Electronic Commerce

and

Competitive First-Degree Price Discrimination

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Abstract

As consumer e-commerce matures on-line retailers are adopting personalisation technologies which significantly increase their ability to undertake first-degree price discrimination by offering different prices to different consumers. We present a model of duoplolistic competition between firms capable of using such technologies. Using first-degree price discrimination firms are able to extract more surplus from their customers, but also face more intense competition, because they compete, in effect, for each and every consumer in the market. Whether or not firms will choose to use this new technology will depend on whether or not the *enhanced surplus extraction effect* dominates the *intensified competition effect*. We present a model which makes these ideas precise, and characterise the conditions under which firms will choose to employ first-degree price discrimination technologies.

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1. Introduction

In recent years an enormous amount of consumer-specific data has been collected by retailers and marketing companies. For example, loyalty cards and air mileage programmes are used to collect data on the shopping patterns of individual consumers. By employing data mining techniques companies are able to infer from these massive databases the preferences of individual consumers. Companies which do not (or cannot) collect data themselves can still purchase relevant consumer-specific information from direct mailing databases specialists.

This consumer-specific information can in principle be used by sellers to undertake first-degree price discrimination by offering consumers the product they want at a price which they are likely to be willing to pay. However, until now, such discrimination has been too costly - for example, a physical catalogue which is individually tailored is hardly likely to be cost effective. With the advent of consumer e-commerce, this needs no longer be the case. In particular, personalisation technologies, such as agents[1], significantly increases the ability of firms to undertake first-degree price discrimination. Using agents, an on-line catalogue can be individually customised, for the agent can identify the shopper and automatically redesign the company's Web site to match the user's likely requirements. In particular the technology can be used to offer different prices to different consumers. Since on-line menu costs are practically zero, on-line retailers can change their prices to match what they expect the individual to be willing to pay for whatever they are selling[2].

The question we wish to address in this paper is whether, if such a technology is available, firms will necessarily choose to use it. At first sight this may seem an odd question, since conventional theory tells us that the ability of a firm to employ first-degree price discrimination always raises its profits, since it can extract greater surplus from consumers. Call this the *enhanced surplus extraction effect*. However, like virtually all the analysis of price discrimination, this conclusion is drawn in the context of price discrimination by a monopolist. A key feature of the environment in which firms are

[1] An agent is a program that is authorised to act independently on behalf of its user. This can range from automatic search (for example, an agent searching for airline tickets on the Web can match preferred dates, price-range, class of travel, etceteras, without consulting its user) to automatic negotiations (for example, agents can place binding bids in a Web auction). Personalisation can be carried out according to Web site demographics (the user profile for a given site); individual domains (attributes inferred from the user's browser, for example by using cookies or agents); learning (the agent monitors and learns about the preferences of the user), and correlation (where the agent compares the user's preferences with other users with similar interests and suggests possible contents based on this correlation. For example, Barnes & Noble and Firefly created a system that recommends books based on this method). An example of personalisation technology in use is MyYahoo! (my.yahoo.com), an agent that allows the construction a individually tailored news web page, while at the same time customising the banner advertising on this page according to the user's profile.

[2] In a recent study, Internet retailers' prices adjustments over time were found to be up to 100 times smaller than conventional retailers' price adjustments (Brynjolfsson and Smith, 1999).

operating using e-commerce is that it is highly competitive. Intuitively one suspects that this will introduce a second important consequence of the decision by firms to use first-degree price discrimination – namely that it will intensify competition between firms, since they will now be competing consumer-by-consumer. Call this the *intensified competition effect*. This will naturally lower firms' profits.

Thus whether or not firms will choose to use this new technology will depend on whether or not the *enhanced surplus extraction effect* dominates the *intensified competition effect* The aim of this paper is to make these ideas precise, and to characterise conditions under which firms might choose to employ first-degree price discrimination in a competitive environment.

While much of the literature on price discrimination has focused on the case of monopoly[3], a number of papers have analysed how price competition operates in a competitive environment - Katz (1984), Borenstein (1985), Holmes (1989), Corts (1998) and Armstrong and Vickers (1999). The latter paper in particular provides an elegant framework that incorporates much of the earlier work. However this analysis concentrates on the case of *third-degree* price discrimination in a competitive environment.

As Armstrong and Vickers (1989) show, the analysis of third-degree price discrimination can essentially be split into two parts. Each firm first determine how much profit it can make for any given level of gross utility that a typical consumer will obtain by buying from that firm. Devices such as price-discrimination and commodity bundling are just ways of extracting more surplus from consumers and so making more profits for any given level of gross utility. Firms then compete in terms of the amount of gross utility they offer their customers. Consumer specific preference characteristics will determine the net utility they obtain from any gross utility provided by a particular firm. The distribution of these characteristics will determine the demand for each firm as a function of the gross utilities offered by both firms. Firms cannot observe these consumer specific characteristics and so cannot influence the net utility a consumer obtains from any gross utility they get from buying from that firm.

In contrast, in the model of competitive *first-degree* price discrimination considered here, firms will face a trivial problem of extracting surplus from consumers once they have chosen to buy from them. However firms can observe individual consumer characteristics, and can use their pricing policy to operate directly on consumers net utility and hence on the decision to buy from one firm rather than the other. It is this that gives rise to the more intense competition between firms.

We use the Hotelling framework to model price competition in differentiated goods between two firms. Consumers are located along a line representing the degree of product differentiation. The two firms are located at either end of the line. The firms

[3] The survey by Varian (1989) has a small section 3.6 covering the analysis for the case of monoplistic competition.

have the same technology with marginal costs independent of output. Firms can either set mill prices, or offer each consumer an individually tailored price.

We obtain the following major results.

1. If neither firm price discriminates, both firms will set price above marginal cost.
2. If a firm chooses to use first-degree price discrimination, then the prices it sets and the profits it obtains are independent of whether or not the other firm chooses to use first-degree price discrimination.
3. If at least one firm operates first-degree price discrimination, the consumer located half-way between the two firms will be offered a price equal to marginal cost by both firms – the conventional Bertrand conclusion.
4. Whether or not profits are higher under first-degree price discrimination depends crucially on the nature of the transport cost function.

To elaborate on this latter point, consider the class of functions $t(z) = t.z^{b}$, $b \geq 1$, where z is distance travelled and β takes integer values. If this function is linear or quadratic (i.e. $b = 1, 2$) then, the prices that a firm offers consumers will be almost everywhere[4] lower than if neither firm discriminates. When $b \geq 3$ then a firm that price discriminates will charge higher prices to those consumers located close to it, than it would if neither firm discriminates. However, since prices are lower for consumers in the middle (result 3), profits are higher if neither firm discriminates. Only when $b \geq 5$ do firms make more profits if they can price discriminate than if neither discriminates.

The intuition is straightforward. When transport costs do not increase very fast with distance, then competition between products is intense, and so the *intensified* competition *effect* is the dominant consideration. However, when transport costs rise very fast with distance then consumers located close to firms are effectively locked in, giving firms considerable powers to extract surplus from them, just as in the traditional monopoly analysis. The extra profits extracted from these consumers can offset the reduced profits made on the consumers located in the middle where competition is intense.

[4] The exception is the consumer located at the same end of the line as the firm.

2. The Model

Suppose there are two firms, A and B, located at either end-point of a line of length L. Consumers are uniformly distributed along this line, and each consumer buys a fixed amount of the good. Choose units so that there is 1 unit of demand at each point on the line.

The firms have identical constant marginal costs of production $c>0$.

Consumers have to incur transport costs to visit firms. Let $t(z)$ be the transport costs of travelling distance x. Assume $t(0)=0;\quad t'(z)>0;\quad t''(z)\geq 0$.

For later purposes let $T(z)$ be the integral of $t(z)$. So $T(z)=\int_0^z t(y)dy$.

<u>Case I: No-Discrimination</u>

Suppose firm A charges a price p while firm B charges a price q. The consumer that is just indifferent between buying from A and B lies a distance x from A where

$$p+t(x)=q+t(L-x) \tag{1}$$

Given the assumption on how we measure units, x is also the demand for firm A, which is defined through (1) as an implicit function of p and q. We have

$$\frac{\partial x}{\partial p}=-\frac{1}{t'(x)+t'(L-x)}<0 \tag{2}$$

For any given q firm A chooses p to

$$\underset{p}{MAX}\quad (p-c).x(p,q)$$

The first order condition is

$$x(p,q)+(p-c).\frac{\partial x}{\partial p}=0. \tag{3}$$

In a symmetric Bertrand equilibrium $p = q$ which implies $x=\frac{L}{2}$. Substitute this into (2) and (3) and then substitute (2) into (3) to get

$$p^{e} = c + L.t'\left(\frac{L}{2}\right).$$

But then the equilibrium profits that each firm makes under no-discrimination is

$$p^{n} = \frac{L^{2}}{2}.t'\left(\frac{L}{2}\right). \qquad (4)$$

<u>Case II: Price Discrimination: Only One Firm Discriminates</u>

Suppose now that firm A can price discriminate, but firm B cannot. A can now set a price schedule $p(x)$.

Suppose that B sets a price of $q \geq c$. Consider consumers located a distance x from A.

If $c + t(x) < q + t(L - x)$ then A can set a price $p(x) = q + t(L - x) - t(x) - e$, pick up all the consumers at x and still make a profit.

Thus we can take A's best response to any price q to be to set a price schedule

$$p(x) = MAX\left[q + t(L - x) - t(x), c\right] \qquad (5)$$

It is now straightforward to show that the **only** Bertrand equilibrium price for B is q = c.

Suppose that this were not the case and that B's equilibrium price were $\bar{q} > c$, and that the corresponding price schedule set by A were $\bar{p}(x) = MAX\left[\bar{q} + t(L - x) - t(x), c\right]$.

Notice that the cost to any consumer located at a distance x from A, of buying from A, is then

$$\bar{p}(x) + t(x) = MAX\left[\bar{q} + t(L - x), c + t(x)\right]$$

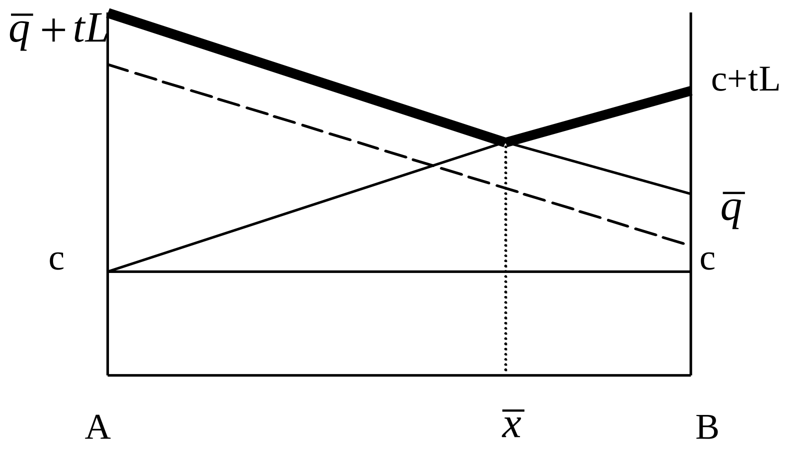
Notice that in such an equilibrium A would serve all consumers that lie a distance $\bar{x}$ or less from itself where

$$\bar{q} + t\left(L - \bar{x}\right) = c + t\left(\bar{x}\right)$$

which implies $\bar{x} > \frac{L}{2}$.

This is illustrated in Figure 1 below for the case of a linear transport cost function. The heavy dark line indicates the cost $\overline{p}(x)+t(x)$ of buying from firm A.

Figure 1



Hence if $\overline{q}$ really were the equilibrium, firm B would make a profit

$$\left(\overline{q}-c\right).\left(L-\overline{x}\right)<\left(\overline{q}-c\right).\frac{L}{2}.$$

Notice that if B makes the normal Bertrand/Nash assumption that A will carry on setting the price schedule $\overline{p}(x)$, then if it now sets a price $\overline{q}-e$ where $\overline{q}>\overline{q}-e>c$ then

$\forall x, \quad 0\leq x\leq L:$

$$\overline{q}-e+t(L-x)<\overline{q}+t(L-x)\leq\overline{p}(x)+t(x)=MAX\left[\overline{q}+t(L-x),c+t(x)\right].$$

Thus B would pick up the entire market and make a profit $\left(\overline{q}-e-c\right).L$. This is illustrated in Figure 1 by the broken line that represents the cost $\overline{q}-e+t(L-x)$ to a consumer located at x of buying from firm B if it has charged a price $\overline{q}-e$.

For sufficiently small ε,

$$(\overline{q}-e-c).L>(\overline{q}-c).\frac{L}{2}>(\overline{q}-c).(L-\overline{x})$$

Hence $\bar{q}$ is not the profit-maximising response by B to the price schedule $\bar{p}(x)$ chosen by A.

Hence the only equilibrium is $p^e(x) = MAX\left[c + t(L-x) - t(x), c\right]; \quad q^e = c$.

Once again each firm serves half the market. The profits made by firm B are clearly zero, while those made by A are

$$p^d = \int_0^{\frac{L}{2}} \left[t(L-x) - t(x)\right] dx = T(L) - 2T\left(\frac{L}{2}\right). \qquad (6)$$

Case III: Price Discrimination: Both Firms Discriminate

Firms compete for consumers at each point on the line. Clearly the only outcome is that the firm that is at a distance disadvantage will have to set a price = *c*, while the other firm will set a price that just picks up all the consumers. On the other hand, at the mid-point of the line both firms are identical, so the conventional Bertrand conclusion holds and both firms' prices are driven down to costs.

This means that on the interval $0 \le x \le \frac{L}{2}$ the solution is as above, namely,

$$p^e(x) = MAX\left[c + t(L-x) - t(x), c\right]; \quad q^e = c .$$

On the other hand if we let $y = L - x$ denote the distance between a consumer and firm B, then, on the interval $0 \le y \le \frac{L}{2}$ the solution is

$$q^e(y) = MAX\left[c + t(L-y) - t(y), c\right]; \quad p^e = c .$$

But then, if both firms price discriminate they both make profits

$$p^d = T(L) - 2T\left(\frac{L}{2}\right). \qquad (7)$$

From equations (6) and (7) we get our first result:

Lemma 1. If a firm price discriminates it makes profits $p^{d} = T(L) - 2T\left(\frac{L}{2}\right)$ whether or not the other firm price discriminates.

And by comparing equations (4) and (7) we get:

Proposition 1. Price discrimination is profitable if and only if
$p^{d} = T(L) - 2T\left(\frac{L}{2}\right) > p^{n} = \frac{L^{2}}{2}.t'\left(\frac{L}{2}\right)$

The following section illustrates our result for a large class of transport costs.

3 Examples

Consider the class of simple transport cost functions $t(x) = t.x^{b}; \quad t > 0, \quad b \geq 1$.

From (4) $p^{n} = \frac{t.b}{2^{b}}.L^{1+b}$.

From (7) $p^{d} = \frac{t.L^{1+b}.\left(2^{b} - 1\right)}{(1+b).2^{b}}$.

If we let $r(b) \equiv \frac{p^{d}}{p^{n}}$ denote the ratio of profits under discrimination to non-discrimination, then we have

$$r(b) = \frac{\left(2^{b} - 1\right)}{b.(1+b)}.$$

It is straightforward to show that The function defined by the above ratio is monotonic increasing in β for β>1.5. It is equal to less than 1 for integer values of $b \leq 4$, but greater than 1 for integers greater or equal to 5.

To see what is going on in more detail consider what happens to the price schedules under discrimination and non-discrimination.

We know that with non-discrimination $p^{e} = c + L.t'\left(\frac{L}{2}\right) = c + \frac{t.b.L^{b}}{2^{b-1}}$

With discrimination we have $p^e(0) = c + t(L) = c + t.L^b$, and the price then falls with distance until $p^e\left(\frac{L}{2}\right) = c$.

Consider then the following cases.

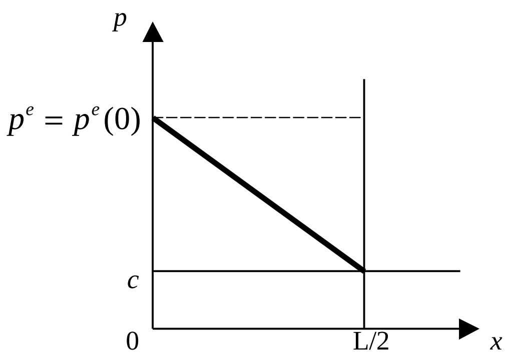
The following table reports the values of these various variables for different values of β.

Table 1

β	p^e	$p^e(0)$	ρ
1	$c+t.L$	$c+t.L$	1/2
2	$c+t.L^2$	$c+t.L^2$	1/2
3	$c+\frac{3}{4}t.L^3$	$c+t.L^3$	7/12
4	$c+\frac{1}{2}t.L^4$	$c+t.L^4$	3/4
5	$c+\frac{5}{16}t.L^5$	$c+t.L^5$	31/30

Figure 2 illustrates the price paths for the case of linear transport costs - $b = 1$.

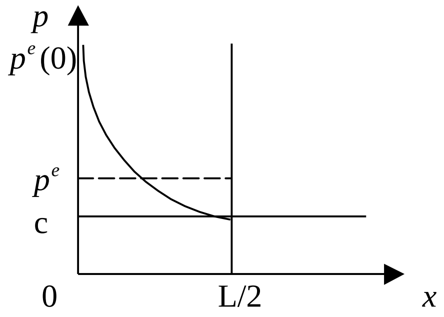
Figure 2



Here the broken line represents the equilibrium price when there is no discrimination, and the heavy line the equilibrium price path under discrimination.

Figure 3 illustrates the situation when $b = 5$.

Figure 3



Once again the broken line represents the equilibrium price when neither firm discriminates. The curve represents the price path under discrimination.

So when β is small - i.e. $b \leq 2$, then $p^e = p^e(0)$ and so prices are almost everywhere lower under discrimination. When $b = 3$ the ability to discriminate means that prices are higher under discrimination for consumers close to firms. But, this is not enough to offset the fact that prices are lower for consumers around the middle so profits are lower under discrimination. As β gets larger so too does the gain from being able to discriminate amongst consumers close to the firms, until, eventually, price discrimination becomes possible.

So, as we mention earlier, there are two effects at work: The intensification of competition between firms, and the ability to discriminate.

Consider first the impact of these two effects on prices. The first effect certainly lowers the prices of consumers that are least loyal to any firm – those in the middle. When transport costs do not rise very fast with distance, then there are almost no loyal consumers and so the first effect means that prices are lower for all consumers. However, when transport costs rise more sharply with distance, then consumers close to a firm are locked in much more and so the firm can really discriminate. This offsets the competition effect and means that firms can now charge higher prices for those closer to them.

Consider now the effect on profits. When prices are driven down for all consumers then profits obviously fall with discrimination. When firms can effectively raise prices for their most loyal consumers, this may or may not be enough to offset the effects of low prices in the middle. Only when the ability to discriminate is very strong because of sharply rising transport costs will discrimination actually be profitable.

4. Discussion

In recent years the Internet has become a popular shopping channel. The Internet offers consumers 24 hour shopping and the convenience of shopping from home. It is also much easier to compare products and prices on-line than it is in any other means of shopping. For homogenous goods, like CDs and books, consumers can use shopping agents (known as ShopBots), like BargainFinder.com to compare prices and buy from the seller which offer the cheapest price.

Internet technologies offer greater opportunities for sellers too. On-line retailers face much lower entry and set-up costs and menu costs are practically zero (once the appropriate software is installed). Easy access to information about their users allows on-line retailers to better segment the market they are serving and to offer customers products which they are likely to want to buy.

It is not clear at this early stage what effects these technologies will have on prices and market structure. Even in the simple case of homogenous goods, it is not clear what the overall effect on prices will be[5]. There is clearly a need for rigorous models of electronic markets where intuitions can be put to the test. This paper can therefore be seen as a contribution to filling that gap.

This paper focus on one particular feature of electronic markets - the ability of sellers to first degree price discriminate. Personalisation technologies have been in the centre of media attention in recent years. Many, including the US Justice Department, have voiced their concern about the possible violation of individual privacy rights through the exchange of information between the user's agent and the host Website, which takes place automatically. In particular, the view that the more information the seller have about the user, the more surplus it is able to extract from her, remains highly popular. While this is always true in a monopoly context, this paper questions this intuition in the context of competitive markets.

We have shown that in that context there are two effects at work:

(i) the *enhanced surplus extraction effect* - which is the effect at work in the traditional monopoly analysis of first degree price discrimination;

(ii) the *intensified competition effect* – the fact that firms end up competing consumer by consumer – with the traditional Bertrand result that at least one of them has its price driven down to marginal cost.

We have used a simple duopoly setting with product differentiation to understand the interaction between these two effects, and to characterise the exact conditions under which firms would prefer to employ first-degree price discrimination. We showed that when the average and marginal transport costs rise very slowly with distance – more

[5] See Vulkan (1999) for a general discussion, and Ulph and Vaughan (1999) for an analysis that shows that increased price transparency can raise or lower prices, depending on whether producers or consumers can better exploit the technology.

precisely when transport costs are linear or quadratic – then the *intensified competition effect* dominates the *enhanced surplus extraction effect* and almost all consumers face lower prices under price discrimination. As transport costs rise more steeply with distance then this strengthens the *surplus extraction effect*. Now consumers with the greatest brand loyalty will pay higher prices under first-degree price discrimination, though those with least loyalty will still face lower prices. Only when transport costs rise sufficiently steeply so that the increased profits extracted from the most loyal consumers exceeds the loss in profits from the least loyal consumers will first-degree price discrimination turn out to be profitable for firms.

Thus, in a wide class of cases, firms may choose not to use the price-discrimination technology.

While the analysis in this paper has been motivated by emerging e-commerce technology, it can be applied in any context where first-degree price discrimination is possible, and can be used to explain why, when there is competition, price discrimination may not always be used.

There are a number of directions in which the analysis can be extended. As pointed out above, e-commerce can be used to tailor not just the price, but also the product to individual consumer needs. This latter phenomenon is often referred to as mass customisation. In a companion paper[6] we explore the implications of this for price discrimination.

[6] Ulph and Vulkan (2000)

References

Armstrong, M. and J. Vickers (1999), “Competitive price discrimination”, Working Paper, Nuffield College, Oxford University.

Borenstein, S. (1985), “Price Discrimination in Free-Entry Markets”, *Rand Journal of Economics*, 16, pp. 380-397.

Brynjolfsson, E. and M. Smith (1999), “Frictionless Commerce? A comparison of Internet and Conventional Retailers”, Working Paper MIT.

Corts, K. (1998), “Third-Degree Price Discrimination in Oligopoly: All-Out Competition and Strategic Commitment”, *Rand Journal of Economics*, 29, pp. 306-323.

Holms, T. (1989), “The Effects of Third-Degree Price Discrimination in Oligopoly”, *American Economic Review*, 79, 244-250.

Hotteling, H. (1929), “Stability in Competition”, *Economic Journal*, 39, pp. 41-57.

Katz, M. (1984), “Price Discrimination and Monopolistic Competition”, *Econometrica*, 52, pp. 1453-1471.

Varian, H. (1989), “Price Discrimination”, in R. Schmalensee and R. Willig, eds., *Handbook of Industrial Organization, Volume 1*, Amsterdam: North Holland.

Ulph, D. and R. Vaughan (1999), “Price Transparency and Market Equilibria”, mimeo.

Ulph, D. and N. Vulkan (2000), “E-Commerce, Mass Customisation and Price Discrimination”, in preparation.

Vulkan, N. (1999), “Economic implications of agent technology and e-commerce”, *The Economic Journal*, 453, pp. 67-90.