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Reciprocal privacy invasion and taxation of online map services

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Abstract

This paper considers privacy invasion, such as Street View, resulting from map services on the Internet. Reciprocal privacy invasion can develop into a Prisoners' Dilemma. A portal site remedies such a dilemma by supplying personal information. However, under excessive supply, the problem worsens with negative utility. Whether such a situation develops or not is dependent on the cost of using a service and the coverage of information. We consider two types of taxation, on personal information and advertisements, in order to bring about a social optimum. Furthermore, we obtain a condition in which taxation brings about large tax revenues to be redistributed to privacy-encroached agents.

JEL Classification: K20, L14

Keyword: Privacy Invasion, Street View

1. Introduction

Google initiated a service in several countries entitled Street View, resulting in controversy regarding privacy invasion. Before this, the company had a map service, using satellite images, which was minimally acceptable. There were complaints of the latter displaying panoramic views of streets even when Google insisted that privacy was not intruded upon according to current regulations. Street View was first launched in several cities in the U.S. in May 2007. In little over three years, the service reached all 7 continents, including Antarctica. The service claimed benefits from assisting home buyers and renters, locating businesses or promoting tourism. However, such development has been controversial. It has been the subject of a lawsuit since the launch[1].

This paper will focus on privacy problems. Before map services on the Internet, there were various roadmaps which collected information. The difference from

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[1] For example, a recent case in Argentina sentenced Google to pay about $12,500 USD to a plaintiff due to privacy invasion by Street View; https://www.foxbusiness.com/technology/court-rules-google-must-pay-man-photographed-naked-street-view-camera.

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Google's Street View was the level of *accessibility* and *coverage*.[2] When transaction costs for such information are high, few people will access it. For example, when we print our home addresses on business cards, few people actually go there since, in most cases, the cost is higher than the benefit. However, Street View makes search costs lower than its benefits. When I send Christmas cards to distant friends, colleagues, or students who have never seen my house, they may easily check it out in detail through Street View. This also applies to former classmates who could previously access me through alumni address lists. Since the beginning of Street View, methods concerning dissemination of personal addresses have changed. What we define and feel regarding public domain now depends on the level of accessibility and coverage of such information.

Another discomforting factor of Street View is that it makes a profit through advertisements on the portal site by using personal information, so-called privacy commodification. Free TV programs also profit from such advertisements, but broadcasting companies produce the content for mass consumption. Mobile software companies also generate revenue by collecting user information to deliver more targeted advertisements or by packaging and selling aggregated user data. With Street View, people may use it to observe personal information of others even though they may feel uncomfortable since others, in turn, may observe theirs.

Before the Internet era, in the 1980s, many considered privacy issues[3] as computers began to be utilized to process huge amounts of personal data. Then, personal information on debts, illnesses, etc. was gathered and disseminated by government and private sectors. They focused on efficient utilization of such information, since imperfect information generally caused inefficient outcomes in the market. Stigler [1980] and Posner [1981] supported use of personal information for economic efficiency. This was later discussed by Varian [1996], Hermalin and Katz [2005], and Liu and Serfes [2006] in the context of price discrimination. These considerations regarding privacy, closely related to those of imperfect or asymmetric

[2] Search engines at portal sites collect personal information uploaded on individual websites. We know in advance that most such information is viewed by others on the Internet. The difference from that of Street View is that it is sorted nation-wide by use of actual home addresses. Furthermore, it is possible to sort by square measure of real estate, the approximate number of persons living in a house, whether there are pets, what kind of cars there are, and so on. Such information can be collected from public roads.

[3] Hui and Png [2005] summarized discussions on privacy whose main points regarded problems caused by asymmetric information.

information, were among the notable issues of the 1980s. Goldfarb and Que [2023] have summarized recent discussions regarding online privacy arising from data collection by companies for marketing and pricing. Such discussions assumed two groups, information users and privacy-invaded people, and the conflicts between them. Also, personal information, unlike celebrity gossip or photos, was not directly consumed but rather was used for marketing purposes.

However, Street View generates a different condition on the Internet, in which agents are not only privacy consumers but are also intruded upon by other agents, ergo, *reciprocal privacy invasion*. It should be noted that such privacy invasion is intentional in order to entice people to use a portal site. In a usual two-sided market created by platforms on the Internet, buyers and sellers mutually obtain benefits or positive externalities through trade. Without privacy invasion caused by collecting personal information, such positive externalities are manipulated by platformers with monopolistic power to determine platform usage fees[4]. Privacy invasion among sellers is related to such manipulation, but it is a different problem from the reciprocal privacy invasion we consider here.

Whilst such reciprocal privacy bears certain similarities to public goods in nature, it differ in that public goods confer undifferentiated benefits upon all users. In the case of reciprocal privacy goods, however, the subjects whose privacy is exposed cannot derive benefit from their own exposed privacy; they can only gain positive influence from the privacy exposed by others.

We compared impacts on the agents themselves with those on others, as well as the resulting supply incentives in cases of mutual privacy infringement, public goods, environmental pollution, and vaccines. In the case of public goods, the effects on both the agents and others are positive. Due to the non-excludability and non-rivalry characteristics of public goods, all users can benefit from positive externalities. Examples include public meteorological data or Wikipedia. However, this also invites free-riding, resulting in a socially insufficient supply. Environmental pollution presents the opposite scenario: polluters reduce waste disposal costs by discharging pollutants, thereby increasing their profits and gaining positive benefits. Yet their emissions impose negative externalities on others, such as deteriorating air quality, heightened health risks,

[4] See Rochet and Tirole [2004].

or greenhouse gas emissions. As pollution costs remain uninternalised, polluters possess incentives for over-emission, resulting in pollution levels exceeding the socially optimum. Vaccines present a distinct scenario where agents may face either positive or negative benefits. Individuals incur costs or adverse effects like side effects when vaccinated, yet simultaneously reduce their own risk of contracting diseases. The impact on others is unquestionably positive: individual vaccination enhances herd immunity, thereby curbing disease transmission. Similar to public goods, individuals often underestimate societal benefits when making decisions, leading to vaccination rates falling below optimal levels unless the government intervenes through subsidies, compulsory vaccination, or public awareness campaigns. Finally, in the case of mutual privacy infringement we shall discuss, disclosers of personal information—such as details about their home or address—incur negative utility. Yet this information holds positive value for other users, as it enhances the richness and utility of platform content, thereby enabling greater convenience or access to information for others. However, since the privacy cost is borne entirely by the discloser while the benefits accrue primarily to others, individuals lack any incentive to provide such information.

Table 1: Types of reciprocal externalities

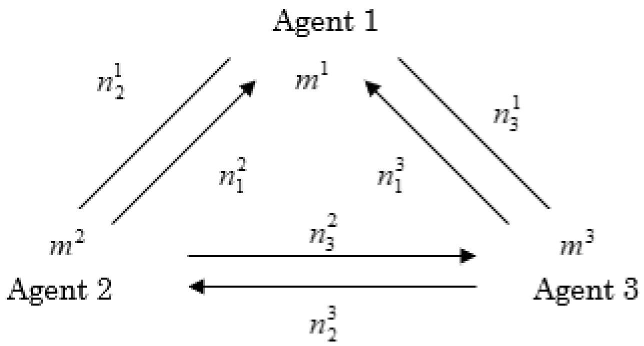
	Agent	Others	Incentive for production
Reciprocal privacy invasion	negative	positive	zero
Public goods	positive	positive	insufficient
Environmental pollution	positive	negative	excessive
Vaccination	positive or negative	positive	insufficient

We analyze the situation caused by Street View in a reciprocal-view model. In Section 2, we set up a model and consider its difference from models of pollution. In Section 3, we obtain results given the number of agents and show the relationship between two tax schemes, a tax on advertisement revenues and one on information collection. In Section 4, we consider the effects of the number of agents on the level of privacy invasion. In Section 5, we consider how the number of agents affects tax schemes. In the final section, we suggest an extension of our analysis and our conclusions.

2. A Model

We lay out a model in which agents reciprocally view others' personal information supplied at a portal site. For example, in Figure 1, $m^i\,(i=1,2,3)$ is the amount of personal information, and n^i_j $(i \neq j; i,j=1,2,3)$ is the time agent i views the information of agent j.

Figure 1: Reciprocal-view model



Policymakers can regulate the amount of personal information in two ways: taxing advertisements and collection of information. New York State's proposed Bill No. 4959 of 2021[5] suggests imposing a tiered monthly consumption tax on data collectors, calculated per capita, with a threshold of five cents per month per New York consumer. Taxing data collection or usage in this manner would require data users to bear a portion of the social costs of their activities, thereby approximating a social optimum. For instance: platforms would be required to pay taxes on the "social value generated by user-contributed data". This could potentially reduce excessive exploitation of user data and incentivise more responsible data collection practices. It may prompt platforms to curtail unnecessary data collection and enhance privacy protection mechanisms. We include such taxes in our model.

We assume symmetry of agents whose utility function is composed in two parts. The first part expresses the utility from viewing content:

$$f^i(n^i; m^{-i}, c)\,, \quad (i \neq j; i,j=1,2,\ldots,h) \tag{1}$$

[5] See New York State Senate [2021] Senate Bill S4959: Creates an excise tax on the collection of consumer data by commercial data collectors.

where $n^i = (n_1^i,,,n_{i-1}^i,n_{i+1}^i,,,n_h^i)$, $m^{-i} = (m^1,,,m^{i-1},m^{i+1},,,m^h)$, and c is cost per view. We assume that this function is strictly increasing with respect to n_j^i and m^j and strictly decreasing with respect to c. The second part expresses the cost resulting from being viewed by others or privacy invasion:

$$g^i(n_i, m^i), \tag{2}$$

where $n_i = (n_i^1,,,n_i^{i-1},n_i^{i+1},,,n_i^h)$. We assume that this function is strictly increasing with respect to n_i^j and m^i. The utility function is expressed as

$$U^i = u^i(f^i, g^i). \tag{3}$$

and is strictly increasing with respect to f^i and strictly decreasing with respect to g^i.

The profit function of a portal site is

$$\pi = (\sigma - t^\sigma)\cdot N - \tau(M) - t^\tau \cdot M, \tag{4}$$

where $N = \sum_i \sum_{j \neq i} n_j^i$, $M = \sum_i m^i$. σ and t^σ are respectively per view revenue and an advertisement tax on the portal site. τ and t^τ are respectively the cost function for gathering information and a tax on the information. The social welfare is

$$W = \sum_i U^i. \tag{5}$$

We assume strict concavity of this function with respect to m^i.[6]

Note that m^i does not have the property of ordinary public goods as usual information since the originals, from whom such personal information is derived, do

[6] We assign zero value to profits in a definition of social welfare. When a strictly positive value is assigned to it, privacy invasion can be socially desirable even if agents' utilities are strictly negative. Stigler [1980] and Posner [1981], of the so-called Chicago School, mainly considered personal information which could lead to an efficient exchange of goods and services. In their considerations, social welfare must assign positive value to profits if discrimination, caused by such personal information, does not socially damage agents. Personal information or privacy considered in this paper is not directly related to efficiency, but to the agents' behavior to satisfy themselves.

not obtain a positive benefit from such. For viewers alone, the information has the property of public goods. Information on Street View cannot be public goods due to its privacy invasion, yet it is not public bads since it produces positive benefits for viewers.

Given the amount of personal information, the problem of privacy invasion is easy. In such a case, we can omit the behavior of a portal site, since it collects only personal information as given in the model. Externalities are caused by viewings by others. Policymakers must internalize these viewers. That is, they can regulate number of views in order for the following condition to be satisfied:

$$\frac{\partial W}{\partial n_j^i} = \underbrace{\frac{\partial u^i}{\partial f^i}\frac{\partial f^i}{\partial n_j^i}}_{+} + \underbrace{\frac{\partial u^j}{\partial g^j}\frac{\partial g^i}{\partial n_j^i}}_{-} = 0\,. \tag{6}$$

If policymakers set a tax per view,

$$t = -\frac{\partial u^j}{\partial g^j}\frac{\partial g^i}{\partial n_j^i}\,, \tag{7}$$

then our discussion is over. However, the essential problem is not number of views, but the level of personal information collected by a portal site. Therefore, policymakers must consider regulation of information collection.[7]

3. Analysis of a Static Network

We first obtain demand for viewing. The first-order condition for maximizing utility with respect to n_j^i is

$$\frac{\partial U^i}{\partial n_j^i} = \frac{\partial u^i(f^i, g^i)}{\partial f^i}\frac{\partial f^i}{\partial n_j^i} = 0 \qquad (i \neq j; i, j = 1, 2, ..., h) \tag{8}$$

We denote the solution as $n_j^i{*}(m^1, m^2, .., m^h; c)$ and assume $\partial n_j^i{*}/\partial c < 0$. A Nash equilibrium among agents under $n_j^i{*}$ is $m^i = 0$. That is, no information is voluntarily supplied by an agent. We denote m^i maximizing W under $n_j^i{*}$ as $m^i{*}$.

[7] A similar situation to this is a tax on an input, such as petroleum, causing negative externalities. However, personal information is basically different from this because of the characteristic of public goods.

We obtain the following result concerning remedies by taxing of a portal site.[8]

Proposition 1.

Suppose that profit and social welfare functions have a unique maximal inner solution under $n_j^i *(m,c)$ with respect to m^i. At $m^i = m^i *$, we have three relationships in terms of taxes. First,

$$\left(\sigma - t^\sigma\right)\sum_{j\neq i}\frac{\partial n_i^j *}{\partial m^i} = t^\tau + \frac{d\tau}{dM}. \tag{9}$$

Second, regarding $\hat{t}^\tau$ for $t^\sigma = 0$ and $\hat{t}^\sigma$ for $t^\tau = 0$,

$$\hat{t}^\tau \begin{pmatrix} > \\ = \\ < \end{pmatrix} \hat{t}^\sigma \Leftrightarrow \sum_{j\neq i}\frac{\partial n_i^j *}{\partial m^i}\begin{pmatrix} > \\ = \\ < \end{pmatrix} 1. \tag{10}$$

Third, regarding tax revenues, $\hat{T}^\tau (\equiv \hat{t}^\tau M)$ and $\hat{T}^\sigma (\equiv \hat{t}^\sigma N)$,

$$\hat{T}^\tau \begin{pmatrix} > \\ = \\ < \end{pmatrix} \hat{T}^\sigma \Leftrightarrow \varepsilon \begin{pmatrix} > \\ = \\ < \end{pmatrix} 1, \tag{11}$$

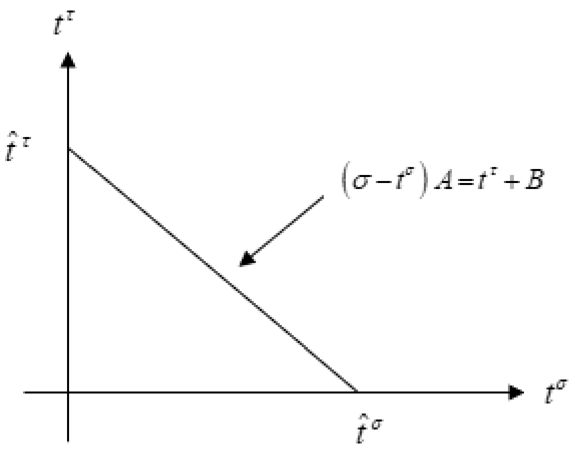
where ε is the view demand elasticity of agent j to personal information of agent i $(i \neq j; i, j = 1, 2, ..., h)$, that is, $\varepsilon = \left(\partial n_i^j * / \partial m^i\right)\cdot\left(m^i / n_i^j *\right)$.

Proof.

See Appendix A-1.

[8] We do not consider an incentive regulation. In this paper, policymakers set a tax under complete information.

Figure 2: Optimal tax combination



Theoretically, policymakers can use a combination of two types of taxes in (9). In reality, however, they are likely to use either tax in order to lead to a social optimum. Under such a situation, this proposition suggests how $\hat{t}^\tau$ and $\hat{t}^\sigma$ depend on a marginal effect on demand for views. From (10), if and only if it is relatively high, then a tax on collecting and uploading information is higher than on advertisement revenues. Moreover, policymakers can increase social welfare through lump-sum transfers of collected taxes to agents. From (11), they must choose either of the two types of taxation, considering the elasticity of viewing demand.

There is another possible taxation which we do not consider here. In order to reduce excessive personal information at a portal site, policymakers can also impose a tax on viewing by agents. Along with this tax, the demand for views, as well as the marginal revenue for a portal site, is reduced. As a result, both information supply and profits decrease. Since viewers pay a price to reduce privacy invasion via a tax on views, this solution for maximizing social welfare is a second-best one. That is, social welfare, W, under such a tax is smaller than that under the above two taxes considered by this paper. There is a problem with a tax on viewing, which is that viewers are responsible for the privacy invasion originated by a portal site. Moreover, if we were responsible for viewing or downloading content from the public domain, we could not safely visit websites. Such a situation would make net-surfing risky and damage safe websites by causing a decrease in visitors. Therefore, we do not consider such a tax.

4. Accessibility and Coverage

We consider a model to explicitly find a solution and obtain effects of the number of agents. A utility function[9] is as follows:

$$f^i = \sum_{j \neq i}^{h} \left(m^j n_j^i\right)^{\alpha} - c \sum_{j \neq i}^{h} n_j^i \;, \;\; (0 < \alpha < 1/2) \tag{12}$$

$$g^i = \sum_{j \neq i}^{h} \left(m^i n_i^j\right)^{\beta} . \;\; (\beta > 1) \tag{13}$$

$$U^i = f^i - g^i . \tag{14}$$

A demand function of views is derived from the following condition:

$$\frac{\partial U^i}{\partial n_j^i} = \frac{\partial f^i}{\partial n_j^i} = \alpha \left(m^j n_j^i\right)^{\alpha - 1} m^j - c = 0 \;, \;\; (i \neq j; i, j = 1, 2, ..., h) \tag{15}$$

$$n_j^i * = \left(\alpha m^{j^{\alpha}} / c\right)^{1/(1-\alpha)} . \tag{16}$$

Therefore, taking into account this demand function, we obtain the following utility function:

$$f^i = (h-1) X^{\frac{\alpha}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} - (h-1) c X^{\frac{1}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} \tag{17}$$

$$g^i = (h-1) X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta}{1-\alpha}} , \tag{18}$$

where $m = m^i$ and $X = \alpha / c$ from symmetry. With respect to m, g^i is strictly convex, and f^i strictly concave for $0 < \alpha < 1/2$ and $\beta > 1$.

We first obtain the $\bar{m}$ that bring about zero utility. Since u^i passes the origin and is strictly concave, one is $\bar{m} = 0$. Another point is obtained from the following condition:

[9] The usual Cobb–Douglas type of utility function, like $\prod_{j \neq i}^{h} \left(m^j n_j^i\right)^{\alpha}$, does not satisfy the second order condition for maximization with respect to m^j. Therefore, we assume an additive function.

$$U^i = f^i - g^i = (h-1)m^{\frac{\alpha}{1-\alpha}}\left(X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{\alpha}{1-\alpha}} - X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta-\alpha}{1-\alpha}} \right) = 0 . \quad (19)$$

Therefore, we obtain

$$\bar{m} = 0 \text{ and } \bar{m} = \left(X^{\frac{\alpha-\beta}{1-\alpha}} - cX^{\frac{1-\beta}{1-\alpha}} \right)^{\frac{1-\alpha}{\beta-\alpha}} . \quad (20)$$

An inner solution for maximizing agents' utilities is obtained as follows:

$$\frac{\partial W}{\partial m^i} = \sum_{i \neq j} \frac{\partial u^j}{\partial m^i} + \frac{\partial u^i}{\partial m^i} = \sum_{i \neq j} \frac{\partial f^j}{\partial m^i} - \frac{\partial g^i}{\partial m^i}$$

$$= \frac{h-1}{(1-\alpha) m^{\frac{2\alpha-1}{1-\alpha}}} \left\{ \alpha \left(X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{1}{1-\alpha}} \right) - \beta X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta-\alpha}{1-\alpha}} \right\} = 0 . \quad (21)$$

Therefore,

$$\tilde{m} = \left\{ \frac{\alpha}{\beta} \left(X^{\frac{\alpha-\beta}{1-\alpha}} - cX^{\frac{1-\beta}{1-\alpha}} \right) \right\}^{\frac{1-\alpha}{\beta-\alpha}} \quad (22)$$

Note that $\tilde{m}$ is not dependent on h.

Compared to this solution, we obtain a profit-maximizing solution for a portal site. We assume the following profit function:

$$\pi = \left(\sigma - t^\sigma\right) N - \tau(M) - t^\tau M = \left(\sigma - t^\sigma\right) N - \left(c^\tau + t^\tau\right) M , \quad (23)$$

where c^τ is a marginal cost for collecting and uploading information. From symmetry, the profit function is

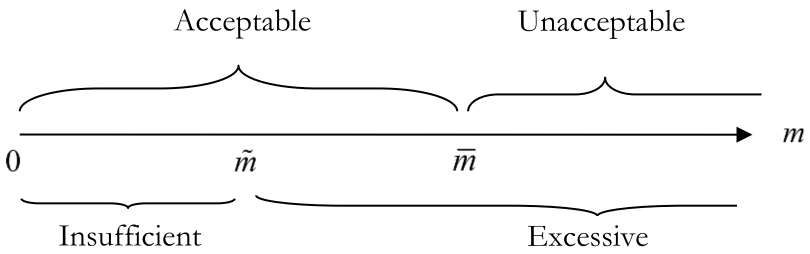
$$\pi = (\sigma - t^\sigma) h(h-1) \left(\alpha m^\alpha / c \right)^{1/(1-\alpha)} - (c^\tau + t^\tau) hm . \quad (24)$$

From the first-order condition, we obtain

$$m^* = \left((\sigma - t^\sigma) \alpha (h-1) X^{1/(1-\alpha)} / (1-\alpha)(c^\tau + t^\tau) \right)^{\frac{1-\alpha}{1-2\alpha}} . \quad (25)$$

Note that m^* increases with h and decreases with c^τ and c due to $X = \alpha / c$.

Figure 3: Excessive and unacceptable privacy invasions



This high level of *coverage* and *accessibility* makes agents uncomfortable. There are two critical numbers of agents, the one denoted as $\bar{h}$, over which m^* is greater than $\bar{m}(>0)$, and the other, denoted as $\tilde{h}$, over which m^* is greater than $\tilde{m}$. We can classify situations into two areas in $m \geq 0$, an acceptable and an unacceptable area for agents. In the first area, $0 \leq m \leq \bar{m}$, they are better off receiving a service from a portal site, compared to zero utility derived by the Prisoners' Dilemma. Although their utilities are not always maximized, the result is acceptable to them. In the second area, $m > \bar{m}$, agents face strictly negative utilities and are worse off. Therefore, they become seriously aware of privacy invasion. From these, it turns out that whether agents fall into the first or the second area depends on the number of agents. Since we can interpret the number as coverage of information, this result indicates how the level of reciprocal privacy invasion is affected by the extent of coverage.[10]

5. Optimal Taxation

Finally, we consider the effects of a network's size on measures with which to cope with privacy invasion. In this section, we solve problems with respect to h and consider regulation in order for the amount of collected information to be at a proper level. Theoretically, a simple regulation is to initiate a tax whose level is calculated as follows:

Social welfare is maximized under the following taxes:

[10] Accessibility also affects privacy invasion. The effect can also be seen in costs for viewing, c, which are included in the condition (23) and (25). We can simulate acceptable areas with respect to c.

$$\hat{t}^{\tau} = \frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}} - c^{\tau}, \qquad (26)$$

$$\hat{t}^{\sigma} = \sigma - \frac{(1-\alpha)c^{\tau}\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}}{\alpha(h-1)X^{\frac{1}{1-\alpha}}}. \qquad (27)$$

These taxes are directly obtained from (22) and (25). Both taxes depend on the number of agents, h. Given h, we show the relationship between them in Proposition 1. Here, $\hat{t}^{\sigma}$ is increasing with respect to h. Its supremum is σ while $\hat{t}^{\tau}$ is increasing with no limit. Therefore, $\hat{t}^{\tau}$ exceeds $\hat{t}^{\sigma}$ beyond h, which satisfies $\hat{t}^{\tau} = \sigma$. The reason is that m^* is increasing with h while $\tilde{m}$ is constant. In order to maintain the increase of m^* by h, $\hat{t}^{\tau}$ must increase with h.

These two tax schemes also bring revenue for policymakers, which may be indirectly returned to agents. Therefore, they prefer the one which brings about greater revenue. Tax revenues are, respectively,

$$\hat{T}^{\tau} \equiv \hat{t}^{\tau}M = \left\{ \frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}} - c^{\tau} \right\} h\tilde{m}, \text{ and} \qquad (28)$$

$$\hat{T}^{\sigma} \equiv \hat{t}^{\sigma}N = \left\{ \sigma - \frac{(1-\alpha)c^{\tau}\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}}{\alpha(h-1)X^{\frac{1}{1-\alpha}}} \right\} h(h-1)\left(X\tilde{m}^{\alpha}\right)^{1/(1-\alpha)}. \qquad (29)$$

We obtain the following result:

Proposition 2.

$$\hat{T}^{\tau} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \hat{T}^{\sigma} \Leftrightarrow h \begin{pmatrix} < \\ = \\ > \end{pmatrix} \hat{h}, \text{ where } \hat{h} \equiv 1 + \frac{(1-\alpha)c^{\tau}}{\alpha\sigma n^*(\tilde{m})}.$$

Proof.

See Appendix A-2.

This proposition shows that $\hat{T}^{\tau} \leq \hat{T}^{\sigma}$ takes place under a large network. Otherwise, $\hat{T}^{\tau} > \hat{T}^{\sigma}$. Furthermore, it indicates that a greater demand for viewings at the social optimum increases the possibility of $\hat{T}^{\tau} > \hat{T}^{\sigma}$.

6. Concluding Remarks

The reason why few authors have addressed the kind of privacy discussed here is because of direct privacy consumption. Up until now, such privacy consumption has been limited exclusively to entertainment industries where privacy leakages are, in part, necessary and useful to keeping and maintaining the spotlight. Therefore, instead of addressing such privacy, most authors have focused on privacy protection within an industry. The problem in this area is how privacy invasion or usage of personal information is permissible for the producers. While such privacy issues are still important, we are facing the new Internet phenomenon addressed by this paper. Even though provoking discussion, there has been no theoretical consideration from an economic perspective.

Our main conclusions in this paper are summarized as follows. First, even if agents face negative utilities, they view each other's personal information while contributing to the profits of a portal site. Second, coverage of agents, expressed by the number of agents, and the costs for viewing, determines whether a privacy invasion caused by a portal site is acceptable or not. Third, we show conditions for a tax scheme creating large revenues, as the criterion for selecting a tax scheme may be the amount of tax revenue, which may be used to compensate for privacy invasion.

We cannot deny a service related to personal information, but we must take into account its appropriate level. New services using inventive technologies are not properly considered by current laws, even though Google stresses that such service is lawful. Those who support this service insist that people will become soon accustomed to it and feel inconvenient without it. However, it is also true that there is a limit to the level at which we become accustomed. Compared to the situation with satellite images, many people complain about Street View. It seems that the service may be near or beyond our limit. Policymakers need to consider regulation of this type of service to reduce privacy invasion at an optimal level.

We finally mention possible extensions of our analysis. First is address of the competition among portal sites, which is likely to aggravate privacy invasion. Second is consideration of the revenue function of advertising.[11] The advertising rate per view

[11] See Evans [2009] concerning a survey of online advertisement from an economic perspective.

depends upon the effectiveness determined not only by view times but also by content. Third is addressing negative externalities such as theft. There are reports that thieves use Street View to search out targets in advance. Although roadmaps may be used, the information they can obtain from Street View is greater than that from roadmaps and makes the threat of theft higher than ever.

Appendix A: Proofs

A-1: Proof of Proposition 1

By solving $\partial W / \partial m^i = 0$, we obtain $m^i *$. A portal site must satisfy the following condition in order to maximize social welfare, that is:

$$\left.\frac{\partial \pi}{\partial m^i}\right|_{m^i = m^i *} = \left(\sigma - t^\sigma\right) \sum_{j \neq i} \left.\frac{\partial n_i^j *}{\partial m^i}\right|_{m^i = m^i *} - t^\tau - \left.\frac{d\tau}{dM}\right|_{m^i = m^i *} = 0 .$$

We denote $\sum_{j \neq i} \partial n_i^j * / \partial m^i \Big|_{m^i = m^i *}$ as $A(>0)$ and $d\tau / dM\big|_{m^i = m^i *}$ as $B(>0)$. From condition (9), $\hat{t}^\tau$ and $\hat{t}^\sigma$ are, respectively, $\hat{t}^\tau = \sigma A - B (>0)$ and $\hat{t}^\sigma = \sigma - B / A (>0)$. Therefore,

$$\hat{t}^\tau - \hat{t}^\sigma = \frac{A-1}{A}(\sigma A - B) \begin{pmatrix} > \\ = \\ < \end{pmatrix} 0 \Leftrightarrow A \begin{pmatrix} > \\ = \\ < \end{pmatrix} 1 .$$

We have obtained the condition (10). Furthermore, due to symmetry of agents, m^i and $n_i^j *$ are the same for $i, j = 1, 2, ..., h$. Therefore, $\hat{T}^\tau = \hat{t}^\tau h m^i$ and $\hat{T}^\sigma = \hat{t}^\sigma h(h-1) n_i^j *$.

$$\begin{aligned} \hat{T}^\tau - \hat{T}^\sigma &= h\left\{\hat{t}^\tau m^i - \hat{t}^\sigma (h-1) n_i^j *\right\} \\ &= h\left\{(\sigma A - B) m^i - \left(\sigma - B/A\right)(h-1) n_i^j *\right\} \\ &= \frac{(\sigma A - B) h}{A}\left\{A m^i - (h-1) n_i^j *\right\} \end{aligned}$$

$$\hat{T}^\tau \begin{pmatrix} > \\ = \\ < \end{pmatrix} \hat{T}^\sigma \Leftrightarrow \sum_{j \neq i} \frac{\partial n_i^j *}{\partial m^i} = (h-1) \frac{\partial n_i^j *}{\partial m^i} \begin{pmatrix} > \\ = \\ < \end{pmatrix} (h-1) \frac{n_i^j *}{m^i}$$

As a result, we obtain (11).

A-2: Proof of Proposition 2

$$\hat{T}^\tau - \hat{T}^\sigma = \left\{ \frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}} - c^\tau \right\} h\tilde{m} - \left\{ \sigma - \frac{(1-\alpha)c^\tau \tilde{m}^{\frac{1-\alpha}{1-2\alpha}}}{\alpha(h-1)X^{\frac{1}{1-\alpha}}} \right\} h(h-1)\left(X\tilde{m}^\alpha\right)^{1/(1-\alpha)}$$

$$= h\left[\left\{ \frac{\alpha}{1-\alpha}\sigma(h-1)X^{\frac{1}{1-\alpha}}\tilde{m}^{\frac{1}{1-\alpha}} - c^\tau \tilde{m} \right\} - \left\{ \sigma(h-1)X^{\frac{1}{1-\alpha}}\tilde{m}^{\frac{1}{1-\alpha}} - \frac{1-\alpha}{\alpha}c^\tau \tilde{m} \right\} \right]$$

$$= h\left[\left\{ \frac{\alpha}{1-\alpha} - 1 \right\} \sigma(h-1)X^{\frac{1}{1-\alpha}}\tilde{m}^{\frac{1}{1-\alpha}} - \left\{ 1 - \frac{1-\alpha}{\alpha} \right\} c^\tau \tilde{m} \right]$$

$$\hat{T}^\tau \begin{pmatrix} > \\ = \\ < \end{pmatrix} \hat{T}^\sigma \Leftrightarrow \underbrace{\frac{2\alpha-1}{1-\alpha}}_{-}\sigma(h-1)X^{\frac{1}{1-\alpha}}\tilde{m}^{\frac{1}{1-\alpha}} \begin{pmatrix} > \\ = \\ < \end{pmatrix} \frac{2\alpha-1}{\alpha}c^\tau \tilde{m} \quad \text{(from } 0 < \alpha < 1/2 \text{)}$$

$$\Leftrightarrow h-1 \begin{pmatrix} < \\ = \\ > \end{pmatrix} \frac{2\alpha-1}{\alpha}\frac{1-\alpha}{2\alpha-1}\frac{1}{\sigma}c^\tau X^{\frac{1}{\alpha-1}}\tilde{m}^{1-\frac{1}{1-\alpha}}$$

$$\Leftrightarrow h \begin{pmatrix} < \\ = \\ > \end{pmatrix} 1 + \frac{1-\alpha}{\alpha}\frac{1}{\sigma}c^\tau X^{\frac{1}{\alpha-1}}\tilde{m}^{\frac{\alpha}{\alpha-1}} = 1 + \frac{1-\alpha}{\alpha}\frac{1}{\sigma}c^\tau \frac{1}{X^{\frac{1}{1-\alpha}}\tilde{m}^{\frac{\alpha}{1-\alpha}}}$$

$$= 1 + \frac{1-\alpha}{\alpha}\frac{1}{\sigma}\frac{1}{n^*(\tilde{m})}c^\tau > 0$$

Appendix B: Calculation process

B-1: Demand function for views

$$\frac{\partial U^i}{\partial n^i_j} = \alpha(m^j n^i_j)^{\alpha-1} m^j - c = \alpha {m^j}^{\alpha} {n^i_j}^{\alpha-1} - c = 0$$

$$n^i_j * = \left(\frac{c}{\alpha {m^j}^{\alpha}}\right)^{\frac{1}{\alpha-1}} = \left(\frac{\alpha {m^j}^{\alpha}}{c}\right)^{\frac{1}{1-\alpha}}$$

B-2: Utility function

$$f^i = \sum_{j\neq i}^{h}\left(m^j n^i_j\right)^{\alpha} - c\sum_{j\neq i}^{h} n^i_j = (h-1)m^{\alpha}\left(\frac{\alpha m^{\alpha}}{c}\right)^{\frac{\alpha}{1-\alpha}} - c(h-1)\left(\frac{\alpha m^{\alpha}}{c}\right)^{\frac{1}{1-\alpha}}$$
$$= (h-1)X^{\frac{\alpha}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} - c(h-1)X^{\frac{1}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}}$$

$$g^i = \sum_{j\neq i}^{h}\left(m^i n^j_i\right)^{\beta} = (h-1)m^{\beta}\left(\frac{\alpha m^{\alpha}}{c}\right)^{\frac{\beta}{1-\alpha}} = (h-1)X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta}{1-\alpha}}$$

$$U^i = f^i - g^i = (h-1)X^{\frac{\alpha}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} - c(h-1)X^{\frac{1}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} - (h-1)X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta}{1-\alpha}}$$
$$= (h-1)X^{\frac{\alpha}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} - c(h-1)X^{\frac{1}{1-\alpha}} m^{\frac{\alpha}{1-\alpha}} - (h-1)X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta}{1-\alpha}}$$
$$= (h-1)m^{\frac{\alpha}{1-\alpha}}\left(X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{1}{1-\alpha}} - X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta-\alpha}{1-\alpha}}\right)$$

B-3: Zero utility

$U^i = 0$: $m^{\frac{\alpha}{1-\alpha}} = 0$ or $X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{1}{1-\alpha}} - X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta-\alpha}{1-\alpha}} = 0$

$$X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta-\alpha}{1-\alpha}} = X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{1}{1-\alpha}}$$

$$m^{\frac{\beta-\alpha}{1-\alpha}} = X^{\frac{\alpha-\beta}{1-\alpha}} - cX^{\frac{1-\beta}{1-\alpha}}$$

$$\bar{m} = \left(X^{\frac{\alpha-\beta}{1-\alpha}} - cX^{\frac{1-\beta}{1-\alpha}}\right)^{\frac{1-\alpha}{\beta-\alpha}}$$

Therefore,

$\bar{m} = 0$ and $\bar{m} = \left(X^{\frac{\alpha-\beta}{1-\alpha}} - cX^{\frac{1-\beta}{1-\alpha}}\right)^{\frac{1-\alpha}{\beta-\alpha}}$

B-4: Social optimum

$$f^j = \sum_{i \neq j}^{h} \left(m^i n_i^j *\right)^{\alpha} - c\sum_{i \neq j}^{h} n_i^j * = \sum_{i \neq j}^{h} \left(m^i \left(\frac{\alpha m^{i\alpha}}{c} \right)^{\frac{1}{1-\alpha}} \right)^{\alpha} - c\sum_{i \neq j}^{h} \left(\frac{\alpha m^{i\alpha}}{c} \right)^{\frac{1}{1-\alpha}}$$

$$= \sum_{i \neq j}^{h} \left(\frac{\alpha}{c} \right)^{\frac{\alpha}{1-\alpha}} m^{i\frac{\alpha}{1-\alpha}} - c\sum_{i \neq j}^{h} \left(\frac{\alpha}{c} \right)^{\frac{1}{1-\alpha}} m^{i\frac{\alpha}{1-\alpha}}$$

$$g^i = \sum_{j \neq i}^{h} \left(m^i n_i^j *\right)^{\beta} = \sum_{j \neq i}^{h} \left(m^i \left(\frac{\alpha m^{i\alpha}}{c} \right)^{\frac{1}{1-\alpha}} \right)^{\beta} = \sum_{j \neq i}^{h} m^{i\frac{\beta}{1-\alpha}} \left(\frac{\alpha}{c} \right)^{\frac{\beta}{1-\alpha}}$$

$$\frac{\partial f^j}{\partial m^i} = \frac{\alpha}{1-\alpha} X^{\frac{\alpha}{1-\alpha}} m^{\frac{2\alpha-1}{1-\alpha}} - \frac{\alpha}{1-\alpha} cX^{\frac{1}{1-\alpha}} m^{\frac{2\alpha-1}{1-\alpha}}$$

$$\frac{\partial g^i}{\partial m^i} = \frac{\beta}{1-\alpha} (h-1) X^{\frac{\beta}{1-\alpha}} m^{\frac{\alpha+\beta-1}{1-\alpha}} ,$$

where $X = \alpha / c$, $m = m^i$.

$$\frac{\partial W}{\partial m^i} = \sum_{i \neq j} \frac{\partial u^j}{\partial m^i} + \frac{\partial u^i}{\partial m^i} = \sum_{i \neq j} \frac{\partial f^j}{\partial m^i} - \frac{\partial g^i}{\partial m^i}$$

$$= (h-1)\frac{\alpha}{1-\alpha}\left(X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{1}{1-\alpha}} \right) m^{\frac{2\alpha-1}{1-\alpha}} - (h-1)\frac{\beta}{1-\alpha} X^{\frac{\beta}{1-\alpha}} m^{\frac{\alpha+\beta-1}{1-\alpha}}$$

$$= \frac{h-1}{(1-\alpha) m^{\frac{2\alpha-1}{1-\alpha}}} \left\{ \alpha \left(X^{\frac{\alpha}{1-\alpha}} - cX^{\frac{1}{1-\alpha}} \right) - \beta X^{\frac{\beta}{1-\alpha}} m^{\frac{\beta-\alpha}{1-\alpha}} \right\} = 0$$

$$\tilde{m} = \left\{ \frac{\alpha}{\beta} \left(X^{\frac{\alpha-\beta}{1-\alpha}} - cX^{\frac{1-\beta}{1-\alpha}} \right) \right\}^{\frac{1-\alpha}{\beta-\alpha}}$$

B-5: Profit maximization

$$\pi = \left(\sigma - t^{\sigma}\right) N - \left(c^{\tau} + t^{\tau}\right) M = \left(\sigma - t^{\sigma}\right) \sum_{j}^{h} \sum_{i \neq j}^{h} n_i^j * - \left(c^{\tau} + t^{\tau}\right) \sum_{i}^{h} m^i$$

$$= \left(\sigma - t^{\sigma}\right) h(h-1) \left(X m^{i\alpha} \right)^{\frac{1}{1-\alpha}} - \left(c^{\tau} + t^{\tau}\right) h m^i$$

$$\frac{d\pi}{dm^i} = \frac{\alpha}{1-\alpha} \left(\sigma - t^{\sigma}\right) h(h-1) X^{\frac{1}{1-\alpha}} m^{\frac{2\alpha-1}{1-\alpha}} - \left(c^{\tau} + t^{\tau}\right) h = 0$$

$$m^{\frac{2\alpha-1}{1-\alpha}} = \frac{(1-\alpha)\left(c^{\tau}+t^{\tau}\right)}{\alpha\left(\sigma-t^{\sigma}\right)(h-1)X^{\frac{1}{1-\alpha}}}$$

$$m^{*} = \left\{\frac{\alpha\left(\sigma-t^{\sigma}\right)(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\left(c^{\tau}+t^{\tau}\right)}\right\}^{\frac{1-2\alpha}{1-\alpha}}$$

B-6: Optimal taxes

$\hat{t}^{\tau}$ for $t^{\sigma}=0$

$$m^{*} = \left\{\frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\left(c^{\tau}+t^{\tau}\right)}\right\}^{\frac{1-2\alpha}{1-\alpha}} = \tilde{m}$$

$$\frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\left(c^{\tau}+t^{\tau}\right)} = \tilde{m}^{\frac{1-\alpha}{1-2\alpha}},\ \left(c^{\tau}+t^{\tau}\right)\tilde{m}^{\frac{1-\alpha}{1-2\alpha}} = \frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)}$$

$$\hat{t}^{\tau} = \frac{\alpha\sigma(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}} - c^{\tau}$$

$\hat{t}^{\sigma}$ for $t^{\tau}=0$

$$m^{*} = \left\{\frac{\alpha\left(\sigma-t^{\sigma}\right)(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)c^{\tau}}\right\}^{\frac{1-2\alpha}{1-\alpha}} = \tilde{m}$$

$$\frac{\alpha(\sigma-t^{\sigma})(h-1)X^{\frac{1}{1-\alpha}}}{(1-\alpha)c^{\tau}} = \tilde{m}^{\frac{1-\alpha}{1-2\alpha}},\ \sigma-t^{\sigma} = \frac{(1-\alpha)c^{\tau}\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}}{\alpha(h-1)X^{\frac{1}{1-\alpha}}}$$

$$\hat{t}^{\sigma} = \sigma - \frac{(1-\alpha)c^{\tau}\tilde{m}^{\frac{1-\alpha}{1-2\alpha}}}{\alpha(h-1)X^{\frac{1}{1-\alpha}}}$$

Appendix C: Case of $n = 3$

We consider the case of $n = 3$ and show externalities caused by personal information. Because of symmetric agents, we focus on the situation of agent 1. Their utility function is

$$U^1 = u^1\left(f^1(n_2^1, n_3^1; m^2, m^3; c), g^1(n_1^2, n_1^3; m^1) \right), \qquad \text{(C-1)}$$

and demand for viewings is determined by

$$\frac{\partial u^1}{\partial f^1}\frac{\partial f^1}{\partial n_2^1} = \frac{\partial u^1}{\partial f^1}\frac{\partial f^1}{\partial n_3^1} = 0. \qquad \text{(C-2)}$$

We obtain $n_2^1{*}(m^1, m^2, m^3)$ and $n_3^1{*}(m^1, m^2, m^3)$. By using the first-order condition for the demand function, the derivative of W is

$$\begin{aligned}
\frac{\partial W}{\partial m^1} &= \underset{-}{\frac{\partial U^1}{\partial m^1}} + \underset{+}{\frac{\partial U^2}{\partial m^1}} + \underset{+}{\frac{\partial U^3}{\partial m^1}} \\
&= \underset{-}{\frac{\partial u^1}{\partial g^1}}\left(\underset{+}{\frac{\partial g^1}{\partial n_1^2 *}}\underset{+}{\frac{\partial n_1^2 *}{\partial m^1}} + \underset{+}{\frac{\partial g^1}{\partial n_1^3 *}}\underset{+}{\frac{\partial n_1^3 *}{\partial m^1}} + \underset{+}{\frac{\partial g^1}{\partial m^1}} \right) \\
&\quad + \left(\underset{+}{\frac{\partial u^2}{\partial f^2}}\underset{+}{\frac{\partial f^2}{\partial m^1}} + \underset{-}{\frac{\partial u^2}{\partial g^2}}\underset{+}{\frac{\partial g^2}{\partial n_2^3 *}}\underset{-}{\frac{\partial n_2^3 *}{\partial m^1}} \right) + \left(\underset{+}{\frac{\partial u^3}{\partial f^3}}\underset{+}{\frac{\partial f^3}{\partial m^1}} + \underset{-}{\frac{\partial u^3}{\partial g^3}}\underset{+}{\frac{\partial g^3}{\partial n_3^2 *}}\underset{-}{\frac{\partial n_3^2 *}{\partial m^1}} \right). \qquad \text{(C-3)}
\end{aligned}$$

The marginal effect of m^1 on U^1 is negative, since both view times from others and the level of privacy invasion per view increase. The marginal effect of m^1 on U^2 and U^3 is positive. The reason is twofold: first, their utility level stemming from viewing m^1 increases, and, second, their damage from privacy invasion decreases due to $\partial n_2^3 * / \partial m^1 \le 0$ or $\partial n_3^2 * / \partial m^1 \le 0$. A corner solution of $m^1 * = 0$ is possible when the negative effect on U^1 exceeds the positive effect on U^2 and U^3 for all $m^1 (\ge 0)$.

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