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Product Development Strategies and Price Dynamics: The Japanese Compact Digital Still Camera Industry, 1997-2005*

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Abstract

The Japanese compact digital still camera (hereafter DSC) industry successfully maintained its global competitiveness from 1997 to 2005. The salient characteristics of the industry are frequent introductions of new models and high initial market prices. These features are in stark contrast to other Japanese digital electronics industries such as flat panel displays which faced severe price pressures from global rivals. Using data on 562 compact DSC models introduced by 31 manufacturers over the years 1997 to 2005, we examine the relationship between new product development and transaction price at the time of the camera model's introduction to the market. We pay particular attention to image resolution upgrades and rapid miniaturization. These two characteristics are the most conspicuous product development strategies in the Japanese DSC industry. We hypothesize that vertical differentiation of image resolution is the primary source of price dynamics in the late 1990s; an increase in the number of competing models drives down DSC prices. However, after 2001, price differentials are mainly explained by miniaturization with horizontal differentiation. Accordingly, an increase in the number of models competing horizontally produced by one manufacturer raises the price of a newly-introduced high-end model significantly. We employ hedonic-type regressions with relevant explanatory variables for the product development strategies such as the firm's product portfolio and the extent of vertical

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and/or horizontal product differentiation. Empirical results indicate that, while regular image resolution upgrades were the most important factor enabling high introductory prices in the late 1990s, rapid miniaturization with horizontal and vertical product differentiation became the key to understanding price dynamics in the 2000s. These findings indicate that it is very unlikely that "modularization" dictates the innovative pattern of the DSC industry. The main source of competitive advantage would arguably be the firm's organizational capability to integrate swiftly into new models various technological advances, which allow firms to demand high introductory prices.

Key words: digital still camera, product development, price dynamics, hedonic regression
JEL Classification: L63, O30

Contents

1 Introduction

The Japanese compact digital still camera (hereafter DSC) industry successfully maintained its global competitiveness from 1997 to 2005. The salient characteristics of the industry are frequent introductions of new models and high initial market prices. These features are in stark contrast to other Japanese digital electronics such as flat panel displays which face severe price competition from global rivals.

The relationship between product development strategies and price dynamics is a key issue in the empirical industrial organization literature. Lerner (1995) examined pricing in the disk drive industry using hedonic techniques and analyzed the impact of predatory practice upon pricing. Verboven (1999) examined the impact of product innovation on price discrimination. Berndt and Rappaport (2001) examined the price dynamics of personal computers using hedonic regressions. Unfortunately, there are very few empirical studies regarding the DSC industry. Bank of Japan (2002, 2005) employs hedonic analyses on Japanese DSC transaction prices using point of sale data. However, the BOJ study does not focus on price dynamics and the strategic behavior of Japanese DSC manufacturers.

Using data on 562 new compact DSC models introduced by 31 manufacturers over the years 1997 to 2005, we examine the relationship between product development strategies and transaction price at the time of the camera model's introduction to the market. We pay particular attention to: (i) regular upgrades of image resolution and (ii) rapid miniaturization. These two characteristics are the most conspicuous product development strategies in the Japanese DSC industry.

We hypothesize that vertical differentiation of image resolution is the primary source of price dynamics in the late 1990s; the increase in competing models drives down DSC prices. However, since 2001, price differentials are mainly explained by miniaturization with horizontal differentiation. Accordingly, an increase in the number of models competing horizontally produced by one manufacturer raise the price of a newly-introduced high-end model significantly.

We collected data on transaction prices and technological specifications from the monthly trade journal *Digital CAPA*. This journal supplies a range of data from technical profiles on new DSC models to the transaction prices for new models via independent surveys of mass retail stores in and around Tokyo. To supplement data on product specifications, we utilized the manufacturers' own product catalog.

We employ hedonic-type regressions with relevant explanatory variables for the product development strategies such as the firm's product portfolio and the extent of vertical and/or horizontal product differentiation. We construct several explanatory variables relating to: (i) vertical differentiation (upgrades to the image resolution); and (ii) rapid miniaturization with horizontal and vertical product differentiation.

The empirical results indicate that, although regular image resolution upgrades were the most important factor that enabled high introductory prices in the late 1990s, rapid miniaturization with horizontal *and* vertical product differentiation became the key to clarifying price dynamics in the 2000s.

This paper is organized as follows. Section 2 gives a brief overview of the Japanese DSC industry. Section 3 describes our main hypotheses. Section 4 explains the data and employs regression analyses concerning product development strategies and price dynamics. Section 5 discusses our findings in the context of product development architectures. Section 6 concludes this paper.

2 Industry Background

2.1 The Evolution of the DSC Industry in Japan

The world's first compact DSC was introduced by Casio in 1995. The Casio *QV-10* had a 0.25 megapixel (MP) charge-coupled device (CCD) and a small liquid crystal display (LCD) monitor. A CCD turns an analog image (i.e. what we see with the naked eye) into digital information (i.e. zeros and ones), thereby replacing the photographic film found in traditional analog cameras. CCDs are a common type of photoelectric light sensor used for applications requiring high light sensitivity[1]. A CCD contains a grid of pixels, which captures light and sends it to one or more image processors. The resolution of an image is measured by the number of pixels, thus a 3 MP camera has 2,048 horizontal and 1,536 vertical pixels yielding a total of 3,145,728 pixels, or roughly 3 MP.

In 1997 and 1998, Olympus and Fujifilm, respectively, were the first DSC manufacturers to introduce a series of new models offering roughly one MP[2]. The introduction of high-resolution DSC models (i.e. models with high pixel count) was a landmark event that triggered rapid technological upgrading in pixel counts among DSC manufacturers (Aoshima, 2003, 2007) resulting in a larger number of DSC models available on the market. The total value of Japan's domestic shipments of DSCs nearly tripled between 1997 and 1999, from ¥55.2 billion to ¥136.9 billion.

Table 1 shows the number of manufacturers that introduced at least one new DSC model annually from 1997 to 2005. Of a total of 40 manufacturers, nine companies (Canon, Casio, Fujifilm, Nikon, Olympus, Panasonic, Ricoh, Sanyo, and Sony) introduced a minimum of one new model per year throughout the nine-year observation period, 1997 to 2005.

[1]CCDs are generally preferred over CMOS (complementary metal-oxide-semiconductor) sensors for compact digital imaging (e.g. compact DSCs and camera phones) because they offer better image quality when used with small (i.e. dark) lenses. CMOS sensors (becoming more commonly known as active-pixel sensors (APS)) work well with large, bright lenses (i.e. lenses that allow in much light) and have a number of other benefits over CCDs, the details of which fall outside the scope of this paper.

[2]The benchmark models were introduced by Olympus (*C-1400L* with 1.41 MP) in 1997 and Fujifilm (*FinePix 700* with 1.5 MP) in 1998.

Table 1: Number of DSC manufacturers that introduced at least one new DSC model annually, 1997-2005

Year	No. of Manufacturers	Avg. MP
1997	23	0.48
1998	17	1.11
1999	17	1.68
2000	20	2.23
2001	22	2.31
2002	19	2.77
2003	21	3.45
2004	21	4.42
2005	17	5.68

Note: A total of 40 DSC manufactures introduced at least one new model between 1997 and 2005; 777 new models were introduced over that period.
Data Sources: *Digital CAPA* (various year).

2.2 Continuous Upgrading of Image Resolutions

Table 1 also gives the average number of pixels in new DSC models which were introduced between 1997 and 2005. The annual average number of MPs increased rapidly every year except in 2001 when the average number of pixels surpassed two million (i.e. 2 MP) and there was a temporary lull. It should be noted that image resolutions of more than 2 MP in a standard photo size are not distinguishable to the naked eye. Logically, it would appear that new models of more than 2 MP—or image resolutions that cannot be recognized by an ordinary person's eye—would be of little interest to consumers. Nonetheless, partly due to the cunning of marketers, consumers quickly became accustomed to rapid pixel count upgrades and actively sought out DSCs with higher MP counts.

The image resolution via MP upgrading, we believe, provides a key to clarifying price dynamics in the Japanese DSC industry. We agree with Aoshima and others that a *myth of higher pixels* (i.e. a higher pixel model represents a higher-end model) prevailed in Japan in the late 1990s. We will discuss this issue further in the following sections.

2.3 Pixel Upgrading and Product Generations

Regular image resolution upgrades enabled high initial market prices for new models in the late 1990s. In Table 2, we classified new compact DSC model introductions from 1997 to 2005 in terms of product generations and pixel upgrading. We identified nine product generations (G1, G2, etc. to G9) based on MP counts from less than one MP to eight MPs or more. We tallied up the total number of new compact DSC models introduced each year and calculated the average price at introduction of the compact DSCs to the market. It is clear from Table 2 that pixel upgrading over product generations is a key feature of the compact DSC market during the period we studied.

We observed two salient features regarding the relationship between the price at introduction and product generation over the 1997 to 2005 period. First, we observed a downward price trend *within one product generation* and this can be observed in every single generation over the entire observation period. In G4, for example, compact DSCs were introduced at an average price of ¥83, 353 in 2000 and then fell to an average price of ¥15, 663 in 2005. Each time a new model was introduced in a new product generation (i.e. a higher pixel count) the price was set higher than in earlier product generations. This can be very clearly seen by comparing the initial DSC introductory price in G5 and G6, ¥136, 500 and ¥144, 333 respectively, and looking down the column to compare those with the average prices of DSC introductions in subsequent years. It follows from this data that the industry-leading manufacturer was likely to set a high DSC price upon introduction to the market, whereas the followers of that generation were likely to set lower prices.

Second, we noticed that price differentials *between product generations* decreased markedly from 2001 to 2005. In 2004, 31 new DSCs were introduced in G5 averaging ¥44, 142 each while 34 DSCs were introduced in G6 at an average price of ¥50, 303. The most price differential between G5 and G6 was only ¥6, 161. In other years, a similar trend can be observed.

2.4 Rapid Miniaturization After 2001

Rapid miniaturization was the second significant aspect of DSC product development after 2001. Before 2000, horizontal differentiation added optional functions, which tended to increase the overall weight of the DSCs. After 2001, however, high-end models became significantly lighter in weight, which translated directly to the thickness of the DSC. In this paper, we take the weight and thickness to be directly correlated and therefore interchangeable.

Table 3 shows that the number of new models introduced into the market with a thickness of less than 30mm, the so-called 'thin models,' rose sharply in 2001. In May 2001, Canon broke through the 30mm thickness barrier with the introduction of the *IXY Digital* at a depth of only 26.9mm[3]. Intense competition to minimize the depth (and weight) of DSCs ensued with the number of new thin DSC camera models reaching nearly 50 percent of the total in 2005.

There has also been a rapid decrease in weight since 2001. Figure 1 depicts the average weight and the average thickness of new models introduced from 1997 to 2005. The average product weight decreased markedly as shown in the rapidly dropping curve between 2001 and 2003. The average product thickness decreased sharply after 2001. The drop in weight mirrors the drop in thickness.

[3]Canon became one of the top three DSC manufacturers after the introduction of the highly popular IXY series (Digital ELPH in North America, and Digital IXUS in Europe).

Table 2: Pixel upgrading and DSC product generations, 1997-2005

Generation	G1		G2		G3		G4		G5		G6		G7		G8		G9	
MP	MP < 1		1 ≤ MP < 2		2 ≤ MP < 3		3 ≤ MP < 4		4 ≤ MP < 5		5 ≤ MP < 6		6 ≤ MP < 7		7 ≤ MP < 8		8 ≤ MP	
1997	29	56,910	4	91,750	0		0		0		0		0		0		0	
1998	7	47,857	24	80,125	0		0		0		0		0		0		0	
1999	3	32,533	12	63,233	19	81,737	0		0		0		0		0		0	
2000	7	12,080	10	53,880	18	67,056	17	83,353	2	136,500	0		0		0		0	
2001	11	11,160	12	34,717	26	51,731	21	74,381	11	82,909	3	144,333	0		0		0	
2002	5	15,188	9	27,200	22	41,355	24	59,792	11	67,727	7	101,429	0		0		0	
2003	1	20,000	4	18,500	11	27,871	39	42,738	13	50,154	14	79,286	2	75,000	0		1	130,000
2004	0		0		2	25,000	24	39,808	31	44,142	34	50,303	8	63,875	6	74,167	6	123,333
2005	0		0		0		3	15,663	6	28,432	40	43,940	16	43,813	10	54,880	14	67,929

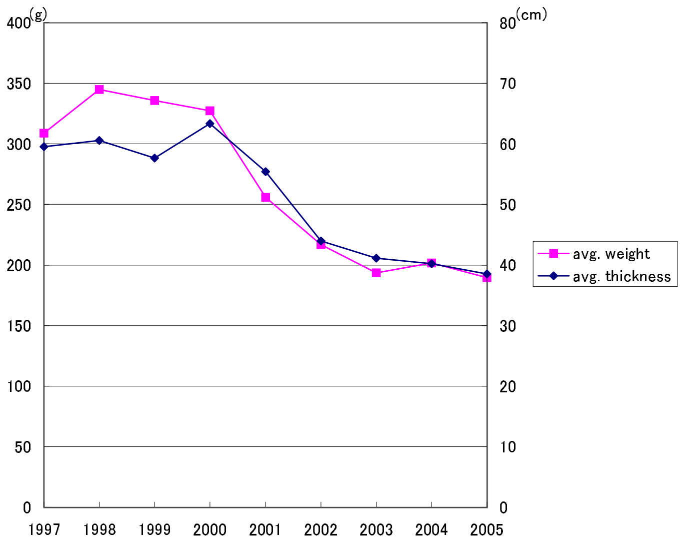
Note: The left is the number of new DSC models each generation. The right is average prices (¥).
Data Sources: *Digital CAPA* (various year).

Table 3: Number and share of new models of a thickness of less than 30mm, 1997-2005

Year of Introduction	No. of New Models (A)	No. of New Models of a Thickness of less than 30mm (B)	Share (B/A)
1997	52	2	3.85
1998	50	0	0
1999	50	0	0
2000	70	5	7.14
2001	100	14	14.00
2002	99	25	25.25
2003	109	29	26.61
2004	139	53	38.13
2005	108	53	49.07

Note: A total of 777 new models were introduced in total from 1997 to 2005.
Data Sources: *Digital CAPA* (various year).

Figure 1: The average weight and the average thickness of DSCs, 1997-2005



Note: A total of 777 new models were introduced from 1997 to 2005.
Data Sources: *Digital CAPA* (various year).

3 Hypothesis Formulations

3.1 Vertical/Horizontal Differentiation, Miniaturization, and Pricing

In this section, we summarize our key findings from the previous section to facilitate the formulation of our hypotheses. First, as discussed above, there was a *myth of higher pixels* among DSC consumers in Japan (and elsewhere), which offers a clue to clarifying price dynamics in the Japanese DSC industry. The pace of upgrading pixel counts was quite rapid in the late 1990s, and vertical differentiation by manufacturers accounted for this upgrading in the main. However, in the 2000s, although pixel count upgrading continued, price differentials between DSC generations gradually declined.

Second, the increase in the number of horizontally competing models produced by one manufacturer lowered the price of each new model introduced on the market in the late 1990s. Since 2001, however, a similar product development strategy led to a pattern of high prices when a new model of a new generation was introduced to the market. Finally, we confirmed that rapid miniaturization started around 2001 in the Japanese DSC industry reducing the average thickness of the DSC to below 30mm. In a similar and related trend, the average weight of DSCs decreased rapidly especially between 2001 and 2003 (from 280 grams to 197 grams). The evidence suggests that the pattern of innovation and product development changed drastically in or around 2001. This coincided with a major increase in the volume of production of all digital cameras including compact DSCs.

3.2 Hypothesis

Reflecting upon these findings, we hypothesize that the vertical differentiation of image resolution was the main source of price dynamics in the late 1990s. The increase in the number of competing models drives down DSC prices. However, since 2001, price differentials are mainly explained by miniaturization with horizontal differentiation. Accordingly, the increase in the number of horizontally competing models introduced by one manufacturer raise significantly the price of each newly introduced high-end model.

If we can confirm this hypothesis, the product development strategy of the Japanese DSC industry would have shifted from simple vertical differentiation (upgrading the pixel count) to a complicated mix of vertical and horizontal differentiation.

4 Empirical Analysis

4.1 Data

We obtained data on transaction prices and technological specifications from the monthly trade journal *Digital CAPA*. This trade journal provides not only technical profiles on new DSC models, but also transaction prices for new models based on the editors' independent surveys of mass retail stores in and around Tokyo, Japan's largest market for DSCs and a convenient testing ground for DSCs before launching new models globally. Transaction prices for 68 models, however, are reported only in special issues of *Digital CAPA*. This means that there may be up to a 6-month time lag between the date when the special issue appears and actual date of the new model's introduction. It should be noted that the price data with such a time lag may be lower than the prices at the date of introduction. We adjust for this possible measurement bias by using a dummy variable in hedonic regressions. We also utilized manufacturers' catalogs to supplement the data on product specifications.

The resulting dataset constitutes 562 new compact DSC models introduced by 31 manufacturers over the years 1997 to 2005. The variable names and definitions used in our analysis are summarized in Table 4 and the basic statistics are shown in Table 5..

4.2 Basic Specifications

The basic specification of the hedonic function is based on a Box-Cox regression model. The specification that we employ is:

$$\begin{aligned} price_i^{(\theta)} =& \alpha + M_i\beta_1 \times (Period1 + Period2) \\ &+ X_i^{(\lambda)}\beta_2 + Z_i\beta_3 + \beta_4 \sum_f D_i^f + \beta_5 \sum_t D_i^t + \beta_6 pld_i + u_i \end{aligned}$$

where $u \sim N(0, \sigma^2)$.

The explained variable (*price*) is an introductory transaction price at the date of introduction of a new model. This is subject to a Box-Cox transform with parameter θ.

We incorporated not only technological specifications but also product development strategies in the hedonic regressions as hypothesized above. That is, we constructed three types of strategic variables regarding: (i) *vertical differentiation in pixel counts*, (ii) *horizontal differentiation*, and (iii) *miniaturization.*

The first strategic variable (*vertical differentiation in pixel counts*) is defined by the absolute difference in pixels between a standard model and a cutting-edge model introduced within the same year. That is, the larger the value of this variable, the lower the level of the technology employed in the model by a particular manufacturer in the same year. The second strategic variable (*horizontal differentiation*) is defined as a dummy variable for each model which takes on the value of unity if the model is a manufacturer's second or later model introduction within a certain pixel generation within one year. The third strategic variable (*miniaturization*) is defined by the absolute difference in weight between a standard model and the lightest model introduced within the same year. That is, the larger the value of this variable, the lower the technology employed in the model by a particular firm in the same year.

Table 4: Variable definitions

price	Transaction price on the date of introduction
pixel	Image resolution (0.01 MP)
zoom	Optical zoom factor (magnification ratio)
lcd	Dummy variable that takes on the value of unity if the liquid crystal display size is more than two inches.
fstop	Dummy variable that takes on the value of unity if the lens takes a wide f-stop value under 2.8, otherwise zero.
fd	Dummy variable that takes on the value of unity if the lens takes a focal distance under 35mm, otherwise zero.
cpd	Closest photograph distance (cm).
weight	Weight without battery (gr).
depth	Dummy variable that takes on the value of unity if the thickness of a model is less than 30mm, otherwise zero.
power	Dummy variable that takes on the value of unity if a disposable battery can be used, otherwise zero.
vr	Dummy variable that takes on the value of unity if vibration reduction mechanism is installed, otherwise zero.
water	Dummy variable that takes on the value of unity if the model is waterproof, otherwise zero.
pld	Dummy variable that takes on the value of unity if the transaction price is observed with no less than six-month lag.

Table 5: Basic statistics

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	1997-2005
price	62057.14	71724.14	70864.71	69712.00	60522.82	53007.20	49913.58	53298.96	48044.44	56927.42
	(31983.55)	(29416.83)	(22860.25)	(36429.95)	(31884.08)	(27529.54)	(22493.44)	(25563.04)	(14767.50)	(27711.84)
pixel	55.82	119.10	176.06	238.28	258.31	291.67	355.44	471.29	593.00	341.14
	(35.09)	(36.74)	(53.85)	(96.38)	(124.70)	(126.90)	(120.25)	(135.27)	(134.84)	(190.59)
zoom	1.54	2.34	2.31	2.97	2.94	2.93	3.39	4.06	4.39	3.29
	(0.88)	(1.83)	(1.45)	(2.24)	(2.08)	(2.00)	(2.25)	(2.54)	(2.70)	(2.33)
lcd	0.29	0.66	0.32	0.30	0.21	0.03	0.07	0.33	0.81	0.32
	(0.46)	(0.48)	(0.47)	(0.46)	(0.41)	(0.16)	(0.26)	(0.47)	(0.39)	(0.47)
fstop	0.14	0.34	0.32	0.30	0.27	0.23	0.19	0.23	0.16	0.23
	(0.36)	(0.48)	(0.47)	(0.46)	(0.45)	(0.42)	(0.39)	(0.42)	(0.37)	(0.42)
fd	0.11	0.24	0.09	0.18	0.14	0.09	0.16	0.23	0.14	0.16
	(0.31)	(0.44)	(0.29)	(0.39)	(0.35)	(0.29)	(0.37)	(0.42)	(0.34)	(0.36)
cpd	25.00	16.52	17.59	12.02	13.97	20.31	13.20	7.24	6.09	13.03
	(20.93)	(10.48)	(16.94)	(10.74)	(13.17)	(30.61)	(21.94)	(5.51)	(6.46)	(17.63)
weight	320.29	322.59	304.69	326.86	280.31	218.15	197.64	212.86	198.36	245.36
	(131.37)	(143.34)	(119.40)	(175.74)	(170.61)	(113.74)	(120.44)	(122.93)	(137.41)	(145.58)
depth	0	0	0	0.08	0.13	0.28	0.31	0.40	0.53	0.26
	—	—	—	(0.27)	(0.34)	(0.45)	(0.46)	(0.49)	(0.50)	(0.44)
power	0.18	0.14	0.29	0.32	0.50	0.56	0.58	0.70	0.67	0.52
	(0.39)	(0.35)	(0.46)	(0.47)	(0.50)	(0.50)	(0.50)	(0.46)	(0.47)	(0.50)
vr	0	0	0	0.04	0	0	0.05	0.08	0.25	0.06
	—	—	—	(0.20)	—	—	(0.22)	(0.27)	(0.43)	(0.24)
water	0	0.03	0.03	0.02	0	0.05	0.01	0.02	0	0.02
	—	(0.19)	(0.17)	(0.14)	—	(0.23)	(0.11)	(0.14)	—	(0.13)
obs.	28	29	34	50	78	75	81	106	81	562

Note: Standard errors are in parentheses.

The first vector M_i represents the product development strategies, i.e., vertical differentiation in pixel counts, horizontal differentiation, and miniaturization. *Period1* (*Period2*) denotes a dummy variable for the years 1997-2000 (or 2001-2005, respectively) which takes on the value of unity if a model is introduced within that period. These dummies are related to the hypothesis testing whether DSCs were dominated by vertical differentiation in the late 1990s and whether horizontal differentiation prevailed after 2001. We expected negative signs for the coefficients of M_i in *Period1*, especially for coefficients of the element of vertical differentiation in pixel and horizontal differentiation. Conversely, we anticipated positive signs for the coefficient of the element of horizontal differentiation in *Period2*. However, we expected negative signs for the coefficient of the element of miniaturization in *Period2*.

The column vector $X_i = (pixel, zoom, cpd, weight)'$ represents technical profiles. These elements are transformed by a Box-Cox transformation with the parameter λ. The column vector $Z_i = (lcd, depth, fstop, fd, power, vr, water)'$ presents technical profile dummies. D_i^f are firm dummies and we take the base firm as Sony. D_i^t represents year dummies; we take the base year as 1997. α is a constant term. We adjust for possible measurement bias due to price observation lags by using a dummy variable *pld* that takes on the value of one if the transaction price is observed with no less than a six-month lag.

4.3 Estimation Results

Table 6 shows the estimation results. We perform likelihood ratio tests on three standard functional forms (i.e. linear, semi-log, and log-log models). The tests indicate that the three functional forms can be rejected at a 1% significance level, which supports a both-side Box-Cox transformation regression model as our basic specification.

The first strategic variable regarding *vertical differentiation in pixel counts* for the years 1997-2000 is statistically significant at 5% level and the coefficient has negative sign as expected. On the other hand, for the years 2001-2005 this strategic variable is statistically significant at 1% level and the coefficient has positive sign. This appears to be puzzling. However, this should make lower price differentials between product generations. These results provide support our hypothesis that although regular upgrades of image resolution constitutes the most important factor that enables high introductory prices for 1997-2000, higher pixel models are priced lower from 2001.

The second strategic variable concerning *horizontal differentiation* for the years 1997-2000 is statistically significant at a 5% level and the sign of this coefficient is negative. In contrast, this strategic variable is statistically significant at a 1% level and has positive coefficient for the years 2001-2005. These results are consistent with our hypothesis that the increase in horizontal differentiation raises the price of each newly introduced high-end model.

The third strategic variable regarding *miniaturization* for the years 1997-2000 has no explanatory power. However, for the years 2001-2005, this strategic variable is statistically significant at a 1% level and the coefficient has negative

Table 6: Hedonic regression results

Variables	Coefficient	Variables	Coefficient
Product development strategies		**Firm dummies**	
Vertical differentiation in pixel counts, 1997-2000	−0.004**	Agfa	1.393
Vertical differentiation in pixel counts, 2001-2005	0.005***	Axia	−2.561***
Horizontal differentiation, 1997-2000	−0.750**	Bandai	−3.125**
Horizontal differentiation, 2001-2005	1.044***	Canon	0.005
Miniaturization, 1997-2000	0.002	Casio	0.256
Miniaturization, 2001-2005	−0.003***	Chinon	−0.725
Technical profiles		Concord	−3.899***
pixel	0.465***	Epson	−0.147
zoom	0.294***	Fujifilm	−0.103
cpd	0.007	Hitachi	1.340
weight	0.503***	Kodak	−1.106***
Technical profile dummies		Konica	−0.432
lcd	0.305**	Konica-Minolta	−0.105
depth	0.801***	Kyocera	0.965**
fstop	0.160	Leica	−0.045
fd	0.331**	Maxell	−0.586
power	1.147***	Minolta	0.750**
vr	0.199	Muji	−2.895**
water	2.495***	Nhj	−2.253***
Year dummies		Nikon	0.362
1998	−0.635*	Olympus	0.062
1999	−1.456***	Panasonic	0.238
2000	−2.852***	Pentax	0.852***
2001	−4.117***	Polaroid	−0.600
2002	−4.937***	Ricoh	0.473
2003	−5.884***	Sanyo	0.445
2004	−7.018***	Sharp	1.571
2005	−8.556***	Tomy	−6.291***
pld	−0.798***	Toshiba	−0.645
constant	20.508	Victor	0.702

Notes: ***, **, * denote significance at 0.01, 0.05, 0.10 levels respectively. The number of observations is 562. The log-likelihood is −5894.09. The estimated parameter θ is 0.178 where the explained variable, *price*, is transformed by a Box-Cox transform. The estimated parameter λ is 0.346 where the explanatory variables, X_i, is transformed by a Box-Cox transform. They are statistically significant.

sign as expected. These results indicate that rapid miniaturization with horizontal as well as vertical product differentiation facilitated higher introductory prices from 2001.

We obtained virtually significant coefficients regarding quality-related variables and other controls. First, *pixel* and *depth* are significant and positive, and they had relatively large impact upon prices. Second, the positive sign of *cpd* appears to be rather puzzling since a closer photographic distance is a desirable function for DSCs. However, the coefficient is not statistically significant at a 10% significance level. Third, year dummies are decreasingly negative and significant. Since the base year is 1997, our result suggests that DSC prices consistently declined throughout our observation period. Finally, several firm dummies are negative and significant.

4.4 Robustness Check

For the purpose of a robustness check, we employed regressions using several different specifications. The estimation results are summarized in Table 7.

Equation (8.1) excludes *Period1* and *Period2* from the basic model. The three variables on product development (i.e., vertical differentiation in pixel counts, horizontal differentiation, and miniaturization) have no significant coefficients without the cross terms of period dummies. This suggests that no particular strategic variable has any explanatory power consistently throughout the entire observation period. In other words, product development strategies qualitatively changed around the turn of the new millennium.

Equation (8.2) defines *Period1* (1997-1999) and *Period2* (2000-2005) using a different breakpoint from the basic model. The first period (1997-1999) produces negative effect of the first and the second strategic variables on prices, whereas the second period (2000-2005) induces a positive effect of the first and the second variables on prices. Hence the basic estimation results on vertical differentiation (i.e., pixel upgrading) and horizontal differentiation (i.e. the increase in competitive models) are robust. However, the third strategic variable (i.e., miniaturization) has no significant impact on prices. A possible reason would be that rapid miniaturization started from 2001, and prices of new models introduced in 2000 confounded the effect of miniaturization on prices in the estimation.

Finally, Equation (8.3) excludes firm dummies from the basic specification. We obtained virtually the same results regarding the three strategic variables.

5 Discussion

5.1 Does Fluid Technical Advance Restrain Modularization?

Modularization of parts and components does not prevail in the Japanese DSC industry. Most developments regarding key components such as imaging devices,

Table 7: Robustness of regression results: alternative specification

Product development strategies	(8.1) Without the cross terms of *Period1* and *Period2*	(8.2) *Period1*	(8.2) *Period2*	(8.3) Without firm dummies	(8.3) Without firm dummies
Observations:	1997-2005	1997-1999	2000-2005	1997-2000	2001-2005
Vertical differentiation in pixel counts	0.000	-0.006^{*}	0.006^{***}	-0.017^{**}	0.023^{***}
Horizontal differentiation	−0.010	-0.516^{**}	0.629^{***}	-3.249^{***}	4.395^{***}
Miniaturization	−0.000	0.000	−0.001	0.010	-0.016^{***}
Log-likelihood	−5909.01	−5960.37		−5960.37	

Notes: Equation (8.1) excludes cross terms of *Period1* and *Period2*. Equation (8.2) defines *Period1* (1997-1999) and *Period2* (2000-2005) differently from the basic model. Equation (8.3) excludes firm dummies. ***, **, * denote significance at 0.01, 0.05, 0.10 levels respectively. The number of observations is 562.

batteries, and lenses, to name a few, occurred sporadically and in unexpected ways. Furthermore, Japanese manufacturers have vastly different origins and industry backgrounds some excelling in optical technologies and others in electronics technologies. Accordingly, very fluid technological advances are likely to induce most Japanese manufacturers to incorporate few modular components into their products (Aoshima, 2003, 2007). This appears to be in stark contrast to other electronics products.

There are two main types of product development architectures: *modular architecture* and *integral architecture* (Clark and Fujimoto, 1990; Henderson and Clark, 1990; Ulrich, 1995; Baldwin and Clark, 2000, among others). Modular architecture includes a one-to-one mapping from functional elements to physical components and specifies decoupled interfaces between components. On the other hand, integral architecture includes a complex (non one-to-one) mapping from functional elements to physical components and/or coupled interfaces between components (Ulrich, 1995, p. 422).

Aoshima (2007) suggests that product development strategies in the Japanese DSC industry have evolved historically on the basis of integral architecture. On the other hand, Itoh (2004) emphasized a different view, that modular architecture has played a role in the Japanese DSC industry. Our findings are consistent with Aoshima (2007). We believe it is unlikely that modularization has dictated the innovative pattern of the Japanese DSC industry. The main source of competitive advantage, arguably, is the firms' organizational capability to integrate swiftly various technological advances into new DSC models which can then command high introductory prices.

5.2 Modular or Integral Architecture?

As noted above, modularization of parts and components did not prevail in the Japanese DSC industry to 2005. Most technological development in the DSC key components (e.g. imaging devices such as image sensors and image processors, batteries such as lithium-ion batteries, and lenses such as zoom and telephoto lenses), occurred sporadically and in unexpected ways. Instead, integral architecture has tended to characterize the Japanese DSC industry. Table 8 shows some of the standards-setting activities of the industry association comprised of DSC and other manufactures of imaging products, the Japan Camera Industry Association (JCIA) and its successor the *Camera & Imaging Products Association* (CIPA) established in July 2002[4].

As is shown in Table 8, the most active period of standards setting for DSCs began in 2003 not long after the formation of the CIPA[5]. All previous activity

[4]The CIPA evolved out of the Japan Camera Industry Association (JCIA) which was dissolved in July 2002. As the DSC manufactures shifted away from traditional film (analog) cameras and moved decisively into digital imaging, they agreed to shift and expand their industry association to include all manufacturers of digital imaging products (Nelson, 2007). In a sense the JCIA's digital camera study group became the core of the JCIA, which created internal pressure for a new organization (the CIPA) to represent digital imaging and replace the old (the JCIA).

[5]The CIPA was preceded by the JCIA and the JCII, the latter of which was especially

in digital imaging had come under the JCIA's digital camera study group, and prior to 1989, most camera and optical goods standards setting took place under the auspices of the internationally-respected Japan Camera Industry Institute (JCII)[6]. Given the strong history of standards setting, it is conceivable that the industry will move away from integral architecture into modular, but in 2005 this was not yet the case.

5.3 Weak Modularization in the DSC Industry

Figure 2 indicates the typical components of compact DSCs. On the left, an analog image (or light) enters the lens and passes through the image sensor which translates the image from analog to digital. Then the digitalized image passes into the 'computer' located inside the camera where the image is processed, i.e. any shortcomings found in the digital image (e.g. the white balance) are handled and the image quality is improved. This is where the top-of-the-line DSC manufacturers differentiate themselves most; how well they can improve the image depends on the content and caliber of the image processing technology in the DSC. The processed image is then stored in the computer's memory where it can be viewed temporarily on the LCD monitor (Figure 2, right side) or transferred to the removable memory, such as a mini-SD card. The DSC is powered by a removable rechargeable battery.

It is possible to identify the basic contents of the typical DSC as we have done in Figure 2, nonetheless there was a great deal of variation in the DSCs on the market as of 2005. The components identified in Figure 2 are only an indication of the components that could be modularized for production, but our findings indicate that modularity was not significant for two reasons. First, the specifications of each component varied considerably by manufacturer. In the case of Canon's IXY Digital, for example, the image processor was branded DIGIC, based on Canon's own proprietary technology developed in-house. Second, each manufacturer combined the components in different ways depending on the specifications of each model. A non-standard, and therefore non-modular, aspect of DSCs was the combination and the method of manufacturing the functions of the DSC's computer. In some cases, the chips were packaged into one system (i.e. system-on-chip) or they were combined in unique proprietary patterns perhaps including additional chips not noted in Figure 2.

In summary, as of 2005, DSCs were not modular, but as Figure 2 indicates, there could be the possibility of modular production for some components in the future.

known internationally as a leading organization in international standards setting. It was a source of information on standards setting not only for cameras and other optical goods but also for completely different industries.

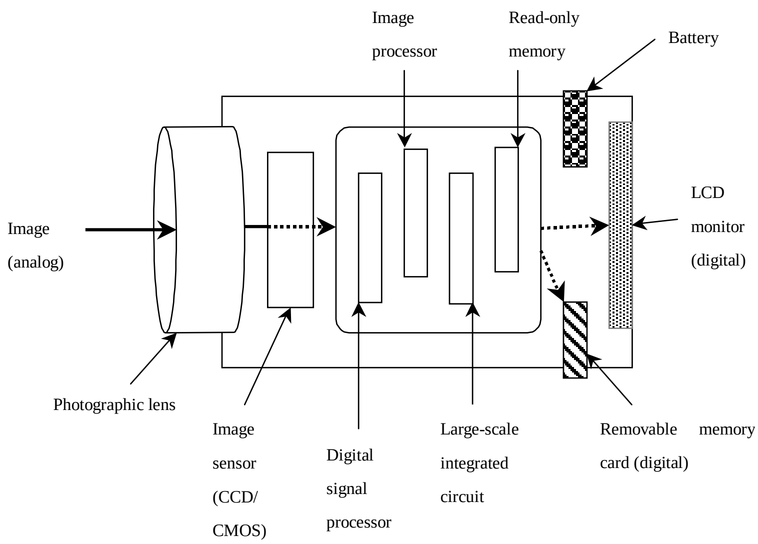
[6] The JCII was established as the Japan Camera Inspection Institute under the Export Control Law of 1954. As the industry expanded, the institute's name changed in 1973 to the Japan Camera and Optical Instruments Inspection and Testing Institute with the acronym JCII remaining unchanged. In 1989, when export inspection duties were deemed unnecessary, the institute's name changed again to reflect its new role as a source of industry information.

Table 8: JCIA and CIPA Standards and Guidelines for Digital Imaging Products

Publication date	Title of standard	Deliberated by	Application policy
March 1999	Guideline for Noting Digital Camera Specifications in Catalogs	JCIA's digital camera study group	
February 2003	Digital Photo Solutions for Imaging Devices	Standard Development Working Group, DPS Sub-Working Group	Proposed on 2002-12-04 by Canon, Fujifilm, HP, Olympus, Seiko Epson and Sony.
December 2003	Standard Procedure for Measuring Digital Still Camera Battery Consumption	Technical Working Group, Battery-Life Sub-Working Group Group	Standardizes the method of presenting the battery consumption of each type of digital camera, which is now being inconsistently described in catalogs, operation manuals, etc. This standard is recommended, but not enforceable.
December 2003	Resolution Measurement Method for Digital Cameras	Technical Working Group, Resolution Sub-Working Group	Standardizes the method of presenting the resolution of each type of digital camera in future catalogs, operation manuals, etc. This standard is recommended, but not enforceable.
July 2004	Sensitivity of Digital Cameras	Technical Working Group, Sensitivity Sub-Working Group	Standardizes the method of presenting the sensitivity of each type of digital camera in future catalogs, operation manuals, etc. This standard is recommended, but not enforceable.
November 2005	"Picture Transfer Protocol" over TCP/IP networks (PTP-IP)	Standard Development Working Group, PTPIP Sub-Working Group	Proposed on 2005-04-06 by FotoNation Inc.

Sources: *Camera & Imaging Products Association* (http://www.cipa.jp/english/hyoujunka/kikaku/)

Figure 2: Typical components in compact digital still cameras (cross-section)



Sources: Interviews with DSC manufacturers, Spring 2007.

6 Concluding Remarks

We examined the relationship between new product developments and introductory transaction prices in the Japanese DSC industry. Empirical results indicate that, although regular upgrading of image resolutions via higher pixel counts is the most important factor that enables high introductory prices in the late 1990s, rapid miniaturization with horizontal as well as vertical product differentiation becomes a key to clarify price dynamics in the 2000s.

It is arguable that the product development strategies of the Japanese DSC industry shifted from simple vertical differentiation to a complicated mix of vertical and horizontal differentiation. The Japanese DSC industry has historically evolved on the basis of an integral architecture, which possibly has kept the product design from moving toward modularization. This study indicates that it is unlikely that modularization dictates the innovative pattern of the Japanese DSC industry. Indeed, this may be a reason for the continued global competitiveness of the Japanese DSC industry.

The present study opens up a number of questions for further study. First, although we obtained price and specification data from *Digital CAPA*, it is not comprehensive enough for us to conclude definitively on global trends in the DSC industry. Point-of-sale data would be more desirable, but unfortunately it is too expensive to be used in the present study.

Second, modular components appear to be gradually prevailing as they are being employed in other related industries. For example, CCDs are used in other electronics such as mobile handsets and video cameras, and the market for them in other new contexts, such as miniature cameras to assist with automobile navigation, is growing steadily. Developments in CCDs and CMOS sensors to the benefit of other industries could change the direction and intensity of manufacturers' DSC product development strategies in the near future.

Third, accurate measurement of product differentiation is difficult to derive in principle, and the index used in the present study may not be robust enough to reflect the extent of real differentiation present in the DSC industry. This is not to mention the practical problem of data availability.

Finally, most Japanese DSC manufacturers are highly diversified. Therefore it is likely that their organizational structure and R&D management are closely interrelated. However, this consideration would require us to construct a structural econometric formulation, which would alleviate possible endogeneity issues and facilitate the interpretation of behavioral hypothesis more directly than reduced from hedonic regressions of the present study.

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