equation (A.1) is the profit to the low-quality type when revealing its true quality to consumers. When signaling is non-trivial, the high-quality type has to depart from its full-information choice of price and scarcity level to satisfy (A.1). For the high-quality type to use price of the new car model as a signaling device, a standard sorting or single-crossing condition needs to be satisfied for the price variable (see Tirole 1988, p. 369). This sorting condition is as follows:

$$\frac{\partial[\Pi(p_j^i, \pi_j^i, H, H) - \Pi(p_j^i, \pi_j^i, H, L)]}{\partial p_j^i} > 0 \tag{A.2}$$

This condition implies that the high-quality type loses less than the mimicking low- quality type by charging a high price for the new car model. Thus, the high-quality type may signal (i.e. satisfy (A.1)) efficiently by distorting its price upwards thereby charging a price higher than the full-information price (cf. Kalra et. al. 1998). The sorting condition, (A.2), is satisfied, for example, when the marginal cost of a high-quality product is higher than that of a low-quality product. To see this, suppose $c^{'}_{jH}$ and $c^{'}_{jL}$ are the marginal costs of new car model *j* for the high- and low-quality types. Further, let *M* be the market size and let $s_j(\pi^i_j, p^i_j, H)$ denote the market share of car model *j* whose introductory price and availability respectively of p^i_j and π^i_j induces a belief that the new car model is of type *H*. Then, we have

$$\frac{\partial[\Pi(p^i_j,\pi^i_j,H,H)-\Pi(p^i_j,\pi^i_j,H,L)]}{\partial p^i_j}=\frac{\partial[(p^i_j-c^{'}_{jH})s_j(\pi^i_j,p^i_j,H)M-(p^i_j-c^{'}_{jL})s_j(\pi^i_j,p^i_j,H)M]}{\partial p^i_j}$$

$$=(c^{'}_{jL}-c^{'}_{jH})M\frac{\partial s_j(\pi^i_j,p^i_j,H)}{\partial p^i_j}>0$$

Next, we claim that the best-response introductory price of car model *j* under full information is increasing in $c^{'}_{jH}$. Suppose, to the contrary, the full-information best-response price decreases from p^{i*}_{jH} to $p^{i\circ}_{jH}$ when the marginal cost increases from $c^{'}_{jH}$ to c°_{jH}. Let p^{i*}_{jH-} and $p^{i\circ}_{jH-}$ represent the corresponding best-response vectors of prices of other car models owned by the firm introducing car model *j*. With a slight abuse of notation, denote the high-quality type's best-response profit with prices, p^i_{jH} and p^i_{jH-} and marginal cost c_{jH} as $\Pi(p^i_{jH}, p^i_{jH-}, c_{jH})$.[3] Further denote the firms' profits from car models other than model *j* as $\Pi((p^i_{jH-})$, and let s^*_{jH} and s°_{jH} represent the market shares of car model *j* at the best-response prices of p^{i*}_{jH} and $p^{i\circ}_{jH}$ respectively. Because $p^{i\circ}_{jH}$ is the best-response price when the marginal cost is c°_{jH}, we must have $\Pi((p^{i\circ}_{jH}, p^{i\circ}_{jH-}, c^{\circ}_{jH}) > \Pi((p^{i*}_{jH}, p^{i*}_{jH-}, c^{\circ}_{jH})$. This inequality implies the first in the following sequence of inequalities:

[3] Note that since a firm acting optimally does not induce scarcity under full information (Stock and Balachander 2005), we do not consider scarcity decisions under this condition.

$$(p^{i\circ}_{jH} - c^{\circ}_{jH})Ms^{\circ}_{jH} + \Pi(p^{i\circ}_{jH-}) > (p^{i*}_{jH} - c^{\circ}_{jH})Ms^{*}_{jH} + \Pi(p^{i*}_{jH-})$$
$$\Rightarrow (p^{i\circ}_{jH} - c^{'}_{jH})Ms^{\circ}_{jH} + (c^{'}_{jH} - c^{\circ}_{jH})Ms^{\circ}_{jH} + \Pi(p^{i\circ}_{jH-}) > (p^{i*}_{jH} - c^{'}_{jH})Ms^{*}_{jH} + (c^{'}_{jH} - c^{\circ}_{jH})Ms^{*}_{jH} + \Pi(p^{i*}_{jH-})$$
$$\Rightarrow (p^{i\circ}_{jH} - c^{'}_{jH})Ms^{\circ}_{jH} + \Pi(p^{i\circ}_{jH-}) > (p^{i*}_{jH} - c^{'}_{jH})Ms^{*}_{jH} + \Pi(p^{i*}_{jH-}) + M(c^{'}_{jH} - c^{\circ}_{jH})(s^{*}_{jH} - s^{\circ}_{jH})$$
$$\Rightarrow (p^{i\circ}_{jH} - c^{'}_{jH})Ms^{\circ}_{jH} + \Pi(p^{i\circ}_{jH-}) > (p^{i*}_{jH} - c^{'}_{jH})Ms^{*}_{jH} + \Pi(p^{i*}_{jH-})$$

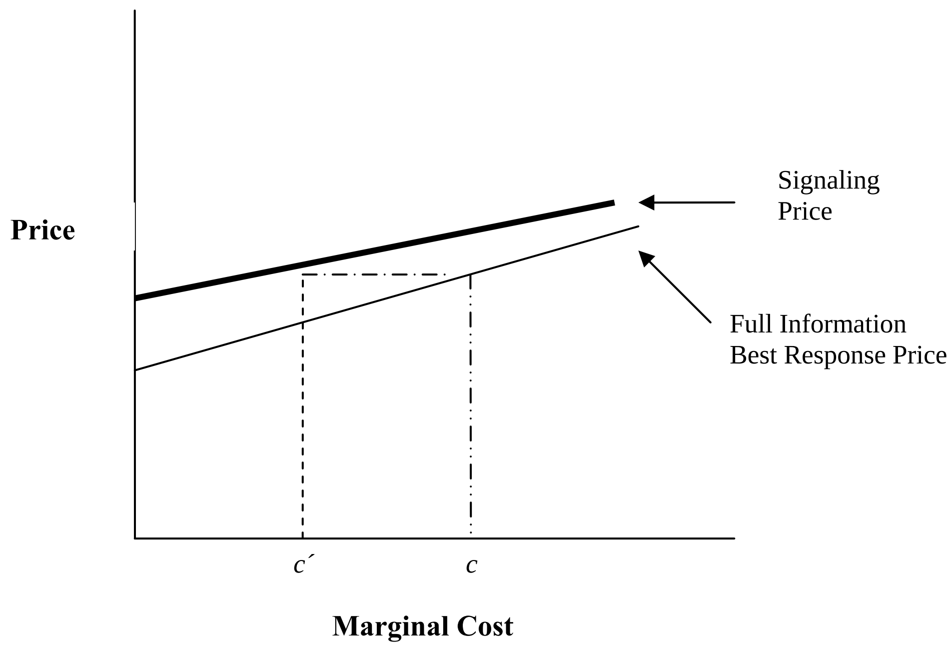
The second and third inequalities in the above set of inequalities involve simple algebraic manipulations of the expressions on both sides of the inequality. The last inequality follows from the third inequality because $c^{'}_{jH} < c^{\circ}_{jH}$ and $s^{*}_{jH} < s^{\circ}_{jH}$ on account of our assumption that $p^{*}_{jH} > p^{\circ}_{jH}$. However, the last inequality contradicts the assumption that p^{i*}_{jH} and p^{i*}_{jH-} are the best-response prices when the firm's cost is $c^{'}_{jH}$. This contradiction establishes that the firm's best response price of car model *j* is increasing in $c^{'}_{jH}$.

Thus, there exists a virtual marginal cost, $c_{jH} > c^{'}_{jH}$ at which the best-response price under full information equals the separating signaling price, p^{i}_{jH}, of a high-quality type with a marginal cost of $c^{'}_{jH}$ (as indicated in Figure B.1 below). This result is the basis of our specification in equation (13) using the concept of a virtual marginal cost. When the high-quality type also uses scarcity as a signaling device, it may improve the efficiency of the signaling strategy (Stock and Balachander 2005). Thus, the upward price distortion may be accompanied by product scarcity. On the other hand, a low-quality type of new car model introduces its product using its full-information price (which is lower than the high-quality type's signaling price) and with no scarcity. Thus, introductory price should be positively correlated with scarcity in the presence of signaling.

Reference

Tirole, J., 1988, "The Theory of Industrial Organization", *The MIT press.* Cambridge, MA

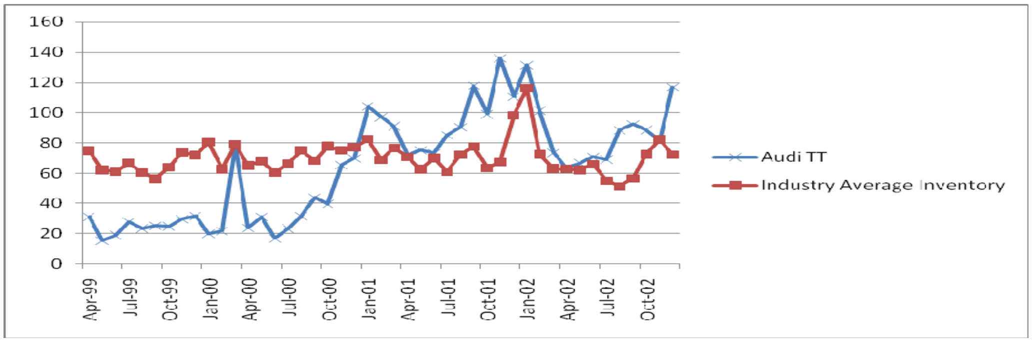
Figure B.1: Signaling Price and Best Response Price under Full Information



APPENDIX C

Figure C.1: Introductory Inventory of Two Scarce Models from Table 1

(Inventory measured in Days' Supply)



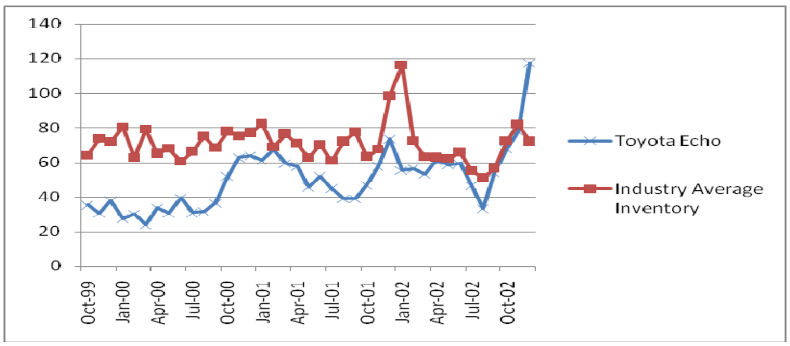
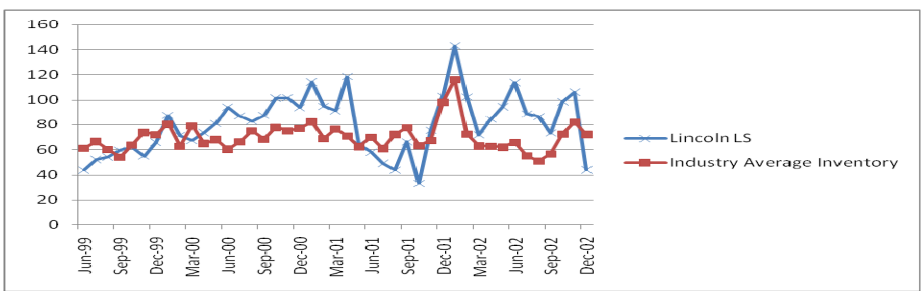


Figure C.2: Introductory Inventory of Non-Scarce Cars

(Inventory measured in Days Supply)



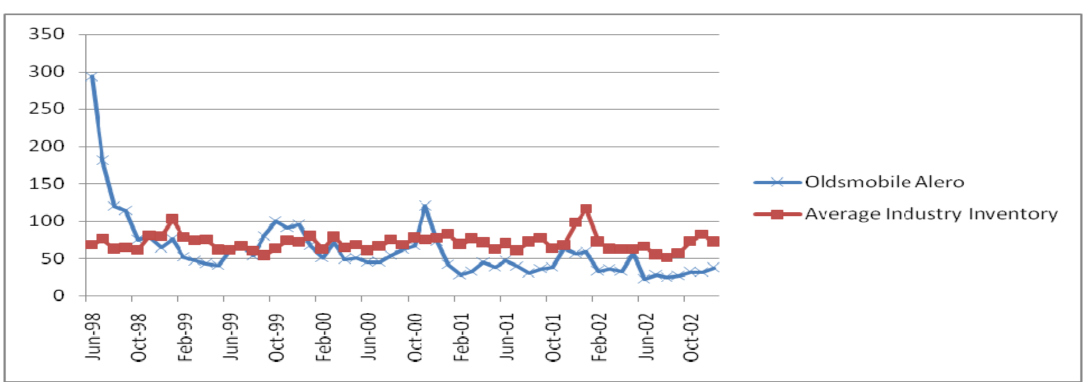


Table C.0: OLS and 2SLS Regression Estimates

	OLS	**2SLS**
CONSTANT	-9.361 (0.207) ***	-9.627 (0.287) ***
HPWT	0.105 (0.013) ***	0.125 (0.020) ***
SIZE	1.851 (0.107) ***	1.951 (0.130) ***
MP$	0.120 (0.032) ***	0.117 (0.032) ***
RELIABILITY	0.010 (0.012)	0.012 (0.012)
2DR	-0.781 (0.035) ***	-0.748 (0.043) ***
LUX	-0.314 (0.061) ***	-0.303 (0.061) ***
SPORT	-0.801 (0.064) ***	-0.806 (0.064) ***
EU	1.325 (0.057) ***	1.367 (0.065) ***
AM	0.889 (0.051) ***	0.875 (0.052) ***
JAP	0.623 (0.059) ***	0.624 (0.059) ***
NEW	-0.178 (0.143)	-0.207 (0.145)
NEW*INVSCAR	-0.501 (0.072) ***	-0.499 (0.072) ***
NEW*TIME	0.033 (0.007) ***	0.034 (0.007) ***
NEW*INVSCAR*TIME	0.000 (0.004)	0.000 (0.004)
Q1	0.069 (0.030) **	0.071 (0.030) **
Q2	0.371 (0.030) ***	0.372 (0.030) ***
Q3	0.206 (0.030) ***	0.206 (0.030) ***
PRSIG*NEW	9.227 (3.973) **	9.773 (3.996) **
PRSIG*NEW*TIME	-0.680 (0.188) ***	-0.695 (0.189) ***
$\ln(\bar{y}_t - p_{jt})$	16.793 (0.619) ***	18.670 (1.538) ***
R^2	0.469	0.469

Notes: Standard errors in brackets. PRSIG is rescaled by multiplying it by 0.000001

***: significant at p = 0.01

**: significant at p = 0.05

*: significant at p = 0.10

Table C.1: Results for Full Model with Heterogeneity and Inventory-Induced Choice Set Restrictions and Excluding Price Signaling Variables

	Parameters β	Std. Error	Parameters σ	Std. Error
CONSTANT	-8.522***	0.409	0.086	1.105
HPWT	-0.003	0.057	0.133**	0.062
SIZE	2.157***	0.192	0.057	0.998
MP$	-0.121	0.094	1.092***	0.121
RELIABILITY	-0.124***	0.042	0.447***	0.094
2DR	-0.228	0.657	0.476	1.811
LUX	-0.803***	0.052		
SPORT	-0.913***	0.108		
EU	1.360***	0.095		
AM	0.912***	0.064		
JAP	0.576***	0.063		
NEW	0.134	0.091		
NEW*INVSCAR	-0.511***	0.078		
NEW*TIME	0.011*	0.004		
NEW*INVSCAR*TIME	0.001	0.004		
Q1	-0.012	0.191		
Q2	0.691***	0.113		
Q3	0.560	0.225		
$\ln(y_{ht} - p_{jt})$	12.711***	2.160		
λ	0.594*	0.312		

Notes: PRSIG is rescaled by multiplying it by 0.000001

***: significant at p = 0.01
**: significant at p = 0.05
*: significant at p = 0.10

Table C.2: 2SLS Regression Estimates with INVSCAR Calculated Over First Six Months

	Parameters	**Std. Error**
CONSTANT	-9.568 ***	0.289
HPWT	0.119 ***	0.020
SIZE	1.926 ***	0.131
MP$	0.123 ***	0.032
RELIABILITY	0.008	0.012
2DR	-0.296 ***	0.062
LUX	-0.748 ***	0.043
SPORT	-0.817 ***	0.064
EU	1.368 ***	0.065
AM	0.876 ***	0.053
JAP	0.644 ***	0.059
NEW	-0.380 ***	0.145
NEW*INVSCAR	-0.283 ***	0.058
NEW*TIME	0.031 ***	0.007
NEW*INVSCAR*TIME	0.002	0.003
Q1	0.071 ***	0.030
Q2	0.374 ***	0.030
Q3	0.208 ***	0.030
PRSIG*NEW	8.841 **	4.074
PRSIG*NEW*TIME	-0.640 ***	0.192
ln($\overline{y_t}$ - p_{jt})	18.313 ***	1.548
R^2	0.464	

Notes: Standard errors in brackets. SIZE is rescaled by multiplying it by 0.0001. PRSIG is rescaled by multiplying it by 0.000001.

***: significant at p = 0.01

**: significant at p = 0.05

*: significant at p = 0.10

Table C.3: 2SLS Regression Estimates with Models Considered New for Five Years after Introduction

	Parameters	**Std. Error**
CONSTANT	-9.452 ***	0.284
HPWT	0.118 ***	0.019
SIZE	1.897 ***	0.129
MP$	0.107 ***	0.032
RELIABILITY	0.011	0.012
2DR	-0.329 ***	0.061
LUX	-0.711 ***	0.044
SPORT	-0.776 ***	0.064
EU	1.340 ***	0.065
AM	0.858 ***	0.052
JAP	0.587 ***	0.059
NEW	0.172	0.116
NEW*INVSCAR	-0.473 ***	0.058
NEW*TIME	0.003	0.003
NEW*INVSCAR*TIME	-0.002	0.002
Q1	0.076 **	0.030
Q2	0.373 ***	0.030
Q3	0.208 ***	0.030
PRSIG*NEW	1.130	3.151
PRSIG*NEW*TIME	0.030	0.089
ln($\overline{y_t}$ **-** p_{jt}**)**	19.610 ***	1.525
R^2	0.471	

Notes: NEW= 1 for the first 5 years after introduction. Standard errors are in brackets. SIZE is rescaled by multiplying it by 0.0001. PRSIG is rescaled by multiplying it by 0.000001.

***: significant at p = 0.01
**: significant at p = 0.05

Table C.4: 2SLS Regression Estimates with Models Considered New for Two Years after Introduction

	Parameters	**Std. Error**
CONSTANT	-9.501 ***	0.287
HPWT	0.115 ***	0.020
SIZE	1.887 ***	0.130
MP$	0.124 ***	0.032
RELIABILITY	0.010	0.012
2DR	-0.315 ***	0.061
LUX	-0.751 ***	0.042
SPORT	-0.796 ***	0.064
EU	1.353 ***	0.065
AM	0.895 ***	0.052
JAP	0.639 ***	0.058
NEW	-0.060	0.042
NEW*INVSCAR	-0.672 ***	0.070
NEW*TIME	0.043 ***	0.007
NEW*INVSCAR*TIME	0.011 **	0.005
Q1	0.070 **	0.030
Q2	0.373 ***	0.030
Q3	0.208 ***	0.030
PRSIG*NEW	5.167 *	2.962
PRSIG*NEW*TIME	-0.781 ***	0.243
ln($\overline{y_t}$ - p_{jt})	17.799 ***	1.537
R^2	0.469	

Notes: Standard errors in brackets. NEW= 1 for the first 2 years after introduction. SIZE is rescaled by multiplying it by 0.0001. PRSIG is rescaled by multiplying it by 0.000001.

***: significant at p = 0.01
**: significant at p = 0.05

Table C.5: Regression of Endogenous Variables on Instruments

	INVSCAR	Price	PRISG
Number of Competitors_CP	-0.001 (0.003)	4.347 (0.084) ***	8.519 (2.213) ***
Number of Competitors_CW	-0.040 (0.034)	27.154 (0.872) ***	-3.809 (1.471) ***
Number of Competitors_OP	-0.092 (0.015) ***	-8.627 (0.376) ***	-2.313 (0.445) ***
Number of Competitors_OW	0.032 (0.003) ***	0.775 (0.089) ***	1.601 (0.505) ***
HPW_OP	-0.177 (0.020) ***	14.430 (0.505) ***	3.838 (2.886)
HPW_CP	0.152 (0.027) ***	1.305 (0.681) **	-7.08 (1.657) ***
HPW_OW	-0.084 (0.017) ***	1.575 (0.431) ***	34.253 (4.245) ***
HPW_CW	1.025 (0.013) ***	-2.697 (0.331) ***	0.494 (1.131)
Size_OP	-0.002 (0.001) ***	0.054 (0.015) ***	0.338 (0.262)
Size_CP	-0.232 (0.026) ***	15.434 (0.656) ***	-7.953 (1.356) ***
Size_OW	-0.027 (0.016) *	3.273 (0.414) ***	-1.552 (0.319) ***
Size_CW	0.215 (0.034) ***	-2.435 (0.872) ***	3.794 (0.847) ***
MPG_OP	0.000 (0.008)	0.262 (0.200)	0.412 (0.077) ***
MPG_CP	-0.003 (0.008)	0.062 (0.200)	0.092 (0.03) **
MPG_OW	-0.003 (0.008)	0.187 (0.199)	-0.6 (0.101) ***
MPG_CW	0.768 (0.122) ***	12.558 (3.107) ***	0.095 (0.018) ***
Reliability_OP	-0.551 (0.081) ***	-6.554 (2.066) ***	2.692 (0.264) ***
Reliability_CP	0.191 (0.025) ***	2.213 (0.625) ***	1.467 (0.114) ***
Reliability_OW	-0.261 (0.028) ***	3.479 (0.709) ***	-0.211 (0.375)
Reliability_CW	-0.363 (0.159) **	-25.630 (4.053) ***	-1.537 (0.18) ***
2door_OP	-0.114 (0.091)	-19.289 (2.328) ***	0.017 (0.105)
2door_CP	1.878 (0.234) ***	30.698 (5.961) ***	0.003 (0.073)
2door_OW	0.524 (0.062) ***	-2.633 (1.588) *	0.506 (0.144) ***
2door_CW	-0.116 (0.014) ***	-1.624 (0.367) ***	0.186 (0.038) ***
HPWT	-0.448 (0.075) ***	-7.396 (1.904) ***	0.033 (0.06)
SIZE	0.110 (0.018) ***	-3.645 (0.447) ***	3.657 (0.621) ***
MP$	0.046 (0.047)	2.393 (1.189) **	-1.999 (0.268) ***
RELIABILITY	0.003 (0.004)	0.676 (0.107) ***	-0.027 (0.063)
2DR	0.000 (0.002)	0.287 (0.042) ***	8.606 (0.359) ***
LUX	-0.010 (0.006) *	-0.350 (0.142) ***	6.746 (0.485) ***
SPORT	0.005 (0.001) ***	0.168 (0.026) ***	3.223 (0.307) ***
EU	-0.050 (0.015) ***	-0.455 (0.371)	26.782 (0.236) ***
AM	-0.041 (0.006) ***	0.908 (0.160) ***	-0.023 (0.01) **
JAP	0.004 (0.021)	1.310 (0.527) ***	5.58 (0.467) ***
NEW	0.038 (0.010) ***	-0.053 (0.253)	0.257 (0.295)
NEW*TIME	0.006 (0.006)	1.659 (0.147) ***	-3.349 (0.621) ***
Q1	0.021 (0.004) ***	0.100 (0.102)	-0.288 (0.143) **
Q2	0.059 (0.008) ***	-1.130 (0.202) ***	-0.111 (0.143)
Q3	-0.004 (0.002) **	0.250 (0.053) ***	0.254 (0.142) ***
R^2	0.70324	0.800	0.846
F-Statistic	529.900***	792.420***	1244.700***

Note: Number of Competitors_CP is within-firm number of competitors belonging to the same car segment (small, medium, large, luxury) and having the same country of origin. Other instrument names follow the same rule as "C" represents without firm, "O" represents within firm, "P" represents belonging to the same car segment (small, medium, large, luxury) and having the same country of origin and "W" represents belonging to the same car segment (small, medium, large, luxury) and having the same Ward's design classification (regular, specialty, sporty).

***: significant at p = 0.01

**: significant at p = 0.05

*: significant at p = 0.10

APPENDIX D: Estimation Using Simulated Data

Our empirical model assumes that a product's observed scarcity level affects a household's utility for the product via equation (2). However, we estimate equation (2) using aggregate data which may raise the issue of whether scarcity effects at the household level can be accurately estimated from aggregate data. We study this issue using simulated data as follows. In each of 50 periods, we generate choice data for 1000 households from among 200 car models. Of the 200 car models, 100 are new car models introduced during the time period of the data with varying levels of introductory scarcity. We use the following specific form of the utility function in equation (2):

$$\max_{j \in \Omega_{ht}} u_{hjt} = \alpha \ln(y_{ht} - p_{jt}) + \sum_{k=1}^{3} X_{jkt}\beta_k + \sum_{k=1}^{3} \sigma_k X_{jkt} v_{hk} + \beta_s N_j \ln(1 - \pi_j^i) + \xi_{jt} + \varepsilon_{hjt} \qquad \text{(D.1)}$$

As seen in equation (D.1), a car model's specifications on three characteristics, $X_{1,}$ $X_{2,}$ and X_3 enter a household's utility function, and the coefficients for these two characteristics are heterogeneous across households. Further, N_j in equation (D.1) is a dummy variable taking on a value of 1 for a new car model and π_j^i is the introductory availability probability of the new car model. Thus, equation (D.1) incorporates the idea that the introductory scarcity of a new car model influences a household's utility function. Substitution of equation (7) in equation (D.1) yields the utility maximization problem:

$$\max_{j \in \Omega_{ht}} u_{hjt} = \alpha \ln(y_{ht} - p_{jt}) + \sum_{k=1}^{3} X_{jkt}\beta_k + \sum_{k=1}^{3} \sigma_k X_{jkt} v_{hk} + \gamma_s N_j D_j^i + \xi_{jt} + \varepsilon_{hjt} \qquad \text{(D.2)}$$

In the above equation, D_j^i is the introductory inventory for car model j and $\gamma_s = -\lambda\beta_s$. In creating the simulated data, we generate the car characteristics, X_1, X_2, and X_3 for the 200 car models, and the household income, $y_{ht,}$ for the 1000 households. Further, we generate ξ_{jt}, D_{jt}, and p_{jt} as follows to allow for correlation between ξ_{jt} with the other two variables.

$$\begin{pmatrix} \xi_{jt} \\ D_{jt} \\ p_{jt} \end{pmatrix} \sim MVN\left(\begin{pmatrix} 0 \\ \overline{D_{jt}} \\ \overline{p_{jt}} \end{pmatrix}, \begin{pmatrix} \sigma_\xi & \sigma_{\xi D} & \sigma_{\xi p} \\ & \sigma_D & 0 \\ & & \sigma_p \end{pmatrix} \right)$$

For any new car model, we obtain the introductory inventory, D_j^i as the average of the inventory (D_{jt}) in the first twelve periods after its introduction. We also generate four instrumental variables that are correlated with D_{jt}, and p_{jt} but are uncorrelated with ξ_{jt}. Given the true parameters (as reported in Table D.1) and the D_{jt}, we calculate the availability probability π_{jt} using equation (7). We use π_{jt} to simulate the household availability vectors Λ_{ht} and generate the households' choice data using equation (2). Thus, if π_{jt} is 0.5, approximately half the households would find car model *j* available at time *t*. We then aggregate the choice data across households to obtain market-level simulated sales data for each car model. We subsequently use the market-level sales data to estimate our model using the GMM procedure described in Section 3.1 of the paper.

Table D.1 shows the parameter estimates for the simulated data as well as the true parameter values. The results indicate that our estimation approach recovers the true parameters fairly closely. More importantly, we are able to recover the effect of scarcity on households' utility function and choice using aggregate data.

Table D.1: Simulated Data Estimation with Heterogeneity and Availability

Parameters/Variable	True Value β	Estimate β (Std. Error)	True Value σ	Estimate σ (Std. Error)
Constant	-20.000	-19.097 (0.740)	1.000	1.025 (0.273)
X_1	1.000	1.138 (0.240)	1.000	0.900 (0.167)
X_2	1.000	1.159 (0.714)	1.000	1.025 (0.539)
X_3	-6.000	-6.097 (0.441)	1.000	1.025 (0.233)
γ	-5.000	-4.930 (0.034)		
$\ln(y_{ht} - p_{jt})$	10.000	10.250 (3.111)		
λ	10.000	10.250 (1.089)		

Note: All parameter estimates are not significantly different from their true values.