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Price Dispersion in the Phenomenon of Big Data Discriminatory Pricing (BDDP)

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Abstract: Theoretically, competition between firms producing homogeneous products would lead to price convergence. However, there is persistent price dispersion in real markets for homogeneous products. Many scholars have built models from different perspectives to explain the existence of price dispersion in retail markets. Moreover, this price dispersion still exists after entering the Internet era. My paper builds a model based on the phenomenon of many monopolies charging different prices to consumers through big data discriminatory pricing (BDDP) since entering the Internet Big Data era to find price dispersion equilibrium from the perspective of firms. My model adds some variables to a Varian-style model in which consumers are divided into three types and firms charge different prices to maximise profits. Moreover, my study simplifies the actual market situation and is theoretically ideal. It does not perform a multi-stage analysis of consumer switching costs and consideration of consumers entering and leaving the market. However, my paper provides some ideas for subsequent research on price dispersion in Internet monopolies and provides a direction for multi-stage research.

Keywords: price discrimination, big data discriminatory pricing, Internet price dispersion

1. Introduction

Textbook models of competitive markets suggest that competition between firms producing homogeneous products will lead to the so-called "law of one price". However, research from 1961 to the present has shown that price dispersion is constant in many homogeneous product markets. As Hal Varian has argued, "the 'law of one price' is no law at all" [1].

After discovering that the "law of one price" does not last forever, a number of scholars began to study equilibrium with respect to price dispersion. Beginning with Stigler's seminal paper, research on price dispersion has continued to develop [2]. Many scholars have developed models to explain price dispersion as an equilibrium outcome from different perspectives. Most of the classic literature on price dispersion examines the existence of price dispersion in retail markets. Since entering the Internet era, scholars have found that price dispersion still exists. My paper is based on the phenomenon that in the era of Big Data on the Internet, many monopolies charge different prices to consumers through big data discriminatory pricing (BDDP) and will investigate this new phenomenon of price dispersion equilibrium by developing a theoretical model.

A typical example of this phenomenon is Uber and Lyft, two monopoly companies in the online car-hailing industry; the two companies charge higher prices for frequent users through big data. In

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contrast, new users get very favourable prices, and after more usage, the companies charge consumers higher and higher prices. Another example is Ctrip and Tongcheng, two famous online travelling companies in China; on their platform, consumers will find that the prices of products such as hotel bookings and tickets will continue to rise with increased use. Therefore, based on this phenomenon, my paper will study the price dispersion equilibrium of monopolies to consumers based on big data discriminatory pricing and build a model to find the equilibrium from the firm's perspective.

The two key concepts of my paper are price dispersion and big data discriminatory pricing. The price dispersion here is referred to the price dispersion in the general sense, which means a situation where firms charge different prices in the market for homogeneous products through their strategies. This paper will focus on price dispersion on the Internet. In addition, based on the relevant literature and the current situation of the market, big data discriminatory pricing (BDDP) in this paper refers to platforms and merchants using big data to obtain personal information about consumers' preferences and then raise prices for them when they buy again, making loyal consumers pay higher prices than new consumers. It is also worth mentioning that industries in which big data discriminatory pricing is present essentially have an oligopolistic market structure. Typically, this paper will study price dispersion in Internet monopolies like Uber and Lyft, and build models to find equilibrium by calculating profits from the firm's perspective.

The second part of the paper summarises some of the classic literature on price dispersion and the latest research on Internet price dispersion. Then, this paper develops a Varian-style theoretical model to find its equilibrium prices in the third part. In the fourth part, the researcher concludes the whole paper, clarifies the limitations of the study and makes suggestions for future research. In summary, this paper investigates the phenomenon of price dispersion in Internet monopolies under big data discriminatory pricing and develops a theoretical model to find the equilibrium strategy of the firm.

2. Literature Review

The earliest literature on price dispersion was presented by Stigler [2]. He presented a pioneering model to describe the phenomenon of equilibrium price dispersion and argued that price dispersion is prevalent even for homogeneous goods because of the ignorance of consumers. After Stigler, many scholars have also researched this area and built models to explain price dispersion. Diamond realised that prices might stabilise at purely monopoly prices, and each firm has a monopoly over its loyal customers [3]. The hypothesis of the famous Bargains and Ripoffs paper argued that consumers differ in their ability to make decisions in the marketplace. Rational consumers with a higher ability make informed decisions, while other consumers make uninformed decisions. In the assumption of this paper, consumers differ only in the cost of acquiring information, leading to price dispersion and equilibrium of monopolistic competition [4]. Shilony demonstrated that a firm's stochastic pricing strategy is a mixed equilibrium strategy, and there is no Nash equilibrium for pure pricing strategies [5]. Varian found that most price dispersion models studied spatial price dispersion and temporal price dispersion. He hypothesised that firms attempt to price discriminate between informed and uninformed customers through sales, with uninformed consumers shopping through a randomly selected shop and informed consumers going to the lowest priced shop to make their purchases. Therefore, he explicitly solved the monopolistic competitive equilibrium problem in random pricing strategies [1]. Burdett and Judd's research showed that even if all firms and consumers are ex-ante identical, dispersion in equilibrium prices can occur in the presence of perfectly rational and identical agents on both sides of the market [6]. Stahl believed a two-stage model in which consumers search in perfect recall order. His model considered consumer search friction based on the Varian model [7].

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Those mentioned above are some of the classic literatures. As the Internet continues to grow and develop in popularity, some have speculated that Internet markets will eventually show pricing consistent with the textbook "law of one price". However, Baye, Morgan and Scholten found little support for this idea. Their result suggested that, in general, price dispersion on the Internet is a persistent equilibrium phenomenon [8]. In addition, Pan, Ratchford and Shankar have further reviewed the empirical and analytical literature to synthesise the reasons for the existence of price dispersion on the Internet, which may stem from consumer price sensitivity or product differentiation, etc. They argued that online markets are not perfectly competitive, and price dispersion is expected to persist [9]. These researches provide further evidence for the persistence of price dispersion on the Internet.

Based on the above literature review, the researcher can identify the persistence of price dispersion from traditional retail markets to Internet markets. This paper, inspired by the phenomenon of big data discriminatory pricing, will investigate the price dispersion in Internet-type monopolies by developing a theoretical model. The specific modelling and analysis will be shown in the next section.

3. Theoretical Model

The basic framework of the model takes reference from the Varian style model and adds other variables to it in conjunction with big data discriminatory pricing. Suppose there are n identical firms sell homogeneous goods, and their marginal production cost is defined as c. There is a unit mass of consumers. Fraction λ of consumers are old consumers, and fraction $1-\lambda$ of consumers are new consumers. Old consumers are divided into informed consumers m and uninformed consumers $\lambda - m$.

For informed consumers m, suppose firms charge them the price p_i. Considering consumer switching costs, informed consumers will continue to use the products when the price is between p_s and p_l; the difference between p_l and p_s is the consumers' switching costs. When the price p_l is reached, informed consumers will abandon their purchase and switch to another company's product. That is to say, p_l is the valuation of old consumers. For uninformed consumers $\lambda - m$, this paper assumes that they are unaware of the existence of big data discriminatory pricing and will continue to purchase products, so a firm can always price discriminate against them and charge them p_l, which is the highest price. Finally, for new consumers $1-\lambda$, suppose firms charge them the price p_j. If new consumers appear in the market, the highest price they are charged is p_s. That is to say, p_s is the valuation of new consumers. Considering p_s is the upper bound price of new consumers, and p_l is the upper bound price of old consumers. To simplify the model by uniting p_i and p_j, it is assumed that p_i and p_j follow the same law of variation and take endpoint values simultaneously.

Some key points about my model need further elaboration. In my model, this paper classifies consumers into three types: informed, uninformed, and new. My model examines a simple initial situation where consumers are assumed to be equally divided among firms with homogeneous products at the very beginning. Profit is calculated from the firm's perspective without considering factors such as consumers who do not enter or leave. In addition, as the study is about price dispersion in a monopolistic industry, this paper assumes that consumers have no search costs, but they switch directly between monopolies.

Moreover, on an actual website, the prices charged by firms should fluctuate within a specific range. However, to simplify the model, this paper assumes that the highest prices charged by firms are denoted by p_s and p_l respectively, representing a specific range of values. In summary, the model describes the process of new consumers entering the market and firms charging them prices between c and p_s. When the price reaches p_s, the new consumers switch to old consumers, divided

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into informed and uninformed consumers, with informed consumers buying at a price between p_s and p_l, and uninformed consumers always being charged the highest price p_l. This model examines the initial situation in the market, assuming that consumers are equally divided, and does not consider the case of consumers leaving or switching. Profit is calculated from the firm's perspective, where p_i and p_j are two variables, so the firm's profit is an equation with two unknowns.

Based on the variables set above, this paper then performs a calculation of the firm's profit and finds the equilibrium prices for the model. So, what are the equilibrium prices in this model? First, this paper will prove that there is no pure strategy in this equilibrium. The proof is as follows:

Can p_{i1}=...=p_{in}= p_{j1}=...=p_{jn}=c be an equilibrium?

The answer is no, because then one firm can deviate by charging p_{j1}=p_s. New consumers still buy products from this firm. Therefore its profit is higher than 0.

Can p_{i1}=...=p_{in}= p_{j1}=...=p_{jn}>c be an equilibrium?

The answer is no, because one firm can deviate by charging p_{i1}=$p_l - \varepsilon$ retaining departing consumers, where ε is infinitely small. There is also a profitable deviation.

Can p_{i1}=...=p_{in}>c, p_{j1}=...=p_{jn}=c be an equilibrium?

The answer is no, because then one firm can deviate by charging p_{j1}=p_s as well.

Can p_{i1}=...=p_{in}=c, p_{j1}=...=p_{jn}>c be an equilibrium?

The answer is no, because one firm can deviate by charging p_{j1}=$p_s - \varepsilon$ as well.

Second, this paper will find the mixed strategy in this equilibrium.

Since the firm charges prices to three types of consumers, where p_i and p_j are two different variables charged from two different type of consumers, this paper looks at a symmetric equilibrium, in which all firms play mixed strategy $T(p_i, p_j) = F(p_i)F(p_j)$, which means the probability that the firm simultaneously charges informed consumers price p_i and new consumers price p_j. Note, the support of distribution is $(p_i, p_j) \in [(p_s, c), (p_l, p_s)]$. The profit of firm 1 is made up of the following components:

The paper supposes each other firm chooses price p_i according to $F(p_i)$. The probability that firm 1 has a lower price is $1 - F(p_i)$. This must hold for all firms. Therefore, the profit from informed consumers is $m[1 - F(p_i)]^{n-1}(p_i - c)$.

Since uninformed consumers always buy products from the firm, the firm can always charge them the highest price. This means that the profit from the uninformed consumers equals to $\frac{\lambda - m}{n}(p_l - c)$.

The paper supposes each other firm chooses price p_j according to $F(p_j)$. Similarly, the probability that firm 1 has a lower price is $1 - F(p_j)$. This must hold for all firms. Firms charge prices to new consumers in the interval from c to p_s, so that consumers who leave or do not enter the market are not considered in the calculation. It is assumed that all new consumers enter the market within this interval. Therefore, the profit from new consumers is $(1 - \lambda)[1 - F(p_j)]^{n-1}(p_j - c)$.

In summary, the total expected profit is

$$\pi_1(p_i, p_j) = m[1 - F(p_i)]^{n-1}(p_i - c) + \frac{\lambda - m}{n}(p_l - c) + (1 - \lambda)[1 - F(p_j)]^{n-1}(p_j - c)$$

Next, this paper needs to find the equilibrium of the model based on this profit formula. The

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equilibrium of the model is that for any p_i and p_j, the firm's profit is always the same. That is to say, the key idea is that the expected profit is constant for any p_i and p_j so the paper solves the problem based on the endpoint values: $\pi_1(p_i, p_j) = \pi_1(p_l, p_s)$. Note, that $F(p_l) = 1$ and $F(p_s) = 1$. This paper calculated that:

$$\pi_1(p_l, p_s) = \frac{\lambda - m}{n}(p_l - c)$$

$$\pi_1(p_i, p_j) = m[1 - F(p_i)]^{n-1}(p_i - c) + \frac{\lambda - m}{n}(p_l - c)$$

$$+(1 - \lambda)\left[1 - F(p_j)\right]^{n-1}(p_j - c) = \frac{\lambda - m}{n}(p_l - c)$$

Therefore, the researcher obtains the equation for the relationship between p_i and p_j.

When $0 \le F(p_j) < 1$,

$$\frac{1 - F(p_i)}{1 - F(p_j)} = \left(\frac{\lambda - 1}{m}\frac{p_j - c}{p_i - c}\right)^{\frac{1}{n-1}}$$

When $F(p_j) = 1$,

$$F(p_i) = 1$$

From the above definition, it is clear that $T(p_i, p_j) = F(p_i)F(p_j)$.

When $T(\underline{p_i}, \underline{p_j}) = 0$, the lower bound support for $T(p_i, p_j)$ is $\frac{\underline{p_j} - c}{\underline{p_i} - c} = \frac{m}{\lambda - 1}$, defined as $(\underline{p_i}, \underline{p_j})$.

When $T(\overline{p_i}, \overline{p_j}) = 1$, the upper bound support for $T(p_i, p_j)$ is (p_l, p_s).

Therefore the support of $T(p_i, p_j) = F(p_i)F(p_j)$ is $\left[(\underline{p_i}, \underline{p_j}), (p_l, p_s)\right]$.

After the above calculations, this paper concludes that firms play a continuous mixed strategy on $\left[(\underline{p_i}, \underline{p_j}), (p_l, p_s)\right]$, in which $(\underline{p_i}, \underline{p_j})$ obeys the relation of $\frac{\underline{p_j} - c}{\underline{p_i} - c} = \frac{m}{\lambda - 1}$.

4. Conclusion

My model adds variables to the Varian style model to find an equilibrium strategy of price dispersion for monopolistic Internet companies based on the phenomenon of big data discriminatory pricing. In the case of Internet price discrimination, consumers are divided into three types, and firms charge them different prices to price discriminate and thus maximise profit. My paper investigates the initial situation where consumers are divided equally, finds the Nash equilibrium through critical values and ultimately obtains the firm's mixed equilibrium strategy.

My study simplifies the actual market situation, considers profit from the firm's perspective and does not carry out a multi-stage analysis of consumer switching. In addition, it does not consider consumers who do not enter and leave the market but assumes a perfect situation where the firm does not charge more than the maximum value of the price. However, my paper provides some ideas for subsequent studies on Internet price dispersion, examining a special case of price

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dispersion equilibrium and providing a direction for multi-stage studies. A possible direction for future research could be to further explore dynamic multi-stage models based on this or to further investigate the existence of consumer switching costs as well as search costs to set up a model.

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