Different Prices for Identical Products? Market Efficiency and Retailer Strategies in B2C E-Commerce

Paper to be presented at the 3rd ZEW Conference
on the Economics of Information and Communication Technologies

Preliminary Version – Please do not cite without the author's permission

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June 2003

Abstract

This paper analyses market efficiency and pricing strategies in digital markets using a data set containing more than 37,000 price observations from the online market for contact lenses as well as detailed information about online retailer and product characteristics. The data allow to implement and to test the concept of virtual location. The empirical results reveal evidence for lower prices and less price dispersion which supports the hypothesis of enhanced market efficiency in electronic markets. Furthermore, the results show that an online shop's virtual location influences its prices and that price dispersion is partially driven by differentiation in retailer service.

Keywords: electronic markets, efficiency, virtual location, pricing

JEL–Classification: L11, D43, L81, C23

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1 Introduction

In the beginning of the Internet hype, economists believed that e-commerce would lead to nearly perfect competition. Theoretical arguments fostering this view are the expectations of highly increased market transparency due to near-to-zero search costs. If perfect competition prevailed in digital markets, one should be able to observe the law of one price which would render price comparisons across retailers needless. Today, conventional wisdom is that comparing prices online can get very tedious, and the variety of online shop designs and general terms and conditions across online retailers can be quite confusing. However, these assessments often rely heavily on personal experience and empirical evidence often relies on heavily selective data sets.
Therefore, the hypotheses which are tested in this paper are as follows:

1. *Market Efficiency:* Online markets are relatively more efficient than conventional markets. This hypothesis is investigated by testing the partial hypotheses of a lower price level, less price dispersion and both more and smaller price changes in online markets.

2. *Location:* In e-commerce, a retailer's physical location has no influence on pricing, but its virtual location does.

3. *Differentiation:* Potential price dispersion is partially driven by differentiation among online retailers.

4. *Pricing Strategies:* There is strategic behaviour with respect to pricing online.

In order to test these hypotheses, a business-to-consumer e-commerce market is observed and analysed: the online market for contact lenses. Contact lenses are homogeneous products and thus well-suited for an empirical analysis of market efficiency and pricing. In order to obtain a judgement on the relative degree of market efficiency online, comparisons are made between retailers which operate solely online (which are called 'e-retailers' in the following) and so-called 'hybrid' retailers. The notion of 'hybrid retailers' refers to those retailers which operate a conventional outlet as well as an Internet shop.[1] This approach is also pursued by Tang and Lu (2001) in their analysis of the online market for CDs and by Pan, Ratchford and Shankar (2002) in their analysis of the prices for eight different product categories.

Tang and Lu (2001) argue that pricing in the online shops of conventional retailers forms a part of their overall pricing strategy. Thus, their pricing strategy is influenced by considerations concerning both sales channels. For example, the prices for products sold

[1]The notion 'online retailer' refers in this text to all online shops, i.e. to e-retailers as well as hybrid retailers. 'Conventional retailer', 'physical retailer' or 'offline retailer' refers to a brick-and-mortar retailer with a conventional shop.

online by a hybrid retailer may be higher than those of an e-retailer because the hybrid retailer does not want to undercut the prices in its conventional outlet – this is a decision a pure e-retailer is not faced with. Bailey (1998a) expresses this view even more strongly: "While physical retailers may have an Internet presence, their purpose is[2] doing so is to promote sales via its other channels and their corporate cultures, cost structures, and dominant strategies stem from their origin in the physical marketplace." Thus, it can be assumed that the online pricing of hybrid retailers is not a stand-alone issue but influenced by considerations with respect to the conventional distribution channel. Consequently, prices from pure online shops should exhibit more evidence for market efficiency than hybrid retailers' prices. If hybrid retailers behave less competitive than their purely online counterparts, this could also be due to market power from the conventional market which can be transferred to the online market (see Tang and Lu, 2001). Such market power could result from typical sources, such as being a well-known brand or having a reputation for being reliable.

The data set contains 37,486 price observations for the market of contact lenses between March and September 2002 on a monthly observation basis. The price observations are enriched by detailed information on the characteristics of the Internet shops as well as on the products. In addition to this, the placement of sponsored links and banner ads in the ten most widely used search engines is recorded each month together with the rank in the Google search engine in order to proxy the virtual location of each retailer.

To the best of my knowledge, this is the first study attempting to test empirically the influence of the 'virtual location' (or "neural real estate", as Smith, Bailey and Brynjolfsson (2000, p. 110) term it). In addition to this, a nearly complete digital market is observed and analysed: Neither is the observed product range restricted to a predetermined subset of products, nor is the number of retailers selected in order to keep the data collection effort manageable. The price observations are collected directly at the retailers' websites instead of using shopbot data or price quotes from price comparison websites. Thus the data set is not a restricted sample but represents the whole population of online shops, which are relevant for consumers ordering contact lenses from Germany.

The results presented in this paper hint to enhanced market efficiency through digital markets. Particularly for the segment of planned replacement contact lenses, evidence is found for lower prices and less price dispersion among e-retailers in comparison to hybrid retailers. Furthermore, the results are consistent with the notion of a *virtual* location and with the irrelevance of the *physical* location of the retailers. Price dispersion can only partially be explained by retailer characteristics.

[2]This typing error is part of the original paper.

2 Pricing and Efficiency in Online Markets

2.1 The Euphoric View on Online Market Efficiency

In the beginning of the Internet era, there have been great expectations that the Internet would lead to strongly increased market efficiency, as lower search costs would lead to a more competitive market environment for retailers. The extreme view of a perfectly competitive market is Bertrand competition, in which the law of one price prevails. The prerequisites for Bertrand competition are homogeneous products, free market entry, perfect information of the buyers (implying very negligible search costs) and a sufficiently great number of sellers and buyers.

The euphoric view on the emerging possibilities of conducting e-commerce comprised expectations for considerably lower search costs, as well as decreased menu costs for producers and retailers. Barriers to entry should be substantially lower than in conventional markets. Thus, the overall transaction costs were expected to decrease, which should lead to increased market efficiency.

In his pioneering dissertation, Bailey (1998b) developed four criteria in order to analyse the relative degree of market efficiency in online markets in comparison to conventional markets. According to Bailey (1998b), a more efficient market leads to lower prices and less price dispersion, because lower search costs lead to more price transparency. Consequently, the law of one price should prevail in a perfectly competitive market and no price dispersion should be observed. Furthermore, lower menu costs lead to more frequent and smaller price changes. And finally, the price elasticity of demand should be higher in a more efficient market with better informed consumers.

Several arguments apply for online markets in this context. There are increased possibilities to search for and compare prices. Not only can consumers get informed about prices more easily, also retailers can quickly screen the offers of their competitors. Instead of the time-consuming walking through different shops on a shopping trip in the 'real world', different sellers are only some mouse clicks apart in the 'virtual world'. Additionally, virtual malls and shopping centers offer links to various online shops, and search engines, price comparison websites and shopbots[3] promise to supply information which is valuable to the consumer in terms of finding quickly the cheapest supplier, thus saving money and/or time. Therefore lower prices and less price dispersion should be observed in digital markets.

At the same time, it is easy to imagine that price setting costs for suppliers of products are online substantially lower than offline. Brynjolfsson and Smith (2000) point out that "On the internet, (...) menu costs should be much lower — comprised primarily of the cost to change a single entry (per title) in a database." Because a retailer will only change

[3]The notion 'shopbots' refers to automated programmes searching retailer websites for prices, whereas 'price comparison websites' means databases where retailers can enter their prices into a data base by themselves.

a price if the expected benefit exceeds the marginal cost of the price change, price changes should occur more often and the amounts of change should be smaller when menu costs are lower.

The following section reviews the empirical results in the literature on price levels and dispersion as well as on price changes on digital markets.

2.2 Empirical Evidence With Respect to Market Efficiency

A growing body of literature analyses the relative degree of market efficiency in online markets. The main results are described according to the four criteria of market efficiency introduced above. Most of the studies compare e-retailers to conventional retailers; hybrid retailers are assigned to one of the two groups according to whether the prices have been collected online or in the conventional shop. For several analyses, price data from price comparison sites or shopbots are used, and hence there is no comparison between online and conventional retailers. Such data sets can naturally only be used for the analysis of pricing or differentiation strategies of online retailers, without any comparison to conventional retailers.

Price Level — There is mixed evidence regarding the relative price level of online retailers compared to conventional retailers. Bailey (1998b) finds higher prices online for books, CDs and software, whereas Brynjolfsson and Smith (2000) find 9-16 percent lower prices on the Internet for books and CDs, depending on the inclusion of taxes, shipping and shopping costs into the price. In a study by Clay, Krishnan, Wolff and Fernandes (2002) there is no significant difference found for book prices online versus offline. When taxes and shipping costs are included in the analysis, book prices at conventional retailers are lower, as sales tax is lower on average than shipping costs. In contrast to this, Scott Morton, Zettelmeyer and Silva-Risso's (2001) results suggest that cars are sold for 2 percent less when bought via an Internet referral service (which refers potential buyers to car dealers). Controlling for retailer characteristics, Pan et al. (2002) find that prices of e-retailers are lower than those of hybrid retailers for CDs, DVDs, desktops and laptops, higher for books and software and not significantly different for personal digital assistants and consumer electronics.

Price Dispersion — The result of substantial price dispersion online is replicated in many studies, but only some of them compare the degree of price dispersion online to the amount of price dispersion prevailing offline. Brynjolfsson and Smith (2000) find relative price ranges[4] of as much as 33 percent for books and 25 percent for CDs on average, respectively. Depending on the measure which is used, price dispersion on the Internet is

[4]The relative price range is defined as the difference of the highest and the lowest price for a given product, divided by its average price.

higher or lower than on the physical channel. Bailey (1998b) finds no empirical evidence for less price dispersion online, too.

Price Changes — With regard to price changes, the empirical results found in the literature are more clear cut. Bailey (1998b) finds significantly more price changes made by online than by conventional book, CD and software retailers, which hints to a more efficient market on the Internet. The analysis of Brynjolfsson and Smith (2000) for the markets for books and CDs reports price changes to be significantly smaller at online retailers — furthermore the smallest observed price change among Internet retailers is 0.01$, compared to 0.35$ being the smallest price change observed in a conventional outlet.

Price elasticity of demand: Goolsbee (2001) finds evidence that consumers are very sensitive to price differences between online and conventional retailers. Also Degeratu, Rangaswamy and Wu (2000) report evidence for a higher price sensitivity when consumers buy online. In the experimental setting of Lynch and Ariely (2000), the price sensitivity of consumers increased when comparisons between online shop were made easier.

2.3 A more Realistic View on Digital Markets

Caused by everyday observation and by empirical research results, a more realistic view on market efficiency in online markets is now accepted. Obviously, the law of one price is not prevailing in online markets. The theoretical considerations explaining this observation are illustrated in the next paragraphs and complemented by e-commerce specific arguments. Possible violations of the Bertrand model, which are relevant in the context of this paper refer to the assumptions of homogeneous products, perfectly informed consumers, and zero search costs.

Product and retailer differentiation — If price dispersion is still present after controlling for observable product characteristics, there may be unobserved factors influencing the price of products. In their study of the online book market, Clay et al. (2002, p. 353) suggest that "(...) the products that firms offer may not be identical, even if the books are." Buying a product from a retailer represents the purchase of a composite good, which consists of the product itself plus complementary services of the retailer, regardless of whether the product is bought online or offline. Therefore differences in retailer characteristics must be accounted for when price dispersion is analysed. But in addition to this, differentiation in retailer services and in the design of online shops make price comparisons more costly and thus leads to incomplete information among potential buyers.

Incomplete information — Price dispersion may result if consumers are imperfectly informed about prices or about the full range of retailers offering a certain product. In mod-

els explaining price dispersion by incomplete information, there are informed consumers, who always buy at the cheapest retailer and uninformed consumers, who randomly choose a retailer to buy from (see for example Varian, 1980; Salop and Stiglitz, 1982). Consistent with these models are observations which hint to information problems in digital markets.

Smith et al. (2000, p. 110) mention: "It is a truism that the three critical success factors for conventional retailers are location, location, and location." The same argument should hold for online retailers in the sense that there certainly exists some kind of 'virtual location', as the probability of passing a certain retailer's website is not equally distributed across retailers. Factors such as the publicity of the company and its Internet address, the listing and position in Internet search engines or banner ads on websites with high traffic should considerably increase the probability of being found by potential customers. Smith et al. (2000, p. 110) point out the high investments in product placement on Internet portals and "content sites". Tang and Lu (2001) note that location merges in the virtual space with brand, which is also a driver of price dispersion among retailers.

The temporal divergence of ordering, paying and receiving the product in the case of online ordering creates additional uncertainty for consumers, who are ex ante not sure if they finally receive the product they have paid for. Therefore there is an increased need for signalling trustworthiness or reliability in online markets. Also consumers who are informed about prices may not buy from the cheapest retailer in the market if retailer branding or reputation plays a decisive role. Brynjolfsson and Smith (2000) argue that providing detailed product information may signal trust and thus leads to price premiums, although information could be consumed separately from ordering a certain product and thus is not part of the composite good consisting of the product itself and additional services that are inseparably connected to the product. The authors show in their empirical analysis that well-known retailers can charge price premiums in the markets for books and CDs.

Search costs — A further source of price dispersion arises when consumers are not perfectly informed and face positive search costs. During the process of getting informed about prices, an imperfectly informed consumer has an incentive to continue searching for a lower price as long as the expected benefit from getting better informed exceeds marginal costs. In models with consumer search costs, price dispersion is a result of different incentives to search for the lowest price (see for example Burdett and Judd, 1983; Stahl, 1996).

On the one hand, search costs should be considerably lower for consumers shopping online. Different online shops are only a few mouse clicks apart, and the services of price comparison websites or shopbots are available at no cost. On the other hand, evaluating the offers of different online shops can be a very tedious task, as "lack of standardization renders comparisons expensive" (see Schmitz and Latzer, 2002, p. 168). Online retailers might use a complex design for online shops in order to distinguish time-sensitive con-

sumers with high search costs from time-insensitive consumers with lower search costs. Thus, retailers with more convenient and easy-to-navigate online shops can maybe charge a premium for this convenience (see Smith et al., 2000). This strategy is obviously related to price discrimination, where a screening mechanism serves as a means to separate the consumers according to their willingness to pay or their individual valuation for retailer services.

Menu costs — Menu costs may lead to price dispersion if consumers are imperfectly informed (Fishman, 1992). If consumers are perfectly informed, they buy only from the cheapest supplier in a setting with Bertrand competition. In the empirical analysis in this paper, quantities sold are not observed, but it can be assumed that all retailers expect to make profits with the prices listed in their online shops, and in order to make profits, the quantity expected to be sold must be positive.

Lock-in effects and switching costs — Consumers can refrain from buying at the lowest price retailer if they repeatedly purchase the same item or products from the same product category and if there are switching costs which lead to lock-in effects (for a review of the switching costs literature see Klemperer, 1995). Different kinds of switching costs can arise naturally (for example, simply by getting familiar with a retailer's website) or can strategically be enforced by retailers (for example by the option of one-click-ordering or personal recommendations for repeat buyers (see Smith et al., 2000)).

3 Empirical Design and Data Collection

3.1 The Online Market for Contact Lenses

According to Liebowitz (2002), four attributes of commodities make them suitable for being sold on the Internet or not: Goods to be sold on the Internet should have a relatively small ratio of weight to price, they should usually not be impulse buyings[5], they must not be perishable, and they must not be experience goods.[6]

It is straightforward to see that contact lenses fulfill all these requirements: the packages are very lightweight and small relative to product value, so that shipping costs do not get too high, and usually consumers do not buy them spontaneously driven by the shopping atmosphere. Furthermore, once a suitable contact lens has been fitted by a contact lens specialist, the consumer knows which product suits her medical needs and there is little need to evaluate the product each time before buying it. In the case of planned

[5]There is one exception to this rule: Digital products can also be bought on the Internet in an impulse buying, as they are delivered immediately.

[6]The author also mentions the role of two additional factors which influence if goods are traded online: thin markets (which means markets with a small number of potential buyers like markets for specialty products), and sales tax reductions.

replacement lenses, there are predetermined exchange intervals, so that there is a continuous replacement requirement. Furthermore, contact lenses are clearly not perishable within a short period of time.

There are additional reasons, why contact lenses are well-suited for an empirical analysis. First, the product is highly standardised – most consumers choose a product which is not made to order, but is chosen among a range of standard parameters. Second, the characteristics can be described in a limited number of objective specifications, and there are no concerns of fashion or individual taste which influence a consumer's valuation of the products. As the choice of a certain product depends decisively on medical needs and on the individual condition of the eyes, there are relatively little possibilities for substitution between the products driven by brand preferences or quality attributes. Third, particularly in the case of planned replacement lenses, there is a continuous replacement requirement, and so there should be a strong incentive for consumers to search for the lowest price.[7] This is a major difference to previous empirical studies evaluating markets for products like books, CDs, software or consumer electronics, where the same product is usually bought only once.

3.2 Data Set

Identification of the Online Shops — The online shops for contact lenses were identified by searching for the German word for contact lenses in its two spellings (*Kontaktlinsen* and *Contactlinsen*) in the 10 most-widely used search engines[8]. From each of these search queries, the first 250 hits were examined in order to identify sellers of contact lenses.[9] Furthermore, in each of the search engines a search was run for the nouns 'contact lenses' and 'Euro' in order to identify online shops with websites in English whose prices are announced in Euros.[10]

The result of this proceeding was a list consisting of 165 online-shops for contact lenses.[11] Interestingly, none of these shops is operated by a contact lens manufacturer, nor

[7] **?** points out that search incentives are only affected by repeat purchases if prices are expected to remain stable over some time. This is clearly the case for the online market for contact lenses (for the frequency of price changes see Section 4.1).

[8] At the beginning of March 2002, these search engines were: www.google.de, www.yahoo.de, search.msn.de, www.lycos.de, www.t-online.de, www.altavista.de, www.web.de, www.metager.de (which is a meta search engine), www.fireball.de and suche.aol.com (source: www.webhits.de).

[9] During the planning of the data collection, a search for price comparison sites or shopbots for contact lenses in German was conducted. At that point of time, there was only one shopbot listing contact lenses from only one retailer, and the prices listed were identical to the prices at the retailer's website itself. Therefore, the sample contains no observations from shopbots or price comparison websites.

[10] This seemed to be an appropriate way to account for the perspective of a German consumer who is willing to order contact lenses from abroad and prefers to have price information without any need to convert currencies and without any risk from exchange rate volatility.

[11] Only those online shops were included in the sample, which at least provided an electronic order form. Those shops, where the consumer willing to order products has to write an e-mail using separate e-mail software, were excluded from the analysis, as this was not seen as being an appropriate way of conducting

can consumers order contact lenses directly on any of the manufacturers' websites. This suggests that there are no attempts from manufacturers to bypass the retailer network in order to increase the manufacturers' margins. This tendency could be due to the indispensable necessity to get contact lenses fitted by a contact lens specialist.[12] During the seven months period of data collection, the list of suppliers was updated by checking the links of shops which were "temporarily under construction" or "to be opened soon" at the time of the first website visit, and by including shops which had banner ads or sponsored links on the 10 search engines within the following months. At the end of the data collection, the supplier list consisted of 176 shops. Some of them were closed during the seven months period, however, or were already closed when the first wave of prices was surveyed. Finally, a list containing 150 online shop remains, for which price information as well as the retailer characteristics could be collected.

Prices — From March until September 2002 the whole range of contact lenses offered by each online shop was gathered, with exceptions of coloured and fun lenses[13] For each offered product and packaging unit, the associated unit price including sales tax and possible quantity discounts were collected every fourth week (between Monday and Wednesday) at each online shop in the sample. The result are 37,486 prices for 287 different products.

The data collection was done manually which was necessary, since automated data collection were only possible if the relevant websites followed a standard design. Alternatively, some studies use data from shopbots, which are automatically recorded by software, so-called "spiders". This bears the disadvantage that many suppliers prohibit automated price queries[14] – or that many price comparison sites do not contain prices identical to those on the online shops' websites. They report prices which are listed and updated by the retailers themselves and may contain rather manipulated prices (such as low prices in conjunction with exorbitant shipping fees, as described by Ellison and Fisher Ellison (2001)).[15]

It is a major advantage of the data set used in this study, that not only selected products, but the whole product range of the retailers was recorded in order not to bias the results. Clay et al. (2002) argue that the differences between their results and those of Brynjolfsson and Smith (2000) could be driven by the different sets of products and shops

e-commerce.

[12]Carlton and Chevalier (2001) report that in their study is no evidence that fragrance and DVD manufacturers use their own websites to circumvent the retailer network.

[13]Coloured and fun lenses (i.e. contact lenses with pictures on it, which are not suitable for driving, for example) were excluded, because this market segment was considered to have low substitution relationships to ordinary contact lenses. Furthermore, the demand for coloured and fun lenses can be assumed to underly more strongly to fashion concerns to a certain amount.

[14]DeLong and Froomkin (2000) report that already in 1997, many online shops blocked shopbot queries.

[15]Baye, Morgan and Scholten (2002) argue that there are strong incentives for online retailers to post reliable prices on price comparison websites, but the results of Ellison and Fisher Ellison (2001) hint in a different direction.

considered for the price comparisons.

Retailer Attributes — The service attributes of the retailers were collected once during the data collection period. No online-shop underwent remarkable changes or was relaunched. All online-shops were extensively browsed and their attributes categorised as detailed as possible in the attempt to capture the immediate judgement one makes when browsing through an online-shop within objective criteria. Therefore, a bulk of variables was created, describing various dimensions of online-shop attributes.
The following attributes were taken into account:

- range of products offered, i.e. if the online shop offers more products than ordinary contact lenses, such as contact lens solutions, accessories for contact lenses, coloured and fun lenses, or glasses and accessories, for example;
- the character of product presentation and description, i.e. if there are product photos, a detailed description of the product characteristics including technical details (such as water content or material) and suggestion of a suitable contact lens solution;
- ease of navigation through the product range, i.e. the possibility of search for a special product, sorting with respect to the product name and sorting with respect to the planned replacement scheme;
- technical configuration of the online shop, i.e. the presence of a shopping cart[16], encrypted data transfer, order tracking or a personal login for repeat customers;
- help and information for potential customers, i.e. information about the order procedure or the general terms and conditions, information about wearing contact lenses in general, or a hint that contact lenses have to be fit by a specialist;
- extra functions, i.e. links to other websites with information about contact lenses[17], a recommendation premium, 24-hours delivery, free trial lenses, the sending of a printed version of the catalogue[18], or a certificate for shop quality[19];
- additional costs for the consumer in terms of money or disutility, i.e. a fee for orders below a certain order value, a minimum order value, or restricted methods of payment for new customers;

[16] In many online-shops, orders have to be filled in an electronic form by hand or products are simply chosen from a pull-down menu

[17] Except links to manufacturer websites, as these usually contain very poor information and fulfill in most cases purely promotional functions.

[18] This does not in all cases indicate that the supplier has been in the mail order business before going online.

[19] Such certificates are awarded by different instances like consumer protection organisations or technical inspection agencies.

- basic information, such as the retailers' addresses and phone numbers.

Virtual location — Various measures for potential effects of location are included into the analysis. Possible influences of the retailers' physical location are proxied by including the relative purchasing power per inhabitant at the district level (*Stadt- und Landkreise*). A novel approach in this study is the attempt of measuring the 'virtual location' of the online-shops, a concept which has been derived from the notion of "neural real estate" by Smith et al. (2000, p. 110). The concept of location (in conventional markets) is derived from the notion that potential customers are in some places more likely to notice and pass a shop and thus to enter it than in other places. Therefore it is advantageous to be settled in a pedestrian zone or in a shopping centre, for example. In analogy to this, customers are more likely to click through to an online shop, which is ranked very high in an Internet search engine or which has ads appearing on the result sites of a search engine whenever a search for a relevant word has been conducted.

Two aspects of the virtual location of an online-shop are considered in the empirical analysis: a constant part of the virtual location, which is created by a retailer's Internet domain itself, and a dynamic part, which consists of a retailer's position in Internet search engines. The static part of an online retailer's virtual location is captured by dummy variables indicating whether the Internet address contains the words contact lenses or lenses (*Kontaktlinsen* or *Linsen*), if the Internet address consists of English words (as these are often notions which are very easy to remember), and if the Internet address is neutral in a sense, that it does not refer to the physical location of a retailer. In this context, an Internet address is regarded as being neutral, as long as it does not contain the words optician, a family name or a geographical name. The dynamic part of the virtual location is measured at each data collection date by the rank in the Google search results list among the first 100 hits for both relevant search terms, and by dummies for banner ads or sponsored links[20] in any of the 10 most used search engines when a search for the both relevant search terms is executed.

Contact Lens Attributes — Information about the product attributes were – as far as possible – gathered from the manufacturers' websites. As many manufacturers supply little detailed information about product characteristics, there was a need for additional information, which was found on the websites of the British and French associations of contact lens manufacturers[21], as well as a website of a British retailer which has very detailed information on its website[22].

[20] 'Sponsored links' refers to the fact that all commercial search engines, firms can pay in order to appear at the beginning of the results list when a search for a certain search term is executed. These links are distinguishable from the 'normal' results list.

[21] The Internet addresses are www.contaguide.fr and www.aclm.co.uk, respectively.

[22] www.jnj-contact-lenses.co.uk

The relevant attributes of contact lenses are the general type of product (frequent replacement, soft or rigid), the type of ametropia which is to be corrected (ordinary myopia/hyperopia, astigmatism, presbyopia) the range of dioptres, base curves, diameters, axes, cylinders and additions (if applicable). Besides there are additional features like handling tint and UV filter, and additional information like centre thickness and dk value (which measures the oxygen permeability of the material). It was possible to collect these characteristics for 237 distinct products. Price observations for products whose attributes could not be found out, are excluded from the data set. As these observations comprise less than 1% of all observations, the empirical results should not be biased.

4 Empirical Analysis

4.1 Descriptive Analysis of Market Efficiency

In a first step, the three criteria for market efficiency which were described in Section 2.1 are compared between the subgroups of hybrid and e-retailers.

Comparison of the price level: In Table 1, the hypothesis of equal mean prices between hybrid and e-retailers against the alternative hypothesis of a lower price level among e-retailers is evaluated using t-tests . The tests include only products which are available at both retailer types, and the degrees of freedom are corrected for the assumption of unequal variances. In order to avoid possible biases due to the choice of products offered by the retailers, the t-tests on equal average prices which are reported in Table 1 are calculated separately for each product and packaging unit. For the product segment of planned replacement lenses, the null hypothesis of equal prices can be rejected for nearly sixty percent of the products. However, these products which are significantly cheaper when bought from e-retailers represent 77% of all prices for planned replacement lenses. If there are more price observations for a certain product than for other products, this product is available from more retailers. This may imply that e-retailers compete more intensively on prices for products which are offered by a higher proportion of online retailers. Although the quantities sold are unknown, it can be assumed that these are the products with high sales volumes within the segment of planned replacement lenses.

For soft and rigid contact lenses, a lower fraction of the products is significantly cheaper among e-retailers. For soft lenses, e-retailers are cheaper for 50% of the products, for rigid lenses, this fraction is merely 27%.

Comparison of price dispersion: With respect to price dispersion, the F-tests, which evaluate the null hypothesis of equal standard deviation of prices versus the alternative hypothesis of a lower standard deviation of prices among e-retailers are reported in Table 2. Separate tests for different products and packaging units have been calculated in order

Table 1: Descriptive analysis of the price level

	Separate t-tests on equality of mean prices		
contact lens type	number of significant tests (H_0: e-retailers = hybrid ret.; H_a: e-retailers < hybrid ret.; p-value ≤ 0.05)	total number of tests	proportion of significant tests
planned replacement lenses			
number of tests	44	74	59.5%
number of observations	12,067	15,668	77.0%
soft lenses			
number of tests	23	46	50.0%
number of observations	2,524	4,491	56.2%
rigid lenses			
number of tests	4	14	28.6%
number of observations	411	1,632	25.2%

Only products available from both types of online retailers are considered. Only prices for one unit of the product are considered. The means are calculated across retailers and across time. The degrees of freedom are corrected for the assumption of unequal variances.

to investigate price dispersion. The results are similar to the results from the price level comparisons. Also in this test procedure, the null hypothesis of equal price dispersion can be rejected in the group of planned replacement lenses at a significance level of 5% for nearly to thirds of the products, which represent 87% of the observations. For soft and rigid contact lenses, the tests are significant for 39% and 25%, respectively.

Menu costs: In order to analyse menu costs (see Table 3), each price observation was compared to the observation of the previous month. In the subgroup of hybrid retailers, a price change occurred in 5.7% of the observations, compared to 6.0% among e-retailers. This difference is statistically not significant, such that the hypothesis of equally frequent price changes across the two types of retailers cannot be rejected. The picture is similar with respect to the average amount of price changes, once a price is changed. While a price is changed on average by 9.6% among hybrid retailers, the average price change has an amount of 9.4% in the subgroup of e-retailers. The null hypothesis of equal amounts of the average price change can therefore not be rejected in favour of the alternative hypothesis of smaller price changes by e-retailers.

Discussion of the results: The descriptive results support the hypothesis of more market efficiency in digital markets only as far as e-retailers are cheaper and have less dispersed prices. However, no differences between the two retailer types can be found

Table 2: Descriptive analysis of price dispersion

	Separate F-tests on equality of price dispersion		
contact lens type	number of significant tests (H_0: e-retailers = hybrid ret.; H_a: e-retailers < hybrid ret.; p-value ≤ 0.05)	total number of tests	proportion of significant tests
planned replacement lenses			
number of tests	42	66	63.6%
number of observations	13,380	15,375	87.0%
soft lenses			
number of tests	13	33	39.4%
number of observations	1,957	3,683	53.1%
rigid lenses			
number of tests	3	12	25.0%
number of observations	384	1,476	26.0%

Only products available from both types of online retailers are considered. Only prices for one unit of the product are considered.

with respect to the frequency and the amount of price changes. These results are obtained from the comparison between hybrid and e-retailers. Therefore, they are not directly comparable to empirical studies in which differences between online and conventional retailers are evaluated (see for example Bailey, 1998b; Brynjolfsson and Smith, 2000; Clay et al., 2002; Lehmann, 2001; Ward, 2002). However, some retailers in the data set emphasise in their general terms and conditions that the prices in their online shops are not valid in their conventional outlets or explicitly mention that the prices in their online shops are lower than in their conventional shops. So it can be assumed that the results were even more pronounced if online prices were compared to offline prices.

Obviously, the results hold primarily for the product segment of planned replacement lenses. This could be due to the fact that ordering contact lenses online is particularly advantageous for planned replacement lenses, as these lenses are replaced in fixed intervals between one day and one month. As soft and rigid contact lenses need to be replaced every 12 or 18 months (or even less often), the eyes should be examined and the contact lenses be fitted by a specialist before replacement. Online ordering should be an alternative only if the lenses are lost or broken shortly after they have been fit. This fact is also represented by the high percentage of observations for planned replacement lenses in the data set.

The result of a lower price level among e-retailers is supported by an Epanechnikov kernel density estimation for standardised prices. Each price is standardised in terms of

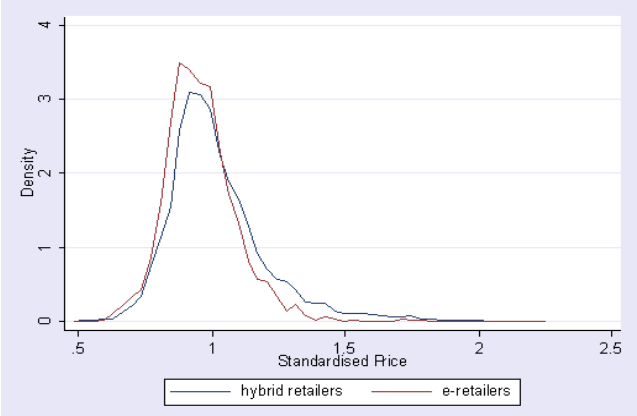
Table 3: Descriptive analysis of price changes

	t-tests on equality of fraction and amount of price changes		
	hybrid retailers	e-retailers	p-value (H_0: e-retailers = hybrid ret.; H_a : e-ret. < hybrid ret.)
fraction of price changes	5.7%	6.0%	0.214
number of observations			19,406
relative price change	9.6%	9.4%	0.597
number of observations			1,115

Only prices for one unit of the product are considered.

a division by the mean of all prices for this product and package size. This standardised price describes the relative deviation of the average price across all online retailers and is a means to control for product heterogeneity. Figure 1 depicts the kernel estimates for both sub-samples. The estimated density curve for the e-retailers lies at the left from the curve for the hybrid retailers which is an indicator of lower prices. This result is further confirmed by a nonparametric Kolmogorov-Smirnov test on the equality of both distributions. The null hypothesis of equal distributions is rejected in favour of the alternative hypothesis that at least one product is cheaper at e-retailers with a p-value of 0.000. Rejection of the null hypothesis in favour of the opposite alternative is not possible (p-value 0.995).

Figure 1: Epanechnikov Kernel Density Estimation of Standardised Prices



4.2 Hedonic Price Regressions

In order to represent retailer service attributes by a reasonable amount of variables to be used in the price regressions, a factor analysis of variables representing retailers' service characteristics was computed. 39 variables describing various aspects of retailer service were included in the principal factor analysis. The factor loadings were obtained after a varimax rotation. Factors were kept, as long as their eigenvalues exceeded 1. The result are 6 principal factors, which are described in Table 4. Reported are those variables whose absolute factor loading exceeds 0.4.

Table 4: Factor analysis of retailer service

Factor	Features of online shops	Sign
Factor 1	Shopping basket	+
	Possibility for individual search	+
	Payment by direct debit or credit card	+
Factor 2	Delivery within 24 hours possible	+
	Personal login at website	+
	Websites at least in German	-
	Payment on account or cash on delivery	-
Factor 3	E-mail contact	+
	Telephone contact	+
	Fax contact	+
Factor 4	Encrypted data transfer	-
	Online shop is certified	-
	Material of product is stated	-
Factor 5	Products sorted according to replacement scheme	-
	General terms and conditions on website	-
	Sale only to experienced users	-
	Legal return policy	-
	Water contents of product is stated	-
Factor 6	Information on order process	+
	Printed catalogue available	+
	Test lenses for free	+

Factor 1 clearly accounts for the most common features of online shops, whereas Factor 2 describes more advanced service attributes in combination with convenient understanding and a negative impact of less convenient payment methods. Various possibilities of communication with staff of the online retailer are accounted for by the third factor. Factor 4 gets a high value if an online shop is less secure (certification also has to do with secure data transfer) or if information concerning the product's material is lacking. The fifth factor represents absolute basics in terms of basic navigation, legal and product

information features and gets higher upon lack of these features. The last factor accounts for more advanced provision of information like order tracking, free test lenses or a printed catalogue. These six factors are scored with the estimated loadings and then included into the regression analysis.

In order to evaluate the influence of retailer service characteristics and the virtual location on product pricing, the following hedonic price function is estimated:

$$log(p_{it}) = \alpha + \beta x_{it} + \gamma r_h + \delta c_i + \lambda s_{ht} \mu d_t + u_i + e_{it} \tag{1}$$

where $log(p_{it})$ denotes the natural logarithm of the price of product i at time t and x_{it} represents the number of packages ordered. r_h describes the characteristics of retailer h, c_i the product characteristics of product i, s_{ht} the virtual location of retailer h at time t, d_t are time dummies and e_{it} is an error term. u_i represents a product-specific unobserved effect, which is either assumed to be zero (estimation with pooled OLS), assumed to be uncorrelated with the explanatory variables (random effects estimation) or correlated with some of the explanatory variables (Hausman-Taylor estimation).

A product i is defined as a combination of product and package size. Because planned replacement lenses are the segment of contact lenses which is most suited for e-commerce, the empirical analysis in the following sections is based only on the sub-sample of planned replacement lenses. In order to receive first results about the factors influencing prices, only observations for single packages are included in the analysis.

Regression results for various estimation techniques are reported in Table 5. In order to get a baseline for comparison with further approaches, Equation 1 is estimated by pooled OLS assuming that there is no unobserved product heterogeneity (the u_i are zero). The dependent variable is the natural logarithm of the price per contact lens in Euros. The estimated coefficients for the package size indicate that the price per lens decreases with package size. Both dummy variables for the type of contact lens and for various product attributes are included in the estimation but not reported in the table. In each specification, these variables are jointly significant. Time dummies indicating the month of observation are included in all specifications, too. The estimation results for the influence of the different factors describing retailer service, which were obtained from the factor analysis described above, are mixed. Three factors have a significantly negative impact, three have a significantly positive effect, which can be interpreted as service premium. The results do only little change across the different specifications.

The different estimation approaches are applied due to the specific nature of the estimation problem. As the effects of several time-constant variables are of special interest, a fixed effects approach seems not to be reasonable. After the random effects estimation, a Hausman test is calculated which indicates correlation between the exogenous variables and the unobserved individual specific effect, so that the estimation results of the random effects cannot be assumed to be consistent. Therefore, a Hausman-Taylor model is

estimated, which allows for correlation between some of the exogenous variables with the random effects (see Wooldridge, 2001). It is therefore assumed that unobserved heterogeneity is correlated with the matter of being an e-retailer and the eventual appearance on the first page of results of a search engine when searching for the notion 'contact lenses'.

Table 5: Hedonic price regressions

	Dependent variable: ln(price per lens)		
	Pooled OLS	Random Effects	Hausman-Taylor
Package size	-0.078***	-0.083***	-0.080***
Package size$^2 * 10^{-2}$	0.234***	0.256***	0.243***
Package size$^3 * 10^{-4}$	-0.248***	-0.273***	-0.258***
Package size$^4 * 10^{-6}$	0.077***	0.086***	0.081***
Extra lenses	-0.057***	-0.067***	-0.048
Factor 1	-0.018***	-0.019***	-0.018**
Factor 2	-0.040***	-0.044***	-0.020*
Factor 3	0.021***	0.025***	0.000
Factor 4	0.016***	0.012***	0.020***
Factor 5	0.054***	0.059***	0.038***
Factor 6	-0.017***	-0.016***	0.010
E-retailer	-0.013***	-0.023***	-0.200***
Physical location abroad	0.037**	0.062**	0.026
Google: Advertisement	-0.077***	-0.005***	-0.003*
Other search engine: Banner ad	0.014**	-0.009***	-0.009***
Other search engine: Sponsored link	0.018***	-0.006***	-0.006***
Google: Hit on 1^{st} page of results	0.037***	-0.004*	-0.005**
Constant	1.849***	1.890***	1.855***
Contact lens attributes: $F(df_1; df_2)$	5112.5*** (15; 15,477)		
Contact lens attributes: $\chi^2(df)$		13045.7*** (15)	5868.8*** (15)
Time dummies: $F(df_1; df_2)$	4.4*** (6;15,477)		
Time dummies: $\chi^2(df)$		9.94 (6)	10.0 (6)
Number of observations	15,516	15,516	15,516

***, **, * = significant on the 1%, 5% and 10% level.
Standard errors are heteroskedasticity consistent for pooled OLS.

The results in the third column of Table 5 indicate that the e-retailers offer significantly lower prices than their hybrid competitors. This further supports the descriptive results of the t-tests and the nonparametric testing in Section 4.1. Also the hypothesis with respect to the influence of virtual location is supported. In the Hausman-Taylor specification, all kinds of virtual location have a significantly negative effect on the product price. The results of the pooled OLS estimation seem to be more plausible, since

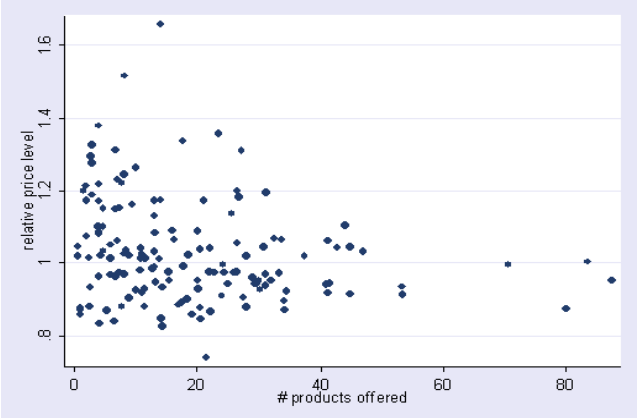
one would expect retailers to exploit a prominent positioning in search engines and thus a favourable virtual location by imposing price premiums. But on the contrary, the negative effect of the three advertising variables on prices could hint to a different retailer strategy: Retailers invest in banner ads and sponsored links in order to increase their website traffic and thus their sales volumes in order to generate higher profits by a low price - high volumes strategy. Nevertheless, the influence of the dummy variable indicating an entry on the first page of results at Google is somewhat surprising, as a retailer's direct influence on its search engine rank is only limited.

To sum up, the results in both specifications support the hypothesis of ceteris paribus lower prices of pure e-retailers. Also the variables measuring each online shop's virtual location have a significant influence on the price. Product characteristics and time dummies are included in the regression, results are available on request from the author.

4.3 Retailer Strategies

An immediate question concerning possible strategic price setting by retailers concerns the possibility that there are some retailers specialised in offering a relatively narrow product range at relatively low prices. Vice versa, other retailers would offer a very broad range of products, but quite expensively. This hypothesis is evaluated descriptively in Figure 2. Upon observation of the figure, the notion is that this hypothesis is not true. In particular, retailers offering a wide product range seem not to be relatively more expensive.

Figure 2: Width of Product Range Offered Versus Relative Price Level of Retailers



A simple OLS regression confirms this notion (see Table 6). The estimated coefficient of the width of the product range for each retailer has a significantly negative effect on its relative prices. The width of the product range offered is measured by the number of different products offered. The relative prices of each retailer are measured by the standardised prices, which are then averaged over the full observation period separately

for each product of a retailer. In order to obtain a measure for the relative price level of each retailer, the average of these transformed price observations is calculated.

A very similar result is obtained based on a criterion which is based on ranks. The product prices are sorted from lowest to highest across retailers separately for each product. Then each retailer is assigned a rank for each product which is available. The relative price level of each retailer can then be described by an average of the ranks across the products which are offered.

Table 6: Relationship between product range and relative prices of retailers

Dependent variable: index for relative prices based on standardised prices	
Width of product range	-0.00358**
Width of product range^2	0.00003
Constant	1.08178***
Number of observations	148

***, **, * = significant on the 1%, 5% and 10% level.
Standard errors are heteroskedasticity consistent.

This result does not confirm the hypothesis described above. Instead, it can be interpreted as evidence in favour of a result from Ward (2002) who describes the possibility of a high-price–low-volume strategy. Vice versa, other retailers would then pursue a strategy in which they generate high sales volumes by attracting customers by low prices. This possibility was also considered in Section 4.2.

5 Conclusions and Hints for Further Research

The results presented in this paper are in favour of enhanced market efficiency through digital markets. Particularly for the segment of planned replacement contact lenses, evidence is found for lower prices and less price dispersion among e-retailers in comparison to hybrid retailers. Furthermore, the results are consistent with the notion of a *virtual* location and with the irrelevance of the *physical* location of the retailers. Price dispersion can only partially be explained by retailer characteristics. In addition to this, there is evidence for strategic price setting of retailers. Particularly this point should be more deeply evaluated in further research. Also the possibility of temporarily lowering prices in order to undercut rivals is to be analysed (see Varian (1980) for a theoretical model and Ward (2002) for an empirical application). Furthermore, the strategic means of offering quantity discounts on certain products needs additional analyses, which can be carried out using the data set being used for this project.

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