An Empirical Study of Price Dispersion in
Homogenous Goods Markets

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ABSTRACT

This paper presents the results of an empirical study of price dispersion in homogeneous goods markets. Modern economic theory suggests that inevitable asymmetries of information in markets lead to an equilibrium in which price dispersion is present even when goods are perfectly homogenous. In this paper we present an empirical analysis in which we employ both cross-sectional and time-series data gathered directly from Pricegrabber.com, one of the most popular and comprehensive online shopping/price-comparison sites on the Internet. In particular our analysis focuses on (i) the effect that the number of firms offering a good has on price dispersion, (ii) the informational value to the consumer of using the Pricegrabber website, and (iii) the persistency of price dispersion over time.

JEL Classification: L81, L86, L11

Keywords: E-commerce, Internet marketing, Price dispersion, Signaling, Search Cost, Gatekeepers, Regression and other statistical techniques

Section 1. Introduction

One of the most well known tenets of classical economic theory is that in an "ideal" world in which information is perfect, increased competition leads to lower prices for consumers. However, the so called "Law of One Price", where price equals marginal cost no longer holds in a more realistic setting, in which information is imperfect, and both consumers and producers are forced to make choices that are marred by uncertainty. Informational asymmetries imply that the consumer and producer base is no longer homogenous with respect to information. Some consumers are well informed about prices. They know for instance, when and where to find sales, which stores have the lowest prices on certain goods, and which stores they should be wary of whether due to high prices or bad reputation. On the other hand, other consumers do not benefit from this information: their cost of acquiring information, also known as “search cost”, is relatively high and as a result they tend to buy from whatever retailer they happen to stumble across. This informational gap in the consumer base, presents sellers with an opportunity to capitalize by selling homogenous goods at different prices. However, the firms themselves also have to make decisions under imperfect information. Ideally they would like to price discriminate between informed and uninformed consumers. Indeed some firms have taken this exact approach; they give special discounts to consumers who reach their site through a shopping comparison site, and charge their average consumers a higher price for the same goods. Most firms, however, charge a single price, and in doing so try to capture both informed and uninformed consumers, a non-trivial feat which has been the focus of much research and will be addressed further on in this paper.

While the extent of price dispersion has traditionally been very hard to measure, the rapid spread of the Internet and e-commerce has opened a window into empirical research in this field. While it may at first appear that the Internet has done wonders in terms of disseminating information, and reducing the informational gap between consumers, this may not necessarily be the case. The tremendous increase in the number of e-retailers since the birth of the Internet has introduced a lot of noise into the picture.

The Internet has also dramatically lowered so called “menu costs”, which are essentially the costs associated with listing each item’s price. E-retailers can now update prices automatically, depending on demand, inventory, time of the day, etc., which causes consumers to face an unprecedented level of price uncertainty. It is therefore plausible that, on the whole, this noise actually outweighs the positive information disseminating effects of the Internet.

In this spirit, we set out to analyze numerous aspects of online price dispersion on homogeneous goods in more detail. In the following section we present a summary of the most important research conducted in this field. In sections 3 and 4 we provide details regarding our data, as well as a qualitative analysis, while sections 5 and 6 are dedicated to quantitative analysis and results. We then conclude with a short summary of our main findings as well as some thoughts on further possible research in this area.

Section 2. Review of the literature

The fundamental importance of information in markets was first emphasized by Akerlof (1970) in his seminal paper “The market for lemons: quality uncertainty and the market mechanism”. However, it was not until Salop (1977) and Salop and Stiglitz (1977) that economists had a theoretical framework that could explain price dispersion based on informational asymmetry. Their model presented a scenario in which natives go to eat at the cheapest restaurant in town, while the tourists, not knowing which restaurant is the cheapest, simply decide to go to a random one. Their model shows that information plays a crucial role for both consumers and restaurant owners. The average tourist can expect to pay a higher price than the natives because only the few tourists who happen to randomly select the cheapest restaurant will pay the lowest price. The restaurant owners, on the other hand, have to make an important decision when setting their prices: they can choose to simply charge a high price and only sell to a fraction of all tourists, or they can set their prices so low as to target both natives and tourists. Their choice depends primarily on the number of natives compared to tourists, i.e. the fraction of informed consumers compared to uninformed consumers. The lower the fraction of informed consumers in the population, the less attractive it will be for firms to specifically target these consumers, and the stronger the incentive it will have to sell to only uninformed consumers. Ultimately the firm will choose its pricing strategy depending on which scheme yields more profits.

A major theoretical step forward in explaining price dispersion was taken by Varian (1980). While Salop and Stiglitz had focused on "spatial price dispersion", where experience can help consumers to eventually become informed, Varian studied the case of "temporal price dispersion", in which consumers can only be informed for short periods of time, because firms continually change their prices. Varian argues that one of the main reasons that firms run sales is to try to keep consumers uninformed about their prices. He demonstrates that even in a perfectly competitive market where firms are making zero economic profits selling a given homogeneous good, price dispersion will be present. In fact, he proves an even more remarkable result, namely that the only equilibrium that is sustainable in such a market is one in which firms charge seemingly random prices. As Varian himself puts it "the law of one price is no law at all!"

While most research in the field of price dispersion had been purely theoretical in the past, the advent of the Internet and online gatekeepers has greatly facilitated the collection of data for empirical research. Early research in this field focused mainly on comparing online price dispersion to that present in conventional retail markets. Some economists expected the Internet to be superior to retail markets in terms of efficiency, because one may expect that the Internet greatly reduces search costs. In theory, lower search costs lead to higher competition between firms, and hence should put downward pressure on prices for both homogeneous and differentiated goods. However, when talking about online markets, it is especially important to distinguish between search costs linked to obtaining price information, and those associated with obtaining product and seller information (While the Internet provides consumers with easy access to prices, determining the reliability and trustworthiness of the seller may involve considerably more effort that in traditional goods markets.)

Empirical studies in this field have yielded diverse results. Some of the earlier studies by Bailey (1998) show that prices are actually higher in electronic markets, while more recent similar studies by Brynjolfsson and Smith (2001) show that prices are significantly lower than in conventional retail markets. However, all studies to date have found that there is a considerable amount of price dispersion in electronic markets.

One of the reasons for this unexpectedly high level of price dispersion could be that the Internet has dramatically reduced menu costs. Menu costs essentially refer to the costs associated with (re)labeling products. In traditional markets, the labeling process may require a considerable amount of physical work, especially for large firms that sell thousands of products. In online markets however, firms incur minimal menu costs, since prices can be updated by simply changing a database entry. In the online marketplace firms can even fully automate this process, making it remarkably easy for them to run price changes depending on demand, time of day or year, or even availability of the product. Moreover, in electronic markets, firms are able to make very small price changes, which are infeasible in conventional markets due to relatively large menu costs. In fact, Brynjolfsson and Smith (2000) find that online retailers make price changes that are up to 100 times smaller than the smallest price changes observed in traditional retail markets.

Some of the most promising recent efforts towards explaining online price dispersion have been made by Baye and Morgan (2001). Baye and Morgan (2001) present a theoretical framework for understanding the complex economics behind gatekeepers. This framework demonstrates how strong network externalities can be in such markets and shows why firms actually choose to pay advertising fees to the gatekeeper, even if they are unsure of whether their price will be the lowest among the listed prices. Their theoretical model has been backed up by both experimental work by Morgan *et al.* (2003) and Baye and Morgan (2004), and empirical research by Baye *et al.* (2004b). The most important empirical finding is that the Internet has not caused prices to converge, instead price dispersion has remained persistent over time. Another interesting finding is that price dispersion decreases significantly as the number of merchants offering a good increases, but still remains persistent. All of their results are based on price data on the most popular products appearing on shopper.com, a well-known shopping comparison site run by cnet.com.

Hence, although the underlying assumptions of the theoretical models of Varian (1980), Rosenthal (1980), Narasimhan (1988), and Baye and Morgan (2001) vary, all of them predict that price dispersion is an equilibrium phenomenon, the size of which depends primarily on the number of firms that list their prices. However, there is somewhat of a debate in the literature as to what the best measure of price dispersion in homogeneous goods markets actually is. Most empirical studies in this field have used some measure that takes on a value of zero when all firms in the market charge the same price, and there is thus no price dispersion whatsoever. Sorensen (2000) for example uses the coefficient of variation (stdev(price)/mean(price)) to measure price dispersion, while other studies focus on the price range (the difference between the min and max prices).

Baye and Morgan (2001) make a compelling argument that these measures may not be an ideal way to think of price dispersion, because they do not truly capture the degree of competitiveness in the market. It is certainly reasonable to assume that the vast majority of users that visit price-comparison sites such as Pricegrabber end up purchasing the product at a comparatively low price given that the goods themselves are perfectly homogeneous. Thus the only real competitors in the market are the firms that sell at the lower end of the price spectrum. As a result it makes sense to define a measure of price dispersion that depends on the difference between the lowest prices charged. Baye *et al.* (2004a) define the "Price Gap" (PG) as the percentage difference between the lowest two prices. When the gap is zero, i.e. at least two sellers are selling at the same low price; the market resembles a Bertrand equilibrium in which no firm can profitably raise its price. Note that in any such competitive market the price gap also has the desirable property of being 0 independent of the number of firms.

Another interesting, yet somewhat untraditional way to measure price dispersion is by the informational value to the consumer of knowing what the lowest price is. The Value of Information (VI) is defined as the amount that an informed consumer can expect to save by purchasing a given good at the lowest available price compared to an uniformed consumer, who can expect to pay the average price across all offers for the same good. While there is reason to suspect that market thickness should affect the value of information, the direction of the relationship may not be clear. Classical economic theory predicts that the average price of a good drops as more sellers enter the market and competition increases. Thus in a perfectly competitive market the average price will equal the minimum price and marginal cost, and the value of information will be zero. Of course, traditional theory assumes that buyers do not face informational asymmetries, which is of course unrealistic, especially in our setting.

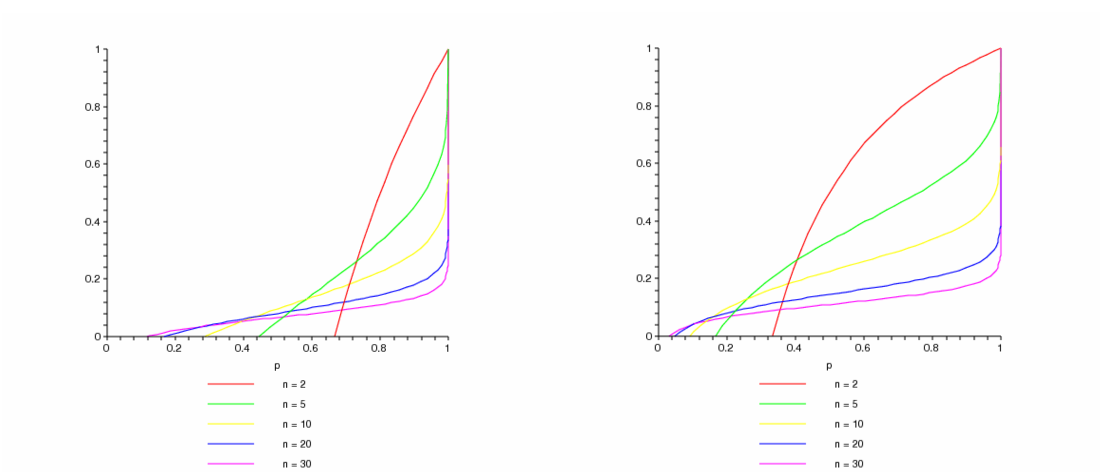
More suitable oligopolistic models that account for informational heterogeneity across the consumer base predict that the value of information will increase as the number of firms in the market increases. As more firms enter the market we can expect (1) the minimum price of the good to decrease, and (2) the average price to increase (!) There is a very sound logical explanation for why this should be the case: On the one hand, as the number of firms increases, competition increases as does the likelihood that one of the firms will charge a lower price; on the other hand the increase of competition implies that it will be harder for firms to target the informed consumers by charging the lowest price, and hence knowing that they will most likely sell to uninformed consumers whom they can charge a higher price, the average price will increase. To provide the reader with a better understanding of what the distribution of prices may look like, we present a slightly modified version of Varian's model below.

Let n denote the number of firms offering a certain homogeneous good, and I the fraction of consumers that are informed, i.e. visit the shopping comparison site. If we normalize the price, then Varian's model predicts that the distribution of prices will be given by the following cumulative distribution function:

$$\begin{gathered} F\left(p\right)=1-\left(\frac{\left(1-p\right)\left(1-I\right)}{npI}\right)^{\frac{1}{n-1}} \\ \text{on the support } \left[\frac{1-I}{nI+\left(1-I\right)},1\right] \end{gathered} \tag{1}$$

Figure 1a and 1b demonstrate what this function looks like for I=0.2, and I=0.5 respectively for values of $n=2,5,10,30$.

Figure 1. Theoretical Distribution of Prices



(a) Distribution of Prices for I=0.2 (b) Distribution of Prices for I=0.5

As the number of firms in the market increases so does the average price, because more firms choose to price at the higher end of the price spectrum and target only the uninformed consumers, since it is less likely that they will end up charging the lowest price. However, the fraction of informed consumers in the population also plays a fundamental role in determining the distribution of prices. The higher the fraction of informed consumers, the greater the incentive for firms to target these consumers, hence they price lower on average.

One of the reasons that the Value of Information is such an interesting measure of price dispersion, is that it allows us to measure the cost of dispersion to the consumer. Traditionally we tend to think of competitive markets as benefiting the consumer, however if the hypothesis is true that the value of information increases as competition increases, then two important results follow: Firstly, the informed consumer can expect to benefit from higher competition, because the lowest price is expected to drop to an even lower level; secondly, the average consumer actually incurs a cost in a more competitive market, because the average price that he expects to pay increases. Baye and Morgan (2003) find that on average consumers save 16% by buying from the shopper.com price comparison site, and that this number increases to 20% for products for which over thirty firms compete. This is a truly remarkable finding because it forces us to think of the benefits and costs of competition as well as the incredible value that such shopping sites provide to consumers.

Section 3. Data

Overview

The data in our study is collected from the popular shopping-comparison site Pricegrabber.com. The site was founded in 1999 and has since grown rapidly in popularity. Pricegrabber hosts a database of 3.5 million different products, and claims to have over 21 million active shoppers on a monthly basis. The service is free for shoppers, but charges an advertising fee to sellers who want to publish their prices. Two different pricing-schemes are available to firms: One of them is commission based, while the other is based on click rates. Prices are updated twice daily, and include details on shipping costs as well as merchant rating.

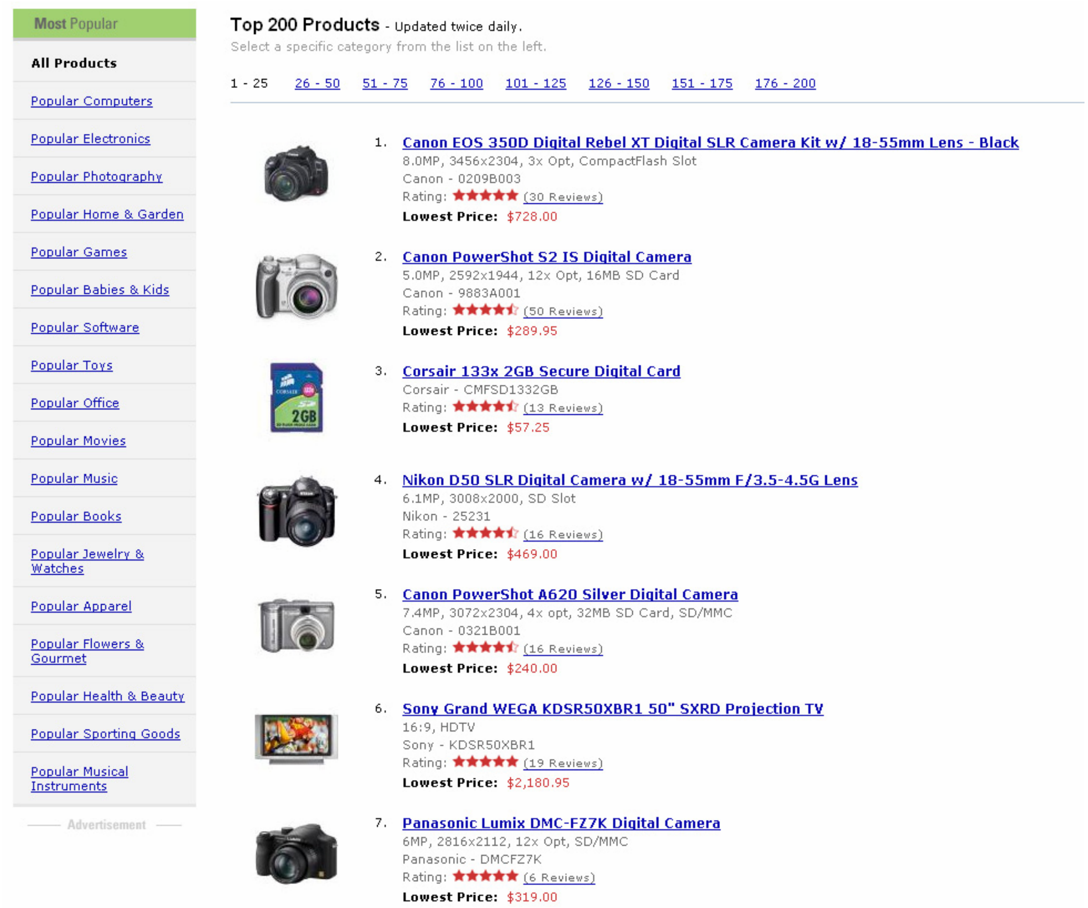
Our program runs queries to the Pricegrabber website twice a day, and retrieves prices, shipping prices, and the corresponding merchant's rating, the name of the merchant as well as other variables described in more detail in the following section. Shipping charges are based on the zip code 05753, which is Middlebury Vermont. The merchant's rating is a discrete variable that varies from 1 (the worst) to 5 Stars in half unit intervals. Please see the appendix for snippets of our code, which explains how these queries are invoked and how data is gathered.

Details on Data

For the purpose of our study we decided to create two separate databases. The first database consists of the 200 most popular products that are listed on the Pricegrabber website. The second one is a fixed sample that includes products belonging to different product categories. While Pricegrabber lists over 15 different categories we only chose to include the top 9, because in the others, products were typically only offered by a single firm. The categories we chose are listed below, along with some example products that belong to them:

1. Computers: Apple iMac 20-inch 2GHz Intel Core Duo Desktop, Logitech Z-5500 5.1 Speaker System, Asus A8N32-SLI Deluxe Motherboard
2. Electronics: Creative ZEN Vision:M 30GB Media Player - Black, Samsung LN-R408D 40" LCD TV, Motorola Razr V3 Cell Phone - Black
3. Video Games: Microsoft Wireless Network Adapter for Xbox 360, UbiSoft Prince of Persia: The Two Thrones (PS2), Logitech Driving Force Pro (PS2)
4. Software: Adobe Acrobat 7.0 Standard, Symantec Norton AntiVirus 2006, Adobe Photoshop CS2
5. Photography: Panasonic PV-GS150 MiniDV Digital Camcorder, Canon PowerShot S80 Digital Camera, Nikon D50 SLR Digital Camera w/ 18-55mm F/3.5-4.5G Lens
6. Office: Texas Instruments TI-89 Titanium Graphing Calculator, Sony ICD-BM1 Digital Voice Recorder, Brother FAX-2820 Laser Fax Machine
7. Movies: Harry Potter and the Goblet of Fire (2005) - DVD, Lord of War (2005) - DVD, 12 Monkeys (1995) - DVD
8. Books: A Tree Grows in Brooklyn, Freakonomics, The South Beach Diet
9. Health: Euphoria for Women by Calvin Klein Eau De Parfum Spray 1.7oz, Panasonic ES8162S Pro-Curve Elite Shaver, Black Code by Giorgio Armani Eau De Toilette Spray 2.5 oz for Men

Figure 2. Popular products and categories



For each of these nine categories we track the prices on a fixed sample of 20 products per category, thereby making a total of 180 products in the category database. The products we chose to include were the most popular products in their respective categories as of February 2006. Throughout our study we shall refer to the first dataset as POP, and to the second one as CAT.

Our datasets contain data fetched directly from the Pricegrabber website. This data includes information on:

1. Prices: This variable captures the prices that appear right away when a consumer searches for a certain product, i.e. they appear independent of whether the user inputs his or her zip code.
2. Shipping and Handling: These prices only appear after the user inputs a zip code. Knowing S&H costs enables us to compute total prices. Note that not all firms choose to post their prices, a phenomenon which we will study in greater detail in section 7 of this paper. For those that do not choose to post prices the words “See Site” appear in the shipping column.
3. Merchant Rating: The merchant rating appears next to the name of the merchant selling the good. It ranges from 0 to 5 starts in half-star intervals.
4. Merchant Name: We also include the actual name of the merchant selling the good in our database. This is useful because it allows us to control by merchant, and also helps us identify bad merchants, i.e. those that post incorrect information.
5. Product Category: This information is available for all products in both of our datasets, but the dataset containing the most popular products only contains goods from one of the top three categories, namely computers, electronics, and photography. However, the CAT dataset contains products from 9 different market sectors as described above.
6. Popularity Ranking: Finally, we also retrieve data on the popularity ranking of each product in our POP dataset. Since this dataset contains 200 products the ranking ranges from 1 to 200.

Figure 3. A comparison of offerings for the Sony Grand Wega 50" Projection TV

Seller	Price	Tax	Shipping	BottomLinePrice	Availability	Seller Rating
Authorized Electronics Merchant Info	$2,429.00	No Tax	Free	Your Best Price $2,429.00	In Stock	286 Reviews
American-Deals Merchant Info	$2,180.95	No Tax	$249.00	$2,429.95	In Stock	309 Reviews
dr plasma & provideo Featured Merchant Merchant Info	$2,354.79	No Tax	$224.00	$2,578.79	In Stock	266 Reviews
US Camera1 .com Featured Merchant Merchant Info	$2,299.99	No Tax	$279.99	$2,579.98	In Stock	1752 Reviews
electrodiscounts Merchant Info	$2,336.95	No Tax	$244.95	$2,581.90	In Stock	355 Reviews
MP SUPERSTORE Merchant Info	$2,336.95	No Tax	$244.95	$2,581.90	In Stock	637 Reviews
plasma HOUSE Merchant Info	$2,358.99	No Tax	$224.00	$2,582.99	In Stock	259 Reviews
Ideal Audio/Video Merchant Info	$2,587.87	No Tax	Free	$2,587.87	In Stock	640 Reviews

Every query provides us with 380 product observations (180 for CAT and 200 for POP). Since there are on average around 20 sellers per product we obtain close to a total of 8000 individual firm/price observations per query. In total our datasets currently include nearly 1,000,000 total price observations and 30,000 product observations.

From this raw data, we then proceed to calculate a number of interesting statistics that relate to various concepts of price dispersion. The most important indicators that we employ in our descriptive and econometric analysis are included in the following list:

1. Market Thickness: $MT = \#$ of firms offering a given product.
2. The Price Gap is the percentage difference between the two lowest prices charged for a given good at a given time. In a market, in which sellers attempt to undercut one another this gap should be small. The price gap is 0 when at least two firms sell at the same lowest price. On the 19th of April 2006 for example, the lowest listed price on the Pricegrabber website for the Sony PSP system was $192.99, and the second lowest price was $212. Therefore the price gap for the good was just over 7%,

which is a relatively large price gap (see Figure 11). Price Gap: $PG = \frac{P_2 - P_1}{P_1}$, where P_1 and P_2 denote the first and second smallest order statistics.

3. The Relative Dispersion is the Coefficient of Variation in prices charged for a given product and is measured in percent. A high value means that the standard deviation of the prices charged is high compared to the mean of the prices, and that thus there is a considerable amount of price dispersion prevalent for the given product. If all sellers charged the same exact price then the value of relative dispersion would be 0, the minimum possible. On April 25th average price and standard deviation for the Nikon CoolPix L4 Digital Camera were \$144 and \$14 respectively. Hence the coefficient of variation was approximately 9.5%, which is very close to the average CV over all products. Relative Dispersion:

$$RD = \frac{\sigma_P}{P} = \frac{\sqrt{\frac{\sum_{i=1}^{n}\left(P_i - \overline{P}\right)}{n-1}}}{\frac{1}{n}\sum_{i=1}^{n} P_i}$$

4. The Value of Information measures the percentage savings of an informed consumer, who buys at the lowest price compared to an uninformed consumer, who buys at the average price. A high value of this variable implies that informed consumers benefit greatly from knowing which firm is charging the lowest price. On the 19th of April the average price for the Canon PowerShot A620 Silver Digital Camera was \$301, while the minimum price was a low \$251, meaning that the value of information

was just about 20%. Therefore an uninformed consumer, who did not search for the lowest price of the camera, could expect to pay 20% more than an informed consumer. The Value of Information: $VI = \frac{\overline{P} - P_{\min}}{P_{\min}}$.

5. The Price Range is the percentage difference in the maximum and minimum prices charged for a given product. When price dispersion is high the price range is high. If all sellers charged the same price the price range would be 0. On the 26th of April the price range for the Western Digital Raptor hard drive, for example, was relatively small at just 29%, meaning that the highest price charged was just 29% more expensive than the lowest price charged. The average price range in our CAT dataset is about 60%. Price Range: $PR = \frac{P_{\max} - P_{\min}}{P_{\min}}$

Section 4. Descriptive statistics

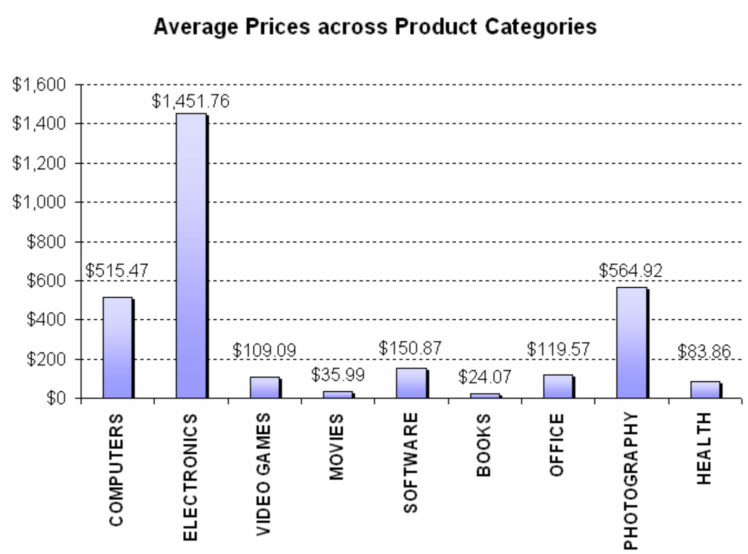
In this section we present summary statistics as well as general trends of our data. We do so to provide a better overview and understanding of the data, before going into actual quantitative analysis in the following section.

Trends across Product Categories

The main importance of the CAT dataset lies in the fact that it contains products from 9 different categories. The question of interest is whether we can detect systematic differences in price dispersion across market sectors, and if so, whether we can also explain the reason for these differences. Economic theory does not explicitly suggest that such differences should exist, however there may be a number of reasons as to why they might arise. The most obvious explanation may be that the number of online retailers varies from one category to the next, implying a more or less competitive market structure. Another reason may be that computers are much more expensive than books, and that people might therefore be more willing to incur search costs when shopping for computers, and not really bother to look around for the lowest price when they buy a book. A much more subtle explanation could be that the consumer base for computers is generally better informed than consumers that buy books online. If this were the case we would expect to see a smaller price gap in the computer category compared to that of books.

Prices

Figure 4. Average price across product categories

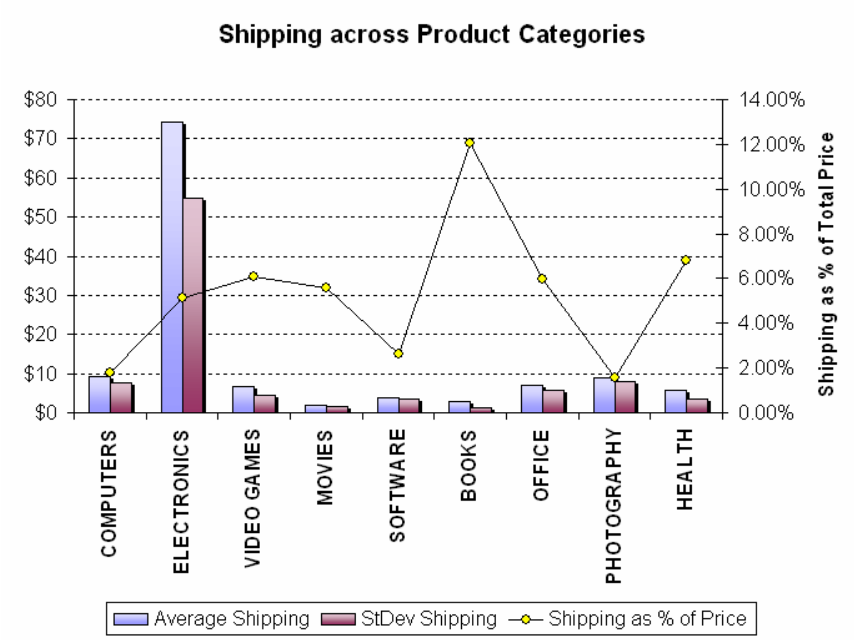


The average price for our CAT dataset across all products and product categories is $339.51. However, the average varies tremendously depending on product category. Books for example only cost $24 on average, while the average price for electronics is an impressive $1450. Products in the computer and photography categories are on average priced above $500, while those belonging to the remaining categories have average prices that are lower than $150.

Shipping

Figure 5 depicts the average shipping charged by firms across all product categories, as well as the standard deviation and the average % of shipping costs relative to the price.

Figure 5. Shipping across product categories

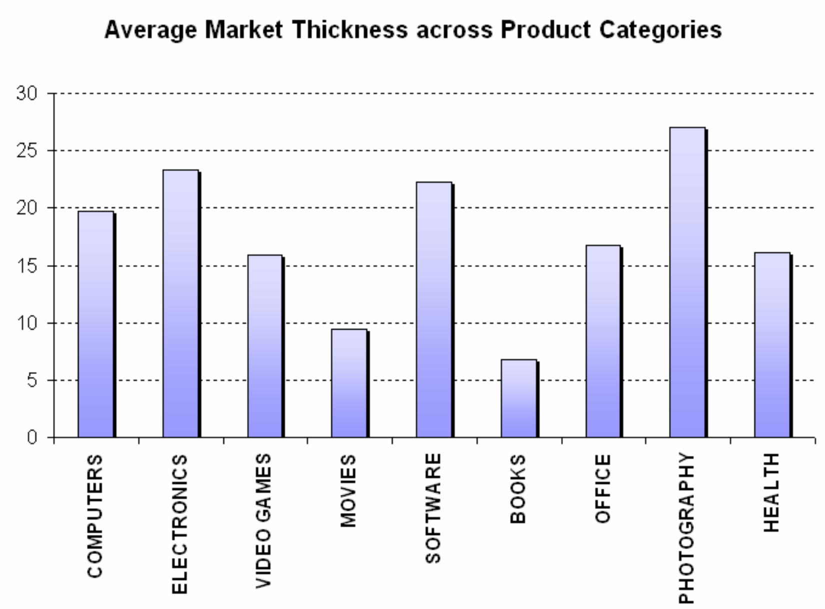


Shipping costs on electronics appear to be much higher than for the other categories. In fact, the average shipping cost for electronics is $74.20, over 8 times that of the second highest average of $9.16 for computer products. One explanation as to what could be the reason for such a dramatic difference, may be that these items are heavier than the goods in other categories and thus cost more to ship. Indeed around half of the products in popular electronics are large screen 32" to 50" televisions, and the standard deviation is huge which further supports the idea that it is truly these heavy TV sets that are pulling up the average. Furthermore, when we compare shipping costs to prices, the electronics category is no longer the leader, in fact it only ranks 6th, with shipping accounting for just over 5% of total price. Thus shipping costs on electronics are perhaps not as unreasonable as they appear at first glance.

Market Thickness

Before taking a closer look at how our price dispersion statistics vary across categories, we look at differences in market thickness, across product sectors to get a better idea of how many firms on average compete per category. Market thickness is essentially an indication of the level of competition in the market. The average market thickness over all products and product categories is 17.5, implying that on average between 17 to 18 firms offer a given homogeneous good. This remarkably high number is likely due to the fact that the products in our category database are popular products in their respective sectors. Market thickness does, however, vary considerably across categories as demonstrated in Figure 6. Electronics, photography and software all have on average over 20 firms selling a given product, while computers, video games, office, and health have between 15 and 20. The laggards are movies and books, which on average have less than 10 firms competing per product.

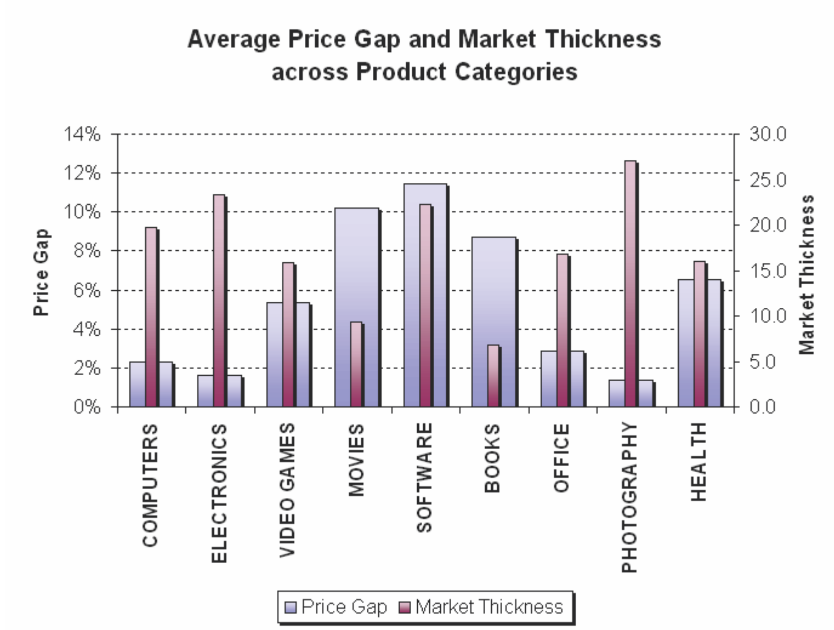
Figure 6. Average market thickness across product categories



Price Gap

The average price gap in our category dataset is 5.6%, but the real question of interest here is whether price dispersion varies depending on the product category and the number of firms that list prices. In Figure 7 market thickness is plotted next to the price gap for each individual category. From the graph we see that in general the price gap (thick bar) is low when market thickness is high (thin bar), which is consistent with both economic theory and findings in previous studies. The price gap is lowest for the photography category (1.36%), which is by far the most competitive sector in terms of the number of firms competing.

Figure 7. Price gap vs. market thickness across product categories

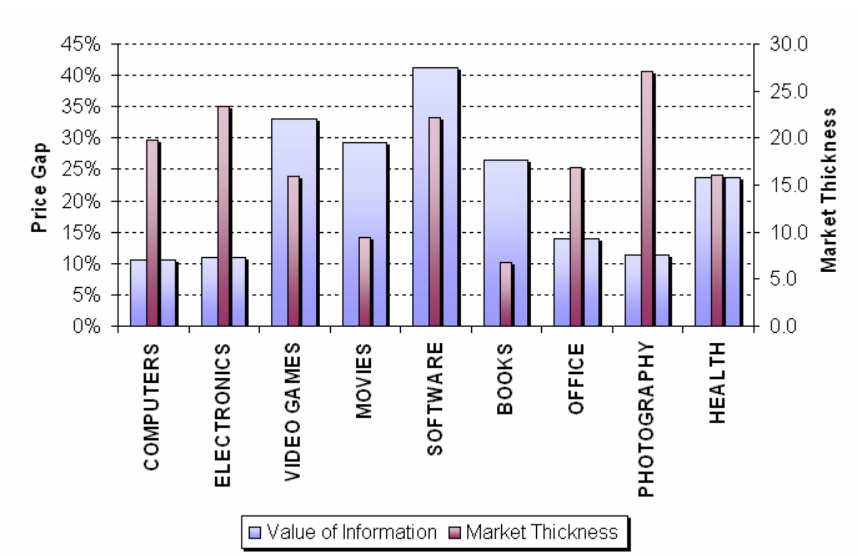


Note that the price gap for the software category is the largest of all at 11.42%, even though this appears to be a very competitive market. This somewhat puzzling result seems to be the only one that doesn't fit the picture. One explanation may be that firms may not truly be offering homogeneous goods even though they advertise so. For example one firm may be offering the full software package including CD, manual, and other goodies, while another may be offering the same piece of software, but for download only. We searched through our database in order to detect whether there were any specific products that were leading to this bizarre result and found that in fact, Microsoft products had an abnormally large price gap compared to other software products. If we disregard software, then books and movies have the largest price gaps, which meets our expectations since they have the fewest number of firms competing per product.

Value of Information

The average value of information in our CAT dataset is 23.12%, meaning that a consumer can expect to save nearly one forth of the total price just by using the Pricegrabber website as a search tool. This is a truly impressive number, especially considering that Pricegrabber's comparison service is entirely free for buyers. However, Figure 8 demonstrates that the informational value of the site varies a lot between product categories. Our data shows that the consumers that benefit the most from the Pricegrabber service are those looking to buy software, video games, books, and movies. These consumers can save on average from 25% to over 40% just by doing a simple search.

Figure 8. Value of information vs. market thickness across product categories

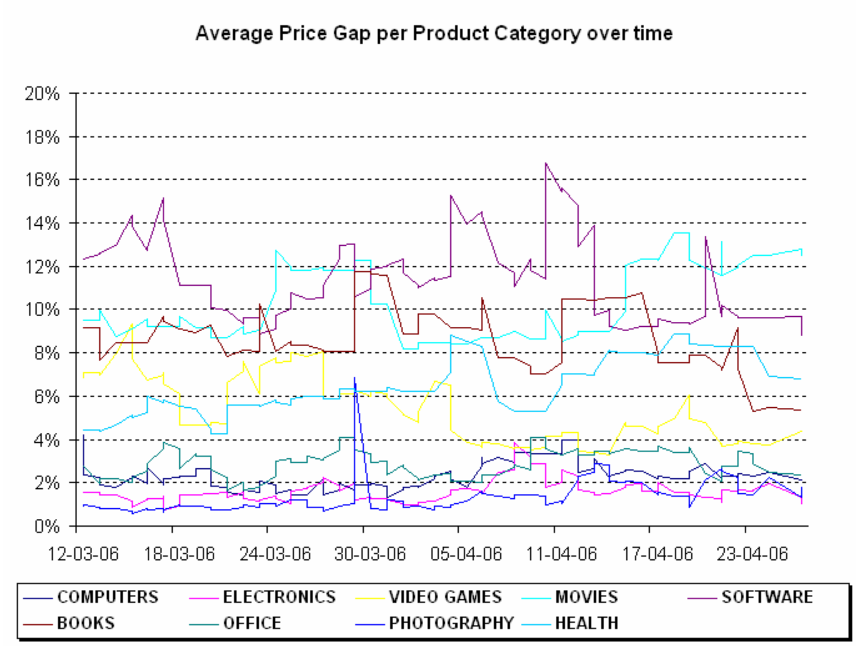


While we hypothesized that higher market thickness should cause the average price to go up and the minimum price to go down leading to an increase in informational value, it is somewhat unclear from the graph as to whether this proposition truly holds. In section 5 and 6 we shall formally test whether the number of firms in the market and the value of information really are positively correlated.

Trends over time

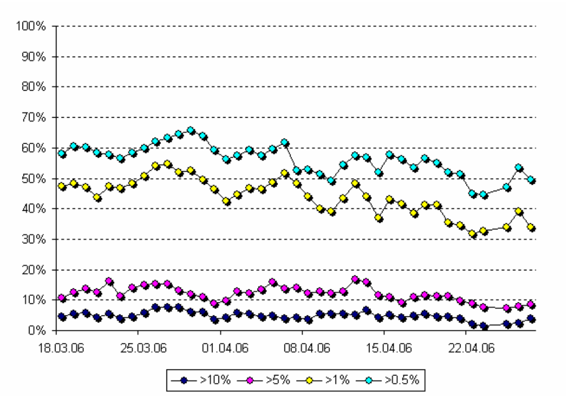
Our analysis in the previous section was based on averages calculated over a two month timeframe, namely from March to April 2006. We now turn our attention towards detecting possible trends in price dispersion over time. One of the most interesting questions of our study regards the persistency of price dispersion. As noted previously, modern economic theory suggests that a market in which price dispersion is present may, in fact, be in a state of equilibrium. If this were so then we should not be able to detect any particular time related trends in our data on popular products. In other words, if price dispersion is in equilibrium then it should remain fairly constant over time. Four different series are depicted in Figure 11, each of which represent the percentage of products in our POP dataset that have a price gap of greater than 10% 5% 1% and 0.5% respectively. The graph demonstrates that there does not appear to be any significant trend over the past two months for any of the series. This is consistent with the findings of other researchers, particularly Baye and Morgan (2003). Our findings show that an impressive 45% have a price gap of under 0.5%, 10% have a price gap between 0.5% and 1%, 30% have a gap that lies somewhere in the 1% to 5% range, while the remaining 15% have a gap over 5%.

Figure 9. Price gap over time across product categories

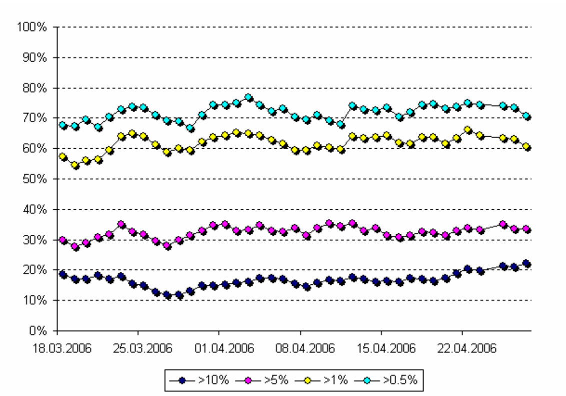


These gaps are somewhat lower than those found in previous research, which may have to do with the fact that these are the 200 most popular products on the Pricegrabber website, thus market thickness and competition are generally higher than for your average good. To determine whether this hypothesis does indeed hold, we plotted a similar graph for our CAT dataset, in which the average popularity of the products is far lower. Figure 10 lets us suspect that popularity has a significant effect on the price gap. Nearly 20% of the products in our CAT dataset have a price gap of more than 10%, and around 35% have a price gap of over 5%. These numbers are 3 to 4 times higher than the corresponding values of the POP dataset. Also, note that the fraction of products in CAT that have a competitive price gap of 0% is only 25%, compared to over 40% in POP.

Figure 10. Cumulative price gap over time



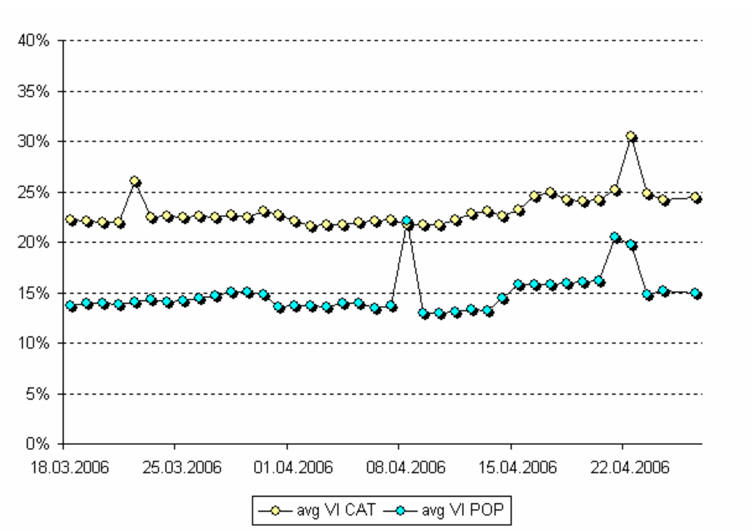
(a) POP dataset



(b) CAT dataset

Similar results hold for the informational value of the Pricegrabber site. Figure 11 depicts the average value of information during the timeframe of this study. The graph clearly demonstrates that the average VI stayed relatively constant, taking on a value of around 22% and 15% for the CAT and POP datasets respectively.

Figure 11. Value of information over time

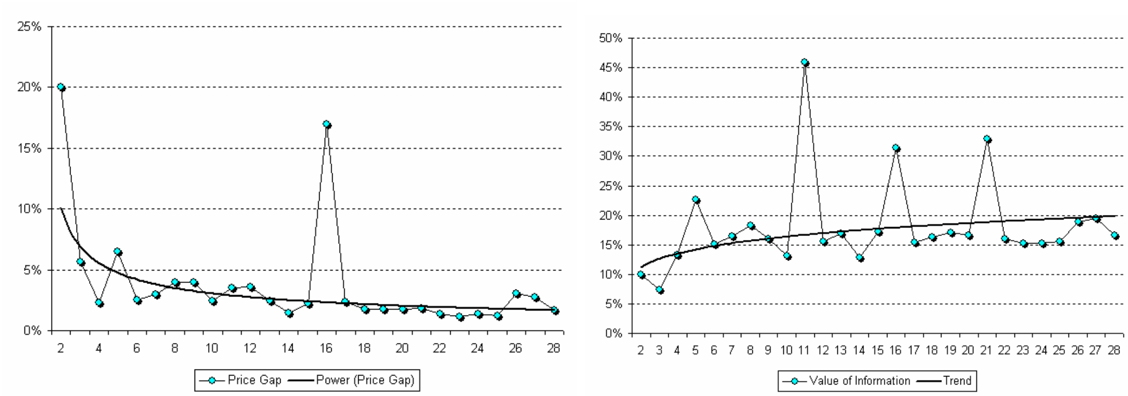


Average value of information over time

Trends by Popularity and Market Thickness

As discussed above, we expect market thickness to have a significant impact on the competitiveness of the market, and as a result also on the price gap. In Figure 7, we saw that the price gap varied across categories for the most part according to how market thickness changed. We shall now focus on the effect of market thickness alone on price dispersion, i.e. independent of product category. In Figure 12, we plot the price gap versus market thickness. As expected, the graph shows a very clear inverse relationship between the price gap and market thickness.

Figure 12. Price gap and value of information across market thickness



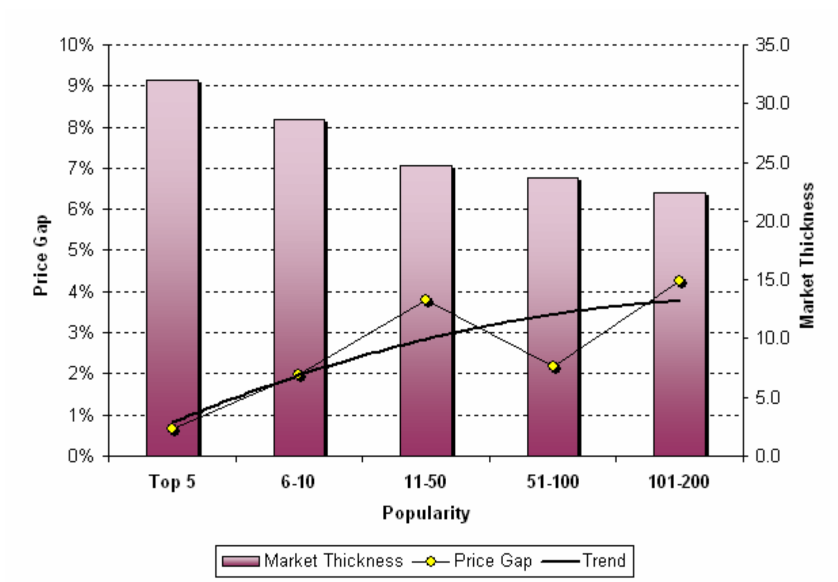
(a) Price gap vs. market thickness (b) Value of information vs. market thickness

Overall the price gap decreases dramatically as the number of firms in the market increases (the large spike at 16 is most likely due to lack of observations of products for which exactly 16 firms compete). The decrease is largest when there are just a few firms competing, whereas after the market thickness goes to above 20 firms its effect on the price gap becomes negligible. This supports the idea that the firms that compete on

Pricegrabber are not truly in a Bertrand equilibrium, but rather act as a monopolies or oligopolies and exert market power.

Figure 12 demonstrates that as market thickness increases the value of information appears to increase as well, although the relationship seems to be weak. However, there may be two effects determining the value of information here, namely a market thickness effect as well as a popularity effect.

Figure 13. Price gap and market thickness versus popularity



In Figure 13, we plot the price gap versus both popularity and the average market thickness per popularity category. The graph demonstrates that there is also a similar inverse relationship between the price gap and popularity. However, it is also evident from the plot that the average market thickness decreases with popularity.

In section 5 we employ econometric analysis to determine whether the effect of popularity on the price gap and value of information truly exists, or if we are in fact just witnessing a market thickness effect.

Section 5. Quantitative analysis

From the summaries of the previous section it appears that the data exhibits various interesting phenomena on both the individual firm and aggregate product level. In order to test whether these phenomena are systematic and truly matter, we employ econometric analysis. The propositions we wish to test are as follows:

Proposition 1. *Market thickness and the price gap are inversely related: A higher market thickness will lead to a smaller price gap and vice-versa.*

As the number of firms offering the same homogeneous good increases we expect the market to become more competitive, which should be reflected by a smaller price gap. This proposition has been tested in previous studies, most notably Baye and Morgan (2003), in which the authors found that market thickness did indeed have a highly significant inversely proportional effect on price dispersion.

Proposition 2. *Market thickness and the value of information are positively related: A higher market thickness will lead to a higher value of information and vice-versa.*

As the number of firms in the market increases Varian's model predicts that the minimum price will decrease, while the average price will increase. Hence we should notice an increase in the value of information as market thickness increases.

While these are our only formal hypotheses, we are also interested in the possible effects of popularity and market sector on the price gap and the value of information. Baye and Morgan (2003) show that a fraction of the observed price dispersion across products is solely due to differences in popularity of the products, although the magnitude of the "popularity effect" is negligibly small compared to the effect of market thickness. To the best of our knowledge we are the first researchers to conduct an analysis by market sector, which makes our findings particularly interesting.

Methodology

We test proposition 1 on both of our datasets. For our fixed sample of products (category dataset) we set up a basic model in which we regress the price gap (PG) on market thickness (MT) and only control for product fixed effects (PROD). From there we incrementally add dummies to capture fixed effects across product category and time. Our models for this dataset are therefore as follows:

$$PG_{it} = \alpha_0 + \sum_{MT} \alpha_m MT_{it} + \sum_{prod} \alpha_p PROD_{it} + \varepsilon_{it} \tag{2}$$

$$PG_{it} = \beta_0 + \sum_{MT} \beta_m MT_{it} + \sum_{prod} \beta_p PROD_{it} + \sum_{cat} \beta_c CAT_{it} + \nu_{it} \tag{3}$$

$$PG_{it} = \gamma_0 + \sum_{MT} \gamma_m MT_{it} + \sum_{prod} \gamma_p PROD_{it} + \sum_{cat} \gamma_c CAT_{it} + \sum_{time} \gamma_t TIME_{it} + \omega_{it} \qquad (4)$$

For our popular products dataset, we use the same approach, but also control for product popularity. However, the disadvantage of this dataset is that nearly all of the top 200 most popular products on Pricegrabber belong to the photography, electronics, or computer category, which of course limits our analysis to just these categories.

The only difference between the models presented above and the ones we employ for our analysis of the main determinants of the value of information, is that we exchange the dependent variable, price gap, with the value of information. Otherwise our approach to testing proposition 2 is identical to that of proposition 1.

Section 6. Results

Price Gap

In Table 1, Table 2, and Table 3 we present the estimates of equations (2), (3) and (4), and for our fixed sample (CAT dataset). Please note that in each table we have suppressed the coefficients of dummies for more than 30 firms as well as all product and time dummies. These are of course available upon request. The estimated coefficients represent the differences from our base category, which is 57 firms, an incredibly high market thickness.

Table 1. Dependent variable: price gap - fixed effects: product

Independent Variable	Coefficient	t-Value	Expected Cell Mean
Number of Firms			
2 Firms	8.07	4.87	11.71
3 Firms	7.22	4.49	10.86
4 Firms	5.37	3.34	9.01
5 Firms	5.74	3.68	9.38
6 Firms	5.13	3.33	8.78
7 Firms	5.27	3.44	8.91
8 Firms	4.18	2.74	7.83
9 Firms	3.04	1.99	6.68
10 Firms	2.21	1.45	5.86
11 Firms	2.11	1.39	5.75
12 Firms	3.26	2.14	6.90
13 Firms	1.84	1.22	5.49
14 Firms	1.01	0.67	4.66
15 Firms	1.13	0.75	4.77
16 Firms	1.11	0.74	4.75
17 Firms	0.50	0.33	4.14
18 Firms	-0.47	-0.32	3.17
19 Firms	0.20	0.14	3.85
20 Firms	0.58	0.39	4.23
21 Firms	0.93	0.63	4.58
22 Firms	0.94	0.64	4.59
23 Firms	0.47	0.32	4.12
24 Firms	0.51	0.35	4.15
25 Firms	0.42	0.29	4.07
26 Firms	1.18	0.80	4.82
27 Firms	2.04	1.42	5.68
28 Firms	0.54	0.38	4.19
29 Firms	0.10	0.07	3.74
30 Firms	1.53	0.95	5.17

N = 14602 $R^2 = 0.7146$

Null Hypothesis:	p-value
All Market Thickness fixed effects are zero	0
All Product fixed effects are zero	0

Table 2. Dependent variable: price gap - fixed effects: product, category

Independent Variable	Coefficient	t-Value	Expected Cell Mean
Number of Firms			
2 Firms	8.07	4.87	11.56
3 Firms	7.22	4.49	10.72
4 Firms	5.37	3.34	8.86
5 Firms	5.74	3.68	9.24
6 Firms	5.13	3.33	8.63
7 Firms	5.27	3.44	8.77
8 Firms	4.18	2.74	7.68
9 Firms	3.04	1.99	6.54
10 Firms	2.21	1.45	5.71
11 Firms	2.11	1.39	5.61
12 Firms	3.26	2.14	6.76
13 Firms	1.84	1.22	5.34
14 Firms	1.01	0.67	4.51
15 Firms	1.13	0.75	4.63
16 Firms	1.11	0.74	4.60
17 Firms	0.50	0.33	3.99
18 Firms	-0.47	-0.32	3.03
19 Firms	0.20	0.14	3.70
20 Firms	0.58	0.39	4.08
21 Firms	0.93	0.63	4.43
22 Firms	0.94	0.64	4.44
23 Firms	0.47	0.32	3.97
24 Firms	0.51	0.35	4.01
25 Firms	0.42	0.29	3.92
26 Firms	1.18	0.80	4.68
27 Firms	2.04	1.42	5.54
28 Firms	0.54	0.38	4.04
29 Firms	0.10	0.07	3.60
30 Firms	1.53	0.95	5.03
Categories			
Computers	-27.09	-28.91	-1.97
Electronics	-27.98	-30.48	-2.86
Video Games	-25.62	-27.78	-0.51
Movies	-13.51	-16.26	11.61
Software	-12.88	-13.68	12.24
Books	-27.03	-30.27	-1.91
Office	-26.04	-29.18	-0.92
Photography	-26.33	-27.74	-1.21
Health			25.12
N = 14602			R^2 = 0.7146
Null Hypothesis			p-value
All Market Thickness fixed effects are zero			0
All Product fixed effects are zero			0
All Category fixed effects are zero			0

Table 3. Dependent variable: price gap - fixed effects: product, category, time

Independent Variable	Coefficient	t-Value	Expected Cell Means
Number of Firms			
2	8.23	4.94	11.63
3	7.16	4.43	10.56
4	5.26	3.26	8.66
5	5.68	3.63	9.08
6	5.14	3.32	8.55
7	5.37	3.49	8.77
8	4.30	2.80	7.70
9	3.11	2.03	6.51
10	2.36	1.54	5.76
11	2.29	1.50	5.69
12	3.40	2.23	6.80
13	2.05	1.35	5.45
14	1.18	0.77	4.58
15	1.31	0.86	4.71
16	1.26	0.84	4.66
17	0.68	0.46	4.09
18	-0.25	-0.17	3.15
19	0.53	0.36	3.94
20	0.83	0.55	4.23
21	1.20	0.81	4.61
22	1.19	0.80	4.59
23	0.68	0.46	4.08
24	0.72	0.49	4.13
25	0.62	0.42	4.02
26	1.41	0.96	4.82
27	2.31	1.59	5.71
28	0.93	0.65	4.34
29	0.52	0.36	3.92
30	1.44	0.89	4.85
Categories			
Computers	-27.23	-29.04	-2.08
Electronics	-28.34	-30.80	-3.21
Video Games	-25.62	-27.76	-0.48
Movies	-13.49	-16.24	11.65
Software	-13.01	-13.81	12.12
Books	-26.84	-30.04	-1.71
Office	-26.12	-29.24	-0.98
Photography	-26.49	-27.88	-1.35
Health			25.13
N = 14602			$R^2 = 0.7166$
Null Hypothesis			p-value
All Market Thickness fixed effects are zero			0
All Product fixed effects are zero			0
All Category fixed effects are zero			0
All Time fixed effects are zero			0.0741

The results support the hypothesis that there is a strong inverse relationship between market thickness and the price gap. Overall our model can explain around 71% of the total variation in the price gap. The model predicts that when just two or three firms compete the price gap will be higher than 10%. It is interesting to see just how quickly the gap shrinks. With just 10 firms in the market the gap is already below 6%, and as of 14 firms it remains between 3 to 5 percent.

These estimates barely change when we add category and time fixed effects. Note that the hypothesis that all time fixed effects are zero in the last model yields a p-value of 0.0741, indicating that the time dummies are insignificantly different from zero at a 5% level, hence price dispersion does not appear to diminish over time; instead it appears to be persistent over time, a result that confirms findings in previous literature.

Another interesting result is that there do appear to be systematic differences between product categories. Moreover, some of the magnitudes of the coefficients are very large. It appears that products in the categories health, software and movies have particularly high price gaps, compared to the other categories. To the best of our knowledge we are the first to test for category specific effects. It is therefore hard to say whether this result should hold in general, or whether this phenomenon is limited to the Pricegrabber website.

When we ran the regressions on the data from the POP dataset, the effect of popularity on the price gap was negligibly small, which confirms the hypothesis that there is no real popularity effect on the price gap. The true reason that we generally observe smaller price gaps for popular products therefore appears to be that the more popular products on average have a greater market thickness than less popular ones (see Figure 13).

Value of Information

In the following tables we present the estimates for the value of information based on models that are similar to the ones we used for the price gap. Table 4, Table 5, and Table 6 display the results for the fixed sample (CAT dataset).

Table 4. Dependent variable: value of information - fixed effects: product

Market thickness	Coefficient	t-Value	Expected Cell Mean
2 Firms	-23.88	-11.33	10.49
3 Firms	-20.00	-9.78	14.36
4 Firms	-19.53	-9.55	14.84
5 Firms	-18.85	-9.51	15.52
6 Firms	-17.11	-8.72	17.25
7 Firms	-15.32	-7.86	19.05
8 Firms	-14.21	-7.32	20.15
9 Firms	-14.97	-7.72	19.39
10 Firms	-13.51	-6.98	20.85
11 Firms	-12.74	-6.59	21.62
12 Firms	-10.08	-5.22	24.28
13 Firms	-10.99	-5.71	23.37
14 Firms	-12.71	-6.6	21.66
15 Firms	-12.43	-6.49	21.94
16 Firms	-14.03	-7.36	20.34
17 Firms	-13.32	-7.04	21.05
18 Firms	-12.48	-6.58	21.89
19 Firms	-11.45	-6.06	22.91
20 Firms	-9.22	-4.88	25.15
21 Firms	-7.98	-4.24	26.39
22 Firms	-7.77	-4.14	26.60
23 Firms	-8.23	-4.38	26.14
24 Firms	-8.70	-4.66	25.67
25 Firms	-9.46	-5.07	24.91
26 Firms	-9.00	-4.82	25.36
27 Firms	-8.03	-4.38	26.34
28 Firms	-9.12	-5.04	25.25
29 Firms	-9.19	-5.1	25.18
30 Firms	-5.34	-2.61	29.02

N = 14602 $R^2 = 0.8794$

Null Hypothesis	p-value
All Market Thickness fixed effects are zero	0
All Product fixed effects are zero	0

Table 5. Dependent variable: value of information - fixed effects: product, category

Independent Variable	Coefficient	t-Value	Expected Cell Mean
Number of Firms			
2	-23.88	-11.33	10.40
3	-20.00	-9.78	14.28
4	-19.53	-9.55	14.75
5	-18.85	-9.51	15.43
6	-17.11	-8.72	17.17
7	-15.32	-7.86	18.96
8	-14.21	-7.32	20.07
9	-14.97	-7.72	19.31
10	-13.51	-6.98	20.77
11	-12.74	-6.59	21.53
12	-10.08	-5.22	24.20
13	-10.99	-5.71	23.29
14	-12.71	-6.60	21.57
15	-12.43	-6.49	21.85
16	-14.03	-7.36	20.25
17	-13.32	-7.04	20.96
18	-12.48	-6.58	21.80
19	-11.45	-6.06	22.83
20	-9.22	-4.88	25.06
21	-7.98	-4.24	26.30
22	-7.77	-4.14	26.51
23	-8.23	-4.38	26.05
24	-8.70	-4.66	25.58
25	-9.46	-5.07	24.82
26	-9.00	-4.82	25.28
27	-8.03	-4.38	26.25
28	-9.12	-5.04	25.16
29	-9.19	-5.10	25.09
30	-5.34	-2.61	28.93
Categories			
Computers	-51.44	-43.18	7.89
Electronics	-49.83	-42.69	9.94
Video Games	-46.09	-39.29	13.11
Movies	-19.54	-18.50	39.12
Software	-6.49	-5.42	51.68
Books	-24.44	-21.52	33.69
Office	-40.79	-35.95	17.49
Photography	-52.81	-43.75	5.30
Health			57.64
N = 14602			R^2 = 0.8794

Null Hypothesis	p-value
All Market Thickness fixed effects are zero	0
All Product fixed effects are zero	0
All Category fixed effects are zero	0

Table 6. Dependent variable: value of information - fixed effects: product, category, time

Independent variable	Coefficient	t-Value	Expected Mean
Number of Firms			
2 Firms	-23.38	-11.07	10.52
3 Firms	-19.80	-9.66	14.10
4 Firms	-19.27	-9.40	14.63
5 Firms	-18.60	-9.35	15.31
6 Firms	-16.74	-8.51	17.16
7 Firms	-14.83	-7.59	19.08
8 Firms	-13.75	-7.06	20.15
9 Firms	-14.56	-7.49	19.34
10 Firms	-12.90	-6.65	21.01
11 Firms	-12.13	-6.25	21.78
12 Firms	-9.51	-4.91	24.40
13 Firms	-10.21	-5.28	23.70
14 Firms	-12.05	-6.24	21.86
15 Firms	-11.73	-6.11	22.18
16 Firms	-13.29	-6.96	20.61
17 Firms	-12.51	-6.59	21.39
18 Firms	-11.59	-6.09	22.32
19 Firms	-10.34	-5.45	23.57
20 Firms	-8.20	-4.33	25.71
21 Firms	-6.95	-3.68	26.95
22 Firms	-6.81	-3.62	27.09
23 Firms	-7.34	-3.90	26.57
24 Firms	-7.88	-4.21	26.02
25 Firms	-8.53	-4.55	25.38
26 Firms	-8.00	-4.27	25.91
27 Firms	-6.97	-3.79	26.94
28 Firms	-7.91	-4.35	26.00
29 Firms	-7.97	-4.40	25.93
30 Firms	-5.38	-2.62	28.52
Categories			
Computers	-51.69	-43.43	7.88
Electronics	-50.53	-43.25	9.45
Video Games	-46.09	-39.35	13.33
Movies	-19.47	-18.47	39.40
Software	-6.73	-5.62	51.66
Books	-24.09	-21.23	34.25
Office	-41.04	-36.20	17.44
Photography	-53.08	-44.01	5.22
Health			57.84
N = 14602			R^2 = 0.8807

Null Hypothesis	p-value
All Market Thickness fixed effects are zero	0
All Product fixed effects are zero	0
All Category fixed effects are zero	0
All Time fixed effects are zero	0

The results show a very strong positive relationship between market thickness and the value of information, which, of course, confirms the proposition that we stated in the previous section. In fact, our model can explain nearly 90% of the total variation in the

VI, indicating that the number of firms offering a good is an even better indicator of the value of information than of the price gap, of which around 70% could be explained.

The expected value of information when only two firms compete is only 10%, but this number quickly increases to over 20% for just 10 firms. From there it increases gradually to approximately 30% for 30 firms, after which it no longer significantly increases no matter how many firms are in the market. As was the case for our price gap results, adding fixed effects for categories and time barely changes our estimated coefficients and expected means.

An interesting finding here is that the variation of the value of information across product categories is very large. For example an informed consumer that buys a camera can only expect to save around 5% over an uninformed consumer, while he or she can expect to save an amazing 58% when buying an electric razor, and nearly 40% when buying a DVD.

When we ran these regressions on the POP dataset, while adding controls for popularity, our findings were similar to those we made for the price gap. Popularity alone does not seem to have any real effect on the value of information.

Section 7. Conclusion

In this paper we analyzed price dispersion on homogeneous goods that is reflected on the Pricegrabber.com shopping comparison site. Our research confirms past findings regarding the determinants of price dispersion on other online gatekeepers. We also found that that price dispersion varies systematically across market sectors, and that the Pricegrabber service provides tremendous informational value to its users.

Our results provide strong supporting evidence regarding the validity of Varian's model in which the number of sellers of a given good has a large impact on price dispersion. Both the percentage gap between the two lowest offerings and the gap between the lowest and average offering depend primarily on the market thickness, although the direction of the effects differ as expected. The price gap is large when there are just a few firms competing in the market, but rapidly decreases as the market becomes more competitive.

The value of information depends even more strongly on the number of firms than the price gap. With just 2 firms in the market, consumers that inform themselves about prices by visiting the Pricegrabber site can expect to save just 10% more than consumers that buy from a random online retailer. However, this number increases to an impressive 30% when 30 or more firms post offerings.

These findings are consistent with previous findings, most notably those of Baye *et al.* (2004a), despite the fact that their data comes from a completely different source (shopper.com) and is nearly 5 years old. It appears that passage of time and the maturing of online retail markets has had no effect whatsoever on the persistency of price dispersion, that price dispersion is in fact, as modern economic theory suggests, an equilibrium phenomenon which results from asymmetries of information in these markets.

Price dispersion also varies across market sectors and popularity ranking. While the magnitude of the effect of popularity on price dispersion is negligible, the same cannot be said for product categories. In fact, our results show that even after controlling across products, and time, there is considerable variation between different categories. Dispersion is generally largest for health products, while it is small for products belonging to the photography category.

In future studies it would be useful to further delve into the possible reasons for the systematic differences of dispersion across categories, and test whether these are also present on other online gatekeepers. It would also be interesting to devise new measures of price dispersion, besides the ones presented here, that directly incorporate merchant rating.

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