Online Appendix for: Trade-ins and Transaction Costs in the Market for Used Business Jets

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A.3 Buyback Heterogeneity

A significant assumption of the model presented in Section 4 is that the buyback parameters, b_m, are constant across consumers, jets, and time within a manufacturer. This assumption of a constant buyback policy within firms makes the counterfactual analysis in which I shut down buyback for one or more firms tractable by reducing the space of buyback policies (buyback is either "on" or "off" for the entire time period covered by the data). In principle, it would be possible to relax this assumption and estimate richer heterogeneity in buyback parameters. This would require adding further micro moments to the GMM objective function. For example, to vary b_m over time would require analogues of moments 6-12 in Table 17 conditioned on different time periods. Because the dataset is relatively small, conditioning these moments further would lead to imprecision in the micro-moments, and heterogeneity in b_m would likely not be estimated precisely (for example, there are only 608 upgrades from used Dassault jets, 63 of which are to new jets of the same brand).

To test whether this restriction on b_m is reasonable, I present descriptive statistics that examine the extent of apparent heterogeneity in buyback across three dimensions: jet owners, time, and jet models.

Figure A.1 reports statistics on upgrades by consumer type. I split all consumers in the estimation sample into terciles of maximum fleet size. Recall that the estimation data, in which each consumer holds one jet at a time, is constructed from raw data in which some firms hold multiple jets. This Figure examines whether upgrade behavior differs across consumers that hold fleets of different sizes. The left panel records the share of buyback-eligible upgrades (upgrades from a used unit to a new unit of the same brand) in which the used unit is: (1) sold to an independent dealer, (2) sold back to the manufacturer, or (3) transferred directly to another consumer ("back to back"). Recall that both (2) and (3) could be manufacturer facilitated "buyback" transactions. I find that the share of transactions in each of these three categories in broadly similar across consumers with different fleet sizes. Consumers with large fleets (>7 jets) are somewhat more likely to sell jets directly rather than using a dealer. Although these statistics do not enter the estimation of the model, if it is easier for some companies (e.g. those with large fleets) to sell directly on the secondary market, this should show up in upgrade frequency and be captured by heterogeneity in ν_i^τ.

The right panel shows the same statistics for all other (non-buyback eligible) upgrades. Notice that for all three fleet size categories the number of sales back to manufacturers is very small, and the share of sales to independent dealers is larger than in the left panel. Comparing the two panels, the upgrade transactions of consumers of all fleet sizes respond similarly to buyback eligibility.

Table A.1 records analogues of the statistics in Table 3 for all manufacturers in different time periods. For each of the three time periods reported, the majority of observed buybacks involve upgrades from used to new jets and are of the manufacturer's own brand. However, the share of used-new upgrades are higher later in the sample period. Similarly, the share of potential buybacks that are observed to be sold back to the manufacturer is lower earlier in the sample, rising from 13% before 1980 to 39% after 1990. These patterns raise the possibility that buyback policies changed over time.

To investigate this possibility further, Table A.2 breaks down changes in observed buyback over time by manufacturer. Each column records coefficients from a separate regression. Observations are all buyback-eligible upgrades for the manufacturer indicated by the column header. The dependent variable is an indicator for whether the used unit in the upgrade was observed to be sold back to the manufacturer. Regressors are time dummies for each decade in the data. Significant coefficient estimates would suggest that, for a specific manufacturer, upgrades are more likely to be bought back in that period of time. Note that there is at least one omitted category for each regression, and some regressions omit two categories because there are no observations in the first decade of the sample.

Although the coefficients on 1991-2000 are positive for all manufacturers, only one (Cessna) is significant at the 5% level. Notice that the number of observations in each regression is quite small. This illustrates the difficulty in precisely estimating heterogeneity in buyback at the manufacturer-decade level. Furthermore, the statistics reported in Tables A.1 and A.2 examine *observed* sales to manufacturers only. As discussed in Section 3.1, these statistics may not capture all manufacturer-facilitated upgrades that I want to classify as "buyback", and this variation is not used in estimation of the model.

To directly examine heterogeneity in the differences in upgrade probability used to identify buyback in the model, I replicate panel A of Table 4 for different time periods, and record these in Table A.3. Recall that b_m is identified by the difference in new jet (or used jet) share between same brand and other brand upgrades. In Table 4 I report a significant difference of 11.7 percentage points. Analogous numbers for the four decades of the sample reported in Table A.3 are: 7.8, 7.7, 10.7, and 12.1 percentage points. These estimate are statistically significant at at least the 10% level for 1971 onward. The point estimates show a slight upwards trend over time, but it is not possible to reject the hypothesis that any two of these estimates are equal.

As with Table A.2 , there is some evidence of changes in the effects of buyback over time, but they are difficult to measure precisely because of small sample size. Note that these descriptive exercises do not take into account the changing composition of consumer types over the time, which is accounted for in the model and might drive some of these patterns (if for example early adopters have low ν_i^τ). Because of this, I view my estimates of b_m in the main specification as average effects of buyback on utility over the entire sample period.

Finally, I examine heterogeneity in observed buyback by characteristics of jet traded in and purchased. In principle, the optimal buyback policy need not be identical for all jets, as I assume it to be in the model. To test for this type of heterogeneity, Table A.4 reports coefficients from regressions of an indicator for observed buyback (sale of the used unit back to the manufacturer) on jet characteristics. The sample is all buyback-eligible upgrades. The first three columns report coefficients from a single regression, arranged over three columns for clarity. They report the coefficient on indicators for the interaction of the size of the jet sold and the size of the jet purchased. Buyback is observed significantly more frequently for upgrades from small and medium jets to new medium jets. The pattern of coefficients suggests that "down-upgrades" from larger to smaller jets are less likely to use buyback, and "up-upgrades" from smaller to larger jets are more likely to use buyback, consistent with heterogeneous buyback policies being used to encourage consumers to "size up". However, most of the coefficients are not statistically significant.

In the fourth column I report coefficients from a regression of observed buyback frequency on jet price and model age. Model age is measured as the number of years since the characteristics (engine power, range, etc.) of the jets in a manufacturer-size category have changed. That is, how long has it been since a manufacturer's production model has been updated. I find that, although there is no effect of price, observed buybacks are more common for older jet models. The final three columns include both sets of regressors and report similar results, though with slightly reduced significance.

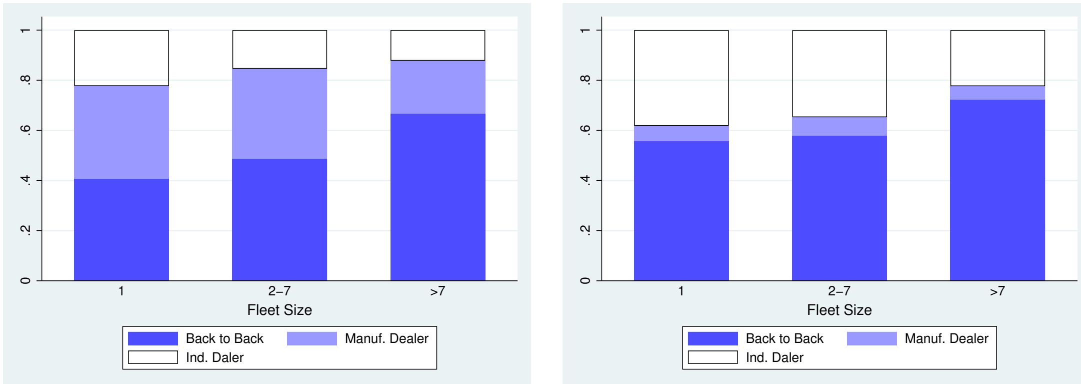
The results reported in Table A.4 point to some heterogeneity in buyback policy across models within the same manufacturer (all regressions include manufacturer and year fixed effects). It may be that firms increase the generosity of buyback programs as their jet models age and become less competitive with other firms' new models. Solving jointly for the firm's dynamically optimal buyback and model upgrade policy is an interesting challenge that is outside the scope of this paper.

A.4 Alternative Specifications

In this section I report results from two alternative specifications.

First, I estimate the main model under an alternative market size assumption. In the main specification, I use the number of consumers who buy jets in the next five years as the size of

Figure A.1: Upgrade Type Heterogeneity by Fleet Size



Same Brand New | Other Upgrade

Notes: The left panel records the share of upgrades from used units to new units of the same brand in which the used unit is sold to an independent dealer, manufacturer dealer, or another consumer ("back to back"). Each bar presents these statistics for consumers whose maximum number of jets held simultaneously falls in the "Fleet Size" bin denoted on the x-axis. The right panel repeats this exercise for upgrades that are no same-brand used-new.

Table A.1: Buyback Patterns for Different Sub-Periods

Manufacturer	Years	Share of Buybacks: Upgrades to New	Share of Buybacks: Own Brand	Share of Potential Buybacks Sold to Manufacturer
All	1961-1980	67%	90%	14%
All	1981-1990	76%	92%	19%
All	1991-2000	90%	88%	39%

Notes: Statistics identical to those recorded in Table 3, recorded separately for transactions in three time periods. "All" manufacturers includes only the top si manufacturers as defined in the text.

Table A.2: Firm-Specific Buyback Heterogeneity by Period

Dependent Variable:	Used Jet Bought Back by Manufacturer						
Manufacturer:	Bombardier	Cessna	Dassault	Gulfstream	IAI	Raytheon	Other
1961-1970	.	.	.	.	.	.	.
	.	.	.	.	.	.	.
1971-1980	0.063	.	0.321	.	.	0.000	0.125
	(0.340)	.	(0.410)	.	.	(0.324)	(0.120)
1981-1990	0.121	0.243	0.093	0.387	0.000	0.214	0.000
	(0.330)	(0.177)	(0.407)	(0.299)	(0.186	(0.283)	(0.132)
1991-2000	0.513	0.407**	0.288	0.480	0.167	0.291	0.000
	(0.323)	(0.162)	(0.407)	(0.294)	(0.186)	(0.259)	(0.270)
N	168	235	135	84	15	156	32

Notes: Each column records estimated coefficients from a regression of an indicator for observed buyback on decade indicators. The sample for each regression is all used-new upgrades of the same brand for the brand indicated in the column. The dependent variable is equal to 1 when the used unit is sold back to the manufacturer. Standard errors are in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table A.3: Time Heterogeneity in Upgrade Shares by New and Same Brand

(A) 1961-1970

	Used	New	Diff	N
Same Brand	0.243	0.757	-0.514	37
Different Brand	0.321	0.679	-0.358	28
Diff	-0.078	0.078	-0.156	
SE	(0.113)	(0.113)	(0.226)	

(B) 1971-1980

	Used	New	Diff	N
Same Brand	0.436	0.564	-0.128	326
Different Brand	0.513	0.487	0.026	271
Diff	-0.077	0.077	-0.154	
SE	(0.041)	(0.041)	(0.082)	

(C) 1981-1990

	Used	New	Diff	N
Same Brand	0.667	0.332	0.335	721
Different Brand	0.774	0.226	0.548	796
Diff	-0.107	0.107	-0.214	
SE	(0.023)	(0.023)	(0.046)	

(D) 1991-2000

	Used	New	Diff	N
Same Brand	0.672	0.328	0.344	1188
Different Brand	0.793	0.207	0.586	1153
Diff	-0.121	0.121	-0.242	
SE	(0.018)	(0.018)	(0.036)	

Notes: Analysis performed on estimation sample. Each panel records the share of new and used jets purchased among all first time and upgrade purchases made by all consumers. Each panel subsets the sample to transactions in the indicated date range. Standard errors of the difference in means for each column on parentheses.

Table A.4: Buyback Heterogeneity by Jet Types

	Dependent Variable: Observed Buyback						
	Upgrading to				Upgrading to		
Upgrading From:	Small	Medium	Large		Small	Medium	Large
Small	0.039	0.270***	0.014		0.037	0.242**	0.193
	(0.078)	(0.092)	(0.156)		(0.111)	(0.120)	(0.197)
Medium	-0.006	0.196**	0.109		-0.012	0.194*	0.132
	(0.088)	(0.084)	(0.111)		(0.112)	(0.107)	(0.139)
Large	-0.009	-0.064			-0.217	-0.013	
	(0.153)	(0.114)			(0.217)	(0.187)	
Price				-0.001	-0.000		
				(0.002)	(0.004)		
Model Age				0.004***	0.006***		
				(0.002)	(0.002)		
N	825			758	758		

Notes: Table reports coefficients from a regressions of an indicator for observed buyback on jet characteristics. The sample includes all used-new same brand upgrades. The first three columns all correspond to the same regression, with estimated coefficients on interactions of sold and purchased jet size are arranged in a 3x3 matrix. Similarly, the last three columns correspond to one regression with coefficients arranged in a 3x3 matrix. All regressions include year and manufacturer fixed effects. Standard errors are in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

the first time buyer market in year t, M_{0t}. This choice has the problem of being a function of future market outcomes. As an alternative, I estimate a model in which M_{0t} is set using counts of active public companies at each year, t. In particular, I use data from the Center for Research on Security prices to generate a count of the number of publicly listed firms each year. This alternative approach has the downside of not counting potential private owners.

The overall magnitudes of the baseline and alternative market sizes are fairly similar. The average value of M_{0t} in the baseline specification is 3125, and the average alternative market size is 2519. Column two of Table A.11 records estimated parameters using the alternative market sizes. They are broadly similar to the main estimates. The first three columns of Table A.5 repeat the simulations reported in Table 7 using the alternative market share estimates. The simulated demand patterns are similar.

Second, I estimate the main model using a different sample of consumers. As discussed in Section 2.3, the estimation sample contains private owners, corporations, and air transport companies. As I illustrate in Table 2, these three groups of owners have similar holding and upgrading patterns. However, one might suspect that air transport companies have different preferences than private users and should be treated separately. To test the sensitivity of the main results, I estimate the baseline model dropping air transport companies from the set of consumers. This reduces the number of consumers in the estimation sample by 15%.

The third column of Table A.11 records the estimated parameters for this specification. Parameter estimates are close to the main specification. One notable difference is that the buyback parameters, b_m, are smaller in the alternative specification (although for only one firm, Bombardier, is the difference statistically significant). In the second set of three columns in Table A.5 I present demand simulations of this specification with and without buyback. The demand patterns are similar to those in the main specifications, with absolute values somewhat lower, consistent with a smaller consumer sample.

Table A.5: Demand Simulation of Alternative Specifications

	Alternative Market Size			Excluding Air Transport		
	No Buyback	Buyback	Δ	No Buyback	Buyback	Δ
(1) Upgrades to New	1308.4	1647.2	338.8	1234.9	1511.6	276.7
(2) Upgrades to Used	3536.9	3396.6	140.3	2409.2	2342.8	66.4
(3) Exits	17520.0	17512.0	-7.8	12396.0	12385.0	-10.4
Used Jet Supply to First Time Buyers = (1) + (3)	18828.0	19160.0	311.1	13631.0	13897.0	266.3

Notes: Table reports statistic analogous to those in Table 7 for alternative specifications. The first three columns report outcomes simulated using parameters estimated under an alternative market size assumption. In particular, I use the count of all publicly listed US firms as the number of potential first time buyers, M_{ot}, each year. The second set of three columns report simulated outcomes using parameters estimated using a reduced sample that drops air transportation companies from the set of consumers. All columns are averages over 100 simulations. All figures are totals for the period 1961-2000.

A.5 Additional Tables and Figures

Table A.6: Aircraft Characteristics

Segment		All		Small	Medium	Large
Model Years		< 1990	≥ 1990			
Range	Mean	2307.8	2905.1	1772.7	2369.3	3928.5
	SD	(790.3)	(997.1)	(270.9)	(579.9)	(469.4)
Power	Mean	20.7	25.9	13.2	18.4	46.0
	SD	(12.2)	(14.7)	(1.8)	(3.4)	(10.5)
Max. Weight	Mean	12772.2	14974.9	7179.4	12157.1	26245.0
	SD	(6980.0)	(8414.9)	(1004.2)	(2433.6)	(6112.5)
New Price ($ Millions)	Mean	8.64	17.896	5.176	9.7871	27.054
	SD	(6.893)	(10.896)	(1.890)	(5.735)	(7.787)
1 Year Used Price ($ Millions)	Mean	8.167	17.332	4.923	9.161	26.177
	SD	(6.739)	(10.739)	(1.696)	(5.571)	(7.960)
5 Year Used Price ($ Millions)	Mean	6.599	14.441	3.558	6.617	20.962
	SD	(6.034)	(9.553)	(1.344)	(4.451)	(7.347)
N		205	118	94	162	67

Notes: An observation is a manufacturer-segment-year. Year refers to the year of manufacture. Characteristics are averaged over models within each manufacturer-segment-year (for example if there are multiple large 1990 Bombardier jets, their characteristics are averaged and treated as one observation). Prices are in millions of year 2009 $. Columns 1 and 2 record the mean and standard deviation of model characteristics for models manufactured before and after 1990. Columns 3 to 6 record the mean and standard deviation of model characteristics by market segment (jet size).

Table A.7: Multiple Jet Ownership

	Share of Owner-Years		
	Corporations	Individuals	Air Transport
Multiple Jets Held	16.62%	5.85%	27.26%
At Least One Jet Purchased	26.37%	26.50%	28.66%
Multiple Jets Purchased	1.70%	0.66%	4.31%
Share of Owner Years	79.04%	6.83%	14.13%

Notes: Figures calculated using estimation sample before owners with multiple jets are split into separate owners, as described in the text.

Table A.8: First Stage and 2SLS

	First Stage				OLS	2SLS
Dependent Variable:	Price				$log(s_{jt}) - log(s_{0t})$	
Price					-0.023***	-0.118***
					(0.002)	(0.008)
Substitute Jets (1)	-0.021***			-0.024***		
	(0.001)			(0.001)		
Substitute Jets (2)		-0.027***		-0.017***		
		(0.002)		(0.002)		
Lagged Price			-0.004	0.042***		
			(0.005)	(0.005)		
1st Stage F-Stat						166.214
Jet Model and Year FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: An observation is a model-year. Substitute Jets (1) is the number of currently held jets in the same category of the same age. Substitute Jets (2) is the number of currently held jets in the same category one year older. Regressions all contain controls for jet characteristics, GDP growth, and manufacturer dummies. The final column is a 2SLS regression using all three instruments. Standard errors are in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table A.9: Mean Utility and Cost Regressions

Dependent Variable:	Mean Utility		Marginal Cost	
Range		0.622***	29.011***	8.678**
		(0.027)	(4.274)	(3.985)
Power		0.030***	-0.335	6.866***
		(0.006)	(0.505)	(0.714)
Max Weight		-0.109***	4.250***	2.434**
		(0.009)	(1.018)	(1.121)
Age	-0.058***	-0.083***		
	(0.001)	(0.001)		
Mean Utility			25.913***	8.830***
			(3.773)	(3.026)
New Jets Only	No	No	Yes	Yes
Year FE	No	Yes	Yes	Yes
Jet FE	Yes	No	No	No
Manuf-Segment FE	No	Yes	No	Yes
N	5874	5874	339	339

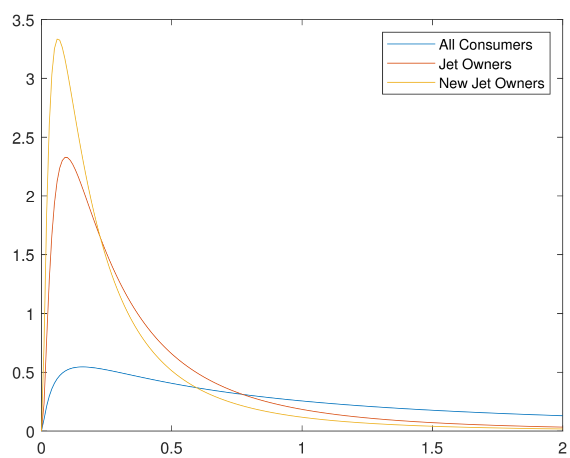
Notes: The first two columns record coefficients from regressions of the estimated values of mean utility, $\int \gamma_{ijt} dF(\nu_i)$ on jet characteristics. Observations are jet-years, and the sample includes all new and used jets in the data. The third and fourth columns record coefficients from regressions of estimated marginal costs, c_j, on jet characteristics. The sample includes all new jets in the data. Standard errors are in parentheses. * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table A.10: Micro-Moments

Moment	Data	Model	Moment	Data	Model
1	0.043	0.041	13-15	9.675	11.766
				9.347	12.034
2	0.133	0.132		8.087	8.767
3	0.301	0.325	16-18	0.099	0.120
				0.131	0.113
4	0.269	0.2693		0.156	0.167
5	0.503	0.460	19	0.942	0.914
6-12	0.070	0.072	20	0.529	0.410
	0.042	0.053			
	0.066	0.090			
	0.190	0.155			
	0.022	0.050			
	0.130	0.059			
	0.168	0.074			

Notes: Table records the values of the micro-moments used in estimation as defined in Table 5, both in the data, and as implied by the model at the estimated parameters.

Figure A.2: Distribution of Price Coefficient



Notes: Figure records lognomal distributions fitted to the empirical distribution of α_i^p among all consumers, all consumers who purchase a jet, and all consumers whose first purchase is a new jet in model simulations at the estimated parameters.

Table A.11: Parameter Estimates: Alternative Specifications

Parameter	No Heterogeneity	Alternative Market Size	Excluding Air Transport
α^p	-1.566	-1.887	-1.425
	(0.201)	(0.112)	(0.151)
α^{new}	2.809	2.551	2.000
	(0.229)	(0.090)	(0.065)
$\alpha^{new}_{upgrade}$	2.676	0.968	1.094
	(0.122)	(0.064)	(0.047)
α^{sb}	1.372	0.259	0.259
	(0.039)	(0.087)	(0.075)
τ	8.880	8.486	8.354
	(0.104)	(0.176)	(0.085)
τ^{exit}	8.559	2.486	4.030
	(0.127)	(0.072)	(0.106)
σ_p		1.392	1.558
		(0.152)	(0.121)
σ_τ		0.802	0.368
		(0.109)	(0.076)
$\sigma_{p\tau}$		-0.311	-0.963
		(0.101)	(0.040)
σ_0		1.965	1.739
		(0.129)	(0.093)
σ_m		0.609	0.345
		(0.099)	(0.043)
Buyback Parameter b_m	No Heterogeneity	Alternative Market Size	Excluding Air Transport
Bombardier	0.730	0.830	0.334
	(0.475)	(0.143)	(0.061)
Cessna	0.597	0.644	0.574
	(0.304)	(0.124)	(0.113)
Dassault	0.785	0.419	0.652
	(0.604)	(0.168)	(0.135)
Gulfstream	0.423	0.290	0.585
	(0.171)	(0.210)	(0.128)
IAI	0.390	0.726	0.660
	(0.198)	(0.085)	(0.095)
Raytheon	0.582	0.521	0.502
	(0.277)	(0.121)	(0.180)
Other	0.705	0.389	0.415
	(0.171)	(0.080)	(0.140)

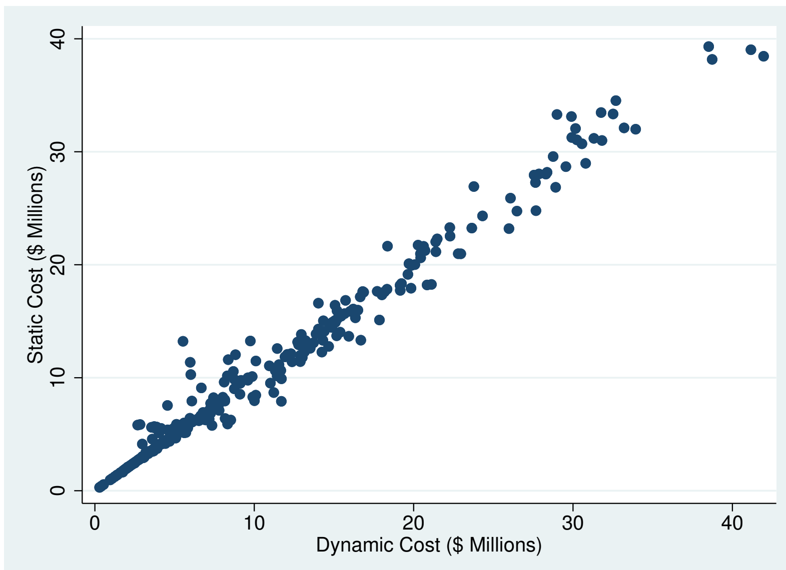
Notes: The first column reports estimated parameters and standard errors for the demand model under the restriction of no preference heterogeneity. The second column reports estimated parameters and standard errors estimated under an alternative market size assumption. In particular, I use the count of all publicly listed US firms as the number of potential first time buyers, M_{ot}, each year. The third column reports estimated parameters and standard errors estimated using a reduced sample that drops air transportation companies from the set of consumers. Prices are in hundreds of thousands of 2009 dollars.

Table A.12: Gross Profit Margins from Financial Reports

Manufacturer	Holding Company	Gross Profit Margin $\frac{p-c}{c}$
Bombardier	Bombardier	9.91%
Cessna	Textron	21.84%
Dassault	Dassault	13.20%
Gulfstream	General Dynamics	16.66%
Raytheon	Raytheon	19.42%

Notes: Figures from annual reports summarized by the Wall Street Journal (WSJ, 2022). Note that profit margins are across all businesses and products, not only business jets.

Figure A.3: Marginal Cost Comparison



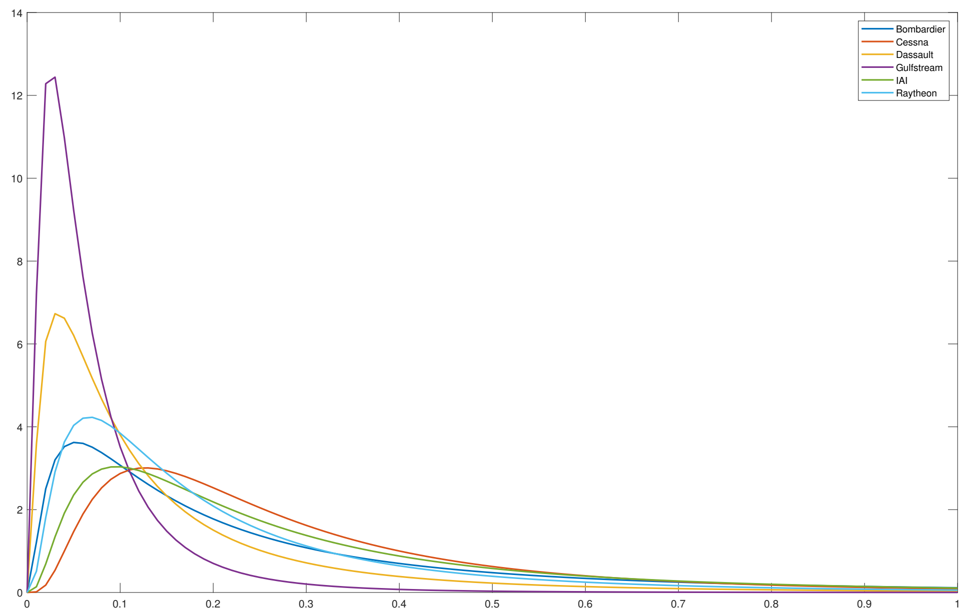
Notes: Figure plots marginal costs estimated using a model of static pricing against marginal costs using a model of dynamic pricing in which firms are forward looking and have perfect foresight.

Table A.13: Firm Profit

Manufacturer	BB units	No BB Profit	BB Profit	Unilateral Deviation Profit
Bombardier	295.31	1.78	1.91	1.72
Cessna	277.59	1.57	1.59	1.52
Dassault	147.03	1.40	1.47	1.36
Gulfstream	146.36	1.96	2.12	1.91
IAI	16.29	0.21	0.21	0.20
Raytheon	100.12	0.90	0.91	0.87
Other	22.48	0.21	0.21	0.21

Notes: Table records manufacturer profits in billions of 2009 $ for various equilibrium simulations. No BB profit is computed using simulations which set b_m to 0 for all manufacturers and otherwise use the estimated parameters. BB profit is computed using simulations at the estimated parameters. Unilateral deviation profit is computed using simulations which set b_m to zero for the firm in question and set b_m to the estimated values for all other firms. BB units records the number of same-brand used-new upgrades for each firm in the buyback simulation.

Figure A.4: Distribution of Jet Holders in 2000



Notes: Figure records lognomal distributions fitted to the empirical distribution of α_i^p among holders of each jet brand in equilibrium simulations at the year 2000, using the estimated parameters.