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Understanding Price Adjustments in E-Commerce

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Price rigidity involves prices that do not change with the regularity predicted by standard economic theory. It is of long-standing interest for firms, industries and the economy as a whole. However, due to the difficulty of measuring price rigidity and price adjustments directly, only a few studies have attempted to provide empirical evidence for explanatory theories from Economics and Marketing.

This paper proposes and validates a research model to examine different theories of price rigidity and to predict what variables can explain the observed empirical regularities and variations in price adjustment patterns of Internet-based retailers. I specify and test a model using more than 3 million daily observations on 385 books, 118 DVDs and 154 CDs, sold by 22 Internet-based retailers that were collected over a 676-day period from March 2003 to February 2005. I obtained a number of interesting findings from the estimation of our logit model. First, quality seems to play a role-I find that both price levels as proxies for store quality, and information on the quality of a product consumers have, affect online price rigidity. Second, greater competition (i.e., less industry concentration) leads to less price rigidity (i.e., more price changes) on the Internet. I also find that Internet-based sellers more frequently change the prices of popular products, and the sellers with broader product coverage change prices less frequently, which seem due to economic forces faced by these Internet-based sellers.

To the best of my knowledge, this research is the first to empirically assess price rigidity patterns for multiple industries in Internet-based retailing, and attempt to explain the variation in these patterns. I found that price changes are more likely to be driven by quality, competitive and economic considerations. These results speak to both the IS and economics literatures. To the IS literature these results suggest we take economic considerations into account in more sophisticated ways. The existence and variation in price

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rigidity argue that simplistic assumptions about frictionless and completely flexible digital prices do not capture the richness of pricing behavior on the Internet. The quality, competitive and economic forces identified in this model suggest promising directions for future theoretical and empirical work on their role in these technologically changing markets. To the economics literature these results offer new evidence on the sources of price rigidity, which can then be incorporated into the development of models of pricing at the firm, industry and even macro-economic level of analysis. It also suggests that there is much to be learned through interdisciplinary research between the IS, economics and related business disciplines.

Keywords : E-Commerce, Price Adjustments, Price Rigidity, Strategic Pricing

I. Introduction

Price rigidity involves prices that do not change with the regularity predicted by standard economic theory. It is a topic of long-standing interest for firms, industries and the economy as a whole. Yet, due to the difficulty of measuring price rigidity directly, only a few studies have attempted to provide empirical evidence for explanatory theories from Economics and Marketing.

Today, the Internet provides unprecedented opportunities to collect data on more subjects with lower costs, fewer restrict assumptions, and greater realism [Bergen *et al.*, 2005]. The ability of researchers to access transaction price data using software agents now offers the ability to explore price adjustment patterns at a level of micro-economic detail previously unimaginable. More observers tend to portray the e-commerce sector as one in which price adjustment costs are almost absent [Brynjolfsson and Smith, 2000]. The limited empirical evidence suggests that Internet-based firms make more frequent price changes than traditional firms. This permits us to tell a story that involves the role of IT relative to diminished menu costs [Kauffman and Lee, 2004a]. In addition, compared to non-Internet markets, the Internet environment makes it possible to more accurately monitor and control inventory and costs, and gauge demand nearly in real-time. So, firms today are able to flexibly manage and optimize prices by reducing the managerial costs and menu costs through the intensive use of information technologies. By combining supply chain management systems with revenue yield management, for example, firms now possess the capability to achieve refined pricing decisions that are in line with both current demand and current supply.

However, I ask: Is it reasonable to expect less price rigidity in e-commerce? My cautious and early answer is probably not. Initial analysis of the data suggests that although firms can change prices more flexibly through technology, Internet pricing patterns still exhibit substantial rigidity across a variety of products, categories and stores. Yet these patterns also exhibit variation. The Economics and Marketing literature offer some promising theoretical and contextual terms: such as *psychological pricing points* [Kashyap, 1995], *customer antagonization* [Blinder *et. al.*, 1998], and *non-price elements*

[Carlton, 1989]. They also offer other ways to think about various competitive and economic considerations. These include managerial capabilities [Zbaracki *et al.*, 2004], the sophistication of competitors [Rotemberg and Saloner, 1987], and a firm's chosen price/quality/service profile in the market [Bergen *et al.*, 2005]. These ideas are representative of a range of theory-based explanations that support an argument against the likelihood of observing greater price flexibility on the Internet—counter to what many think.

In this research, I explore the efficacy of a number of price rigidity theories for e-commerce including asymmetric information, quality signaling, psychological pricing points, market demand, industry concentration, managerial costs, and non-price competition. Specifically, I propose two *digital price rigidity models* based on these theories. They include a *consumer-level model* involving quality signaling and price points, and a *firm-level model* involving competition and the economics of the Internet business. I tested the models using more than 3 million daily observations collected over a 676-day period from March 2003 to February 2005 that pertain to 385 books, 118 DVDs and 154 CDs sold on the Internet.

I obtained a number of interesting findings. (1) Price levels as proxies for online store quality have positive effects on price rigidity. (2) The more information on the quality of a product that consumers have, the more often the price will be changed by the online seller. (3) Online prices may be rigid due to sellers' incentive to sustain price endings at a higher level to maximize profits. (4) High competition (i.e., less industry concentration) leads to less price rigidity (i.e., more price changes) on the Internet. (5) Internet-based sellers frequently change the prices of popular products. (6) Product coverage as a proxy for managerial costs positively affects online price rigidity. (7) Free shipping options may be a factor to online retail prices.

The rest of the paper is organized as follows. I begin by reviewing several theories of price rigidity from the Economics and Marketing literature. I provide a formal basis for a set of hypotheses and propose research models to explain the observed price adjustment patterns on the Internet. I then discuss the empirical research methods and present the main results of the study. Finally, I conclude with an interpretation of the empirical findings and discuss the limitations and implications for academic research and pricing strategies on the Internet.

Ⅱ. Research Framework

Many observers have commented that physical price adjustment costs are almost entirely absent in e-commerce because they primarily consist of the costs of simple database updates, which may be easily programmed [Brynjolfsson and Smith, 2000]. This suggests that Internet-based retailers have the capability to adjust prices more flexibly than traditional retailers, like financial markets [Bergen *et al.*, 2005]. However, there appears to be more going on with price adjustment than just menu costs associated with making the price changes-even on the Internet. For example, the Internet apparently does not necessarily reduce the related managerial costs for price changes. This may be due to integration efforts that firms make to get

their operations in the Internet channel in synch with their efforts to sell in traditional channels [Gulati and Carino, 2000]. In addition, price changes on the Internet are more likely to be driven by demand considerations than inventory levels. So, I propose a research model based on two levels of price rigidity on the Internet: consumers and firms. Specifically, the model predicts how *information asymmetries, competition and demand considerations* may affect *digital price rigidity.*

2.1 Consumer Level: Information Asymmetry, Price Points and Price Rigidity

It is difficult for customers to observe quality even at the time of purchase because they are imperfectly informed about product characteristics [Stiglitz, 1987]. Just as in the traditional market, online consumers also have difficulties with examining the quality of products, or the product and service delivery capabilities of stores. As a result, the consumer's assessment of the actual features or true quality of a product that is to be purchased online may be inaccurate. Monroe [2003] suggests that consumers may use prices as a cue for assessing quality. Stiving and Winer [1997] also argue that *image effects* transmit signals that enable consumers to infer something -"images"- about a product or store based on price. So, a favorable impression of a product's or a store's quality might occur as a result of *high price image* [Monroe, 2003].

Blinder *et al.* [1998] argue that firms are reluctant to decrease prices even in economic downturns for fear that customers may misinterpret the lowering of prices as a signal for the quality reduction of the product. So, prices are less flexible for high-priced products to sustain and signal their high quality images. In addition, unexpected price changes, especially price increases when implicit contracts exist, may antagonize customers and diminish the firm's reputation [Kauffman and Lee, 2004a].

Notice that the Internet gives consumers access to more information about products and firms than has ever been available before. Moreover, it has changed the composition of firms in the marketplace, and the ways customers interact with Internet-based firms, as well. So, consumers can easily detect such violation of implicit rules for price changes unlike in traditional channels. So, firms may lose more of their profits when they break consumer expectations about pricing patterns for high-priced products. In addition, high-quality firms that signal the market with their higher prices are more sensitive to consumers' responses to the unexpected price changes. Baylis and Perloff [2002] find evidence that the price ranks of Internet-based firms selling electronics products do not change frequently: high-price firms usually keep their prices high over long periods. With these ideas in mind, I present the following hypotheses on the *relative prices*:

H1a (The Relative Product Price Hypothesis): *Due to reduced search and switching costs on the Internet, Internet-based firms change the prices of high-priced products less frequently than those of low-priced products.*

H1b (The Relative Store Price Hypothesis): *To signal high-quality store images successfully, high-price Internet-based firms change the prices of products less frequently than low-price Internet-based firms.*

Allen [1988] proposes a formal model of price rigidities based on the idea that the variations of unobservable quality make prices inflexible as long as demand shocks are sufficiently serially- correlated. He shows that prices are inflexible for products (e.g., automobiles) whose quality cannot be easily observed, while prices are flexible in industries (e.g., petroleum) where the quality is easier to gauge. As discussed in *Relative Price Hypotheses* (H1a and H1b), information asymmetries also prevail on the Internet. Also, it is doubtful that Internet retailers with low online prices will be the most reliable (Kauffman and Lee, 2004a]. So, digital intermediaries, such as trusted third-parties or an *online reputation* mechanism, will play a role in building trust between buyers and sellers to "perfect" their business processes associated with Internet-based transaction-making. So, I suggest the following hypothesis:

H2 (The Information Quality Hypothesis): *If consumers have more information on the quality of a product sold on the Internet, then the price of the product will be changed more frequently by Internet-based sellers.*

Kashyap [1995] argues that pricing managers attach great psychological importance to *price points*, such as $9 or 9¢, which consumers may misperceive, not round up, etc., for different cognitive reasons. Moreover, he shows that catalog prices tend to be stuck (i.e., rigid) at certain ending prices. I focus on "9" price-endings, as a means to examine the possibility of rational inattention. *Rational inattention theory* posits that it may be rational for consumers to be inattentive to the rightmost digit(s) of a price because they are constrained by time, resources, and information processing capacity [Sims, 2003]. Since many consumers appear to ignore the last digit of the price, firms have an incentive to make it as high as possible at $9 or 9¢. Given the firm's reaction to its customers' inattention to the last digit of the price, rational consumers expect that firms will set it equal to "9." Thus, "9" price-endings may be a rational expectations equilibrium outcome [Basu, 1997].

Consumers on the Internet can easily compare prices as well as trace product information through shopbots or search engines. The technology provides a basis for consumers to achieve a higher level of attention to price-if they use it. So, shopbots may actually "flatten" some of the potential behaviors that would support this theory. Despite the lack of generalizing evidence, I expect that rational inattention will be a source of price rigidity in e-commerce due to the fact that online sellers have an incentive to sustain prices at a higher level to maximize profits. So I propose the following hypothesis:

H3 (The Price Points Hypothesis): *Similar to traditional firms, Internet-based sellers have an incentive to make the price endings equal to $9 or 9¢; they change the prices with "9"-endings less frequently than those with other price-endings.*

2.2 Firm Level: Competition and Economic Forces in Internet Retailing

Economists have emphasized monopoly power of sellers in markets as the primary cause of price rigidity [Rotemberg and Saloner, 1987]. Various observers say that the Internet environment offers less concentrated markets but nevertheless creates more competition by lowering technological barriers to entry due to lower set-up costs, as well as lowering the marginal costs of

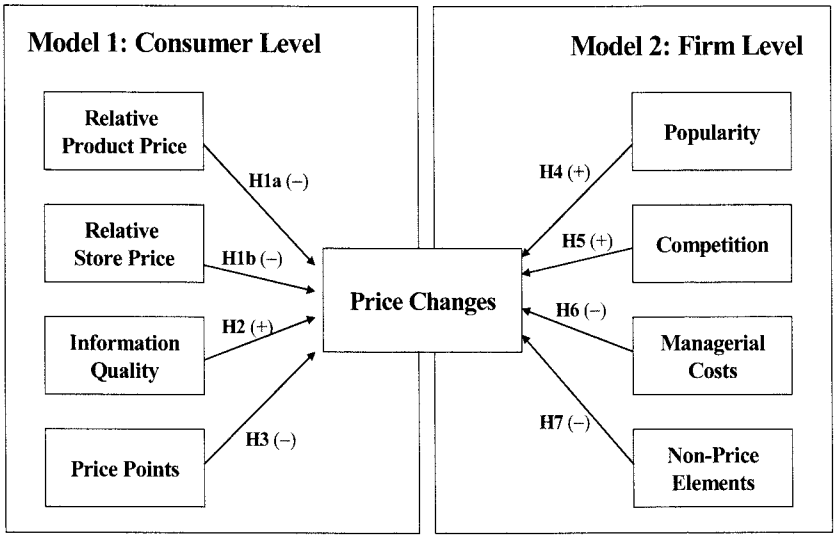
production and distribution [Daripa and Kapur, 2001]. However, to survive in such competitive environments, e-commerce firms require a significant level of investment in advertising and IT infrastructure. But the necessary economies of scale for these kinds of investments raise barriers to entry and may induce greater industry concentration [Daripa and Kapur, 2001]. Highly-concentrated online markets may allow firms to exploit market power by reducing the costs of driving traffic to their Web sites. Although the true relationship between industry concentration and price rigidity is not clearly defined in prior research, I still expect that highly concentrated industries on the Internet (e.g., books, CDs) will behave as oligopolies with the corresponding price coordination problems. So, I propose the following assertion:

H4 (The Internet Market Competition Hypothesis): *On the Internet, high industry concentration leads to greater price rigidity; the more highly competitive an industry, the more frequently will firms adjust prices in response to changes in market conditions.*

From an economic perspective, firms want to be able to adjust prices to react to changes in demand. Yet this is often difficult to do in a traditional bricks and mortar retail setting. The flow of data, and the processes and costs associated with changing prices can limit a traditional bricks-and-mortar store's ability to react to these changes. Compared to traditional channels, Internet-based retailers are able to more accurately control inventory and costs, and sample demand any time they need to. The new technologies associated with the Internet also provide traditional bricks-and-mortar retailers with opportunities to adopt bricks-and-clicks retail capabilities, such as leveraging logistical and operational expertise with traditional distribution channels, as well as connecting their technology infrastructures with the Internet. As a result, it is now possible to integrate a firm's Internet channel with traditional distribution channels while ensuring product, price and promotion consistency [Gulati and Carino, 2000]. So, price changes are more likely to be driven by *demand* considerations for Internet-based resellers. As the demand and popularity of a product increases, firms have an incentive or a capability to more frequently change prices to maximize their profits by attracting their customers. So, I present the next hypothesis:

H5 (The Product Popularity Hypothesis): *Internet-based sellers have an incentive to frequently change the prices of highly-demanded products; product popularity positively affects the likelihood of a price change.*

Although the Internet may reduce some of the physical or menu costs of changing prices, it does not necessarily reduce the managerial costs for price changes due to the integration efforts of a firm's Internet channel with traditional channels by ensuring product, price and promotion consistency [Bergen *et al.*, 2003]. These *managerial costs* can limit the ability of firms to change their prices promptly in response to changes in the firm's economic situation if many individuals' decisions in a hierarchical organization are required to process a price change [Blinder *et al.*, 1998]. Zbaracki *et al.* [2004] uncovered evidence from industrial markets that shows the managerial costs are significantly greater than the menu costs associated with price changes. So, Internet retailers



<Figure 1> Digital Price Rigidity Model

may have more price rigidities that stem from managerial costs. I propose the following hypothesis related to the managerial costs:

***H6 (The Product Coverage Hypothesis)**: Due to managerial costs, Internet firms change the prices of products less frequently if they cover many different kinds of products.*

Carlton [1989] points out the fact that markets often clear through means other than price. He views price as only one of many dimensions of the terms on which products are exchanged. *Non-price competition*, thus, can be used most effectively when a seller can make its product stand out from the competition by stressing customer service, conducting promotional efforts, etc.

As Clay *et al.* [2002] point out, online consumers care about other non-price aspects, such as seller reputation, delivery locations and times, contract lengths, etc. Internet-based sellers, as a result, may charge higher shipping costs instead of higher product prices, even if the underlying market conditions get worse. I also observe that the more important emphasis may be the competition to obtain new customers and to maintain high customer loyalty. Kauffman and Lee [2004b] also provide case study and empirical evidence that an online retailer, Buy.com, makes use of shipping costs, instead of direct price adjustments in its approach to strategic pricing. Apparently non-price elements causing price rigidity can be used effectively by the retailer in the e-commerce context. This leads to the following assertion:

***H7 (The Non-Price Promotions Hypothesis):** Internet-based sellers make use of non-price promotional efforts (e.g., free shipping or coupons) instead of price changes for competition; so the use of non-price promotions is negatively related to the observed price changes.*

This leads to propose a research model for price rigidity on the Internet with two levels of analysis, whose predictions I will test. (See <Figure 1>).

Ⅲ. Research Methods

3.1 Data Collection

I collected price-related data from multiple Internet sites, including a price comparison site, BestWebBuy.com, and the two major Internet retailers, Amazon.com and BN.com. I used a *price information gathering agent*, which automatically obtains information for multiple product categories (i.e., books, CDs and DVDs) providing a setting where the products in the samples are all identical. In addition, these categories do not change in quality and the market structure of these industries also was stable during the time of our study. These characteristics are different from those in markets with perishable goods, such as the airlines, hotels and rental car companies, whose price changes are volatile to reflecting demand and capacity. For the purpose of intra-group comparative analysis and sampling bias control, I grouped our price observations into two broad sub-categories: bestsellers and non-bestsellers.

Collecting the data involved different activities. From a list of products available at Best WebBuy.com, I generated a large sample of unique product IDs belonging to different subject categories using *stratified proportionate random sampling* [Wooldridge, 2002]. With the list of product IDs, the software agent extracted information for each product. Our data consist of 676 daily observations of prices (i.e., list prices, selling prices and total prices including shipping fees) in 657 products (i.e., 385 books, 154 CDs and 118 DVDs) sold by 22 Internet- based retailers (10 for books, 5 for CDs and 7 for DVDs), covering from March 2003 to February 2005. I also collected qualitative information (e.g., consumers' ratings of products, number of reviews, and sales ranks) from Amazon.com and BN.com. The total number of observations is 3,013,846 (i.e., 2,117,908 for books, 430,782 for CDs, and 465,156 for DVDs).

3.2 Data Analysis

<Table 1> presents descriptive statistics. The selling price range of all the product categories is $2.99 to $199.99, and the mean values of different categories vary from $14.77 (CDs) and $22.28 (books) to $22.62 (DVDs). The mean values of our different price data (list price, selling price, and total price) are also different by categories (See <Table 1>).

Total price includes fees for standard shipping. So, the mean values of shipping costs are $3.20 for books, $2.90 for CDs and $2.15 for DVDs. In addition, the maximum price increase is $60.00 for books while the maximum price decrease is $45.00 for DVDs. The data on *number of reviews* (used as a proxy measure for *product information quality*) and *sales rank* (used for *product popularity*) are collected from Amazon.com and BN.com. The number of reviews also varied from 0 to 8,309 (books). The most popular product ranked at 1 for books, 58 for CDs and 103 for DVDs while the least popular one ranked at 1,348,743 for books, 592,955 for CDs and 60,864 for DVDs.

I observe the frequencies of the last digit in cents for selling prices. The digit "9" occurs at 26.7% of the time overall (21.1% for books, 53.9% for CDs, and 26.8% for DVDs) as price endings in cents more frequently than others. I also look at the distribution of the last digit in

<Table 1> Descriptive Statistics by Categories

Series (Books)	Obs.	Mean	Std. Err.	Min	Max
List Price ($)	2,117,908	29.14	23.24	2.99	199.99
Selling Price ($)	2,117,908	22.28	17.89	2.09	199.99
Total Price ($)	2,117,908	25.48	17.27	2.99	203.96
Price Change ($)	2,114,775	0.001	0.44	-40.00	60.00
Shipping Cost ($)	2,117,908	3.20	1.29	0.00	6.30
Number of Reviews	2,117,908	195.36	650.81	0	8309.00
Sales Rank	2,117,908	56,794.19	92,145.42	1	1,348,743
Series (CDs)					
List Price ($)	430,782	18.43	5.77	6.29	67.99
Selling Price ($)	430,782	14.77	4.57	4.49	67.99
Total Price ($)	430,782	17.67	4.64	7.47	71.98
Price Change ($)	430,111	0.0009	0.27	-8.00	9.00
Shipping Cost ($)	430,782	2.90	1.10	0.00	5.99
Number of Reviews	430,782	151.10	386.40	0	3706
Sales Rank	430,782	86,013.32	136,588.73	58	592,955
Series (DVDs)					
List Price ($)	465,156	31.41	20.50	6.99	134.98
Selling Price ($)	465,156	22.62	15.70	3.39	134.98
Total Price ($)	465,156	24.77	15.55	4.99	137.96
Price Change ($)	464,448	-0.0023	0.50	-45.00	39.53
Shipping Cost ($)	465,156	2.15	1.45	0.00	6.99
Number of Reviews	465,156	240.72	457.62	0	3,600
Sales Rank	465,156	12,524.42	14,334.91	103	60,864

dollars. The distribution of the last digit in dollars ranges from 4.1% to 13.8%. These results are consistent with previous marketing research, which contrasts what happens with big-ticket items like cars and low-priced items like grocery items. For the former, "9"-ending prices will end with $9, while lower-priced items will end with 9¢ [Bergen *et al.*, 2003]. The average selling price of the data is not very high at $22.62, so I include the last digit in cents as an explanatory variable.

Among the book categories, the bestseller category shows the highest percentage of price changes (1.20%) including price increase and decrease. In addition, the bestseller category in CDs and DVDs changed prices more often than the non-bestsellers category. These results support the *Product Popularity Hypothesis* (H4), which states that firms change the price of popular products more frequently. Also, I found some variations in price change frequencies across product categories: price changes of books for every 98.29 days on average (2,114,775/21,517), 44.84 days for CDs (430,111/9,593), and 28.69 days for DVDs (464,448/16,189). The result of book price adjustments is almost consistent with what Bergen *et al.* [2005] found from Amazon and BN data (i.e.,

every 90 days).

3.3 Defining the Variables for the Empirical Model

To examine what drivers are the most important in explaining price adjustments in e-commerce, I created the binary dependent variable Δ as either "changing" or "not changing" prices. The prices are the actual selling prices without any shipping fees, adjusted for promotions or discounts. The definitions of each variable used in the models are provided in the <Table 2>.

At the consumer level, I look for proxies of quality that are accessible in the kind of data that I was able to collect. So, I created three explanatory variables related to quality: *RelStore, RelPrice, and InfoQuality.* I defined *RelStore* as a relative measure of the prices charged by each Internet-based seller. Some retailers sell many different categories of products, so I determine an average price for each category-store combination. Then, I calculate a relative price, defined as the average price divided by the mean price of each product category to produce a store's relative price for each product category. I create *RelPrice* to capture the relative price of each observation within its product category. I calculate a relative price, defined as the price of the product, divided by the average price for the product category. I also define *InfoQuality*

<Table 2> Description of Key Variables

Variable	Definition
$\Delta_{i,j,t}$ *(Price Change)*	Binary *dependent variable* indicating that store *i* changes price of product *j* at time *t*; coded as 1, and 0 otherwise.
$RelPrice_{i,j,t-1}$	Price of product *j* divided by the average price for the product category across stores at time *t-1*.
$RelStore_{i,j,t-1}$	Store *i*'s average price for each product category divided by average price for each product category for all stores at time *t-1*.
$InfoQuality_{i,j,t-1}$	Consumers' perceived information quality of product *j* at time *t-1* in each product category, measured by number of reviews from Amazon and BN.com.
$NineEnding_{i,j,t-1}$	Binary variable indicating that the last two digits of the price of product *j* in store *i* is "9" at time *t-1*; coded as 1, and 0 otherwise.
$Competition_{i,j,t-1}$	The number of stores that sell product *j* divided by total number of stores in each product category (10 for books, 5 for CDs, and 7 for DVDs) at time *t-1*.
$Bestseller_{i,j,t-1}$	Binary variable indicating that product *j* is in the bestseller category at time *t-1*; coded as 1, and 0 otherwise.
$Popularity_{i,j,t-1}$	Product popularity of product *j* at time *t-1* in each product category, based on weekly sales rank from Amazon and BN.com.
$ProdCoverage_{i,j,t-1}$	The ratio of the number of products that store *i* sells to the total number of products in each product category (385 for books, 154 for CDs, and 118 for DVDs) at time *t-1*.
$FreeShipping_{i,j,t}$	Binary variable indicating that store *i* provides free shipping for product *j* at time *t*; coded as 1, and 0 otherwise.
$CD_{i,j,t}$	Binary control variables indicating that the category of product *j* is a CD or a DVD; coded as 1, and 0 otherwise. *Book* is the base category.
$DVD_{i,j,t}$	

as consumers' perceived information quality of a product. I derive *InfoQuality* from the number of reviews collected weekly from Amazon and BN.com (i.e., $(NumReviews_{AMAZON} + NumReviews_{BN})/2$) divided by the mean of the number of reviews in each product category. Also I create an explanatory variable, *NineEnding*, to proxy for price points.

To measure the firm-level characteristics of demand and competition on the Internet, I create five explanatory variables including *Competition*, *Bestseller*, *Popularity*, *ProdCoverage*, and *FreeShipping*. *Competition* is defined as the number of firms that sell a product divided by total number of firms in each product category. So, if a book is sold by 5 retailers in a given time period, the value of *Competition* will be 0.5 (i.e., 5/10) because total number of firms for books is 10. I also create two explanatory variables, *Bestseller* and *Popularity*, to measure the demand of a product. The reader may wonder why *Popularity* (measured by sales rank) is negative. A higher sales rank has a small number and its values lie between 1 and 1,348,743. I multiply the values of sales rank by -1 after transforming them with a logarithm to reduce outlier effects. *ProdCoverage*, a proxy for managerial costs, is defined as the ratio between the number of products that a firm sells and the total number of products in the product category. For example, if a firm sells 77 CDs in a given time period, the value of *ProdCoverage* is 0.5 (i.e., 77/154) because the total number of CDs is 154. I also create a binary variable, *FreeShipping*, indicating a firm offers a free shipping option for a product in a given time period. I operationalize two binary dummy variables to control the variations across product category: *CD* and *DVD*. <Table 3> provides summary statistics for the variables.

<Table 4> shows pairwise correlations between the explanatory variables. The highest absolute values of correlation are 0.252 for Model 1 and 0.513 for Model 2, which are below the frequently-used threshold of 0.6 suggested by Kennedy [1998]. I also calculated variance influence factors (VIFs) to detect multicollinearity among the explanatory variables. The highest VIFs are 1.11 for Model 1 and 1.59 for Model 2. So, there was no evidence of these problems.

<Table 3> Statistics of Key Variables(N = 3,013,846)

Variables	Mean	S.D.	Min.	Max
RelPrice	1.03	1.007	0.13	16.88
RelStore	1.00	0.161	0.66	1.32
InfoQuality	1.78	5.956	0	80.20
NineEnding	0.27	0.442	0	1
Competition	0.86	0.125	0.10	1.00
Bestseller	0.32	0.465	0	1
Popularity	-9.46	1.992	-13.82	-1.25
ProdCoverage	0.89	0.159	0.25	0.98
FreeShipping	0.14	0.347	0	1

<Table 4> Correlations between Key Variables

Model 1(N = 3,009,334)						
	V1	V2	V3	V4	V5	V6
V1	1.000					
V2	-0.011	1.000				
V3	-0.059	-0.009	1.000			
V4	0.015	0.041	-0.022	1.000		
V5	-0.013	-0.000	-0.046	0.252	1.000	
V6	-0.013	-0.000	-0.053	0.001	-0.175	1.000
Model 2 (N=2,999,413)						
	V5	V6	V7	V8	V9	V10	V11
V5	1.000						
V6	-0.174	1.000					
V7	0.153	0.203	1.000				
V8	0.020	0.266	0.513	1.000			
V9	0.157	0.171	0.237	0.403	1.000		
V10	0.024	-0.044	-0.023	-0.094	-0.179	1.000	
V11	-0.037	0.162	0.011	0.016	0.093	-0.108	1.000

Note: V1 (*RelPrice*), V2 (*RelStore*), V3 (*InfoQuality*), V4 (*NineEnding*), V5 (*CD*), V6 (*DVD*), V7 (*Bestseller*), V8 (*Popularity*), V9 (*Competition*), V10 (*ProdCoverage*), V11 (*FreeShipping*).

3.4 Binary Logit Model

I assume that Internet-based sellers are profit maximizers with respect to choices between "changing" and "not changing" prices. So, I use a *logit* model as a means to represent firms' binary decisions of whether to make a price change. As with the linear probability model, the disturbance terms in a logit model exhibit *heteroskedasticity* [Greene, 2003]. So instead of using ordinary least squares (OLS), I use maximum likelihood estimates (MLE) to correct this defect. The full form of the binary logit model is:

Model 1 (Consumer-Level Model)

$$P(\Delta_{i,j,t}=1)=\beta_0+\beta_{RelPrice}RelPrice_{i,j,t-1}+$$
$$+\beta_{RelStore}RelStore_{i,j,t-1}+\beta_{InfoQuality}InfoQuality_{i,j,t-1}$$
$$+\beta_{NinEnding}NineEnding_{i,j,t}+\beta_{CD}CD_{i,j,t}+$$
$$\beta_{DVD}DVD_{i,j,t}+u_{i,j,t}$$

Model 2 (Firm-Level Model)

$$P(\Delta_{i,j,t}=1)=\beta_0+\beta_{Competition}Competition_{i,j,t-1}+$$
$$\beta_{Popularity}Popularity_{i,j,t-1}+\beta_{Bestseller}Bestseller_{i,j,t-1}$$
$$+\beta_{ProdCoverage}ProdCoverage_{i,j,t-1}+\beta_{FreeShipping}$$
$$FreeShipping_{i,j,t-1}+\beta_{CD}CD_{i,j,t}+\beta_{DVD}DVD_{i,j,t}+u_{i,j,t}$$

Some of the variables-*Competition*, *Bestseller*, and *InfoQuality*-do not vary by product. If these variables are being used across repeated observations, this may lead to the inflation of the standard errors. So, to correct for repeated observations, I also adjust the standard errors by *clustering* our data at the product level.

Ⅳ. Estimation and Results

I used STATA 8.0 (www.stata.com) to esti-

mate the empirical models I developed in the previous section. I used both *likelihood ratio* (LL) statistic and the *count-R^2* to validate the results. The *count-R^2* is defined as the number of correct predictions divided by total number of observations [Greene, 2003].

4.1 Empirical Results for All Categories of Data

I first examine the results empirical model using all the data available. Estimation results of the logit regression for the consumer-level and firm-level models are reported in <Table 5>.

First, the effect of *RelPrice* on the choice of price changes ($\beta_{RelPrice} = 0.017$; $p = 0.372$) is positive and insignificant in Model 1, the Consumer-Level Model. This is inconsistent with the *Relative Product Price Hypothesis* (H1a), which states that Internet-based sellers changes the prices of high-priced products less frequently than those of low-priced products. The results indicate that the online consumers may not use prices as a cue for assessing quality of the product. Compared to the previous studies that used data of heterogeneous products (e.g., clothes, electronics) in traditional channels, our data consist of homogenous products (e.g., books, CDs) where quality is rarely in doubt. For example, high-priced CDs do not necessa-

<Table 5> Results of Logit Model for the Consumer and Firm-Levels

	Model 1 (Consumer-Level)			Model 2 (Firm-Level)		
Variable	Coeff.	S. E.	O/R	Coeff.	S. E.	O/R
RelPrice	0.017***	0.019	1.017	NA		
RelStore	-1.178***	0.096	0.308			
InfoQuality	0.010***	0.003	1.010			
NineEnding	-0.482***	0.045	0.617			
Competition	NA			0.913***	0.145	2.491
Popularity				0.092***	0.010	1.096
Bestseller				0.206***	0.035	1.229
ProdCoverage				-0.647***	0.112	0.524
FreeShipping				0.299***	0.038	1.349
CD	0.986***	0.071	2.680	0.609***	0.047	1.838
DVD	1.324***	0.040	3.761	0.900***	0.039	2.461
Constant	-3.385***	0.099	NA	-3.998***	0.203	NA
Observations	3,009,334			2,999,413		
-2LL (*Count-R^2*)	469,430 (98.43%)			465,179 (98.43%)		

Note: Logit (MLE estimation). Dependent variable = Δ (price change). Standard errors (S.E.) are robust because I clustered the data at the product level. Significance levels: *** = 0.01, ** = 0.05, * = 0.10. O/R = odds ratio. Estimated coefficients in gray indicate results that are not consistent with our hypothesis.

rily signal a high quality of the product. Instead, they may signal the brand of the product or prices may highly depend on the demand or popularity of the product. So, it seems unreasonable to view quality signaling as a cause of price rigidity in many online products.

The effects of *RelStore* ($\beta_{RelStore}$ = -1.178; p = 0.000) show negative and consistent results with the *Relative Store Price Hypothesis* (H1b). The result indicates that high-quality firms that signal the market with higher prices are more sensitive to consumers' responses to the unexpected price changes. This also lends support to the argument that firms compete on quality on the Internet, and not just on price. Moreover, it is possible that the high quality firms are actually winning. As expected, there is a positive and significant effect of *InfoQuality* ($\beta_{InfoQuality}$ = -0.010; p = 0.001) on price changes, and the *Information Quality Hypothesis* (H2) is well supported. The demand in selected product categories (i.e., books, CDs, and DVDs) may indeed be serially-correlated.

The effect of a *NineEnding* on the price changes is negative and significant ($\beta_{NineEnding}$ = -0.482; p = 0.000). This is consistent with the *Price Points Hypothesis* (H3), which states that an Internet-based seller is likely to change prices less frequently to make the price endings equal to "9." This result is very interesting. Consumers on the Internet can easily compare prices as well as obtain product information through shopbots or search engines. However, even on the Internet, consumers may be rationally inattentive to the last digit of the price, and sellers may take advantage of their inattention and make the price-ending as high as possible.

I also assessed our model at the firm level. I obtained an interesting finding that *Competition* ($\beta_{Competition}$ = 0.913; p = 0.000; odds ratio = 2.491) positively affects price changes. So, the *Internet Market Competition Hypothesis* (H4) is also well supported. The result indicates that highly-concentrated industries behave as oligopolies with the attendant problems of pricing coordination [Carlton, 1986; Rotemberg and Saloner, 1987]. Another explanation for this relationship is *pricing to prevent entry*, also known as *limit pricing*. Firms in concentrated industries are able to enjoy increasing returns to scale, and thus they tend to keep their prices lower than they otherwise would to discourage or delay new firm entry [Stiglitz, 1987].

In addition, the effects of *Popularity* and *Bestseller* are positive and significant ($\beta_{Popularity}$ = 0.092 and $\beta_{Bestseller}$ = 0.206), support of the *Product Popularity Hypothesis* (H5). The results indicate that Internet-based retailers may have business rules or strategies focusing on bestselling products to maximize their profits. This result is consistent with the results of Kauffman and Wood [2005], who find evidence of follow-the-leader pricing behavior among Internet-based sellers. It also suggests that Internet-based retailers have the capability to adjust prices more flexibly due to intensive use of information technologies, which offers opportunities to implement algorithmic price discrimination and to segment customers. I also assessed the implication of managerial costs on price rigidity on the Internet. Consistent with the *Product Coverage Hypothesis* (H6), I find negative and significant effects of *ProductCoverage* on price changes ($\beta_{ProdCoverage}$ = -0.647; p = 0.000). Thus, there appears to be more going on with price adjustment than just menu costs associated with mak-

ing the price changes—even on the Internet. The Internet apparently does not necessarily reduce the related managerial costs for price changes. This may be due to integration efforts that firms make to get their operations in the Internet channel in synch with their efforts to sell in traditional channels [Bergen *et al.*, 2003]. I found a positive and significant effect of *FreeShipping* ($\beta_{FreeShipping}$ = 0.299; p = 0.000) on price changes, indicating that the non-price promotions like free shipping are positively related to the observed price changes. So I reject the *Non-Price Promotions Hypothesis* (H7).

Finally, as I've already noticed in the previous data analysis, the coefficients of the control variables, *DVDs* (β_{DVD} = 0.986 and 0.609 for Model 1 and 2, respectively) and *CDs* (β_{CD} = 1.324 and 0.900 for Model 1 and 2, respectively), indicate that these categories change prices more frequently compared to books. We may find a number of reasons why such variations in price adjustments occur across product categories. One may argue that industry concentration or market competition may be a source for more rigidity in the online book industry, for example. Latcovich and Smith [2001] report that the online book market has become more concentrated than the traditional book market in the United States—the top four-firm aggregate market share for online booksellers at 93% and for the traditional book retailing industry at 45%.

4.2 Additional Results across Product Categories

Two explanatory variables, *RelPrice* (H1a) and *FreeShipping* (H7), exhibited some contradictory results for the proposed hypotheses. I previously observed some variations in the price adjustment patterns across the product categories. So I conducted further analyses on our proposed model by product category. I present the results of logit model by product category next in <Table 6>.

In the book category, most of the results are consistent with those I found for the disaggregated level for all of the categories reported in <Table 5>. The only exception was *RelPrice*. So, the *Relative Product Price Hypothesis* (H1a) is well supported by our data on books ($\beta_{RelPrice}$ = -0.020; p = 0.017). This suggests that it is reasonable to view quality signaling as a cause of price rigidity in Internet-based bookselling. However, as reported in <Table 6>, quality signaling does not make sense for CDs and DVDs as a means to explain digital price rigidity. In the CD category, *FreeShipping* showed a negative and significant effect on price changes ($\beta_{FreeShipping}$ = -0.449; p = 0.000), which is consistent with the *Non-Price Promotions Hypothesis* (H7). However, in the other two categories, books and DVDs, I found results that did not match this hypothesis. The results suggest that only a few product categories—like CDs—may make use of free shipping options instead of direct price changes. In other product categories, shipping costs may be a part of total price and appear to cause price choices, but instead they are more likely to be *endogenously* determined. Among the categories in the data set, DVDs showed the least consistent results relative to our proposed hypotheses. This indicates that the price adjustment patterns for DVDs may be influenced more by competitive or demand factors (i.e., *Competition, Popularity,* and

<Table 6> Results of Logit Model by Product Categories

Variable	Books		CDs		DVDs	
Model1	Coeff. (S. E.)	O/R	Coeff. (S. E.)	O/R	Coeff. (S. E.)	O/R
RelPrice	-0.020*** (0.010)	0.981	0.276*** (0.134)	1.318	0.084*** (0.035)	1.088
RelStore	-1.542*** (0.012)	0.214	-2.232*** (0.952)	0.107	5.142*** (0.269)	171.14
InfoQuality	0.004*** (0.001)	1.004	0.065*** (0.024)	1.067	0.053*** (0.019)	1.054
NineEnding	-0.169*** (0.053)	0.845	-0.994*** (0.083)	0.370	-0.213*** (0.061)	0.808
Constant	-3.034*** (0.090)	NA	-1.498*** (1.044)	NA	-8.597*** (0.277)	NA
Observations	2,114,775		430,111		464,448	
-2LL (*Count-R^2*)	238,175(98.98%)		89,208(97.77%)		138,094(96.51%)	
Model 2	Coeff. (S. E.)	O/R	Coeff. (S. E.)	O/R	Coeff. (S. E.)	O/R
Competition	0.460*** (0.177)	1.584	0.991*** (0.404)	2.694	1.350*** (0.244)	3.858
Popularity	0.063*** (0.012)	1.065	0.187*** (0.024)	1.206	0.058*** (0.020)	1.060
Bestseller	0.163*** (0.046)	1.178	0.123*** (0.107)	1.131	0.242*** (0.083)	1.274
ProdCoverage	-1.184*** (0.112)	0.306	-1.213*** (0.276)	0.297	1.513*** (0.275)	4.542
FreeShipping	0.338*** (0.056)	1.403	-0.449*** (0.141)	0.638	0.703*** (0.061)	2.019
Constant	-3.414*** (0.181)	NA	-1,994*** (0.569)	NA	-5.808*** (0.416)	NA
Observations	2,108,700		426,265		464,448	
-2LL (*Count-R^2*)	237,245 (98.98%)		88,704 (97.75%)		127,323 (96.51%)	

Note: Logit (MLE estimation). Dependent variable = Δ(price change). Standard errors (S.E.) are robust because I clustered the data at the product level. Significance levels: *** = 0.01, ** = 0.05, * = 0.10. O/R = odds ratio. Estimated coefficients in gray indicate results that don't match those that were hypothesized.

Bestsellers) than other factors that I proposed.

V. Conclusion

In this paper, I proposed and validated two levels of *digital price rigidity* models to examine a range of different theories of price rigidity and explain the observed empirical regularities and variations in price adjustment patterns and strategies of Internet-based retailers. To the best of my knowledge, this research is the first to empirically assess price rigidity patterns for multiple industries in Internet-based retailing, and attempt to explain the variation in these patterns. I found that price changes are more likely to be driven by quality, competitive and economic considerations. These results speak to both the IS and economics literatures. To the IS literature these results suggest we take economic considerations into account in more sophisticated ways. The existence and variation in price rigidity argue that simplistic assumptions about frictionless and completely flexible digital prices do not capture the richness of pricing behavior on the Internet. The quality, competitive and economic forces identified in this model suggest promising directions for future theoretical and empirical work on their role in these technologically changing markets. To the economics literature these results offer

new evidence on the sources of price rigidity, which can then be incorporated into the development of models of pricing at the firm, industry and even macro-economic level of analysis. It also suggests that there is much to be learned through interdisciplinary research between the IS, economics and related business disciplines.

I conclude with several comments about the possible limitations of our results. First, some of our arguments (e.g., *RelPrice, RelStore*) can be also applied to traditional offline channels. From the findings, however, I believe that our argument is valid and concrete in terms of the role of IT in strategic pricing on the Internet. Pricing managers at Internet-based retailers should be wary of the signals associated with strategic pricing approaches, especially if they are competing in the marketplace on the basis of quality. In addition, what is not as clear is why particular competitive pricing patterns which I have found have emerged in online retailing industries. My first reaction is that it will be necessary to understand what I observe in terms of explanatory theories that emphasize the competitive dynamics (e.g., competition between Amazon and BN) that are at play on the Internet. It might also be the case that there is an explanation that is based on managerial capabilities and costs that BN, as a later entrant to Internet-based selling, may have more strategic pricing expertise from its traditional store operations.

Consistent with the idea of a *variance theory of Internet-based price rigidity*, the reader should consider a natural next question in this line of research: Will these results generalize to other product categories, and other retailers on the Internet? Our findings may be limited to more homogeneous product categories (e.g., books and DVDs) whose quality is rarely in doubt. I do not yet include other products that may be subject to different price change considerations and dynamics. For example, we need to ask: Will the same findings be obtained for electronics products sold on the Internet that are subject to rapid price adjustments as new generations come to market? Will these findings obtain on the Internet for products which have competitive substitutes (e.g., laser printers and hand-held computing devices)? Future research will inform us.

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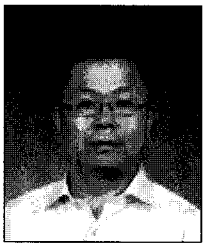
◆ 저자소개 ◆



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현재 고려대학교 경영대학 교수로 재직 중이다. 서울대학교에서 경영학사 및 경영학 석사, University of Arizona에서 MIS 석사, University of Minnesota에서 경영학 박사를 취득하였다. 주요 관심연구분야는 전자 상거래 가격 전략, 온라인 소비자 행동 분석, 정보 시스템 투자 및 활용, 지식 공유 및 관리 등이다.

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