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Product innovation and adoption in market equilibrium: The case of digital cameras ☆

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ABSTRACT

This paper studies the effect of competition on product innovation in the market for digital cameras during the years 1998 to 2001. The analysis is based on a structural dynamic model that is estimated and used to simulate the innovation behavior of firms in counterfactual environments. The model features heterogeneous consumers, who time optimally purchase goods, depending on the expected evolution of the prices and the characteristics of available cameras. On the supply side, firms introduce new camera models and choose their characteristics, accounting for the dynamic value of new products and the optimal dynamic behavior of consumers. The counterfactual simulations imply that an increase in competition in the industry would not have generated better products on average and, depending on the type of competition, would have generated products with lower average quality.

1. Introduction

This paper studies the relationship between competition and innovation in the market for digital cameras, using data on the sales and characteristics of virtually all camera models sold in the U.S. between 1998 and 2001. Since no exogenous variation in the structure of the market is observed during the time span of the sample, a dynamic structural model is estimated, in which the relationship between competition and product innovation is identified from the structure of the behavioral model. In the model, firms make their product introduction decisions, depending on the expected evolution of the set of available camera models and the adoption behavior of consumers, taking the observed set of competing firms as given. The estimated model can then be simulated under counterfactual assumptions, in which more or less firms of different types are active trying to introduce new camera models. The model is also used to simulate the innovation decisions of firms under counterfactual assumptions regarding the size of the market and the product innovation costs.

The results imply that competition alone has little effect on the variety and average quality of introduced camera models. Specifically, the presence of an increased number of average firms has no significant effect on the total number of camera models or their average quality. However, an increase in the number of "high quality" firms (i.e. firms with products that consumers systematically value more irrespective of their observed attributes) has a positive effect on the variety of camera models, but has a negative effect on their average quality. The reason is that increased competition, in general, "crowds out" the introduction of new products by existing firms. Increased competition stemming from a higher number of "high quality" firms, on the other hand, leads to the introduction of more products, but erodes the value of the introduction of higher quality cameras, so that new products tend to have a lower quality than in the benchmark scenario.

On the demand side of the model, consumers are assumed to time optimally their camera purchases and then leave the market. On the supply side, firms price their existing products and introduce new ones in a competitive way. It is assumed that firms do not consider the effects of their individual product introduction and pricing on the behavior of other firms or on the dynamics of the market, which is consistent with the small market shares of individual products observed in the data. Nevertheless, the introduction of new products depends on their expected profitability in the future, which in turn depends on the expected evolution of the whole market which is specific to the observed equilibrium.

Since firms have rational expectations and know the distribution of the dynamic states, the computation of any counterfactual equilibrium requires the computation of the consistent beliefs that drive the innovation decisions of firms. In other words, if there is more competition – or, for that matter, if the product introduction costs are lower or if the market is bigger – firms expect more camera models to be introduced and more consumers to anticipate their camera purchases, which in turn reduces the incentives of firms to introduce more and better models. The dynamic equilibrium is therefore a fixed point of the mapping of expectations into behavior, which has to be solved in any counterfactual simulation.

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Table 1
Summary statistics.

Quarter	Units sold	Sales in million $	# of models	Average price	Average resolution	Average zoom	Product concentration	Average share
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1998:1	0.22	131	86	609.4	0.52	4.56	0.14	1.2%
1998:2	0.23	134	95	585.0	0.61	4.13	0.10	1.1%
1998:3	0.27	154	98	577.2	0.70	3.73	0.07	1.0%
1998:4	0.31	208	101	668.5	0.83	4.27	0.07	1.0%
1999:1	0.28	181	112	647.8	0.86	4.74	0.07	0.9%
1999:2	0.34	220	126	641.2	0.97	4.58	0.06	0.8%
1999:3	0.54	263	139	483.9	0.93	3.65	0.06	0.7%
1999:4	0.90	393	143	436.8	0.97	3.09	0.06	0.7%
2000:1	0.73	341	172	463.9	1.11	3.54	0.05	0.6%
2000:2	0.80	392	185	490.4	1.39	3.32	0.04	0.5%
2000:3	0.98	434	216	444.6	1.41	2.91	0.03	0.5%
2000:4	1.91	782	210	408.8	1.45	2.59	0.03	0.5%
2001:1	1.12	445	221	396.0	1.53	3.04	0.02	0.5%
2001:2	1.17	451	245	384.1	1.58	3.17	0.02	0.4%
Total	9.81	4528	352	461.7	1.26	3.27	0.02	0.7%

The demand model is related to a growing literature on the estimation of dynamic models of demand for differentiated products. For example, Chintagunta and Song (2003), Erdem, Imai and Keane (2003), Gowrisankaran and Rysman (2006) and Hendel and Nevo (2007) rely on the use of a nested fixed point algorithm to solve the dynamic problem of individuals along the estimation algorithm which makes the estimation computationally difficult. I use, instead, an approximation of the dynamic problem solution, which facilitates substantially the estimation of the dynamic demand, especially when using product-level data and allowing for consumer heterogeneity. The specification also nests the standard static model as described in Berry, Levinsohn and Pakes (1995)(BLP).

The literature on the dynamics of product innovation is scarce and includes working papers by Holmes (2005) on location choice without strategic interactions and Goettler and Gordon (2008) on the endogenous innovation in the U.S. market for PC processors. There is a separate set of papers that fully account for the strategic interactions of firms, as Mazzeo (2002), Seim (2006) and Jia (2008), but ignore the dynamic aspects of the problem.

The paper is organized as follows: in the next section, the data set on which the estimation is based is introduced and described. In the third section, the detailed model of market equilibrium is discussed. In the fourth section, the empirical implementation and the estimation results are presented. In the fifth section, I discuss and show the results of the counterfactual simulations. The last section contains a concluding discussion.

2. Data: the U.S. digital cameras market

The methodology proposed in this paper is tailored specifically to study the digital photocameras market, which is a good example of a growing durable good market, with a rapidly improving technology, and its study may give insights on similar cases. The data set, on which the estimation is based, is a panel of monthly sales, prices and characteristics of more than 350 camera models, aggregated into quarterly data. In the data, each camera model has a set of attributes. The only characteristic that changes after the model is introduced is the price. Any change in the set of observed attributes is considered as an introduction of a new model. The data set spans the months between January of 1998 and September of 2001 and has a coverage of around 90% of the U.S. market. The sales and price data were obtained from a leading market research firm, whereas the information on the characteristics of the different camera models was obtained from many sources, mainly the Internet.

The centerpiece of a digital photocamera is a chip called Charge Coupled Device (CCD)[1]. A CCD is an integrated circuit comprising an array of photosites. The higher the number of these photosites ("pixels"), the better the quality of the picture (i.e. the resolution). Other main components of a camera are its lenses, which may have an adjustable focal length (optical zoom), a built-in liquid crystal display (LCD) of varying size and a magnetic storage device, which may be fixed or removable.

Table 1 contains some illustrative summary statistics of the data. Column (1) shows how the volume of sales of digital cameras increased throughout the whole time span of the sample, going from 215.000 units sold in the first quarter of 1998, to the more than one million sold in the first quarter of 2001[2]. Moreover, the quarterly value of sales, shown in column (1), more than tripled between 1998 and 2001.

The quality of the cameras also grew substantially. The main indicator of the quality of a camera, in particular during the time span of the sample, is its resolution. As can be seen in column (5), the average resolution of sold cameras increased from around 0.5 to slightly more than 1.5 megapixels[3]. The average optical zoom of sold cameras shown in column (6) decreased slightly during the time span of the sample. The reason is that increased resolution, which facilitates the use of a digital zoom, is a good and cheaper substitute for the optical zoom, especially among lower-quality cameras.

On the other hand, prices fell significantly over time, even as the quality was increasing dramatically. As seen in column (4), the average price paid for sold cameras fell from more than $600 at the beginning of the sample, to less than $400 at the end, without controlling for the change in quality. A hedonic price regression was estimated using the following specification:

$$\log\left(p_{jt}\right) = a_t + a_1 x_j^{res} + a_2 x_j^{zoom} + a_3 x_j^{card}$$

where x_j^{res} is the resolution (in megapixels) of camera j, x_j^{zoom} is the log of its optical zoom, and x_j^{card} is an indicator variable that takes value

[1] An alternative technology called CMOS gained importance in low-quality/low-cost applications, such as cell phone and PDA cameras. It was no factor, though, during the time span of this study.

[2] There is a big seasonal effect in December of each year; for example, in 2000 December sales accounted for 30% of the year's sales.

[3] Notice that averages on this table are computed over *sold* units.