Direct substitutes and indirect complements in durable goods market: The digital camera market 2001-2004

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Abstract

This paper examines the rapid diffusion of digital as opposed to film cameras in the period 2001-2004. It investigates those factors contributing to the displacement of film cameras by digital cameras by estimating demand equations for digital cameras as well as for two kinds of film cameras. The estimation results show that Windows XP adoption and PC household ownership as well as rapidly dropping prices of digital cameras have played significant roles in the market penetration of digital cameras.

摘要

这篇论文简要分析数码相机市场在 2001-2004 年间飞速发展，替代胶卷相机的过程。通过估计消费者对于数码相机以及胶卷相机的需求曲线，本文研究数码替代胶卷相机的诸因素。实证分析的结果证明，计算机操作系统 Windows XP 的使用，计算机的普及，以及数码相机价格的下降是导致数码相机迅速进入消费者家庭的重要因素。

Key word: Substitutes Complements 3SLS

1. Introduction

Digital cameras, in the sense of a device meant to be carried and used like a handheld film camera, appeared in 1981 with the demonstration of the Sony Mavica. However, they did not become commercially available until Kodak launched its DCS-100 in 1991. For many years, digital cameras have remained a privilege only of news agencies and journalists. Sales of digital cameras have not taken off until a decade later.

However, over the past few years, we have observed soaring sales of digital cameras whereas in the meantime sales of film cameras have fallen drastically. Relative to film, digital cameras offer enhanced quality of picture reproduction plus improved ease-of-use; both properties are especially critical to amateur photographers. Data from the Photo Marketing Association International (PMAI) show that the 1996 unit sales of digital cameras in the US were 0.4 million only but increase to 18.2 million by 2004. By contrast, the 1996 unit sales of film cameras were 15.1 million but dropped to 6.7 million by 2004[1]. In a 2005 PMAI[2] report, 12.2% of the households surveyed reported that they planned to buy a digital camera in the next 3 years, while only 2.2% of households planned to buy a film camera. As far as cameras are concerned, digital technology appears to be displacing film. The changes in their respective market shares between 1995 and 2004 are depicted in Figure 1.

At first sight, it looks only natural that digital cameras would replace film counterparts in the market. However, things may not be so simple. Digital cameras were developed first from the technology very different from the traditional cameras. The first attempt, Sony Mavica, was built on television technology and was essentially a video movie camera. Research in marketing has also shown that, as a “really new product” (Lehmann 1994) and due to its many features, a digital camera can be categorized rather differently (Moreau, Markman, and Lehmann 2001) as a substitute for different products, such as film cameras and scanners, etc. Even compared within the broad category of film

1 2004-2005 PMA Industry Trends Report Retail Markets--A Performance and Trends Analysis the U.S. Imaging Industry.

2 2005 PMA U.S. Consumer Photo Buying Report.

cameras, digital cameras with LCD screens on the back are very akin to instant cameras (e.g., Polaroid) which can also show how the pictures look like right after they are taken. In light of these complex substitution patterns, it is unclear how the rise of the digital camera sales affects that of the traditional cameras. Previous research (Song and Chintagunta (2003), Carranza Romero (2002) and Lakishyk (2003)) has investigated the rise of the digital camera industry by employing characteristics space method. They are able to point out the characteristics contributing to the brand success, however, they do not analyze how the digital camera as a brand new product takes the place of the film camera. In this research, we investigate this issue by looking the demand functions for digital cameras and two types of film cameras, namely, the single-lens reflex film cameras (hereafter, SLR cameras)[3] and the lens-shutter compact film cameras[4]. Particularly, we investigate the interaction between prices and demands of the two camera sectors: what is the impact of falling digital camera prices on the demand for film cameras, and, in return, what is the impact of the consequential fall in film-camera prices on the demand for digital cameras?

In addition, another purpose of this is to identify the factors that contributed to the rise of the digital cameras. Conceivably, as the adoption process of many other digital technologies, the adoption of digital cameras requires the complementors in both hardware and software. Gupta, Jain, and Sawhney (1999) proposed a model of indirect network externalities and presented results of application to the U.S. digital television manufacturing industry. Their results demonstrated that the demand for digital television sets is indirectly affected by the availability of programming for digital TV. Nair et al (2004) investigated the indirect network effects between the PDA hardware and the relevant software. The empirical evidence indicates that the indirect network effect

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3: Focal plane shutter means "a camera shutter which lies inside the camera body, immediately in front of the film surface. Such shutters are rectangular and made of narrow blinds or curtains which move along, exposing the film surface to light. Since they use moving curtains they are vulnerable to the X-sync problem when used with flash photography. Most SLRs have focal plane shutters, which are of the behind-the-lens kind. Not all cameras do, however. Other cameras place the shutter within the lens itself - leaf shutters. Therefore, FP shutter camera here indicates the high-end amateur camera, mainly the SLR (single lens reflex) camera," Photonotes.org.

4: A lens-shutter compact camera is defined as "Any compact non-SLR camera that does not support interchangeable lenses and which has either very simplified controls or is highly automated or both. Such cameras are meant to be used by ordinary consumers who want to record snapshots of everyday life without having to learn about how to use a camera," Photonotes.org.

explains 22% of the difference in sale between Palm O/S compitable PDAs and MS O/S compitable PDAs. Similar for digital cameras, the availability of hardware (e.g., high-quality color printers, home PCs, etc.) and proper software (e.g., computer operating system) will also impact the demand of digital cameras. We consider the diffusion of Windows XP and the increase in PC home ownership as providing such indirect externalities. Windows XP was first released on October 25, 2001 and as of 2006 is the most recent consumer version of the Windows operating system available, with over 400 million copies in use. Windows XP is designed to cater to digital photography and makes picture transfer and editing easy. We would expect to see its adoption boost the sale of digital cameras. Digital cameras tend to have limited storage in themselves, especially so in its early days; thus consumers typically rely on home PCs to store and process digital images. Hence we also expect to see a strong positive correlation between the home PC ownership and digital camera demand.

This paper is organized as follows. The next section proposes a camera demand model suitable for estimation. Section 3 describes the data and discusses some hypotheses testable with the data. Section 4 examines the empirical results, and the final section summarizes my findings.

1.1 Recent Camera Market Development

In a broad sense, the camera market consists of three sub-markets: the lens-shutter compact camera (lens-shutter camera), the focal plane shutter camera (SLR camera), and the digital-camera market. Both SLR and lens-shutter cameras record light images on photosensitive material, film, while digital cameras record the image using an electronic sensor chip. Figure 1.2 plots the average prices[5] of shipment, from Japan to North America, for these three types of cameras by month over the period August 2001 to August 2004. If prices map perceived qualities, the price gaps reveal that SLR cameras are regarded as a high-end product within the set of film cameras. Digital cameras have the highest prices of all camera types.

5 In terms of FOB (free on board price).

Figure 1.4 shows the quantity of cameras shipped from Japan to North America over the same period as in Figure 1.2. It can be easily observed following the industry features for the period 2001 to 2004:

First, shipments of both lens-shutter and SLR film cameras are falling over the years of the sample while shipments of digital cameras are rising. The decline in lens-shutter-camera shipments in conjunction with the rise in digital-camera shipments is noteworthy. For example, at the beginning of the sample period in August 2001, the shipments of film cameras were greater than those of digital cameras. By the last period, however, the shipments of digital cameras outnumbered those of film cameras by a factor of three to one. These time-series data are consistent with the belief that digital displaced film cameras.

Second, while there is a monthly fluctuation in camera prices, the prices reveal an annual decline. Over the early parts of the sample period, what declines markedly is the price of digital cameras, which is not matched by the price drop of film cameras. In the last few periods, however, the prices of lens-shutter cameras dropped in a larger magnitude. Figure 1.3 graphs the price ratio of digital cameras to film cameras. The price ratio of digital cameras to SLR is stable, but that of digital cameras to lens-shutter cameras shows a U-shape, which says the prices of lens-shutter cameras dropped in a larger magnitude recently.

The observed phenomena can be understood by studying the structure of these markets. The digital-camera market is highly concentrated. The top five manufacturers account for 80% of the total unit sale. These major players compete in price, so their prices are driven down to their marginal costs. As technology develops, the cost of digital cameras is declining, which shifts the supply curve out and drives down the price. This price drop in the digital-camera market increases the quantity demanded and impacts the demands negatively in the other two markets as well because demands in these sub-markets are correlated: the three sectors of cameras are substitutes for each other. On the other side, the SLR and lens-shutter camera markets are mature. Both the entry and exit of firms are rare, and the technology has also been normalized, which means that the supplies in both markets are stable. Hence, drops in both price and quantity are caused by the shift-in of demand curves, which as mentioned before, may be driven by the price drop in the digital-camera market. Therefore, the key for a reasonable explanation of the phenomena is to investigate the substitution between cameras.

The U-shape relative price (Figure 1.3) associated with an increasing gap in camera shipments between digital and lens-shutter cameras, however, suggests that price competition itself cannot explain the market-share trends in this industry. It entails other factors besides prices to explain the competition between digital and film cameras. Table 1.1 reveals the fact that digital cameras are intimately tied with computers: most digital camera buyers are also owners of personal computers. PCs are critical complements for the successful use of digital cameras since PCs permit digital photos to be stored, organized, archived, shared, edited, printed, and viewed. Hence, digital-camera purchasing behavior is conditioned on computer ownership. We can decompose this relationship with the use of Bayes' Rule as follows:

$$P\left\{DC \quad buyers\right\} = \frac{P\left\{DC \quad buyers \middle| PC \quad owner\right\} P\left\{PC \quad owner\right\}}{P\left\{PC \quad owner \middle| DC \quad buyers\right\}}$$

where $P\left\{DC \quad buyers\right\}$ is the probability of a household buying a digital camera. The denominator on the RHS is the probability of a digital camera buyer owning a personal computer. The product of these two terms is the probability of a household owning a PC and buying a digital camera as well. Using the Bayesian theorem reveals that this product should be equal to the numerator on the RHS, which also indicates the same probability conditional on the household owning a PC.

Table 1.1 reveals that the probability of a digital camera buyer owning a personal computer is relatively unchanged between 2000 (91.9%) and 2003 (93.5%) so that the denominator in the above expression is relatively constant. Consider the two terms in the numerator. The first term indicates how likely it is for the PC owner to buy a digital camera. The observation[6] is that PC owners' buying digital cameras went from 16.8% in 2000 to 41.9% in 2003. Meanwhile, PC penetration in households increased from 51% to 61.8%. Thus, not only was there an increase in the households with PCs buying digital cameras in 2003 as compared to 2000, but there was also an increase in the households buying PCs in the same time period.

In general, this discussion suggests that any demand function for digital cameras should take into account the penetration of computers into households and, consequently, those factors driving PC owners to buy a digital camera. Windows XP adoption is such a key factor, due to the special features of XP designed to work well with digital cameras. As is stated in the "PC buyer's guide for photography fans,"[7]

> Microsoft Windows XP. . . . is a great operating system for the digital photography enthusiast. With Windows XP, many of the common functions related to digital photography, such as downloading your photos from your camera to your computer and printing your photos, are easily handled through wizards that walk you through these tasks. More important, Windows XP supports more third-party software than all other operating systems in the world combined, so you have many more choices when it comes to choosing digital photography software.

Also, Windows XP have a built-in package supporting a Universal Serial Bus or USB 2.0, which is the medium most digital cameras adopt to transfer pictures to computers. Previous operating systems, such as Windows 2000, however, need to install USB drives to be compatible to a specific digital camera. Therefore, Windows XP adoption helps digital cameras to bundle with computers, so it may encourage the purchase of digital cameras. This suggests that my empirical model of camera demands will have an operating-system market share of Windows XP as an explanatory variable.

6 2001 and 2003 PMA U.S. Consumer Photo Buying Report

7 Microsoft website.

2. Empirical Model

To investigate the substitution between similar products, this paper estimates a demand structure, specifically to derive estimates of the cross-price elasticity of demand for these three sectors. With the demand function, $\log q_i = f_i(\log p_i, \log p_{-i}, \log z_i)$ where z_i measures other non-price variables that affect the demand for q_i, the cross-price elasticity of demand is $d \log q_i / d \log p_j$.

Here I adopt the following specification:[8]

$$\begin{aligned} \log SHIPMENT_{it} = {} & \alpha_0 + \alpha_1 \log PRICE_{it} + \alpha_2 \log PRICE_{-it} \\ & + \alpha_3 I_{\{i=DC\}} XPshare_t + \alpha_4 \log PCshare_t + \alpha_3 MONTH_t + \varepsilon_{it} \end{aligned} \tag{1.1}$$

$\log SHIPMENT_{it}$, the logarithmic unit shipment of commodity i at time t is the dependent variable. Shipment data reflect the demand of both retailers and wholesale merchants; the latter is a derived demand driven by the final sale of cameras to consumers. Vendors usually keep a relatively stable inventory/sale ratio for electronics products,[9] which means that shipment data track camera sales trends in the North American market.

$\log PRICE_{it}$ and $\log PRICE_{-it}$ are the logarithmic prices of product i and its substitutes respectively. Prices are reported in terms of FOB prices. Logarithmic transformations of both prices and unit shipments mean that the price elasticities of interest α_1 and α_2 are directly measured in the estimated equations.[10]

$\log PCshare_t$ is the log of PC household penetration in US. As I have only yearly data for this variable, there is no corresponding monthly variation in this measure.

8 This specification for differentiated products is assumed to be derived by a representative consumer with a polynomial utility function of degree higher than 2. With quadratic utility function, the demand function will be linear in prices.

9 US Census Bureau reports the adjusted inventory/sale ratio for US electronic stores in 2004 is 1.63, 1.63, 1.63, 1.64, 1.67, 1.64, 1.63, 1.66, 1.66, 1.64, 1.65 and 1.69 over 12 months.

10 $\frac{\partial \log(q_i)}{\partial \log(p_j)} = \frac{\partial q_i}{\partial p_j} \cdot \frac{p_j}{q_i} = \varepsilon_{ij}$, which is the cross-price elasticity of demand for product i w.r.t. product j.

$I_{\{i=DC\}}$ is an indicator function, which is equal to 1 if product i is a digital camera. $XPshare_t$ is the market share of Windows XP among all the operating systems. This variable cannot be directly measured from household survey data. There is, however, another measure that I will use. Some online survey institutes (such as W3Schools) track the type of operating system used in PCs. For computer hits on the reference websites, this measure records the number of computers using Windows XP. There are two potential flaws of this measure. First, it does not exactly equal the Windows XP household penetration rate because some households may access the website more than once while the others may not. Second, while my price and shipment data are from North America (as described below), this measure is used worldwide. As Windows XP users can access the internet more easily, this variable likely overestimates actual Windows XP ownership. Also, any difference between internet users in North America and those in other areas will also bias this measure.

The $Month_i$ term consists of dummies for observation months. This term is normalized to January so that the coefficients show any monthly effect on shipments in comparison to the first month of every year. Monthly fluctuations in shipments will be defined as the variation of these coefficients.

The error term captures all unidentifiable effects on shipments. For example, the 2001 recession in the travel business and subsequent slow recovery likely had a negative impact on camera sales over the past several years. Since our prior is that digital and film cameras are substitutes, the expectation is that unobservable factors impacting shipments of digital cameras will also impact shipments of film cameras. Hence, the empirical demand equations for the three sectors should be correlated, and the covariance of their disturbance terms should be positive in a given period. I therefore assume the error terms in the demand functions are contemporaneously correlated, but are not correlated across time. Thus, the OLS estimation will not yield efficient estimates. I need to estimate the parameters of the three equations simultaneously, taking into account their contemporaneous correlation. This is a so-called Seemingly Unrelated Regression (SUR) system. For such a problem, I choose the GLS estimation method.

Furthermore, the prices in the demand equations are correlated with the error terms because they are the solution to both the demand and supply equations. To deal with the classical simultaneous equation bias and obtain the consistent estimator, I will use instrumental variables to regress prices in the equations. Zellner and Theil (1962) explain in detail how to deal with such SUR embedded with this endogeneity problem. Using Three-Stage Least Square (3SLS) generates consistent estimators. What is key is the identification of the proper instruments for prices. My set of instrumental variables (IV) includes variables contributing to cost changes in the production of cameras because the price is usually a function of marginal cost and the markup. One reasonable IV variable is the average monthly wage index in Japan (the index of average monthly total cash earnings per regular employee). Another IV used is the capacity utilization rate[11] of Japan Manufacture of Electronic Parts and Devices. In general, if market demand grows, the capacity utilization will rise, and vice versa. When the demand on the electronic parts and devices rises, their prices—the costs of cameras—rise, so it should be an efficient IV variable. Also, for camera sector *i*, I also use the average production price (factory shipping-out value) of sector *i* at the same period as instrumental variables. These variables also reflect the cost trends. Prices may also depend on preceding-period unit sales and on disposable income, so I also have these two terms as IV. The last IV is the price of exchangeable lenses shipped from Japan to America and Europe. It is the cost for this critical part of all cameras.

3. Data

The shipment data are collected from the Japanese Camera and Imaging Products Association (CIPA).[12] CIPA has monthly production and shipment data from July 2002 to the present. Integrated into these are similar data for August 2001 to June 2002 from

11 Capacity Utilization Rate=$\frac{\text{Actual Achievement of Production}}{\text{Production Capacity}}$. This variable covers the semiconductor devices, electron tubes and miscellaneous electronic parts manufacturing industry, which provides parts or accessories for cameras.

12 CIPA is a Japanese organization whose members are engaged in the production or distribution of silver halide cameras, digital cameras, or related devices, instruments and software. CIPA members report their production and export shipment monthly. These data include measures of the amounts of cameras produced abroad by the surveyed companies.

the Japan Camera Industry Association (JCIA).[13] I will use the following part of the database: data on production, export shipments of both film and digital cameras to North America, and lens shipments to North America and Europe. The selected sample is from August 2001 to August 2004. The data record both unit sales and the corresponding revenue.[14]

The production data, from both Japanese and members' overseas facilities, record the factory-ship-out revenues and unit sales. That is, these are the Original Equipment Manufacturer (OEM) data. Revenue is measured in 1000's of JAP Yen. The export shipments use FOB prices to calculate the total revenue.

The OS market share data for Windows XP come from W3Schools, which is an Internet Developers Portal started by a Norwegian company, Refsnes Data, in January 2000. They record the market share in the OS of the computers accessing their website. Data are aggregated monthly and are available to subscribers. In July 2001, W3Schools broke the 10 million page-views-per-month record. In September 2002, it passed 20 million page views per month, and in February 2004 it passed 30 million. To make sure their data are representative, I also check similar data from www.hitslink.com.[15] The data from these two websites have a correlation of 97.3, which means that either of them can capture the trend of the Windows XP share. W3Schools differs from Hitslink in that it is a website for people with an interest in web technologies. Unlike the average users, more of these people use linux, so the market share for Windows XP collected from W3Schools is a little lower than that from Hitslink. However, considering that data about the OS share before October 2004 are not available from Hitslink, W3Schools may be my only option .

Windows XP was introduced in October 2001. However, the supplementary software supporting USB2.0 is built into its service package (SP1), which did not come

13 JCIA was dissolved in June 2002. CIPA started July 1 immediately after the dissolution, but it is a new institution.

14 If we could get the unit sale in North America as comparison and see how much percentage the data will cover, that will be great.

15 Their data are from the browsers of site visitors to their exclusive on-demand network of small to medium enterprise live stats customers. These sites include more than 40,000 urls such as golf-gift.com etc. This site visitor and referral information is summarized on a monthly basis.

out until September 9, 2002. Therefore, I collected data from then on, setting this variable to zero for the pre-periods when it was unavailable.

Yearly PC household ownership data come from the US Census Bureau, Current Population Survey, 1984-2003. PC ownership for 2004 then is estimated based on the trend of previous years. The instrumental variables are measured as follows: Japanese workers' wage index data come from the Statistics and Information Department, Minister's Secretariat, Ministry of Health, Labor and Welfare in Japan. The capacity utilization rate for the manufacture of electronics parts and devices is collected from the Japan Ministry of Economy, Trade and Industry. Statistics of the data are shown in Table 1.2.

4. Empirical findings

Table 1.3 shows empirical results of OLS (independent regressions for each equation), Feasible General Least Square (FGLS, allowing for correlation between the disturbance terms), and 3SLS estimation (which addresses the endogeneity problem). The results of FGLS are quite similar to those of OLS, except for the higher efficiency of FGLS. Hence, allowing for the contemporaneous correlation among the sub-sectors leaves the estimation relatively unchanged. However, we are unable to conclude that the equations are actually unrelated since there are other circumstances under which OLS and FGLS are identical. Zellner (1962) and Dwivedi and Srivastava (1978) analyze some special cases. They point out that if the equations have identical explanatory variables, OLS and FGLS are identical. For my case, the independent variables in the three equations are quite similar. Therefore, this may be the reason OLS and FGLS yield similar results. However, as pointed out by these two papers, the greater the correlation of the disturbances, the greater the efficiency gains that accrues to FGLS. Therefore, this finding suggests that the equations may be actually correlated, and that FGLS produces more efficient estimates. A Lagrange Multiplier test will be performed to formally examine the correlation between demand equations.

The FGLS estimation, however, is also not consistent when an endogeneity problem is embedded in the SUR system. To solve the endogeneity problem, I use the measured instrumental variables to regress prices first (the results are shown in Table 1.4). Then, I perform FGLS using predicted prices. The results of FGLS and those of 3SLS differ in both their means as well as in the t-statistics of the estimated coefficients, which implies that endogeneity is, indeed, present. One of the important differences lies in the price elasticity of demand. With 3SLS, it is -0.55, -0.14 and -1.1278 for SLR, lens-shutter and digital cameras respectively, compared to -0.16, -0.28 and -1.04 with FGLS. Therefore, the endogeneity problem leads to an underestimation of the effect of price on shipments for SLR and digital cameras, but an overestimation for lens-shutter cameras. This indicates that the price is negatively correlated with the error term in the demand function for both SLR and digital cameras, and the reverse is true for lens-shutter cameras. This may be due to the fact that no quality variables are in the demand function, so the error terms also cover the uncertain impact of product quality on shipments. Lens-shutter cameras are the simplest cameras in structure, so the uncertainty is the smallest, while for SLR and digital cameras, the error terms also measure the quality uncertainty. For these two types of cameras, expensive models usually carry more uncertainties. The correlation between price and those uncertain features undermines the price effect. Table 1.4 shows the results for the regression of prices on the instrumental variables. Although most terms are not significant, the joint test and r-square show that these variables still instrument prices well.

In the face of the obvious endogeneity problem, the 3SLS method achieves consistent and efficient estimations, so I conclude my findings derived from this method alone:

First, the estimated price elasticity is negative for all cameras. The results indicate that a 1% price increase will drive down the shipment of the SLR, lens-shutter, and digital camera by 0.55%, 0.14% and 1.23%, respectively. These results fit the intuition that sales of digital as opposed to lens-shutter cameras should be more price sensitive as the prices of digital cameras are higher. The hypothesis test shows that the price coefficient for digital cameras is higher than that of lens-shutter cameras at a 10% statistical significance level (t-statistics for the hypothesis test is 1.62). Also, I cannot reject the hypothesis that the price elasticity for SLR or lens-shutter cameras is zero. Most SLR consumers are photography amateurs, so they purchase cameras for their hobbies or even their photography-related jobs. Hence, their demand is not so sensitive to the price. The average price for lens-shutter cameras is less than $60 and the deviation is less than $10. For durable goods like cameras, this kind of price fluctuation may be too small to cause any significant shipment changes. The average prices, during January to August 2004, dropped by 33.54% and 13.61% for lens-shutter and digital cameras, respectively, compared to the same period in 2003. That is translated to a 4.7% and 16.74% increase in their respective shipments. Hence, the drop in the lens-shutter camera's price actually saved part of its market, but not significantly.

Second, the estimated parameters suggest that lens-shutter cameras and digital cameras are gross substitutes in terms of the cross-price elasticity. The estimated cross-price elasticities are close in value and statistically significant. A t-test ($|t| = 0.08$) cannot reject the null hypothesis that the cross-price elasticities are identical between these two sectors, so their substitution effects defined in terms of elasticity are actually symmetric. Moreover, lens-shutter and SLR cameras are also substitutes. But, the sign of the respective cross-price effect indicates that digital cameras are complementary goods to SLRs, while SLRs are not complementary goods to digital cameras.[16] Over the data periods, digital SLR only accounts for less than 4% of total digital camera purchases.[17] Since some optical effects can only be produced by film SLR with functions necessary for photography fans, it is not surprising to see that photographers or amateurs with special photographic needs still stick to SLR rather than digital cameras. Also, these

16 This asymmetry of definition comes from the gross definition about complements and substitutes. A Slutsky decomposition for cross price effects similar to that proposed in Small and Rosen (1981) can be written as,

$$\frac{\partial X_i}{\partial p_j} = \frac{\partial X_i^c}{\partial p_j} - \frac{X_j}{\pi_j}\left[\frac{\partial X_i}{\partial Y} - (1-\pi_j)\frac{X_i}{\pi_i}\frac{\partial \pi_i}{\partial Y}\right],$$

where π_i is the fraction choosing good i at the given prices and incomes Y. For SLR, $\frac{\partial \pi_i}{\partial Y} < 0$ since its market share is decreasing while the average income is steadily increasing. For digital cameras, on the other hand, this term is positive. Therefore, the demand effect for SLR might be higher than that for digital cameras. Given the symmetric substitution effect, due to the higher income effect for the SLR, the consumption of SLR may increase along with the price drop of digital cameras, which means digital cameras are compliments to SLR. For digital cameras, however, if the income effect is smaller than the substitution effect, then SLR are gross substitutes to digital cameras. In other words, the presence of income effect results in the asymmetry of the gross definition.

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amateurs usually possess digital cameras as well as SLR. When the price of the digital camera drops, they may have extra money to displace their old SLR. In that sense, the digital camera is not an efficient substitute to the SLR.

My results conclude that the fall in the price of digital cameras contributes to replacing the film camera. On the other hand, however, the drop in the price of film cameras somehow slowed down the propagation of digital cameras. Figure 1.5 illustrates predicted digital-camera shipments for a scenario in which lens-shutter camera prices do not decline. In the figure, predicted shipment refers to the digital-camera unit shipment with the lens-shutter camera price fixed at its initial level; and the estimated dependent variable from the digital-camera demand function is used as a comparison base and labeled as estimated shipments. From 2001 to the end of 2003, the predicted shipments of digital cameras are almost equal to both estimated and actual shipments. Since 2004, the price of the lens-shutter camera has fallen by more than 30%, so it is not a surprise to observe an obvious gap between actual digital camera shipments and the counterfactual results. Digital-camera makers won consumers by decreasing their prices while manufacturers of lens-shutter cameras successfully seized part of potential digital-camera consumers as well.

Another important finding is that household PC-ownership rates are positively correlated with digital-camera sales but negatively correlated with SLR and lens-shutter-camera sales. Since both the shipment and the PC-ownership rate are in log terms, the coefficient of PC ownership is the PC-ownership elasticity of shipment, defined as a relative change of shipment with respect to the 1% PC-ownership rate change. It is -0.018, -2.46 and 3.70 for SLR, lens-shutter and digital cameras respectively. The PC-ownership rate increased by 11.39% from 2003 to 2004, which is translated into decreases of shipment by 0.21% and 28.02% for SLR and lens-shutter cameras, but a 42.14% increase for digital cameras. The total shipments of lens-shutter cameras from January to August of 2004 decreased by 35% as compared to the same period in 2003. Our empirical model shows that a significant part of the noticeable deterioration in shipments can be explained by the household PC-ownership rate change over years (the other factors such as the own-price and substitutes' price changes also play roles in its shipment drop, but they are less effective, as shown above). This phenomenon means that PC owners would be more likely to choose digital cameras than lens-shutter cameras. Why do they prefer digital? Because when most pictures are stored in computers rather than in albums and are shared via email rather than surface mail, digital cameras work with computers more easily. Especially after Windows XP was introduced, digital photography has become dominant.

Windows XP, therefore, plays a significant role in the sale changes of digital cameras. Since October 2002, Windows XP penetration has increased by 45%, which contributes to a 62.7% increase in digital-camera shipments using the estimated parameter. The adoption of Windows XP accelerated the diffusion of digital cameras. As mentioned in the last section, Windows XP differs from its previous operating system in digital-photography editing and picture-transferring technology. Ease-of-use is a prominent attribute of this system. More importantly, Windows XP supports the third party software, which imposes indirect network effects on the digital camera. As the third-party softwares, such as Adobe Photoshop, accumulate, the beneficial cycle between the digital camera (hardware) and the software means that demand for digital cameras expands further. Hence, the effect of Windows XP on the sales of digital cameras *may* be interpreted as a successful case of ease-of-use and indirect network effect..

Finally, the assumption of a contemporaneous correlation between demand functions comes from economics intuition. To test it, I perform a Lagrange Multiplier test as suggested by Breusch and Pagan (1980). The test statistics are $\lambda_{LM} = T\sum_{i=2}^{M}\sum_{j=1}^{i-1} r_{ij}^2$, where $r_{ij}^2 = \hat{\sigma}_{ij} / \left[\hat{\sigma}_{ii}\hat{\sigma}_{jj}\right]^{1/2}$ is the estimated correlation between the demand functions. The null hypothesis of this test is no correlation between the demand functions of these 3 camera sectors. This statistic has a limiting chi-squared distribution with 3 degrees of freedom. The results for 3SLS and FGLS are $\lambda_{3SLS} = 22.84$ and $\lambda_{3SLS} = 18.03$, respectively. The critical value for this test at the 0.5% level is 12.84; therefore, I reject the hypothesis that the variance-covariance matrix of the residuals is diagonal. Also, by checking the variance-covariance matrix of the error terms, I found that all the covariance terms are positive. Hence, it proves the hypothesis that demand equations are positively correlated.

To show how the factors in demand functions impact digital-camera shipments, I set prices, operating-system penetration and PC ownership at their first-period levels, and estimate shipments separately in each scenario using my model. The corresponding estimated shipments are named price effect, OS effect and PC-ownership effect shipments. I also estimate shipments using the independent variables in their actual values, and set the estimates as a comparison base. The results are illustrated in Figure 1.6. The gap between the base shipment and the PC ownership effect is the largest, which suggests that the rise in PC-household ownership makes choosing a digital camera favorable. The OS effect is also obvious, which means that compatibility with the PC-operating system accelerates the diffusion of digital cameras. Compared to these two effects, the price effect is not as deep as I expected. This means that over the sample period, non-price factors play more important roles in the sale of digital cameras, which motivates us to dig out how manufacturers compete on non-price sides. Especially in such a highly concentrated industry, non-price competition can make firms avoid direct competition in price, which can bring these firms higher profit.

5. Conclusion

This paper investigates how price and non-price factors impact shipments of cameras, taking into account the contemporaneous correlation among the demands of different camera sectors. Empirical facts show that price cuts in the film camera actually slowed down the spread of the digital camera. Another interesting finding is that the growth in shipments of digital cameras should be attributed primarily to an abrupt rise in PC-household penetration while the downfall of film cameras are mainly due to PC-ownership change and competition from digital cameras. Windows XP adoption explains why PC owners prefer digital cameras to film cameras so that it plays a significant role in the diffusion of digital cameras.

This paper does not analyze how the price drop starts, which is essential for price competition. Price competition in the digital-camera market forces down prices close to the products' marginal costs. The observed price drops, therefore, are assumed to be triggered by a sharp cost decrease in the digital-camera market. Then, the substitution forces down demand in the other two markets and results in lower prices and quantity demanded in both markets. A complete model for equilibrium quantity demanded and price should include cost measures. Thus, the supply side of the camera industry deserves further study.

Further research also entails other demand-shifting variables. Current research is based on observation of household computer ownership and operating-system changes. The other factors may also affect demand, which means the current results actually overestimate the effects of these two factors. For instance, the change in the quality of digital cameras should be a significant factor causing the demand of digital cameras to rise.

Table 1.1 Demographic Characteristic of Still Camera Buyers

Ownership	2000		2003	
	35mm Lens-shutter	digital camera	35mm Lens-shutter	digital camera
personal computer	70.50%	91.90%	70.90%	93.50%
windows 98 OS	26.40%	55.90%	33.60%	35.30%
windows XP			20.90%	35.10%
access Internet	55.90%	83.00%	73.90%	91.90%
Win XP/Internet			28.28%	38.19%
average household computer ownership	51.00%		61.80%	

Source: Photo Marketing Association Survey

Table 1.2 Statistics of Data (August 2001-August 2004)

		Average	Standard Deviation
Unit Shipment to North America ('000)	SLR	81.95	38.07
	Lens-shutter	402.13	222.01
	Digital	928.33	424.39
Shipment Value to North America (million JPY)	SLR	1429	711
	Lens-shutter	2564	1633.8
	Digital	26916	9507.8
Average Price of Shipment to North America ('000 JPY)	SLR	17.1532	2.6302
	Lens-shutter	6.1359	1.2957
	Digital	30.5048	4.1806
Windows XP ownership		36.57%	14.18%
PC Household Ownership		61.8%	4.43%
Japanese Monthly Wage (2000=100)		99.46	32.66
Capacity utilization rate (2000=100)		81.59	10.43

Table 1.3 Empirical results (108 observations)

	OLS			FGLS			3SLS		
Dependent variable	(1)[1]	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Const	10.4805***	6.3249***	15.7625***	10.4805***	6.3249***	15.7640***	8.9997***	5.5810***	16.0437***
	(5.2400)	(4.4796)	(7.1182)	(7.0302)	(6.0100)	(9.8505)	(4.7027)	(4.5123)	(7.6865)
$\log p_{fp}$	-0.1584	0.6639*	0.0791	-0.1584	0.6639**	0.0790	-0.5541	0.3229	0.0432
	(-0.2986)	(1.7727)	(0.2136)	(-0.4006)	(2.3784)	(0.2939)	(-0.9768)	(0.8808)	(0.1218)
$\log p_{ls}$	1.2860***	-0.2841	0.8052***	1.2860***	-0.2841	0.8052***	2.2103***	-0.1396	1.2140***
	(3.4897)	(-1.0920)	(3.2384)	(4.6820)	(-1.4650)	(4.4577)	(5.2422)	(-0.5123)	(4.5813)
$\log p_{dg}$	-0.9438	0.7120	-1.0376*	-0.9438**	0.7120**	-1.0379***	-0.2223	1.2528***	-1.1278**
	(-1.5234)	(1.6277)	(-1.9330)	(-2.0438)	(2.1839)	(-2.6702)	(-0.3502)	(3.0537)	(-2.0591)
$XPshare_t$	--	--	1.1815***	--	--	1.1812***			1.0758***
			(2.8782)			(3.9940)			(3.0903)
$\log PCshare_t$	-3.4558*	-3.3021**	2.3820	-3.4558**	-3.3021***	2.3823**	-0.0176	-2.4630*	3.7022***
	(-1.7579)	(-2.3793)	(1.7225)	(-2.3585)	(-3.1922)	(2.3730)	(-0.0087)	(-1.8767)	(2.9563)
R^2	0.9075	0.9628	0.9529		0.9451			0.9389	

Notes: (1): (1)—(3) represents the SLR camera, the compact lens-shutter camera and the digital camera, respectively.

(2): t-statistics in parentheses.

(3): *--10% significance; **--5% significance; ***--1% significance;

Table 1.4 Results for Regression of Prices on Instrumental Variables

Dependent Variable: Price	SLR Camera		Lens-shutter Camera		Digital Camera	
	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Const	-191.83	-0.44	248.08	1.13	1093.90	1.41
Amr Cam Lens Price	-7.97	-2.11	0.48	0.26	-7.00	-1.37
Eur Cam Lens Price	3.39	1.05	-0.46	-0.29	-4.60	-0.96
log(SLR production P)	9.44	2.91				
Log(lens Production P)			2.62	1.65		
Log(digital production P)					-9.90	-0.76
log(lag sale SLR)	0.23	1.45				
Log(lag sale Lens)			-0.01	-0.22		
Log(lag sale digital)					-0.01	-0.02
Wage	-70.83	-1.83	-8.62	-0.43	60.10	1.00
Disposable Income	47.61	1.12	-23.09	-1.17	-116.40	-1.82
Capacity Utilization Rate	1.90	0.45	6.25	3.05	-11.20	-1.72
log(PC ownership)	-20.82	-0.99	-2.56	-0.25	45.00	1.28
Windows XP					-9.40	-1.02
	-0.96	-0.81	-0.27	-0.45	-11.20	-1.72
	-2.05	-1.56	-0.37	-0.57	-3.20	-2.14
	-3.25	-3.22	-0.89	-1.65	-3.30	-1.87
	30.10	1.61	3.01	0.31	-1.50	-1.16
	31.95	1.61	3.37	0.33	-28.80	-0.99
season	1.13	0.41	-0.19	-0.14	-29.30	-0.95
	-2.26	-1.68	-0.30	-0.46	-2.30	-0.52
	-3.77	-2.62	-0.67	-0.93	-1.30	-0.71
	-1.51	-0.53	0.03	0.02	-3.60	-1.95
	54.39	1.65	6.78	0.40	-6.90	-1.78
	-1.36	-0.67	0.50	0.48	-52.60	-1.04
R^2	0.91		0.90		0.90	
$\bar{R}^2$	0.80		0.79		0.79	
F-statistics	397.67		199.60		748.51	

Figure 1.1 Market Share of Film and Digital Cameras 1996-2004

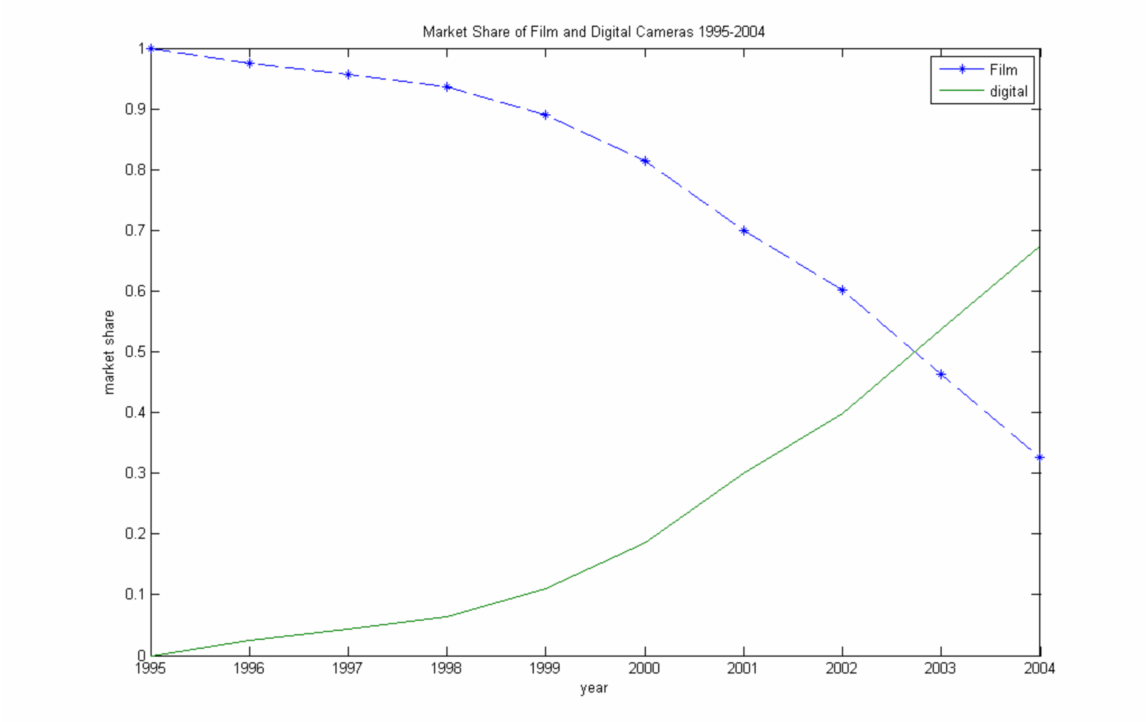


Figure 1.2 The Average Price for Cameras Shipped to North America (1000 JPY)

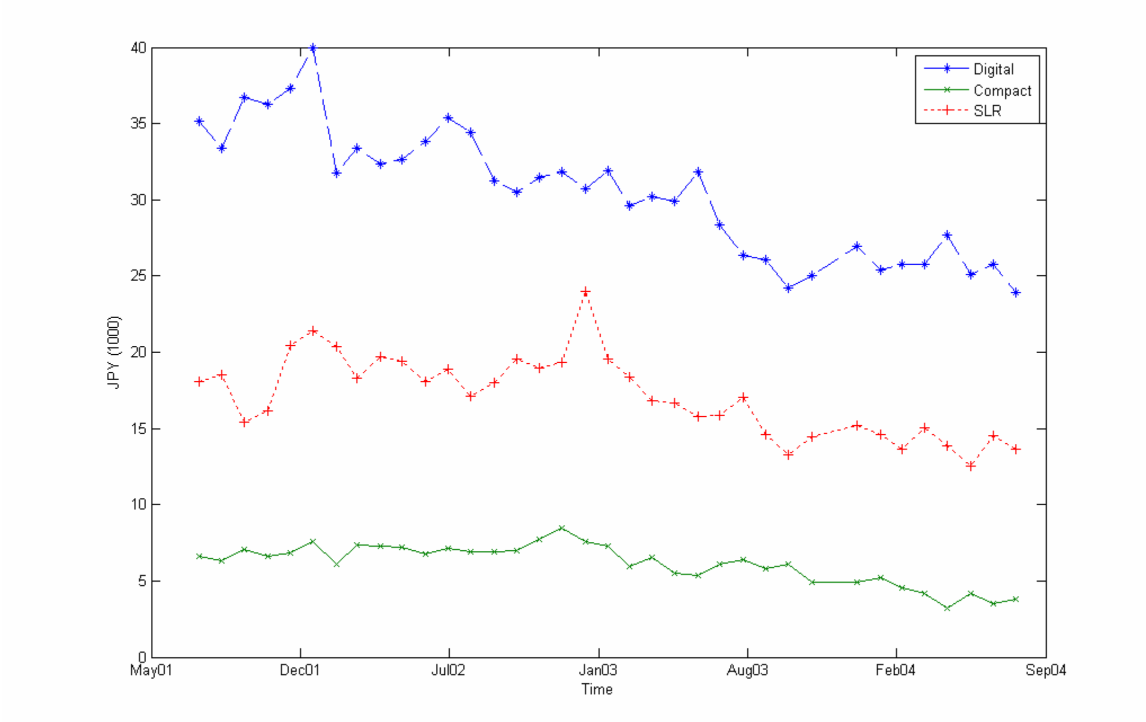


Figure 1.3 Camera Relative Price Changes (2001-2004)

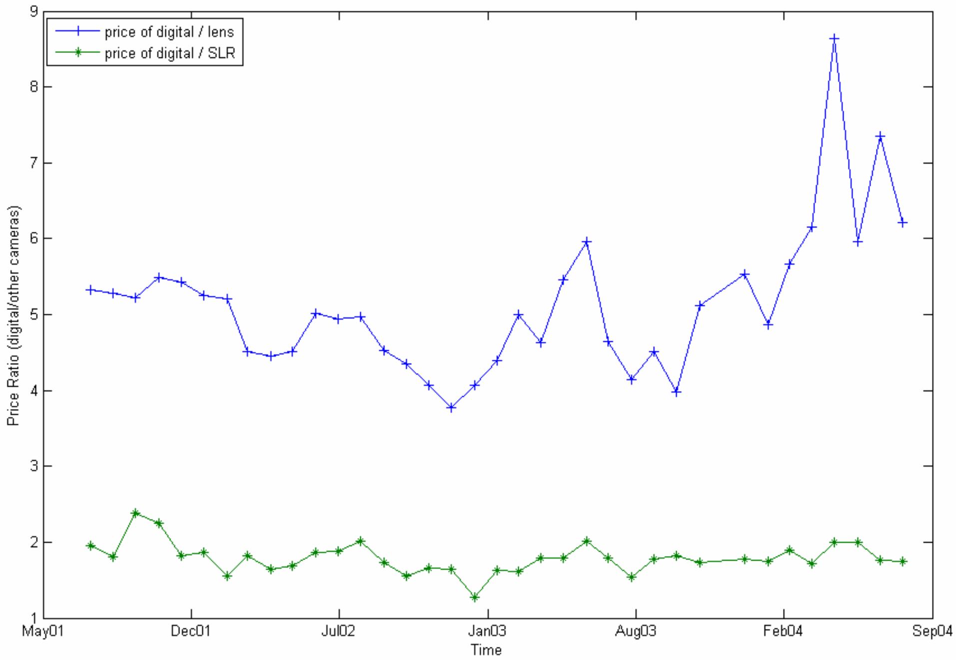


Figure 1.4 The Unit Shipment of Cameras to North America (units)

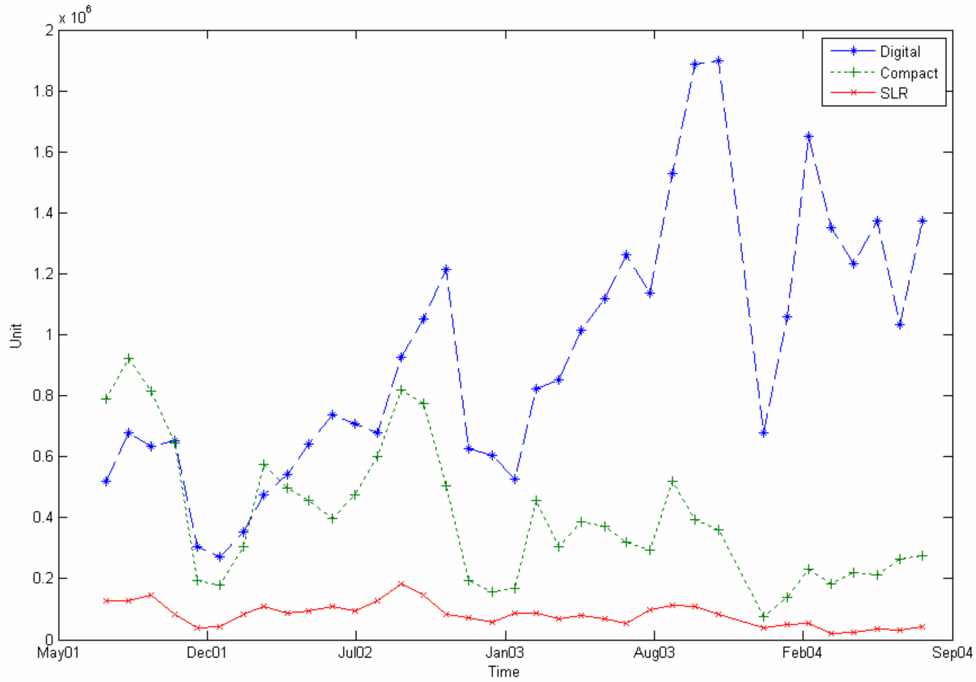


Figure 1.5 Counterfactual experiment with price of lens-shutter camera fixed at the level of Aug 2001

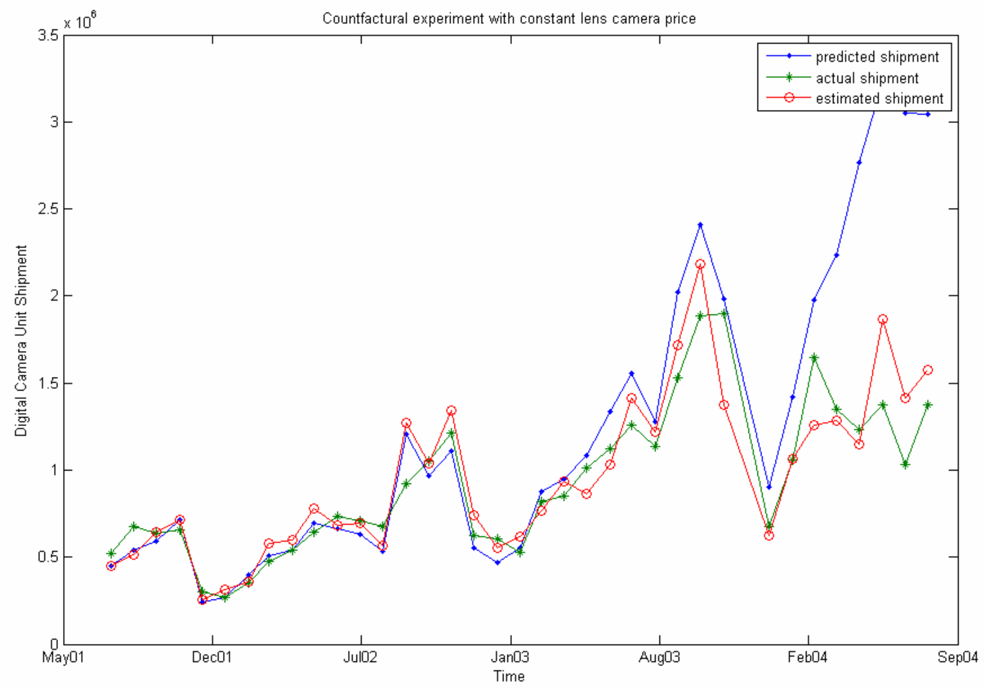
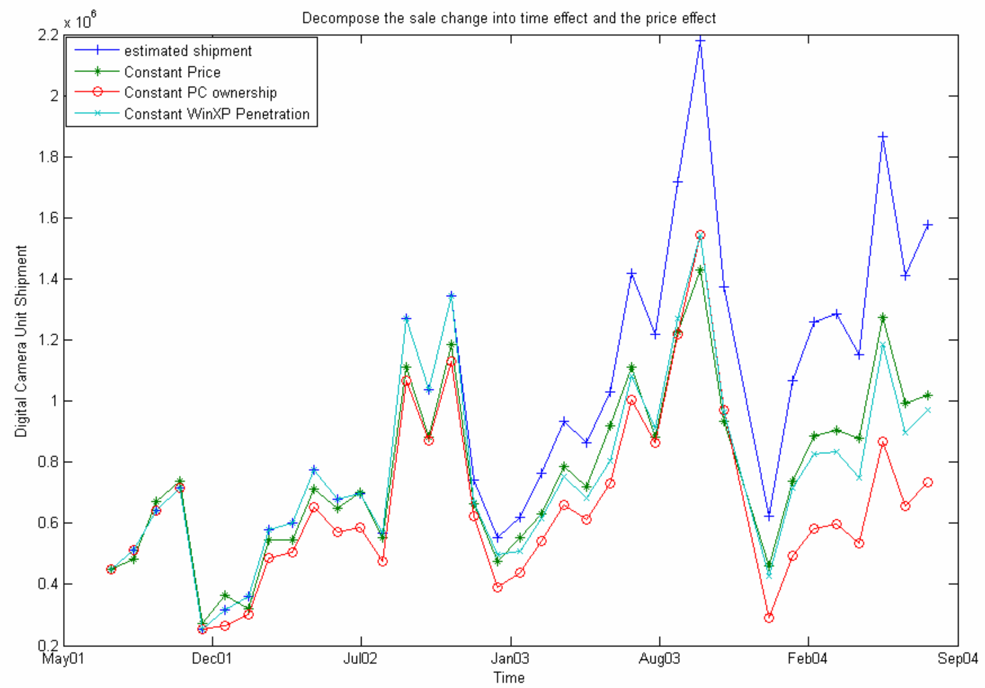


Figure 1.6 Decomposition of shipment change of digital cameras



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