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Consumer profiling, price discrimination, and consumer privacy

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This paper considers a monopolist who exercises first-degree price discrimination by acquiring consumer data to infer reservation prices. The monopolist uses profiling technology to obtain consumer information whose cost is a function of the fraction of consumers it profiles. We first describe the market equilibrium where consumers do not have access to privacy technology that prevents the monopolist from acquiring their data. The paper then introduces a costly privacy technology that allows consumers to prevent their information from being obtained and used by the monopolist. Equilibrium analysis shows two important results that depend on the level of privacy costs. With sufficiently cheap privacy technology, we show that the monopolist profiles fewer consumers compared to when privacy is not an option for consumers. This reduces the incidence of price discrimination in the market. However, if privacy cost is sufficiently expensive, the monopolist profiles the same fraction of consumers as in the case when privacy was not an option. In this case, privacy technology does not reduce the incidence of price discrimination. Regardless of the level of privacy cost, however, the availability of privacy technology to consumers induces the monopolist to set a higher uniform price level for consumers it was not able to profile. Also, regardless of the cost of privacy, this combination of strategies on profiling and uniform price level reduces the incentive of consumers to use the privacy technology and results in an equilibrium where no consumers choose to privatize. Thus, in equilibrium, privacy technology only acts as a deterrent, and can only function as such, against aggressive consumer profiling and price discrimination if its cost is sufficiently low.

JEL classification: L12, D42, D82
Keywords: price discrimination, monopoly, consumer privacy

1. Introduction

1.1. Consumer profiling

The current state of information technology allows firms to extract a wide variety of data ranging from images, texts, and socio-economic information, among others, from consumers and other agents in large volumes and

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high velocity. These data, which are generally referred to as Big Data, are information assets characterized by high volume, velocity, and variety that require specific technology and analytical methods for use [Mauro et al. 2016; Fotaki et al. 2014]. One of the important drivers of interest in big data analytics is its potential to allow firms to optimize their marketing, pricing, and other business decisions [Hofacker et al. 2016]. Together with the availability of big data, the rise of interconnected personal devices creates a situation where the more information consumers provide, the more firms and enterprises can tailor their business strategy to the consumers' desires [Barutcu 2017]. The key role of big data analytics here is to profile consumers and give a more in-depth understanding of customers' behavior and preferences which is something that traditional market knowledge might fail to offer. To accomplish this, many firms resort to gathering important information from consumers through the use of sophisticated data extraction technologies and analytic techniques.

Consumer profiling is especially true for transactions occurring on online platforms such as Amazon, Netflix, and Facebook.[1] These sites routinely gather data from their online customers and use them for various purposes. Casual observation on streaming websites like YouTube, for example, shows how big data analytics and corresponding algorithms play a role in what contents and advertisements an individual sees based on their previous interaction with the platform. Facebook *likes* (and more generally *reactions*) on the other hand can be used to predict a person's highly sensitive attributes such as sexual orientation, ethnicity, religious and political views, among others. with some degree of accuracy [Kosinki et al. 2013]. Naturally, political issues such as privacy and security emerge with consumer profiling. For example, insights gained from these data can be used to design targeted political campaigns to sway people for or against certain political agendas.[2] Generally, countries differ in how they deal with these issues. In the Philippines for example, there is no specific law that directly addresses privacy issues on social media/online platforms [Brutas n.d.]. However, the most relevant statute to this is the Data Privacy Act of 2012 (RA 10173). The act provides for what is lawful processing of personal information that applies to both public and private institutions. The law requires, among other things, that personal information processing is done with the consent of the person whose information is being processed. The personal information holder (i.e. the institution that gathered personal information) is also allowed to pursue the processing of data if it is predicated on a legitimate interest of their institution.

[1] Based on the respective privacy policies of these firms.

[2] The 2016 US Presidential election provided a picture of how data analytics from information in social media can have tremendous social repercussions. Although 'voluntarily' provided by consumers, the information provided to and analyzed by Cambridge Analytica was allegedly used to sway voters 'at the margin' in favor of the now President Donald Trump. This was done by sending voters targeted political campaign ads based on the personal information gathered from them.

Aside from these political challenges posed by big data, important economic issues can also come to the fore. Theoretically, this information can potentially give firms the ability to personalize product advertisements sent to profiled consumers. Another potential use of personal information gathered through consumers' online activities is price discrimination, which is the central interest of this study. This paper explores a monopoly market to analyze the potential consequences of the use of data to exercise first-degree price discrimination and the consequent privacy decisions of consumers.

To provide a brief overview, this paper analyzes a monopoly market where a single firm has access to a costly tracking technology that allows it to know the reservation prices of some of its consumers. This allows the monopolist to practice first-degree price discrimination against the profiled consumer. The firm chooses the fraction of consumers profiled in the market. This *endogenizes* the profiling *reach* of the monopolist. In this market, I analyze two alternative environments: (1) a case where consumers cannot privatize and hide their reservation price and (2) a case where the consumers have access to a costly privacy technology that allows them to hide their reservation price from the monopolist. It follows that the fraction of consumers who will hide is endogenous in the second environment. What we find, however, is that in both environments, no consumer uses the privacy technology. The reason why no consumer uses the privacy technology in the first case is obvious; it is not available. In the second case, the monopolist will find it optimal to set a sufficiently high uniform price level and sufficiently low level of tracking reach such that consumers have no incentive to use the privacy technology. This results in a lower tracking reach, and hence a lower incidence of price discrimination, but a higher uniform price level in the market. The privacy technology then serves as a deterrent to price discrimination.

1.2. Price discrimination and consumer profiling

Price discrimination exists when there is a variation in the price of the same commodity that cannot be explained by variation in marginal costs [Stigler 1987]. Following the terminology of Pigou [1920], we can classify price discrimination into three categories. First is the first-degree or perfect price discrimination. First-degree price discrimination exists when firms charge each consumer their valuation for the commodity it sells such that the firm captures all the consumer surplus. Second-degree price discrimination, on the other hand, involves charging consumers based on the quantity bought (ex. bundle pricing and quantity discounts). This type of price discrimination is also known as non-linear pricing, as the total payment of buyers does not linearly depend on the quantity of the commodity purchased. When prices vary across different market segments, on the other hand, we say that third-degree price discrimination exists. Classic examples of third-degree price discrimination are student and senior citizen discounts. Both second and third-degree price discrimination involve sorting consumers into broad groups. However, second-degree price discrimination sorts individuals via pricing schedules, which leads consumers to self-select via non-linear pricing [Stole 2007].[3] This is in contrast with third-degree price discrimination which requires the firm to sort consumers into segments via some exogenous criterion such as location, gender, etc., after which all consumers belonging to a single segment pay the same price. Alternatively, it can be argued that second-degree price discrimination results in consumers sorting themselves.

Normally, price discrimination allows firms to extract consumer surplus and increase their profits. However, the practice of price discrimination can only exist under three important market conditions. First, firms must possess some degree of market power that allows them to charge a price above marginal cost. This condition entails some degree of price-setting power. Thus, it is easier to expect price discrimination to persist in monopoly and oligopolistic environments where firms have substantial market power. Secondly, firms must be able to sort consumers based on some observable characteristics, especially in the case of first and third-degree discrimination, or by some other sorting mechanism in the case of second-degree price discrimination. Lastly, arbitrage across different-priced goods must be infeasible. It can be shown that with arbitrage between consumers with different valuations of goods, price discriminatory behavior cannot be an equilibrium outcome. Arbitrage is conditional on the degree of transferability of both commodity and utility among consumers. The lower the degree of transferability and/or utility of the commodity, the more difficult for arbitrage to exist. Product differentiation and large transaction costs of resale are, therefore, effective hurdles to arbitrage and can make price discrimination more feasible [Branco and Brossard-Ruffey 2017].

Unlike second and third-degree price discrimination, most of the interest in first-degree price discrimination is only driven by academic curiosity. Especially in the time of Pigou, first-degree price discrimination was seen as "scarcely ever practicable" since it requires information on consumer valuation which is very hard, if not impossible, to observe. However, the current wealth in consumer information in the form of big data and the emergence of more advanced data analytics technologies puts the supposed impracticability of first-degree price discrimination into question. Firms now can access vast amounts of consumer information that can be used to estimate consumer valuations, which in turn, can be used to practice first-degree price discrimination provided that the other market conditions are also satisfied.

There was already a wealth of literature that explored price discrimination even before the use of big data analytics. The models in this literature range from monopoly market settings to models where competitive forces among firms exist. Stole [2007] provides a useful review of some of these models especially those

[3] Pigou did not consider second degree price discrimination as a mode of self-selection. See Stole [2007] for discussion.

in competitive environments.[4] However, models of price discrimination that are closest to the present study are those that make explicit the source and nature of the requisite consumer information for first-degree price discrimination to exist. Incorporation of the characteristics of consumer information allows us to analyze more thoroughly the effects of price discrimination in the context of data analytics. The models allow insights into the effects of factors like data gathering and consumer profiling cost, data provision and estimation accuracy issues, as well as consumer responses like the use of online privacy services, among others, that might otherwise be absent in models where the enabling source of price discrimination is implicit. For example, Chen and Ayer [2002] explored a model where firms' profiling cost is an increasing function of the level of its 'reach'. Belleflamme and Vergote [2016], Belleflamme et al. [2017], and Esteves [2014], on the other hand, explored accuracy issues relating to consumer valuation estimation. The paper by Acquisti and Varian [2005], Montes et al. [2018], as well as the same paper by Belleflamme and Vergote [2016] provide a theoretical analysis of how consumer privacy affects market equilibrium in monopoly and duopoly markets.

Most models of price discrimination share several key characteristics. First, most models are in game-theoretic setup. As with most economic models, the game-theoretic setup allows an analyst to fully understand interactions between and among economic agents. It is an approach to analyze how a system finds its equilibrium (or evolves) taking into consideration the motivations and strategies available to agents in the game. Second, the models operate as a pricing strategy game, which naturally, if it exists, yields an equilibrium in prices before quantity can be computed. The pricing game is seen as a more natural environment for models with price discrimination [Stole 2007]. Third, the models make explicit consumer heterogeneity, especially with respect to their valuations of goods. This heterogeneity of consumers is at the core of models with price discrimination and consumer profiling. This is because consumer profiling and the associated price discrimination are more easily described by allowing consumer valuation of a good to vary among one another. The use of a location in a Hotelling line as a proxy for preference and consumer distribution over reservation prices are two of the most common methods encountered in literature to model consumer heterogeneity. The models in this paper will generally follow these broad characteristics of price discrimination models.

The present paper aims to analyze how a monopolist with the capacity to price discriminate will decide on the extent of its consumer profiling, especially in the case where consumers can opt to privatize their personal information with a cost. Crucial to this analysis is the assumption that consumer profiling allows the

[4] Nevertheless, and for reasons stated above, much of the literature are on second degree and third degree price discrimination. See for example, Fudenberg and Villaboas [2005] for third-degree price discrimination or Stokey [1979] for her seminal work on intertemporal, third-degree price discrimination.

firm to know a consumer's valuation of the good, which then allows it to offer price-discriminatory price. We show that under some conditions, the capacity of consumers to privatize their information acts as *a deterrent to profiling* by the price-discriminating monopolist. That is, the threat of privatizing keeps the firm from pursuing more aggressive consumer profiling. This leads to firms choosing to track a smaller fraction of consumers, which in turn lowers the number of consumers offered discriminatory price levels. Absent this consumer option to privatize, we show that the monopolist profiles more consumers. We also show that the presence of privacy technology induces the firm to *set a higher uniform price level* for those consumers it was not able to track.

In the next section, we will briefly introduce a standard monopoly model without consumer profiling and price discrimination. Against this benchmark, the third section will compare the market outcomes when there is price discrimination. The fourth section will provide an analysis of the case when consumer privacy technology is available.

2. Benchmark standard monopoly model

Throughout this paper, we will assume a market with a unit mass of consumers uniformly distributed over the unit line with respect to their valuation of the goods being sold by the monopolist. We denote the valuation of consumer i as r_i. The valuation ranges from [0,1]. Thus, the probability density function (PDF) is given by $f(r) = 1$ with the support [0,1]. For simplicity, we are also assuming that the monopolist's cost of production is zero.

The consumer has a unit demand for the good. For any price p, the demand of any consumer i with valuation r_i is given by

$$D_i(p) = \begin{cases} 1 \text{ if } r_i - p \geq 0 \\ 0 \text{ if } r_i - p < 0 \end{cases} \tag{1}$$

From these assumptions, it follows that the market demand is given by the equation

$$D(p) = 1 - p \tag{2}$$

where p is the uniform price charged by the monopolist for its good. The profit function of the monopolist, π, is given by the equation

$$\pi(p) = p(1 - p) \tag{3}$$

The problem of the monopolist is to maximize (3) by choosing the optimal uniform price p_o to be charged. With zero marginal cost, the profit-maximizing price level is equal to $p_o = 1/2$. The maximum profit is equal to $\pi_o = 1/4$. The consumer surplus in equilibrium is $CS_o = 1/8$. Defining total welfare in this market as $W_o = CS_o + \pi_o$, we get $W_o = 3/8$ in equilibrium. Throughout this paper, we will refer to these price, profit, consumer surplus, and total welfare as *benchmark* levels as they result from a monopoly market without price discrimination.

3. Price discrimination, endogenous consumer profiling, and consumer privacy

3.1. The reach and cost of consumer profiling

In this section, we introduce the model which incorporates a profiling technology that allows the monopolist to know the reservation prices of consumers. We are concerned with first-degree price discrimination as defined by Pigou [1920] and as used in the models of Chen and Ayer [2002] Belleflamme & Vergote [2016], Belleflamme et al. [2017], and Bar-Gill [2018]. The model is closest to that of Belleflamme & Vergote [2016] but differs in two important ways. In our model, (1) consumer profiling is costly and (2) the fraction of consumers to be profiled is chosen by the firm and is, therefore, endogenous to the model. These are in contrast to the original model of Belleflamme & Vergote [2016] where the cost of technology is zero and the fraction of profiled consumers is exogenously determined. Here, we will incorporate a costly technology whose cost depends on its *reach*—how large the fraction of consumers the monopolist firm can profile. The profiling technology has a level of reach denoted by $\lambda \in [0,1]$. This parameter measures the fraction of consumers whose reservation price is (correctly) estimated by the firm. In this segment, the firm will charge the corresponding reservation price of each consumer. Note that in the discussion of Belleflamme & Vergote [2016], λ is referred to as the accuracy or precision of profiling technology. In this study, λ is best thought of as the 'reach' of the technology to reflect that (1) what the firm chooses is the fraction of consumers that will be profiled and *not* the probability that its estimate of the consumer's reservation price is correct, and (2) that once the consumer is profiled (i.e., within the reach of the monopolist's profiling) the estimate of her reservation price by the firm must be accurate, which is similar to how Chen & Ayer [2002], Montes et al. [2018] and Belleflamme et al. [2017] modeled consumer profiling. Once a consumer is profiled, she is offered the good at her reservation price r_i. If the consumer is not profiled, the good is offered to her at the uniform price level. It follows that the fraction $(1-\lambda)$ is the fraction of consumers whose reservation price is not known and, therefore, must be charged a uniform price. This essentially divides the market into two groups: the profiled with size λ and unprofiled consumers with size $(1-\lambda)$.

We also assume that the probability that an individual is profiled given the level of reach chosen by the monopolist is independent of her valuation. This implies that given any level of reach, high-valuation consumers are not more likely to be profiled than low-valuation consumers and vice versa.

Another firm exists which provides the profiling technology to the monopolist. We are assuming that this technology firm is not behaving strategically. The case of strategically behaving technology firms is explored by Montes et al. [2018]. It is also assumed in this paper that arbitrage involves prohibitively high transaction costs. This prevents a consumer from reselling the commodity at a higher price to another consumer, thus allowing price discrimination to emerge in equilibrium.

The cost of technology, T, is a function of the level of reach λ with the following properties: (1) the cost is increasing at an increasing rate in the level of reach λ, (2) the limit of T as λ approaches the maximum attainable reach, one, is infinity. These properties reflect the view that consumer profiling becomes more and more expensive as the firm tries to reach a higher fraction of the consumer population. Similar to Grossman & Shapiro [1984], this may be due to media platform saturation or heterogeneity in preferences to use platforms where data extraction may take place. Thus, the firm must incur an increasing cost as it attempts to increase the reach of the technology. The cost function T is specified as

$$T = \frac{\tau\lambda}{1-\lambda} \tag{4}$$

where τ is the cost parameter and λ is the level of reach chosen by the firm. The firm, therefore, can choose any level of technology within the range [0, 1]. This approach in modeling the cost of profiling is similar to Chen & Ayer [2002] in so far as the cost is a function of the level of reach of profiling. However, it differs from Chen and Ayer [2002] because, in the latter, the cost of profiling as the reach approaches one is finite.[5]

We maintain the following assumptions: (1) the cost of producing the good sold by the monopolist is zero, (2) we have a unit mass of consumers uniformly distributed in their valuation ranging from [0,1] and (3) for each level of price p, each consumer i with valuation r_i has a unit demand described by Equation (1) under the standard setup without profiling and price discrimination. The total demand, $D(p)$ for the monopolist's good is, therefore, given by the survival function, which is Equation (2).

3.2. Monopoly equilibrium with price discrimination

The problem of the monopolist is to choose p^* and λ^* that maximize the profit generated from two sources: the profiled segment (price discrimination) and the unprofiled (uniform price) segment of the market.[6] To derive the equation for profit from these two sources, we first ask the following questions: What is the expected revenue from consumers the firm was able to profile as well as the consumers it was not able to profile? We use the term expected because before deciding whether to use and to what extent (level of λ) the profiling is to be used, the firm is *not* yet

[5] In Chen and Ayer [2002], firm i's cost of profiling is given by the function $c_i(a_i) = (ka_i^2/2)$ where a_i is the level of reach of firm i.

[6] We use * to denote equilibrium values in this market with price discrimination

certain which λ fraction of the population is going to be part of the profiled segment (and consequently consumers not part of the profiled segment).

For a given distribution function $F(r)$ of valuation r with mean μ_r with N consumers, we show in Appendix A.1 that the expected revenue from the profiled segment which we denote as R_t given any level of reach λ is

$$E(R_t|\lambda) = \lambda\mu r \tag{5}$$

while the the expected revenue from the unprofiled segment denoted as R_o is given by

$$E(R_o|\lambda) = Np(1-\lambda)(1-F(p)) \tag{6}$$

where p is the uniform price to be charged to consumers not profiled by the monopolist.

This implies that if the firm wants to price discriminate, it must set λ and p without any prior knowledge about who are the consumers who will be exactly profiled. In effect, the firm must decide whether to use the profiling technology based on the expected revenue from the two segments.

As mentioned earlier, the expected revenue of the firm is the sum of revenues from both the profiled and unprofiled segments. Since we have a unit mass of consumers distributed uniformly over [0,1] and denoting π_t as the expected profit, we get the uniform distribution case of the same expression in the model of Belleflamme and Vergote [2016],

$$\pi_t = [(\lambda/2) + (1-\lambda)\, p\,(1-p)] - \frac{\tau\lambda}{1-\lambda}\ . \tag{7}$$

Differentiating with respect to p and λ gives us the following first-order optimality conditions.

$$\frac{\partial\pi_t}{\partial p} = (1-\lambda)\,(1-2p) = 0 \tag{8}$$

$$\frac{\partial\pi_t}{\partial\lambda} = \frac{1}{2} - p(1-p) - \frac{\tau}{(1-\lambda)^2} = 0 \tag{9}$$

Notice that since λ must be positive, the level of price p^* the solves Equation (9) is the same as the benchmark case. That is, $p^* = p_o$. It follows that the level of profiling that maximizes profit must be

$$\lambda^* = 1 - 2\sqrt{\tau} \tag{10}$$

At (p^*, λ^*), the following are true: (i) $\partial^2\pi_t / \partial p^2 < 0$, (ii) the cross derivatives $\pi_{tp\lambda} = \pi_{t\lambda p} = 0$, and (iii) $\partial^2\pi_t / \partial\lambda^2 < 0$.

These three preceding expressions imply that the determinant of the Hessian, $\mathbf{D}(\pi_t)$, evaluated at (p^*, λ^*) is positive,

$$D(p^*, \lambda^*) = \frac{\partial^2 \pi_t}{\partial p^2} \frac{\partial^2 \pi_t}{\partial \lambda^2} - (\pi_{p_o \lambda})^2 > 0 \qquad (11)$$

which, with $\pi_{tp_o p_o} < 0$ and/or $\pi_{t\lambda\lambda} < 0$ indicates that (p^*, λ^*) is a maximizer of π_t.

Suppose high-valuation consumers are more likely to be tracked, then we could expect the uniform price level $p^* < p_o$. The lower p^* maximizes the profit of the firm over the low-valuation consumers who are less likely to be tracked. However, the solution shows that the monopolist will not find it optimal to deviate from the uniform price level p_o such that even with price discrimination and profiling, it still charges p_o to unprofiled consumers. This is due to the independence of consumers' valuation from their probability of being tracked and offered a discriminatory price. Since all consumers have an equal probability of being tracked being λ, the monopolist will find it optimal on average to keep its uniform price level at p_o.

The result for λ^* in Equation (10) is more straightforward to interpret. As the cost parameter τ increases, the level of profiling λ^* decreases in equilibrium. Notice that when profiling is costless such that $\tau = 0$, we expect the monopolist to fully track the market with $\lambda^* = 1$. However, the monopolist will find it optimal not to track any consumers if the cost parameter $\tau \geq 1/4$. This indicates that equilibrium with price discrimination can only emerge if the cost parameter is sufficiently low such that $\tau \in [0, 1/4]$, otherwise, the market reverts to the benchmark case. We formalize this result in the proposition below.

Proposition 1. *If the cost parameter is sufficiently low such that* $\tau \in [0, 1/4]$ *then the monopolist will track a positive fraction of consumers and there will be price discrimination in equilibrium, that is* $\lambda^* \in [0,1]$.

The profit of the monopolist in equilibrium is given by

$$\pi_t^* = 1/2 + \tau - \sqrt{\tau} \qquad (12)$$

where $\tau \in [0, 1/4]$. As expected, the profit gained from price discriminating is higher than the benchmark if the cost parameter is sufficiently low as indicated in Proposition 1. The profit gains due to price discrimination can be expressed as

$$\Delta\pi = \pi_t^* - \pi_o \qquad (13)$$

From this, we can state the following proposition.

Proposition 2. *If* $\tau \in [0, 1/4]$, *then (a) profit as a price discriminating monopolist is higher than as a benchmark monopolist and (b) the gains from price discrimination vanish as* τ *approaches* 1/4 .

Part (a) of the Proposition 2 directly follows from Proposition 1 while part (b) can be verified by noting that $(d\Delta\pi/d\tau) = 1 - 1/2\sqrt{\tau}$ and is negative over the range $\tau \in (0, 1/4)$. This indicates that as profiling becomes more costly, the gains from price-discriminating decreases. Further, due to the character of the cost function $T(\lambda)$, the gains from price discrimination vanish faster as profiling becomes more and more costly.

3.3. Welfare analysis

The consumer surplus is enjoyed by consumers whose reservation price is above $\sqrt{p_o}$ but is not profiled by the monopolist. The size of this segment is 2τ. The consumer surplus can be expressed as

$$CS_t = \frac{\sqrt{\tau}}{4} \tag{14}$$

which unambiguously increases with the cost of technology τ. It is also important to note that Equation (14) can be expressed as

$$CS_t = 2\sqrt{\tau} CS_o \tag{15}$$

It is easy to see that if $\tau \in [0, 1/4]$ then $CS_t < CS_o$ and consumers are worse off since the monopolist tracks, price discriminates, and extracts consumer surplus equivalent to λ^* of the benchmark surplus CS_o. The impact of changes in τ is also important to note: the consumer surplus decreases as profiling becomes cheaper since the monopolist will be able to track a higher fraction of consumers in the market and offer discriminatory price levels. We state these results in the following proposition.

Proposition 3. *If* $\tau \in [0, 1/4]$ *then (a) consumers are worse off with surplus extraction equivalent to* $\lambda^*/8$ *and (b) consumer surplus decreases as profiling becomes cheaper.*

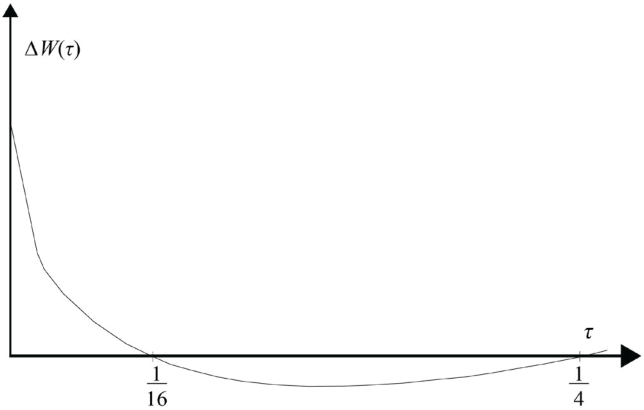
Welfare is given by the sum of π_t and CS_t which can be simplified to

$$W_t = \frac{1}{2} + \tau - \frac{3\sqrt{\tau}}{4} \tag{16}$$

We can write another equation for the difference in welfare between price discrimination and the benchmark monopoly market, $\Delta W = W_t - W_o$. Since this difference depends on the level of profiling employed by the monopolist, which in turn depends on the level of τ, we can write this new equation as a function $\Delta W(\tau)$. Using Equation (16) and benchmark welfare level W_o in Section 2, we get the expression for $\Delta W(\tau)$,

$$\Delta W(\tau) = \frac{1}{8} + \tau - \frac{3\sqrt{\tau}}{4} . \tag{17}$$

FIGURE 1. Curve of $\Delta W(\tau)$ which represents the difference $W_t - W_o$



Over the range $\tau \in [0, 1/4]$, it is clear from Propositions 2 and 3 how price discrimination impacts profits and consumer surplus. Monopoly profits increase while consumer surplus decreases. However, as can be observed in Equation (17), the impact of price discrimination on total welfare is not linear and will depend on the level of τ. This is precisely because of the opposing effect of price discrimination on the two components of total welfare. We can use Equation (17) to identify the range of τ where price discrimination is welfare increasing and where it is welfare decreasing. If for some range of τ, $\Delta W(\tau) > 0$, then we say that in that range of τ, price discrimination is welfare increasing in that range. Similarly, if for some range of τ, $\Delta W(\tau) < 0$, then price discrimination is welfare decreasing in that range. From this, we have the following result:

Proposition 4. *If $\tau < 1/16$ then price discrimination results in welfare improvement compared to benchmark monopoly. If $\tau > 1/16$ then price discrimination results in inferior welfare compared to benchmark monopoly.*

To demonstrate Proposition 4, note that the function $\Delta W(\tau)$ is a U-shaped curve over τ as shown in Figure 1. Notice that for the range $\tau < 1/16$, the function is positive, which means that price discrimination results in higher overall welfare compared to benchmark monopoly. On the other hand, when τ is in the range (1/16, 1/4) , ΔW is negative, which implies that for this range of τ, price discrimination results in a loss in total welfare compared to welfare in the benchmark case. In equilibrium with price discrimination, we can ignore the values of cost parameters above 1/4 since the monopolist will not find it profitable to price discriminate when τ exceeds 1/4 . In this case, the benchmark monopoly welfare holds. From this, another important result can be inferred.

Proposition 5. *If $\tau \in$ (1/16, 1/4), the monopolist's decision to track and price discriminate will result in total welfare loss, $W_t < W_o$.*

Proposition 5 highlights that welfare-decreasing price discrimination may result in equilibrium if profiling cost is sufficiently high but not high enough to completely discourage profiling. In the case where $\tau \in$ (1/16, 1/4), the monopolist will find it profitable to use the profiling technology since profit from price discrimination is still higher than from uniform pricing e.g., $\Delta\pi > 0$. However, in this case, the loss in consumer surplus due to price discrimination is higher than the gains in profit of the monopolist versus the benchmark case.

To be precise, in the range $\tau \in$ (1/16, 1/4), $|\Delta CS| > \Delta\pi$ (where $\Delta CS = CS_t - CS_o < 0$); welfare is inferior versus the benchmark case. Put alternatively, an increase in τ increases consumer surplus, but this increase is less than the decrease in profits, resulting in a net decline in total welfare.

4. Price discrimination and consumer privacy

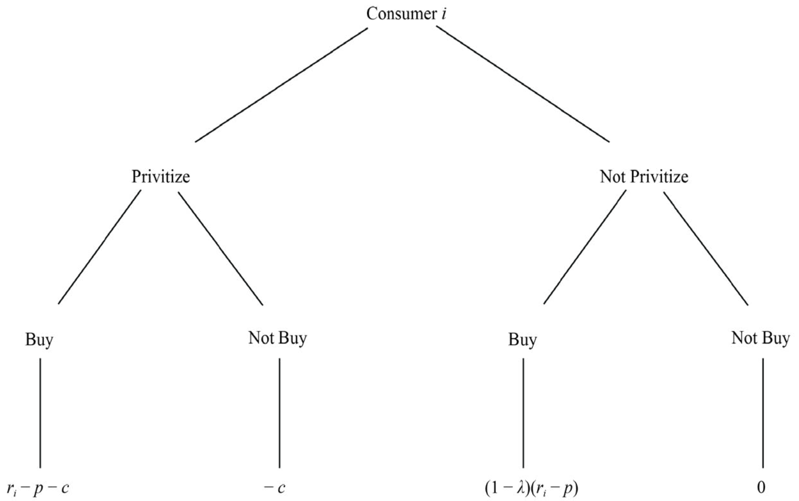
4.1. Privacy decision of consumers

In this section, we will explore a version of the model of Belleflamme and Vergote [2016] developed above with the additional assumption that consumers can now utilize a technology that allows them to privatize and become anonymous to the monopolist. The valuation of consumers who decide to use this privacy technology becomes completely unobservable and, therefore, cannot be price discriminated by the monopolist. However, the technology is not free and consumers must incur a cost $c > 0$ to prevent consumer profiling.

We will consider a model where in the first stage, the firm chooses the level of profiling and uniform price level. In the second stage, consumers observe the profiling decision of the firm and decide whether to privatize or not. Price offers are only made known in the third stage. Those who did not privatize may fall into two groups with two different types of price offers. First, the consumers who are tracked are offered a discriminatory price. The second group consists of those who did not privatize but were not tracked and, therefore, will be offered the good at the uniform price level. The fourth stage is the consumption stage where consumers decide to buy or not.

It follows from this timing that each consumer must condition the decision to privatize or not based on profiling and uniform price expectations. In the fourth stage, consumers will only consume if the utility of buying the good is higher than not buying given their decision to privatize or not from the previous stage. For consumers who choose to privatize, consumers will buy if $r_i - p - c > -c$ since the privacy cost has already been incurred. Notice that it is possible for a privatizing consumer to buy the good even at negative utility just to cover some of the privacy cost c. This happens when $c > r_i - p > 0$, where the surplus from paying a uniform price p can partially cover the cost c. Obviously, a consumer who hid and only bought in the third stage to cover the losses from privatizing is not in his equilibrium strategy. In the case of a consumer who decided not to privatize, the buying is optimal if $r_i - \lambda r_i - (1 - \lambda)p$. This can be simplified to $(1 - \lambda)(r_i - p) > 0$. Since $\lambda \in [0, 1]$ in equilibrium, these condition translates to $r_i > p$ which says that a non-privatizing consumer will automatically buy if offered a price-discriminatory rate equal to his reservation price or if the uniform price is lower than his reservation price. Figure 2 depicts the consumer decision tree.

FIGURE 2. Consumer *i*'s decision tree



From Figure 2, we can already eliminate the path (Privatize, Not Buy) as an equilibrium strategy. This is because any consumer who does so is better off not privatizing and having an expected utility of $(1 - \lambda)(r_i - p)$. Thus, in equilibrium, the decision whether to use the privacy technology is based on whether the expected utility in doing so is at least as high as the expected utility from not privatizing, that is

$$r_i - p_E - c \geq (1 - \lambda_E)\,(r - p_E\,) \tag{18}$$

where p_E are the expected uniform prices to be charged by the monopolist to those it was not able to profile. The term λ_E, on the other hand, represents the expectation with respect to the monopoly profiling choice.[7] The left-hand side of the Equation (18) is the utility from privatizing and paying the expected uniform price while the right-hand side is the expected utility when the consumer decides

[7] The formulation of Equation (18) is similar to that of Belleflamme and Vergote [2016].

not to privatize. Simplifying the inequality in (18) gives us the cut-off valuation, r_c, of those who will be using the technology given the expected price p_E and expected level of profiling λ_E. Then consumer i will privatize if his reservation price satisfies the following inequality

$$r_c \geq p_E + c/\lambda . \tag{19}$$

The mass of consumers who will privatize is given by $1 - p_E - \lambda c$. Notice that the mass of consumers who will opt to privatize given a price expectation is decreasing in c, which implies that the fewer consumers privatize the higher its cost is. On the other hand, the cut-off is decreasing in the level of reach λ, which implies that the higher the reach, the higher the number of consumers who will use the privacy technology. This is because the higher the level of reach chosen by the firm, the more likely they are going to be offered a personalized price, which in turn makes privatizing more attractive. Notice also that the higher the expected uniform price p_E, the fewer are consumers who will choose to privatize. This is because the higher the expected uniform price, the lower the incentive to privatize over being offered a discriminatory price. We assume that all consumers share the same expectation on the uniform price, i.e., all consumers have the same p_E.

Notice also that there is a level of cost, c that makes the threat of consumer privacy binding to the monopolist. Recall that the maximum valuation present in the market is $r = 1$. If c is sufficiently costly such that

$$1 < p_E + c/\lambda^*, \tag{20}$$

then no consumer will find it optimal to privatize and the monopolist can optimally set its profiling to λ^* as if privacy technology did not exist. It also follows in that case that $p_E = p_o = 1/2$. Substituting this price level and solution to λ^* from Equation (10), into Equation (20) then we can derive an expression in terms of price expectation and τ,

$$c > 1/2 - \sqrt{\tau} . \tag{21}$$

We will denote the right-hand side of the inequality as c_m. If the cost of privacy is higher than the threshold c_m, then the monopolist can very well ignore the existence of privacy technology in its decision process.

This is because the cost of privacy is already prohibitively high for any consumer to use.[8] Our primary interest is in cases where c is low enough such that the threat of consumers privatizing is binding and affects the firm's profiling decision. Thus, we impose the condition that

$$0 < c < 1/2 - \sqrt{\tau} . \tag{22}$$

[8] The no-consumer-privacy model in Section 1 can be interpreted as a case of prohibitively costly privacy.

Since c is positive, it must also be the case that

$$\tau < 1/4 \tag{23}$$

The profit of the firm in the presence of a privacy option denoted as π_c, is derived in Appendix A.2 and can be expressed as

$$\pi_c(p, \lambda) = \begin{cases} p(1-p) + \dfrac{\lambda p^2}{2} + \dfrac{c^2}{2\lambda} + \dfrac{\tau\lambda}{1-\lambda} & \text{if } p + \dfrac{c}{\lambda} \leq 1 \\ \dfrac{\lambda}{2} + (1-\lambda)\, p(1-p) - \dfrac{\tau\lambda}{1-\tau} & \text{if } p + \dfrac{c}{\lambda} > 1 \end{cases} \tag{24}$$

In general, the profit depends on four variables: the monopolist's choice of uniform price level p_o and reach λ, the profiling cost parameter τ, and the cost of privacy technology c. The top expression in Equation (24) when $p + (c/\lambda) \leq 1$ corresponds to the case where p is low and λ is high such that some consumers opt to privatize. But as p increases and/or λ decreases such that $p + (c/\lambda) > 1$, privatizing becomes unattractive to all consumers. The profit in this case is given by the bottom part of Equation (24). The behavior of the profit function will be discussed in the next section.

4.2. Equilibrium analysis

4.2.1. Equilibrium λ and p with consumer privacy

We solve the Subgame Perfect Nash Equilibrium with respect to firm pricing and profiling strategy and consumers' decision to privatize. The equilibrium outcome will be summarized by the profile consisting of the uniform price level, profiling level, and the mass of consumers who will decide to privatize and will be denoted as the ordered set (p_c, λ_c, N_c) respectively. Note that the mass of privatizing consumers N_c can be calculated given the level of uniform price and profiling according to Equation (19).

The monopolist chooses the uniform price level and profiling reach that maximizes its total profit given the expectation of the consumers. The privatizing decision of the consumer on the other hand must provide the maximum possible utility during the consumption period. In equilibrium, expectations must be met such that,

$$p_E + c/\lambda_E = p_c + c/\lambda_c \tag{25}$$

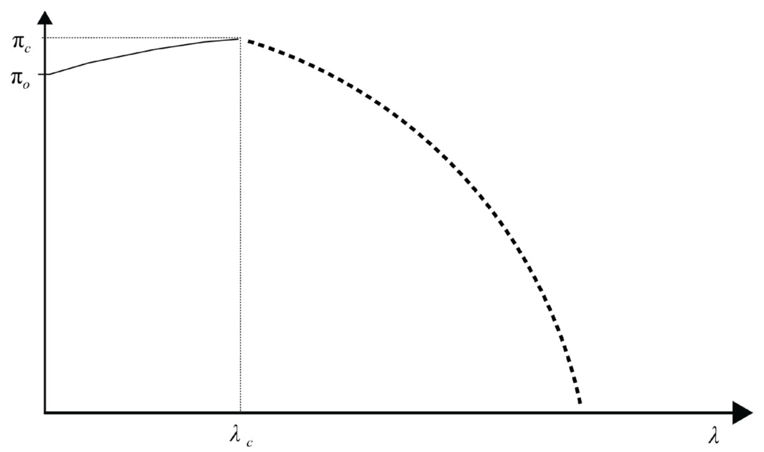
where p_c and λ_c are equilibrium levels as set by the profit-maximizing monopolist. The condition requires that the consumer's uniform price expectation must be correct, $p_E = p_c$ and $\lambda_E = \lambda_c$.

The monopolist strategy in equilibrium must consist of a uniform price level and profiling level that maximizes its profit given its expectation of the consumer decision to privatize. We analyze an equilibrium in this market that corresponds to a relatively expensive profiling cost τ. This results in a low level of profiling where no consumer finds it attractive to privatize.

Notice that at low levels of profiling such that no consumer finds it attractive to privatize i.e., $p + (c/\lambda) > 1$, $(\partial\pi_c)/(\partial\lambda) > 0$. Hence, the firm can increase its profit by increasing its profiling reach in this region. This region is represented by the solid curve in Figure 3 where λ is less than λ_c. As long as the firm increases its profiling level within this region, it can increase the number of consumers offered the discriminatory price without pushing consumers into privatizing. Since total profiling cost increases at a slower rate at low levels of λ, the increase in reach of profiling below λ_c results in higher profit.

However, when the profiling cost parameter τ is sufficiently high such that for p + (c/λ) ≤ 1 then profit will start to decrease once λ increases beyond λ_c as in Figure 3. Like before, this higher level of profiling cost increases the price discriminatory segment which increases revenue. However, in this region, the high level of profiling cost already drives some high-valuation consumers to privatize. Additionally, the cost of profiling increases much faster at these levels of profiling. These two forces result in lower profits as λ increases.

FIGURE 3. Profit function of the monopolist with consumer privacy



Thus, the level of λ that maximizes the firm's profit is where the two segments of the curve meet in Figure 3, where $p + \lambda_c = 1$. We provide the following results for the profit-maximizing level of λ and p, which we derive in Appendix A.2.

Proposition 6. *If* τ is sufficiently high such that $\partial\pi_c/\partial\lambda > 0$ for $p + \lambda^c > 1$, *then in equilibrium* $\lambda_c(c) = 4c/(1 + \sqrt{c^2 - 6c + 1} + c)$ and the optimal price level is $p_c(c) = (3 - \sqrt{c^2 - 6c + 1} - c)/4$.

We add the following result on the consumer privatizing decision.

Proposition 7. *If τ is sufficiently high such that $\partial\pi_c/\partial\lambda > 0$ for $p + (c/\lambda)$, then no consumer privatizes, that is $p_c + (c/\lambda_c) = 1$.*

Figure 4 shows the behavior of λ_c and p_c as a function of privacy cost c. First, notice that λ_c is increasing in c. In equilibrium, the firm chooses a higher λ_c the more expensive it is for consumers to privatize. This is because a higher cost of privacy prevents more consumers from using the technology. This in turn allows the firm to profitably track more consumers with less fear that they are going to privatize their valuation. Second, the uniform price level p_c is also increasing in c. Recall that that higher c results in higher λ_c which encourages some high-valuation consumers to privatize. To prevent this privatizing in the face of higher λ_c, the monopolist uses a higher uniform price level p_c to *penalize* privatizing. To understand this *penalty*, recall that consumers privatize to avoid price discrimination and instead get a uniform price offer. A higher uniform price, therefore, makes privatizing less attractive for any given level of λ_c.

4.2.2. Effect of privacy technology on the aggressiveness of firm profiling and the uniform price level

We now turn to the question of how the availability of privacy technology impacts the decision of the monopoly when consumers do not have the option to privatize their information. To answer this, we also present in Figure 4 the *no-privacy* level of profiling λ^* derived in Section 3.2. We also include in Figure 4 the upper limit c_m from Equation (21) as the vertical line $c_m(\tau)$. We can identify the level of λ^*, represented by the horizontal line in Figure 4, by noting that $\lambda^* = 2c_m(\tau)$. Hence, for any given value of τ, we can determine $c_m(\tau)$, which in turn allows us to determine λ^*. We will show that the presence of privacy technology leads to less aggressive consumer profiling and price discrimination depending on its *affordability*, that is, the level of c.

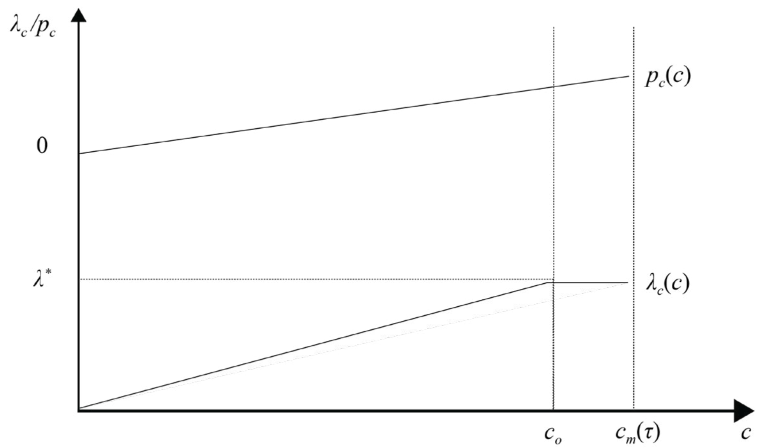
The level c_o is the level of privacy cost where $\lambda_c = \lambda^*$ and where λ_c starts being flat at λ^*. Notice that in Figure 4, when $c < c_o$, then $\lambda_c < \lambda^*$, that is, the level of profiling when privacy is an option is lower than when privatizing is not available to consumers. This means that as long the privacy technology is sufficiently cheap, it can reduce the level of profiling, and thus, the incidence of price discrimination by the monopolist. Furthermore, although no one uses the privacy technology in equilibrium, the privacy technology serves as a *deterrent* against more aggressive profiling and price discrimination.

However, when the privacy cost c is sufficiently high such that $c \geq c_o$ in Figure 4, then $\lambda_c = \lambda^*$. This means that if the privacy technology is relatively expensive, the monopolist chooses a level of profiling equal to the case when privacy technology is not available to consumers. This is represented by the flat region of the λ_c curve in Figure 4. In this case, the presence of technology does not result in less profiling by the monopolist. Notice that in this case, while $\lambda_c = \lambda^*$, the uniform price is higher than before . This implies that the privacy technology can only lessen the profiling and number of consumers' price discriminated against if privacy is sufficiently cheap (i.e., $c < c_o$); otherwise, the privacy technology only results in the same level of profiling, but a higher uniform price level.

We summarize these results in the following proposition.

Proposition 8. *If the privacy cost is sufficiently low, $c < c_o$, then the presence of privacy technology results in less aggressive profiling of the monopoly. However, a sufficiently expensive c, $c > c_o$ results in profiling that is as aggressive as in the case where privacy technology is unavailable to consumers, but with a higher uniform price level.*

FIGURE 4. Equilibrium profiling and price level



This result agrees with the finding of Bellefamme and Vergote [2016] for markets with an exogenous level of profiling. Their result shows that privacy technology may increase uniform price levels in markets where the firm has a fixed and exogenous level of λ.

4.3. Equilibrium impact of less costly profiling technology

Another relevant question we will answer concerns the impact of decreasing profiling cost parameter τ, perhaps due to improvements in consumer profiling technology. Since a lower τ decreases the cost of profiling, one might expect that a lower τ should generally increase λ_c in equilibrium. However, the results of the analysis show that whether a decrease in τ increases λ depends on the level of privacy cost c.

The impact of less costly profiling is graphically presented using Figures 5 and 6. What we find is that a lower profiling cost parameter τ may result in more aggressive profiling only if c is sufficiently high. Otherwise, changes in τ will not impact λ_c. To see this, consider a case where we have an initial level of τ such that the upper bound of c is c_m in Figure 5. Suppose also that the current cost of privacy is c_1 such that $c_1 < c_o$ in Figure 5. This level of privacy cost c_1 implies a level of profiling equal to λ_c as in Figure 5. Now, suppose τ declines, which implies less costly profiling, increasing the monopolist's capacity to track. This increases $c_m(\tau)$ from c_m to c_m'.[9] The increase in threshold privacy cost is due to the fact that consumers are now willing to pay a higher privacy cost due to the higher capacity of the monopolist to track. Recall from Equation (10) that this decrease in τ increases the profiling reach had there *been no privacy technology* from λ_1^* to λ_2^* in Figure 5. This change increases c_o to c_o' and extends the upward-sloping region of the λ_c^o curve from the dashed curve λ_c^o to include the solid portion λ_c^1. The new curve representing the optimal level of profiling is now λ_c^1 which only starts to flatten at λ_2^* in Figure 5. Notice that if privacy cost is at c_1, this change brought by lower τ does not impact the level of profiling which stays at λ_c. Thus, as long as c is below the threshold c_o, less costly profiling will not impact the aggressiveness of profiling. This is because with low c, consumer privacy is a threat and the firm will find it unprofitable to expand consumer profiling even with declining profiling cost parameter τ.

However, notice the alternative case where the initial level of c is greater than c_o as in $c_1 > c_o$ in Figure 6. With the initial value of τ and the original dashed λ_c^o curve, the optimal level of profiling is $\lambda_c = \lambda_1^*$. Consider again a decline in τ such that c_m increases to c_m'. This again extends the curve for the optimal level of profiling that is now given by the λ_c^1 curve. The new optimal level of profiling implied by c_1 is now λ_c', which is greater than the previous λ_1^*. This result suggests that if the privacy technology cost c is sufficiently high, the firm will find it optimal to increase profiling when it becomes less costly. This is because when c is costly, the firm has more ability to increase its profiling aggressiveness without the threat of some consumers privatizing. However, when privacy cost is sufficiently cheap such as c_1, even a less costly profiling will not increase λ.

Thus, in equilibrium, the impact of the declining cost of profiling will depend on how costly privacy is as measured by c. We summarize the result in the following proposition.

Proposition 9. *A lower τ will increase the profiling if $c > c_o$; otherwise, a decrease in τ will not impact the level of profiling.*

[9] We suppress the functional notation $c_m(\tau)$ to declutter the diagram and instead just use c_m and c_m'.

FIGURE 5. Effect of lower τ on λ^* and λ_c when $c < c_o$

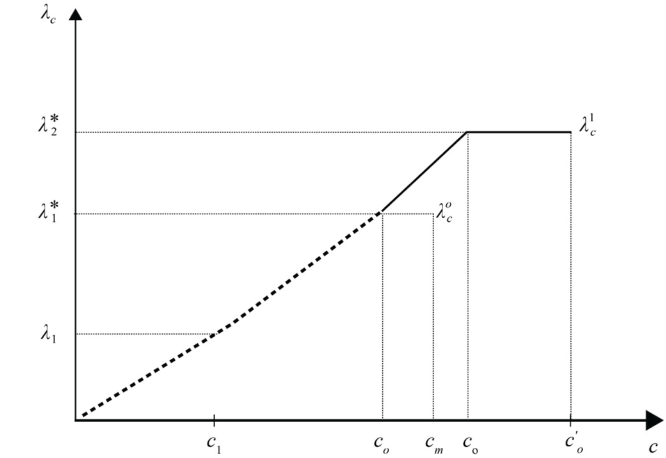
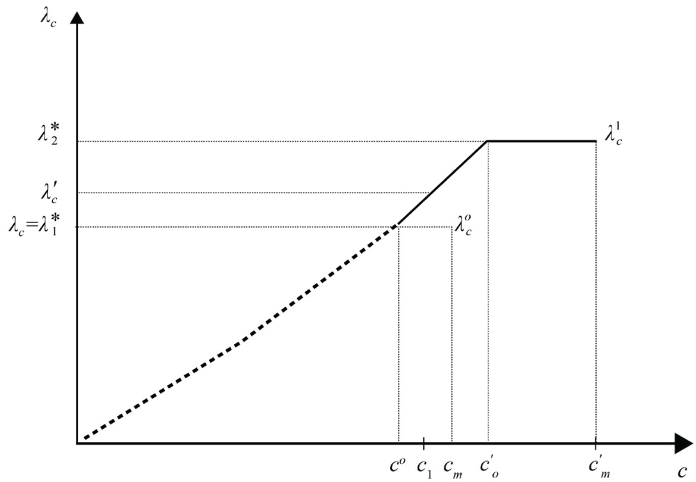


FIGURE 6. Effect of lower τ on λ^* and λ_c when $c > c_o$



5. Summary

Driven by developments in technology that allow the extraction of individual-level consumer information, this paper analyzed the impact of price discrimination and consumer privacy decisions on market outcomes. We considered two scenarios: (1) a case where consumers have no option to privatize their information and (2) a costly privacy technology exists that allows consumers to privatize and prevent profiling by the monopolist.

Absent the availability of privacy technology that protects consumers from monopoly profiling, we find that consumers generally lose due to price discrimination. This theoretical result is well-known and forms the basis of the general aversion towards price discriminatory practices. Because the monopolist only tries to maximize its profit, it may pursue price discrimination even if the strategy results in lower total welfare. Our analysis showed that this happens if consumer profiling is sufficiently cheap for the monopolist but is expensive enough from the viewpoint of total welfare.

Turning to the case where consumers have the option to use privacy technology, we find that the monopolist chooses a consumer profiling reach and uniform price level such that consumers find no incentive to privatize. This results in an equilibrium where no consumer chooses to use the privacy technology. Although no consumer privatizes their information, the privacy technology may reduce monopoly profiling if privacy costs are sufficiently low. This leads us to an important result: privacy acts as a *deterrent* against price discrimination only if it is *sufficiently inexpensive* for consumers. However, if privacy is sufficiently costly, results show that the monopolist tracks consumers as aggressively as in the case when privacy was not an option. For the uniform price level, the attempt of the monopolist to discourage privacy induces it to charge a higher uniform price level compared to when privacy was not an option for consumers. This result about the uniform price level is true for all positive levels of privacy costs.

Lastly, we analyzed the impact of cheaper consumer profiling on the profiling reach decision of the monopolist. We find that a cheaper profiling cost will only induce more aggressive profiling if privacy cost is sufficiently high such that consumer privatizing is not much of a threat. Otherwise, with a sufficiently inexpensive privacy cost, a cheaper profiling cost will not change the monopolist's choice of its profiling reach.

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Appendix

A.1. Expected revenues from profiled and unprofiled segments

We first derive the expected revenue from the profiled segment. Let L_t be the set of profiled consumers after deciding to use the profiling technology. The size of this set L_t is λN. The total number of possible sets L_t with size λN that can be drawn from the population is given by the expression.

$$C, (N, \lambda N) = \frac{N!}{\lambda N!\,(N - \lambda N)!} \tag{A.1}$$

Thus, for any given λ, only one out of $C(N, \lambda N)$ combinations of profiled consumers will be actualized. We denote the set of all possible L_t as Λ.

For a given actualized set of consumers profiled $L_t \epsilon \Lambda$, the revenue R_t by charging their reservation prices, is

$$R_t = N\int_{i\epsilon L_1} r_i f(r)dr \tag{A.2}$$

The expected revenue in the case of continuous reservation can be calculated using the following process.[10] Let $g(x)$ be a function of a random variable x and $f(x)$ be the probability density function of x. Then

$$E(g(x)) = \int_{-\infty}^{\infty} g(x)f(x)dx\ . \tag{A.3}$$

Letting $g(x) = R_t(r_i)$, then the expected revenue is given by

$$E(R_t|\lambda) = \int_0^R [N\int_{i\epsilon L_t} r_i f(r)dr]\, f(r)dr \tag{A.4}$$

Interchanging the order of integration, we get

$$E(R_t\, \lambda) = N\mu_r \int_{i\epsilon L} f(r)dr\,. \tag{A.5}$$

Since the proportion of consumers profiled with respect to the total size of the market is λ, the following statement must also be true

$$\lambda = \int_{i\epsilon L_t} f(r)dr = \sum_{i\epsilon L_t} \int_a^b f(r)dr \tag{A.6}$$

for all a, $b \epsilon [0, R]$ such that all i, i.e., consumers with valuations in the interval $[a, b]$ are members of L_t. Thus, (A.5) reduces to

$$E(R_t|\lambda) = \lambda N\mu_r\,. \tag{A.7}$$

Note that the expressions above indicate that the expected revenue is the mean of valuation of the whole market multiplied by the number of individuals profiled.

[10] The underlying principle behind this process is more commonly known as The Law of the Unconscious Statistician [Ross 1980].

This expectation does not depend on any particular L_t but is fully characterized by the mean and total number of consumers profiled.

The result in (A.7) makes more intuitive sense if we consider discrete r_i. Like before, the revenue will be

$$R_t = \Sigma_{i \epsilon L_t} r_i \tag{A.8}$$

Getting the expectation of (A.8) we get

$$E(R_t|\lambda) = E(\Sigma_{i \epsilon L_t} r_i) \tag{A.9}$$

Invoking the linearity of expectations over summation operation

$$E(R_t|\lambda) = \Sigma_{i \epsilon L_t} E(r_i) \tag{A.10}$$

since there are λN consumers profiled, the expectation is reduced to

$$E(R_t|\lambda) = \lambda N \mu_r \tag{A.11}$$

(A.7) and (A.11) imply that the firm, before any actual set of consumers is profiled, has an expected value of revenue from profiled consumers equal to $\lambda N \mu_r$.

The second part of the revenue of the firm comes from the unprofiled segment. This segment is composed of consumers whose reservation prices are unknown to the firm. The price offered to this segment is p and is uniform. The size of this segment is $(1 - \lambda)N$. However, out of $(1 - \lambda)N$ consumers in this segment, only those with valuations equal to or above p_o are going to buy from the firm. Let $P(H)$ and $P(L_t')$ be the probabilities that a consumer has a valuation higher than p_o and that the consumer is unprofiled respectively. Assuming that the chances of one being profiled does not depend on his/her valuation, then the probability that a consumer is both unprofiled and has a valuation above p_o is given by the expression:

$$P(H \cap L_t') = P(H)P(L'). \tag{A.12}$$

Noting that $P(H) = \int_{p_o}^{R} f(r)dr$ and $P(L') = (1 - \lambda)$, then

$$P(H \cap L') = (1 - \lambda) \int_{p_o}^{R} f(r)dr. \tag{A.13}$$

The expected revenue R_o from this segment is therefore

$$R_o = (1 - \lambda)N \int_{p_o}^{R} p_o f(r)dr. \tag{A.14}$$

A.2. Derivation of profit function with consumer privacy technology

The profit of the monopolist, given the levels of c and τ, is function of the uniform price level it charges, p, and of the profiling level, λ. The profit function will have two parts.

First, notice that if the levels of p and λ are such that some consumers are privatizing, i.e., $p + (c/\lambda) < 1$, then the profit of the monopolist can be decomposed into four distinct sources:

a. Low-valuation consumers who are **profiled** with profit $\lambda\int_o^p rdr$.
b. *Non-privatizing consumers* with valuations between $[p, r_c]$ who are **profiled** with profit $\lambda\int_p^{r_c} rdr$.
c. *Non-privatizing consumers* with valuations between $[p, r_c]$ who are **not profiled** and charged the uniform price level p with profit $(1-\lambda)p\int_p^{r_c} rdr$.
d. *Privatizing consumers* with valuations between $[r_c, 1]$ charged the uniform price level p with profit $(1-\lambda)\, p\int_{r_c}^1 dr$.

Noting that $r_c = p + \lambda c$, adding profit from these sources results in $\pi = p(1-p) + (\lambda p^2/2) + (c^2/2\lambda) - (\tau\lambda/1{-}\lambda)$ if $p + (c/\lambda) < 1$.

This is the first part of our profit function in Equation (24).

The second part of the profit function is obtained when $p + (c/\lambda) = 1$. In this case, no consumer privatizes and there are only two sources of profit for the monopolist. First, it derives a profit equal to $\lambda\int_0^1 rdr$ from those it was able to track and price discriminate. Second, those who are not tracked and charged their reservation price are offered the goods at a uniform price level p. From this second segment, the monopolist gets profit equal to $(1-\lambda)\, p\int_p^1 dr$. Adding these two sources gives us $(\lambda/2) + (1-\lambda)\, p\,(1-p) - (\tau\lambda/1-\lambda)$. This is the second part of the profit function in Equation (24) if $p + (c/\lambda) = 1$.

A.3. Derivation of profit-maximizing level of profiling and price levels

We know that the maximum profit is obtained when $p + (c/\lambda) = 1$, i.e., when the monopolist squeezed every consumer out of privatizing. Thus, a strategy to derive the equilibrium values of p and λ is to maximize profit and impose the condition that no consumer privatizes.

To do this, we differentiate the relevant section of the profit function in Equation (24) with respect to p, the variable where the function is continuous when $p + (c/\lambda) = 1$, and equate it to zero. We get

$$\frac{d\pi_c}{dp} = 1 - 2p + \lambda p = 0 \cdot \tag{A.15}$$

Note that $p + (c/\lambda) = 1$ also implies that $\lambda = (c/1 - p)$. We substitute this expression to Equation (A.15). Solving for the optimal level of p yields $p_c = (3 - \sqrt{c^2 - 6c + 1} - c)/4$. Substituting this to the equation $p + (c/\lambda)$ gives us the optimal level of λ which is $\lambda_c = 4c/(1 + \sqrt{c^2 - 6c + 1} + c)$. These expressions for p_c and λ_c are the same given in Proposition 6.

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