Online Appendix:

A Dynamic Model of Consumer Replacement Cycles in the PC Processor Industry

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Appendix C: The PC Processor Industry

The relationship between Intel and AMD dates back to the early 1980s. Intel developed the first microprocessor in 1974. IBM helped it become the market leader after IBM chose Intel's processor design as the standard for PCs. However, not wanting to depend on a single supply source, IBM demanded Intel contract with another company and license it to manufacture Intel's x86 chips. AMD agreed to abandon its own competing architecture and began producing x86 chips as a second source. Relations between the two firms later turned sour, and AMD sued Intel in 1987 over the alleged use of anticompetitive tactics that breached the good faith of the original licensing agreement.

AMD continued to produce Intel's chip designs under the disputed contract until the lawsuit was completely settled in January 1996. The resolution of the lawsuit marked an important turning point in the industry because afterward each company's strategy to evolve in its own way. Intel concentrated on the Pentium chip, which AMD had no legal right to produce. In response, AMD purchased NexGen in an attempt to upgrade its microprocessor design capabilities and to establish itself as a credible alternative to Intel. From 1995 to 1999, AMD reduced the lag time between Intel's release of a new design and AMD's release of a competing chip from over 18 months to almost nothing. In mid-1999, AMD introduced the Athlon processor, its first x86-based chip that did not depend on any previously licensed technology from Intel. According to McKinsey, this evidence of stronger competition from AMD prompted Intel to increase the frequency of new chip releases.[1] Older products became obsolete more rapidly as both firms increased the pace of innovation. These actions reduced the average market lifespan of a PC processor from about three years to one and half years (Stevens 1994).

Despite AMD's efforts, Intel has always been the recognized market leader: its market share has fluctuated between 70 percent and 92 percent since the early 1990's. AMD's market share has been less stable, hovering around 15 percent for most of the early 1990's, then dropping to as low as 6 percent in 1997, and later rising to nearly 23 percent in 2001.

[1] McKinsey Global Institute (2001).

Appendix D: Model Fit

The table below provides information on fit of the empirical and simulated moments for a subset of the model specifications. The MSE's for the moments show that the two-segment dynamic model fits best. The myopic model performs the worst, particularly on fitting the replacement share and ownership share moments. This is not surprising because one would not expect a static demand model to adequately capture replacement behavior, which is inherently dynamic.

Model	Myopic	One Segment	Two Segment
Moments		Mean Squared Error	
Penetration Rate	1.298	0.622	0.446
Replacement Share	5.894	2.838	1.577
Market Shares	10.027	8.655	7.120
Ownership Shares	18.703	9.630	6.359

Appendix E: Estimates from Alternative Models

Table 1: Estimates from Alternative Models

	Model with Alternative Expectations		Model with Aggregate Shocks	
	Segment 1	Segment 2	Segment 1	Segment 2
Quality	0.541	0.671	0.498	0.613
	(0.062)	(0.071)	(0.058)	(0.075)
Price	−1.825	−1.644	−1.868	−1.694
	(0.434)	(0.530)	(0.477)	(0.509)
Intel	2.131	2.520	2.205	2.662
	(0.391)	(0.328)	(0.355)	(0.414)
AMD	0.260	0.325	0.283	0.380
	(0.056)	(0.048)	(0.049)	(0.054)
$\sigma_{\gamma i}$	-	-	0.008	0.004
			(0.004)	(0.003)
Segment Size	0.874	0.126	0.868	0.132
	(0.057)		(0.063)	
Obj. Val.	0.085		0.080	
J-Statistic	11.73		11.04	
p-value	0.704		0.631	

Estimates from two alternative models presented in the Appendix.

Appendix F: Alternative Model of Consumer Expectations

The table below contains the parameter estimates from the model with alternative consumer expectations, detailed in Appendix A in the paper.

Table 2: Estimates of the Alternative Expectations Process

Frontier Vector Autoregression	Intel F Price(t)	AMD F Price(t)	Intel F Quality(t)	AMD F Quality(t)
Intel F Price($t-1$)	0.5629	0.3201	−0.0703	0.0409
	(0.0926)	(0.1458)	(0.0399)	(0.0517)
AMD F Price($t-1$)	0.1304	0.7287	0.0069	−0.0299
	(0.0538)	(0.0847)	(0.0231)	(0.0300)
Intel F Quality($t-1$)	0.1120	0.0983	0.9540	0.1678
	(0.1413)	(0.2223)	(0.0608)	(0.0789)
AMD F Quality($t-1$)	−0.1868	0.0092	0.0262	0.8651
	(0.1371)	(0.2158)	(0.0590)	(0.0766)
Constant	2.4097	−1.2215	0.5626	−0.3068
	(0.4472)	(0.7039)	(0.1924)	(0.2498)
R^2	0.7921	0.8306	0.9981	0.9976

Non-Frontier Regressions	Intel NF Price(t)	Intel NF Quality(t)	AMD NF Price(t)	AMD NF Quality(t)
Constant	0.3228	1.0809	0.6355	0.8839
	(0.4092)	(0.0320)	(0.4383)	(0.0501)
Slope	1.1668	0.9169	1.0931	0.9449
	(0.0841)	(0.0046)	(0.1041)	(0.0072)
R^2	0.6448	0.9748	0.7954	0.9664

Estimates of the alternative expectations process for the model described in the Appendix.

Appendix G: Incorporating Instruments

The table below compares the estimates of the model with and without the instruments, as described in Section 4.3 of the paper. The table shows that the parameter estimates were mostly unaffected by instruments. While the lack of change in the parameters might suggest that the instruments are weak, the instruments are consistent with those used by others (such as Bresnahan, 1981, Berry, Levinsohn, and Pakes, 1995, and Gowrisankaran and Rysman, 2007). The benchmark model in the paper includes the instruments.

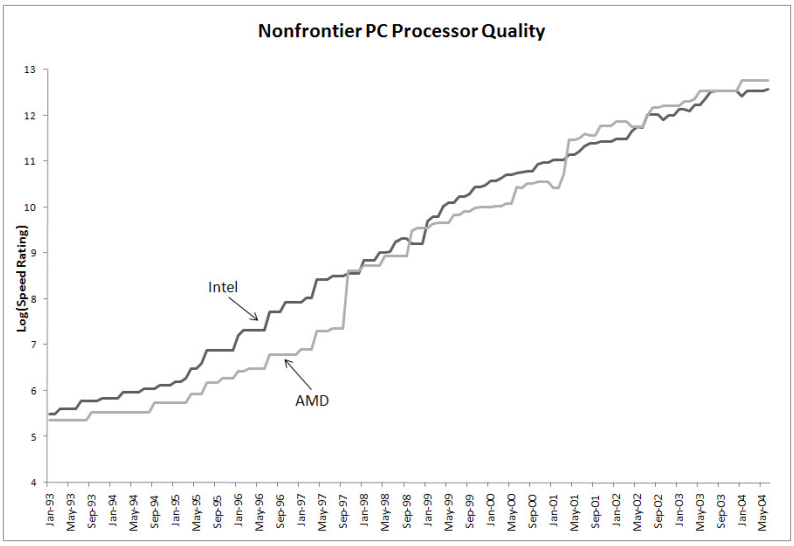
Table 3: Effects of Instruments on Structural Parameters

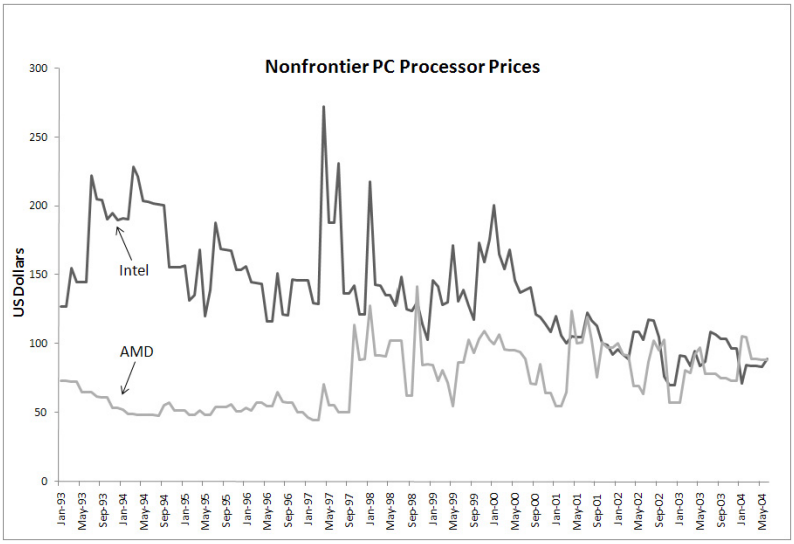
	Two Segment		Two Segment (IV)	
	Seg 1	Seg 2	Seg 1	Seg 2
Quality	0.563	0.625	0.582	0.679
	(0.635)	(0.078)	(0.071)	(0.79)
Price	−1.718	−1.604	−1.803	−1.620
	(0.408)	(0.457)	(0.423)	(0.430)
Intel	2.029	2.488	2.084	2.568
	(0.376)	(0.384)	(0.392)	(0.386)
AMD	0.247	0.323	0.257	0.341
	(0.059)	(0.047)	(0.050)	(0.054)
Initial Cond.				
Non-owners	0.909	0.091	0.923	0.077
	(0.113)		(0.125)	
Frontier	0.706	0.294	0.684	0.316
	(0.098)		(0.096)	
Non-Frontier	0.784	0.216	0.761	0.239
	(0.129)		(0.131)	
Segment size	0.876	0.124	0.863	0.137
	(0.060)		(0.062)	
Objective Value	0.079		0.081	
J-statistic	10.902		11.178	
p-value	0.282		0.264	

Estimates from the two-segment dynamic model with and without the instrumental variables in the estimation process.

Appendix H: Nonfrontier Quality and Price

This plot shows the composite nonfrontier qualities and prices for Intel and AMD. Prices are in constant January 2000 dollars.





References

[1] Berry, S., Levinsohn, J., and Pakes, A. (1995), "Automobile Prices in Market Equilibrium," *Econometrica*, 63, 841–890.

[2] Bresnahan, T. F. (1981), "Departures from Marginal Cost Pricing in the American Automobile Industry: Estimates for 1997-1978," *Journal of Industrial Economics*, 17, 201–277.

[3] Gowrisankaran, G. and M. Rysman (2007), "Dynamics of Consumer Demand for New Durable Consumer Goods," Working paper, Boston University.

[4] Stevens, J. (1994). *New Games: Strategic Competition in the PC Revolution*, Pergamon Press, New York.