Competing with Privacy*

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Abstract

We analyze the implications of consumer privacy for competition in the marketplace. We consider a market where firms set prices and disclosure levels for consumer information and consumers observe both before deciding which firm to patronize and how much information to provide it with. The provision and disclosure of information presents tradeoffs for all market participants. Consumers benefit from providing information to the firm, as this increases the utility they derive from the service, but they incur disutility from information disclosure. This in turn benefits the firm providing an additional source of revenue, but reduces consumer demand for the service. We characterize equilibrium information provision, disclosure levels, and prices as a function of the consumer population's valuation for the service, and show that competition has three main effects on the marketplace. First, competition drives the provision of services with a low level of disclosure. Second, competition ensures that services with a high level of disclosure subsidize consumers. And third, higher competition intensity tends to increase the volume of consumer information disclosed by firms. Our findings are particularly relevant to the business models of Internet firms and contribute to inform the regulatory debate on consumer privacy.

Keywords: Information Acquisition, Information Disclosure, Online Privacy, Privacy Regulation

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1 Introduction

Digitalization has dramatically lowered the costs of storing and processing large stocks of consumer information, enabling new forms of advertisement targeting, personalization tools, and price discrimination schemes. Personal consumer information has therefore become a valuable asset in the marketplace and an important element of firm strategy. Nowhere is this trend more visible than in online services, where firms are aggressively capturing large stocks of consumer information. Usage of these information-intensive services by consumers implies provision of personal information, and firms exploit such information to generate new sources of revenue. These tradeoffs are defining business models and the role of privacy in online marketplaces.

Prominent examples of these trends can be identified among major Internet players. Google provides consumers with services to search the web, manage their email correspondence (gMail), contacts (Google+), calendar events (Google Calendar), and documents (Google Docs). Consumers provide personal information to use these services, informing Google about their location, interests, and social connections when performing searches, communicating with others, and managing their documents, and derive a direct benefit from the services in doing so. Google in turn derives revenues by disclosing the information to advertisers, charging them to selectively target users. A larger stock of consumer information increases the effectiveness of the targeting and allows Google to derive higher disclosure revenues, although advertising reduces the benefits consumers derive from the services. The deal Google offers consumers is readily understood: free services in exchange for ads.

Other major Internet players such as Microsoft and Amazon compete with different approaches. Microsoft has recently introduced Office 365, an online service which competes with Google's by allowing consumers to edit documents, manage email, contacts, and calendar events. In contrast with Google, however, Microsoft charges consumers for the service and does not disclose their information for advertising purposes. Microsoft's recent Scroogled! campaign emphasized the difference in the following terms: "Google goes through every gMail that's sent or received, looking for keywords so they can target gMail users with paid ads. And there's no way to opt out of this invasion of your privacy. Outlook.com is different — we don't go through your email to sell ads."

Amazon plays an important role in online search by indexing a large number of products and allowing third-party sellers to supply them through its websites, competing with Google as a search gateway in the retail arena. Amazon also exploits consumer information to profile users based on their search interests and past purchases, and derives revenues by disclosing this information to advertisers. Furthermore, through its *Special Offers* program, Amazon has started to subsidize consumers willing to accept targeted advertising. Consumers currently benefit from $15 and $20 discounts when purchasing Kindle tablets and e-readers, respectively, if willing to accept advertisements on it. This subsidy renders the basic Kindle e-reader one of the cheapest devices of its kind.

These examples illustrate the choices consumers face when providing their personal information to online services and the revenue streams firms can tap into by disclosing it. The question is now, how does this shape competition? Should firms exploit all available revenue sources, prices and disclosure, or focus on one? If so, which is more profitable and what does it depend on? In this paper we present a model to analyze the strategic interactions generated by consumer information provision and firm disclosure, and how they affect competition in the marketplace. To the best of our knowledge, we contribute the first analysis that explains how the provision and disclosure of consumer information shapes the competitive interaction of firms.

We build on a standard vertical differentiation framework to capture the informational dimension of the problem, and do so by adopting a reduced-form specification for service quality which captures the tradeoffs outlined above. Firms provide a homogeneous service to consumers and compete on prices and information disclosure.[1] On the demand side, consumers are the gatekeepers of their personal information, and they observe the degree of information disclosure firms engage in as well as their price before deciding which service to patronize (if any) and how much personal information to provide it with. The perceived quality of the firm's service for each consumer increases with information provision and decreases with the firm's level of disclosure. On the supply side, there are two revenue sources available to firms: sales revenues originating from the prices charged to consumers, and disclosure revenues which depend on their degree of disclosure and stock of consumer information. Firms may choose to exploit both, to forego sales revenues by subsidizing consumers, or to forego disclosure revenues by not engaging in disclosure.

Our analysis provides insight on how firms compete for consumer information. We show that firms exploit consumer heterogeneity by differentiating in their levels of information disclosure, even when doing so sacrifices disclosure revenues. Firms choose to compete by focusing on a single revenue source and foregoing the other. A firm engaging in a high level of disclosure (low-quality service) chooses to subsidize consumers, and a firm engaging in a low level of disclosure (high-quality service) charges positive prices. Such an outcome is a direct consequence of competition, as we show that a monopolist tends to exploit both revenue sources and never subsidizes consumers. Moreover, competition benefits the high-disclosure (low-quality) firm, which is generally more profitable and obtains a larger market share than the low-disclosure competitor, contrary to what would be predicted by a standard vertical differentiation framework.

Our analysis also provides insight on the effect of competition on consumer privacy by explaining the aggregate stock of consumer information disclosed by firms. We find that the stock of consumer information disclosed in the market is always lower under competition than under monopoly. Thus consumers derive higher surplus and benefit from competition, as should be expected. But perhaps counterintuitively, higher intensity of competition between firms (which can be captured in

[1] We use the term *disclosure* to refer to the exploitation of consumer information for revenue-generating purposes, although some forms of exploitation may not imply the transfer of information to third parties. For example, spot markets for online advertising may not allow advertisers to observe the identity of the target consumer. Nonetheless, the outcome is equivalent to the extent that they enable advertisers to reach their target audience.

our analysis by the heterogeneity of the consumer population) increases the stock of information disclosed in the market, reducing consumer privacy. Consumers still benefit, but do so mainly through prices (or subsidies) rather than through reductions in the disclosure of their information. In addition, the high-disclosure firm tends to generate higher consumer surplus in equilibrium. From a policy perspective, this implies that higher levels of disclosure should be expected in a competitive marketplace and do not reduce consumer welfare when compensated by subsidization.

The model we use to derive our results is internally complex but tractable, and provides for clean qualitative predictions in equilibrium. We fully endogenize all the information decisions of market participants, and the only exogenous parameters in our analysis are those that define the distribution of valuations across the consumer population. To obtain the results, several simplifications are needed. We consider a market where engaging in disclosure is profitable for firms and restrict our analysis to covered market equilibria where all consumers choose to sign up for one of the services. We also assume consumer valuations are uniformly distributed and firm marginal costs are zero. Our analysis is best suited to online services operating with negligible marginal costs and large userbases.

Our model provides a benchmark for consumer privacy in the context of informed and rational consumers. We assume consumers are aware of disclosure policies and internalize their impact in their decisions and usage of services. Although we recognize that factors such as bounded rationality or cognitive biases can distort consumer decisions regarding the use of their personal information, we expect consumers to become increasingly familiar with privacy tradeoffs in the marketplace. Such consumers can be interpreted as *privacy pragmatists* according to survey classifications of privacy attitudes: they are concerned about privacy but are willing to trade it off if an evaluation of the benefits and risks pays off. A growing majority of US consumers have been reported to pertain to this category.[2]

In the next section, we position our paper in the context of the recent managerial and economics literature relating to online privacy. Section 2 introduces the building blocks of our model and the timing of the game. We characterize the monopoly solution in Section 3. This serves as a benchmark to evaluate the implications of competition. We proceed to solve for the case of duopoly in Section 4, characterize the equilibrium and provide a qualitative comparison of its characteristics with respect to the monopoly outcome. In Section 5, we consider policy implications by evaluating consumer surplus and the stock of information accumulated and disclosed by firms. Section 6 concludes.

[2]See Alan Westin's report 'How online users feel about behavioral marketing and how adoption of privacy and security policies could affect their feelings,' Privacy Consulting Group, March 2008.

1.1 Literature

Privacy is a multidisciplinary concept which has been studied across several fields including economics, law, sociology, and political science. Our work relates to the economic dimension of privacy, understood as the control over access to information by economic agents and its associated tradeoffs. Posner (1981) and Stigler (1980) famously argued that privacy can lead to allocation inefficiencies, and is therefore undesirable in the absence of externalities or explicit preferences for privacy. This view has been challenged more recently. Hermalin and Katz (2006) analyze the implications of different privacy regimes and their impact on allocative efficiency in the absence of such externalities and preferences, and find that privacy can be socially desirable in some cases. Calzolari and Pavan (2006) evaluate information disclosure between two principals sequentially contracting with a common agent who strategically decides whether to report her true type, and show that the effect of privacy on welfare is ambiguous. Hui and Png (2006) provide a survey on the economics of privacy and argue that externalities generally play an important role in the collection and exploitation of consumer information.

Our approach is motivated by the most prevalent forms of exploitation of consumer information in online services, such as advertising. These forms of exploitation can impose negative externalities on consumers in the form of attention costs or search bias (or do so beyond some overload threshold). In addition, consumers generally exhibit an explicit preference for privacy over their communication channels. Noam (1995a, 1995b) provides a prescient account of the privacy implications of advances in electronic telecommunications, and argues that a competitive marketplace can contribute solutions to consumer demands for privacy. Spulber (2009) reviews the evolving market structure of online search and advertising services, and argues that competition in this market can discipline the disclosure policies of search firms and increase the share of the surplus appropriated by consumers. Our contribution formalizes these arguments and explains the precise impact of competition in this market. In particular, we show that gains in consumer surplus associated with higher intensity of competition need not result in privacy improvements when information disclosure is profitable for firms.

A recent strand of the theoretical literature has examined the implications of consumer privacy with regard to anonymity and price discrimination. If firms can identify returning consumers, they may infer their willingness to pay and set prices accordingly. Villas-Boas (2004) considers the case of a monopolist facing both new and returning consumers, and shows that optimal pricing can exhibit price cycles over time. Taylor (2004) considers the case of two sequential sellers and examines how information disclosure between sellers affects their pricing strategies. Acquisti and Varian (2005) examine the case where sophisticated consumers can use anonymizing tools and firms can offer improved service to those that choose to remain identifiable. Conitzer, Taylor and Wagman (2012) analyze the impact of the cost of anonymity for consumers facing a monopolist, and show that increasing the cost of anonymity can benefit consumers.

Our focus differs from the above contributions in that we consider the effect of consumer information provision on the quality of services rather than on prices. Our approach relates to that of Akçura and Srinivasan (2005), who first examined the tradeoff faced by the monopolist deriving both sales revenues and disclosure revenues. They analyze the case where the monopolist decides the supply of information required of consumers in order for them to participate in the service. Our approach differs in that we examine the case where consumers unilaterally decide how much information to provide and we also analyze competition. Because consumers derive positive utility from information provision in our model, our approach is better suited to applications where consumers directly benefit from providing information (e.g., search engines, cloud storage) and Akçura and Srinivasan's model is better suited to applications where consumer information mainly benefits the firm (e.g., airline bookings, retail banking). We further relate our findings to those of Akçura and Srinivasan in our monopoly analysis in Section 3.

In recent years, several papers have examined consumer attitudes toward online privacy. Chellappa and Sin (2005) present a survey to evaluate the tradeoff consumers face when providing personal information to online services. They measure consumer valuations for the personalization benefits as well as consumer concerns regarding alternative uses of their information by the firm. They find that consumers' positive valuation for personalization exceeds their negative concern for privacy. Tsai et al. (2011) report an online shopping experiment based on a search engine where results are annotated with privacy ratings based on sellers' privacy policies. They find that subjects are willing to pay a premium for privacy when such information is salient. Tucker (2011) analyzes the effectiveness of a personalized advertising campaign in a social network, and finds that it is positively affected by consumers' perceived control over the use of their personal information. The findings reported in these papers suggest that consumers account for privacy considerations when deciding which firms to patronize and how much personal information to provide.

Other empirical contributions have considered the supply side of the market. Preibusch and Bonneau (2013) analyze the degree of differentiation in the data collection policies of major Internet sites according to traffic rank in several service categories. They find a significant degree of differentiation in search engines and social networking, categories that meet the characteristics of those considered here. They also find that services operating under less competition tend to request consumers to supply more personal information. Goldfarb and Tucker (2010) evaluate the impact of privacy regulations in Europe on the effectiveness of online advertising. These regulations restrict the information that can be collected and processed from consumers for the purpose of targeted advertising, in effect restricting information disclosure by firms. They find that such restrictions significantly reduce advertising effectiveness, and should therefore be expected to reduce the disclosure revenues of firms.

2 The model

Consider a market with two firms and a unit mass of consumers. Firms supply a homogeneous service and compete on two separate dimensions: price and privacy. Each firm sets a price p_j and a level of consumer information disclosure d_j for its service. Consumers are heterogeneous in their valuation of the service, which is uniformly distributed across the consumer population. The valuation of consumer i is given by $v_i \sim U[v, V]$. We will assume that $v > v_{min}$ and $V \leq 1$, where v_{min} is characterized in the Appendix. The lower bound on v ensures that the market is covered in equilibrium, and the upper bound on V ensures that disclosure is profitable in the market.

Consumers participating in the market and signing up to the service of one of the firms decide how much personal information to provide, and we denote the information provision of consumer i to firm j by $y_{i,j}$.[3] The utility derived by consumer i from firm j, given price p_j and disclosure level d_j, is given by

$$u_{i,j} = \mu(y_{i,j}, d_j)\, v_i - p_j, \tag{1}$$

where $\mu(\cdot)$ is the informational quality of the service and $\mu(\cdot)\, v_i$ captures the willingness to pay of consumer i for firm j's service. We assume $\mu(\cdot)$ is inverse U-shaped in $y_{i,j}$ and decreasing in d_j as follows

$$\mu(y_{i,j}, d_j) = y_{i,j} - y_{i,j}^2 - d_j y_{i,j}.$$

The specification ensures that consumers benefit from providing information $y_{i,j}$ to the firm but incur disutility from firm disclosure d_j.[4] The marginal benefit of information provision is decreasing: the information provided by each consumer is decreasing in its relevance to the service. Note that both $y_{i,j}$ and d_j are endogenous and will be jointly determined in equilibrium; consumers need to provide some information to derive positive utility from the service and firms may choose to engage or not in disclosure, $y_{i,j} \geq 0$ and $d_j \geq 0$. Consumers may sign up for the service of one of the firms or remain out of the market, and so we normalize the outside utility of consumers to zero.

Firm profits originate from two revenue sources, the prices directly charged to consumers and disclosure revenues originating from the exploitation of consumer information. We simplify the latter by adopting a reduced form for disclosure revenues. The profits of firm j when serving consumers $v_i \in [\underline{v}, \overline{v}]$ are given by

$$\pi_j = \frac{1}{V - v} \int_{\underline{v}}^{\overline{v}} p_j + d_j y_{i,j}\, \mathrm{d}v_i.$$

[3] When usage of the service implies information provision, $y_{i,j}$ can also be interpreted as usage intensity.

[4] We assume for simplicity that consumers always derive disutility from disclosure. If consumers exhibit an acceptance threshold for disclosure, for example if a certain degree of advertising is acceptable, then disclosure in our model can be interpreted as the level of excess advertising that firms engage in.

Note that the relative weight of price revenues with respect to disclosure revenues will depend on consumers' willingness to pay, which in turn depends on the firm's disclosure and consumer valuations for the service. We let firms set negative prices if they choose to subsidize consumers. We assume that firms face zero marginal costs to simplify the analysis, and without loss of generality, assume fixed costs are zero.

The timing of the game is as follows. In the first stage, firms simultaneously set their disclosure level d_j.[5] In the second stage, firms simultaneously set prices p_j. In the third stage, having observed disclosures and prices, consumers choose to sign up for the service offered by one of the firms or to stay out of the market. In the fourth stage, consumers patronizing a firm decide how much information $y_{i,j}$ to provide it with.

3 Monopoly benchmark

We start our analysis by considering the monopoly case, which serves as a benchmark to evaluate the impact of competition in the next section. We proceed to solve the game by backwards induction.

Consumer information provision. Consider the problem of consumer v_i in the fourth stage when deciding how much information to provide firm j with when using its service. The consumer maximizes utility $u_{i,j}$ in (1) with respect to $y_{i,j}$ given the firm's disclosure level d_j and price p_j. Consumers' optimal information provision is determined by disclosure d_j and is given by (dropping subindex i because it does not depend on v_i)

$$y_j = \frac{1 - d_j}{2}. \tag{2}$$

Optimal information provision is homogeneous across consumers, so that the firm obtains the same amount of information from each of its users.

Consumer purchasing decision. We next consider the problem of consumer v_i in the third stage when deciding to sign up for firm j's service or stay out of the market. The consumer will evaluate the utility derived from the service given by $u_{i,j}$ in (1), anticipating optimal information provision given by (2), and will only sign up if $u_{i,j} \geq 0$. We proceed by identifying the *indifferent consumer* v_f who is strictly indifferent between signing up or not. Solving for $u_{f,j} = 0$ yields

$$v_f = \frac{4p_j}{(1 - d_j)^2}. \tag{3}$$

[5]Firms are committed to their announced levels of disclosure and cannot increase it after obtaining personal consumer information. Reputational concerns can provide incentives for firms not to engage in such tactics. And when such incentives fail, privacy regulators can intervene to avoid consumer deception. For example, when Toysmart.com filed for bankruptcy in the US and attempted to sell its personal customer information, the FTC blocked the sale because the company's privacy policy stated that 'when you register with Toysmart.com, you can rest assured that your information will never be shared with a third party.' See 'FTC Sues Failed Website, Toysmart.com, for Deceptively Offering for Sale Personal Information of Website Visitors,' FTC press release, July 2000.

Note that $\partial u_{i,j}/\partial v_i > 0$ given optimal information provision in (2), so consumers with a higher valuation than the indifferent consumer $v_i > v_f$ will prefer to sign up and those with lower valuation $v_i < v_f$ will prefer to stay out. Therefore, when $v_f > v$, some consumers do not sign up and the market is uncovered, and when $v_f \leq v$, all consumers sign up and the market is covered. Because the monopolist's demand differs in the covered and uncovered market configurations, both cases need to be considered separately in what follows.

Monopoly pricing. Consider the pricing problem of a monopolist in the second stage given disclosure level d_m. Consider first the case of an uncovered market. Given that consumer information provision in (2) is homogeneous across all consumers signing up for the service, we can write the monopolist's profits as

$$\pi_m^u(p_m, d_m) = \frac{V - v_f}{V - v}(p_m + d_m y_m), \tag{4}$$

and solving for the monopolist's optimal price in an uncovered market, to be denoted by p_m^u, obtains

$$p_m^u = \frac{(1 - d_m)(V(1 - d_m) - 2d_m)}{8}. \tag{5}$$

Consider next the case of a covered market. Monopoly profits can be written as

$$\pi_m^c(p_m, d_m) = p_m + d_m y_m, \tag{6}$$

and the monopolist's optimal price in a covered market, denoted by p_m^c, is given by the highest price that ensures all consumers sign up. The indifferent consumer v_f must then be identified by the consumer with the lowest willingness to pay in the population, $v_f(p_m^c, d_m) = v$, which implies

$$p_m^c = \frac{v(1 - d_m)^2}{4}. \tag{7}$$

Monopoly disclosure. Consider the first stage of the game where the monopolist sets disclosure level d_m. Inspection of y_j in (2) reveals that the valid disclosure range of the firm is given by $d_j \in [0, 1]$, given that negative disclosure or negative information provision are both unfeasible.

In an uncovered market configuration, plugging optimal price p_m^u in (5) into profits π_m^u in (4) obtains monopoly profits as a function of disclosure $\pi_m^u(d_m)$. Inspection reveals that $\partial \pi_m^u(d_m)/\partial d_m > 0$ within the parameter space for our analysis, so no uncovered market solution exists because it is always profitable for the monopolist to cover the market. To see this, note that the monopolist increases market coverage when increasing disclosure, $\partial v_f(p_m^u, d_m)/\partial d_m < 0$, and the feasible disclosure range always yields a covered market, $v_f(p_m^u, d_m = 1) < v$.

Consider a covered market configuration. Plugging optimal price p_m^c in (7) into profits π_m^c in (6) obtains profits as a function of disclosure $\pi_m^c(d_m)$. Recall that optimal price p_m^c ensures that the market is effectively covered. Maximizing $\pi_m^c(d_m)$ with respect to d_m identifies optimal disclosure in a covered market, and the solution is always well defined within the feasible disclosure range.

The following proposition summarizes the result.

Proposition 1. *The monopoly solution is given by disclosure level* $d_m = (1-v)/(2-v)$ *and price* $p_m = v/(8-4v)^2$*, and the market is always covered in equilibrium.*

The monopolist's problem consists of determining both the price and the level of disclosure of consumer information, which determine the userbase of the service and the stock of information obtained from consumers. The monopolist faces a tradeoff in making this choice. On the one hand, increasing the price reduces demand for the service, and this reduces the userbase and the information stock over which the firm can extract disclosure revenues from. On the other hand, increasing the level of disclosure reduces consumers' willingness to pay for the service, reducing price revenues.

In addition to the above tradeoff, the monopolist faces an information provision tradeoff when setting the level of disclosure. The provision of information by consumers signing up for the service is decreasing in the level of disclosure, and consumers prefer not to provide information to the firm when it engages in maximum disclosure. Increasing the level of disclosure, therefore, has a non-monotonic impact on disclosure revenues, and the highest feasible level of disclosure is never optimal. The monopolist will consider only intermediate levels of disclosure, striking a balance between the information stock obtained from consumers and the revenues from disclosing it.

In equilibrium, the monopolist chooses to cover the market by ensuring that all consumers sign up for the service and exploits both revenue sources, quoting a positive price as well as engaging in information disclosure.[6] The tradeoffs outlined above imply that the higher the price quoted for the service, the lower the level of disclosure in equilibrium (and vice versa). The exact price and disclosure level set by the monopolist will depend on the consumer population's valuation for the service, which is a function of the two exogenous parameters in our model, v and V. Consumer valuations determine consumers' willingness to pay for the service and therefore the optimal weight the monopolist should attach to price revenues with respect to disclosure revenues.

To characterize the monopoly solution it is useful to evaluate separately the impact of changes in the mean and the spread of the consumer population's distribution of valuations, as depicted in Figure 1. Consider first an increase in the mean that preserves the spread. This increases the valuation of the average consumer, which is reflected in their willingness to pay, and therefore increases the potential price revenues for the firm. As a result, an increase in the mean valuation drives the monopolist to increase the price and reduce disclosure, increasing the monopolist's profits. It can be shown that in the corner case where all consumers exhibit maximum valuation, $v \to 1$, the monopolist chooses not to engage in disclosure and relies exclusively on price revenues.

Consider next a mean-preserving increase in the spread of the distribution (which increases the standard deviation as depicted in Figure 1, given that we are considering a uniform distribution).

[6] It can be shown that if consumer valuations are sufficiently high, $V > 1$, the monopolist chooses not to engage in disclosure (and may not cover the market). We restrict our attention to the case where $V \leq 1$, which ensures that disclosure is profitable.

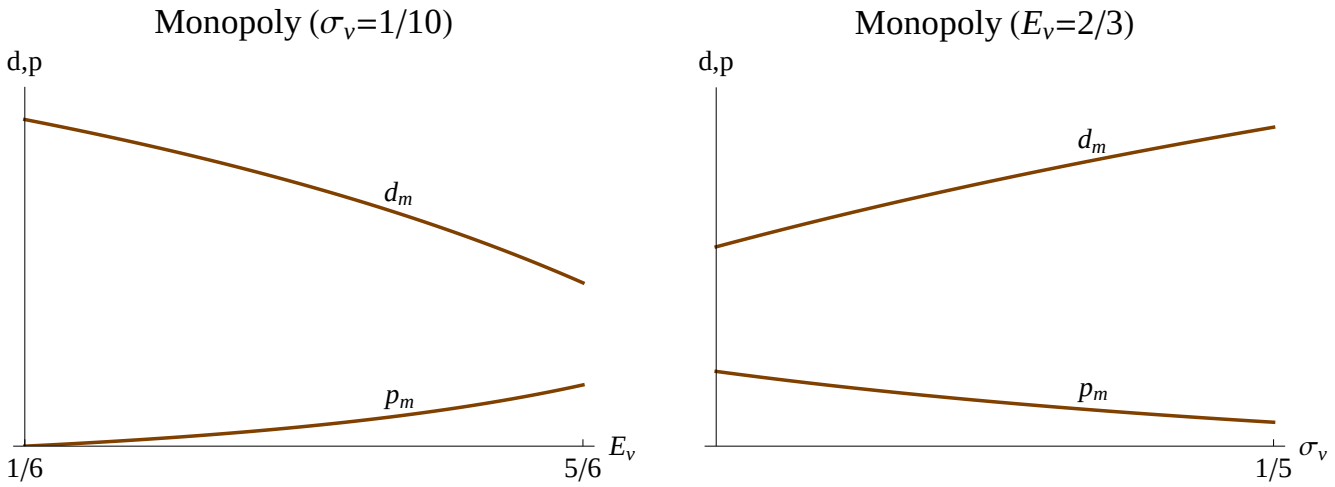

Figure 1: Monopoly disclosure and price as a function of the consumer population's valuation mean (left) and spread (right). The axes origins are located at (0,0) in all plots unless otherwise noted.

This implies that consumer valuations become more heterogeneous across the population, reducing the price revenues the firm can extract from the service. This drives the monopolist to lower the price in order to ensure that all consumers participate and to increase disclosure, reducing the monopolist's profits. In the corner case where some consumers exhibit negligible willingness to pay, $v \to 0$, the monopolist chooses not to charge for the service and relies exclusively on disclosure revenues.

Our monopoly analysis is closely related to that of Akçura and Srinivasan (2005), who first analyzed the problem of the monopolist facing a tradeoff between sales revenues and disclosure revenues. In both cases, higher levels of information disclosure in equilibrium command lower prices for consumers. An important difference, however, is that the monopolist may subsidize some consumers in their model. This outcome arises in Akçura and Srinivasan's analysis because they consider the case where the monopolist can decide the supply of information required of consumers and also price-discriminate across them. In our model, the monopolist sets a common price for all consumers, and consumers decide unilaterally how much information to provide. In this context the monopolist never chooses to subsidize consumers, and we show in the next section that subsidization will only arise under competition.[7]

It is also worth noting that Akçura and Srinivasan (2005) consider a specification where disclosure revenues depend on consumer valuations. In our model, consumer valuations for the service and disclosure revenues are independent; higher consumer valuations do not translate into higher disclosure revenues. However, in some cases, both may be correlated. Wealthier consumers with a

[7]In effect, we have restricted our analysis to the case where the monopolist supplies a single service on the market. When the distribution of valuations exhibits a high spread so that consumers are very heterogeneous, the monopolist could benefit from catering different service tiers to different consumer segments. In the next section, we show that consumer heterogeneity is the main determinant of the intensity of competition when additional firms are present in the market.

higher willingness to pay are also more valuable targets for advertisers. We note that if consumer valuations were positively correlated with disclosure revenues in our model, this would reduce the monopolist's incentives to cover the market, given that serving low valuation consumers becomes comparatively less profitable.

4 Competing with privacy

We next evaluate the case of duopoly. A straightforward implication of our model is that firms supplying homogeneous services will benefit from differentiating in their disclosure levels. Note that if two firms set the same disclosure level in the marketplace, inspection of $u_{i,j}$ in (1) reveals that they become perfect substitutes for consumers, and pure price competition then drives their profits down to zero. Therefore, one firm will set a high disclosure level and the other firm will set a low disclosure level, and we proceed by letting $j \in \{h, l\}$ identify both firms when $d_h > d_l$.

To solve for the duopoly equilibrium, note that consumer information provision in the fourth stage characterized in (2) carries over to the case of duopoly for each firm. We start by characterizing purchasing decisions in the third stage. We restrict our analysis to covered market configurations where all consumers choose to participate in the market. Below we characterize the duopoly solution in a covered market, and in the Appendix we show that it constitutes an equilibrium for the parameter range considered in our analysis.[8]

Consumer purchasing decision. Consider the problem of consumer v_i when deciding to sign up with firm h, sign up with firm l, or stay out of the market. Consider first the case where the high-disclosure firm sets a lower price than the low-disclosure firm $p_h < p_l$. Note that $\partial u_{i,l}/\partial v_i > \partial u_{i,h}/\partial v_i > 0$ given optimal information provision y_j in (2), so that high-valuation consumers will sign up with firm l and low-valuation consumers will sign up with firm h. We can identify the *pivot consumer* v_p who is strictly indifferent between signing up with firm l or firm h by equating $u_{p,l} = u_{p,h}$,

$$v_p = \frac{4(p_l - p_h)}{(d_h - d_l)(2 - d_h - d_l)}. \tag{8}$$

The consumer who is indifferent between signing up with firm h or staying out of the market carries over from our previous analysis and will be given by $v_f(p_h, d_h)$ in (3). Consumer purchasing decisions can then be characterized as follows: consumers $v_i \in [v, v_f)$ stay out of the market, consumers $v_i \in [v_f, v_p)$ sign up with firm h, and consumers $v_i \in [v_p, V]$ sign up with firm l. Note that a covered market configuration requires $v_f \leq v$ for all consumers to sign up with one of the firms. We proceed to characterize optimal prices and disclosures assuming the market is covered and will verify that the solution indeed satisfies $v_f \leq v$. We also show in the Appendix that no firm

[8] We have also analyzed uncovered market configurations under duopoly, but unfortunately found them to be intractable. Nonetheless, we believe that the covered market configuration is empirically relevant given the high market penetration enjoyed by free or subsidized online services.

has incentives to unilaterally deviate to an uncovered market configuration so that the solution constitutes an equilibrium.

The remaining case is that where the high-disclosure firm does not price below the low-disclosure firm, $p_h \geq p_l$. All consumers then derive higher utility from firm l, so firm h faces no demand and derives zero profits. For simplicity, we omit further analysis of this case and show below that firm h can obtain positive profits by undercutting the price of firm l, so $p_h \geq p_l$ will never arise in equilibrium.

Duopoly pricing. Consider the pricing problem of both firms in the second stage given disclosure levels d_l and d_h. The profits of both firms in a covered market configuration when $p_h < p_l$ are given by

$$\begin{aligned} \pi_l(p_l, p_h, d_l, d_h) =& \frac{V - v_p}{V - v}(p_l + d_l y_l) \\ \pi_h(p_h, p_l, d_h, d_l) =& \frac{v_p - v}{V - v}(p_h + d_h y_h). \end{aligned} \tag{9}$$

Solving for the optimal prices of both firms obtains

$$\begin{aligned} p_l =& \frac{1}{12}\left(d_h^2(2 + v - 2V) - 2d_h(1 + v - 2V) + d_l\left(d_l(4 - v + 2V) - 4 + 2v - 4V\right)\right) \\ p_h =& \frac{1}{12}\left(d_l^2(2 - 2v + V) + d_l(-2 + 4v - 2V) + d_h\left(d_h(4 + 2v - V) - 4 - 4v + 2V\right)\right). \end{aligned} \tag{10}$$

Duopoly disclosures. Consider the problem of both firms in the first stage when choosing disclosure levels d_l and d_h. Plugging optimal prices p_l and p_h in (10) into firm profits π_l and π_h in (9) obtains the profits of both firms as a function of disclosures, $\pi_l(d_l, d_h)$ and $\pi_h(d_h, d_l)$. Solving $\partial \pi_j(d_j, d_{-j})/\partial d_j = 0$ for each firm identifies three candidate best-responses per firm. Denote the candidate best-responses of firm j by $\hat{d}_j^k$ and let superscript $k \in \{a, b, c\}$ identify each of the three solutions, then

$$\begin{aligned} \hat{d}_l^a =& 2 - d_h - \frac{2}{v - 2V + 2} \\ \hat{d}_l^b =& \frac{3 - d_h}{2} + \frac{\sqrt{(2V - v - 2)(1 - d_h)\left(2\left((1 - V)d_h + V - 5\right) - v(1 - d_h)\right)}}{4V - 2v - 4} \\ \hat{d}_l^c =& \frac{3 - d_h}{2} - \frac{\sqrt{(2V - v - 2)(1 - d_h)\left(2\left((1 - V)d_h + V - 5\right) - v(1 - d_h)\right)}}{4V - 2v - 4} \\ \hat{d}_h^a =& 2 - d_l - \frac{2}{V - 2v + 2} \\ \hat{d}_h^b =& \frac{3 - d_l}{2} + \frac{\sqrt{(V - 2v + 2)(1 - d_l)\left(V - 2v(1 - d_l) - (2 + V)d_l + 10\right)}}{2V - 4v + 4} \\ \hat{d}_h^c =& \frac{3 - d_l}{2} - \frac{\sqrt{(V - 2v + 2)(1 - d_l)\left(V - 2v(1 - d_l) - (2 + V)d_l + 10\right)}}{2V - 4v + 4}. \end{aligned}$$

To identify valid best-responses, note that $\hat{d}_l^k$ is only a best-response for firm l when it satisfies

the second-order condition $\partial^2\pi_l(\hat{d}_l^k, d_h)/\partial d_l^2 < 0$, given the disclosure ordering $\hat{d}_l^k < d_h$ taking d_h as exogenous. This obtains a parameter space over v, V, and d_h for each valid best-response of firm l, and allows us to discard $\hat{d}_l^a$ and $\hat{d}_l^c$ which are never valid best-responses. The same process can be repeated to identify the valid best-responses of firm h, where the disclosure ordering is given by $\hat{d}_h^k > d_l$ taking d_l as exogenous. This allows us to discard $\hat{d}_h^a$. The valid best-responses of both firms are given by:

$$\begin{aligned}
&\hat{d}_l^b \text{ is a valid best-response for firm } l \text{ when } \tfrac{1+v-2V}{2+v-2V} < d_h < 1\\
&\hat{d}_h^b \text{ is a valid best-response for firm } h \text{ when } d_l < 1\\
&\hat{d}_h^c \text{ is a valid best-response for firm } h \text{ when } d_l < \tfrac{1-2v+V}{2-2v+V}.
\end{aligned}$$

We next identify candidate equilibria by solving for d_l and d_h based on each combination of valid best-responses for firm l and firm h, and evaluate whether the solution is contained in the parameter space where both best-responses hold. It can be readily verified that $\hat{d}_l^b$ and $\hat{d}_h^b$ never constitute a candidate equilibrium. The single candidate equilibrium in the game is given by $\hat{d}_l^b$ and $\hat{d}_h^c$. Also note that $\partial\hat{d}_l^b/\partial d_h > 0$ and $\partial\hat{d}_h^c/\partial d_l > 0$, so firm disclosures are strategic complements. Firm disclosures in the candidate equilibrium are characterized by

$$\begin{aligned}
d_l^{bc} =& 1 + \frac{2}{3(V-v)} - \frac{2}{3}\sqrt{\frac{V-2v+2}{(2+v-2V)(V-v)^2}}\\
d_h^{bc} =& 1 - \frac{2}{3(V-v)} + \frac{2}{3}\sqrt{\frac{2V-v-2}{(2v-2-V)(V-v)^2}}.
\end{aligned}$$

For the candidate equilibrium to hold, firm disclosures must be contained within the valid disclosure range, $d_j \in [0,1]$. Corner solutions need to be considered when valid best-responses fall outside the valid disclosure range. Inspection of d_l^{bc} and d_h^{bc} reveals that there is an interior solution where $0 < d_l^{bc} < d_h^{bc} < 1$, as well as a corner solution where $d_l^{bc} \leq 0$. The parameter space for the corner solution is given by a threshold value v^* which ensures that $d_l^{bc} \leq 0$ when $v \leq v^*$. In the corner solution, firm l does not engage in disclosure, $d_l = 0$, and the disclosure of firm h is given by its best-response $\hat{d}_h^c(d_l = 0)$.

Both the interior and corner solutions provided by $\hat{d}_l^b$ and $\hat{d}_h^c$ will constitute an equilibrium if they yield a covered market and no firm has incentives to unilaterally deviate to an uncovered market configuration. Evaluation of the indifferent consumer $v_f(p_h, d_h)$ in (3) for both solutions reveals that $v_f \leq v$ within the parameter space for each solution, so the market is effectively covered. The Appendix establishes that no unilateral deviations pay off in the parameter range considered in our analysis. The following proposition summarizes the results.

Proposition 2. *The covered market duopoly solution is given by disclosure levels*

$$d_l = \begin{cases} 0 & \text{if } v \leq v^* \\ 1 + \frac{2}{3(V-v)} - \frac{2}{3}\sqrt{\frac{V-2v+2}{(2+v-2V)(V-v)^2}} & \text{if } v > v^* \end{cases}$$

$$d_h = \begin{cases} \frac{3}{2} - \frac{10-2v+V}{2\sqrt{(2-2v+V)(10-2v+V)}} & \text{if } v \leq v^* \\ 1 - \frac{2}{3(V-v)} + \frac{2}{3}\sqrt{\frac{2V-v-2}{(2v-2-V)(V-v)^2}} & \text{if } v > v^* \end{cases}$$

where $v^* = \frac{1}{6}\left(9V - 2 - \sqrt{52 - 60V + 9V^2}\right)$ *and prices are given by* p_l *and* p_h *in (10).*

Firms competing with privacy choose to differentiate in their level of disclosure in order to cater to distinct consumer segments. One firm chooses to engage in a high level of disclosure and exploits disclosure revenues while the other firm chooses to engage in a lower level of disclosure (or performs no disclosure at all) and also exploits price revenues. An important property of the duopoly solution is that firms (mostly) focus on a single revenue source. Across most equilibria, firms engaging in disclosure subsidize consumers by quoting negative prices, and firms that do not engage in disclosure quote positive prices instead. Differentiation, therefore, is reflected on both the level of disclosure firms engage in and also (as a consequence) on the revenue source they exploit.

There is an interior equilibrium where both firm engage in disclosure ($d_h > d_l > 0$) and a corner equilibrium where only one of the firms engages in disclosure ($d_h > d_l = 0$). Disclosure levels exhibit strategic complementarity; if one firm increases its level of disclosure the best-response of the other firm is to also increase its own level of disclosure (given that equilibrium best-responses satisfy $\partial \hat{d}_l^b / \partial d_h > 0$ and $\partial \hat{d}_h^c / \partial d_l > 0$), so disclosures are mutually reinforcing. In order to characterize the solution and understand disclosures and prices under duopoly, we proceed by separately reviewing the impact of changes in the spread and the mean of consumers' distribution of valuations.

The scope for differentiation in the marketplace depends on the spread of the distribution of valuations. This implies that consumer heterogeneity determines the intensity of competition, because it affects the ability of firms to compete when setting different levels of disclosure.[9] Figure 2 depicts the impact of variations in the spread that preserve the mean of the distribution. When the spread is small, so that consumer valuations are almost homogeneous, both firms engage in a similar level of disclosure. This results in intense price competition and low profits, driving both firms to heavily subsidize consumers by quoting negative prices. As the valuation spread is further reduced, $V - v \to 0$, the disclosure of both firms converges to the monopoly solution and firm profits converge to zero.

[9] Although our analysis is restricted to the case of duopoly, we expect the implications of consumer heterogeneity to apply more generally. Note that a lower valuation spread reduces the valuation differential between the consumers served by each firm. This drives firms to reduce their effective differentiation, or the difference in their levels of disclosure, in order to attract consumers. The same mechanism would be present with the entry of additional firms in the market.

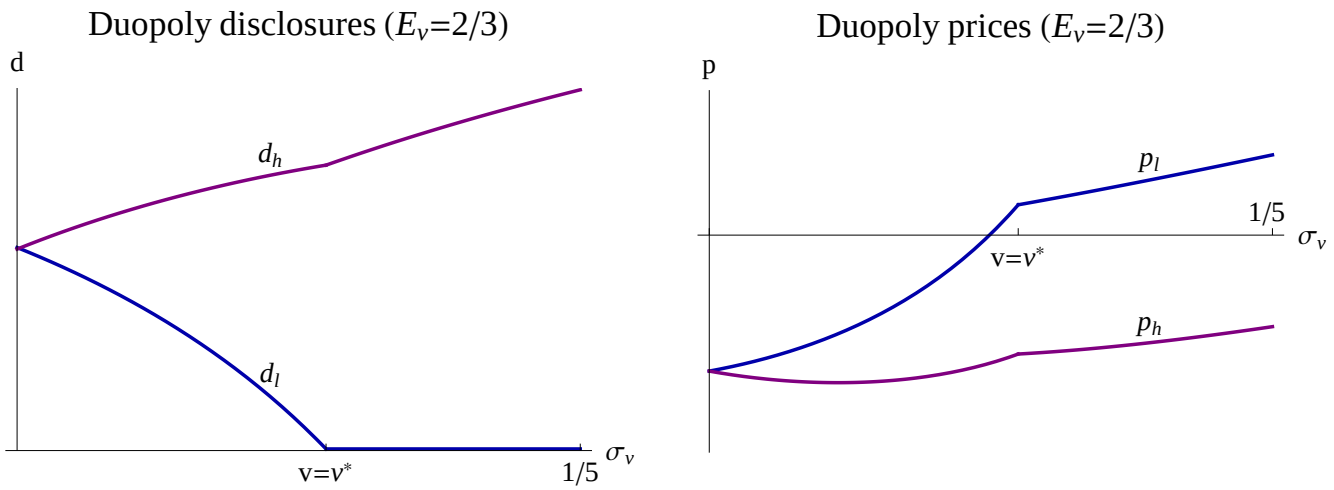

Figure 2: Duopoly disclosures (left) and prices (right) as a function of the consumer population's valuation spread.

An increase in the spread of the distribution increases the scope for differentiation. One firm chooses to increase its disclosure above that of the monopoly solution and the other firm reduces its disclosure below it, so that the effective differentiation of both firms increases. This softens price competition and allows firms to increase prices, thus increasing profits. When the spread is sufficiently large (such that $v \leq v^*$), the low-disclosure firm chooses not to engage in disclosure and focuses exclusively on price revenues. This is the only instance of positive prices that arises in equilibrium (with the exception of a small neighboring range of the parameter space)

Consider next the impact of a spread-preserving increase in the mean of the valuation distribution, as depicted in Figure 3. This increases consumers' average willingness to pay and therefore increases potential price revenues for firms, which choose to reduce their disclosure levels. When both firms are actively engaged in disclosure, $v > v^*$, they can do so increasing their differentiation, which allows them to increase their price and their profits. However, when $v \leq v^*$ and the low-disclosure firm does not engage in disclosure, differentiation is reduced. The low-disclosure firm still benefits, increasing its price and deriving higher profits, but the high-disclosure firm is forced to cut its price and its profits are reduced. The result shows that an increase in consumers' willingness to pay can actually render the high-disclosure firm worse off.

The high-disclosure firm is generally more profitable and obtains a larger market share than the low-disclosure firm. It can be shown that both factors are complementary: the profit ranking of firms corresponds with their market share ranking. The comparative advantage of the high-disclosure firm holds across most of the parameter space, and is only reversed when consumers exhibit very high valuations, $v \to 1$. It is worth noting that this outcome differs from a standard vertical differentiation model, where the highest quality firm is the most profitable (and which corresponds to the low-disclosure firm in our model, which has the highest informational quality for consumers). The divergence in our model is due to the presence of an additional revenue stream

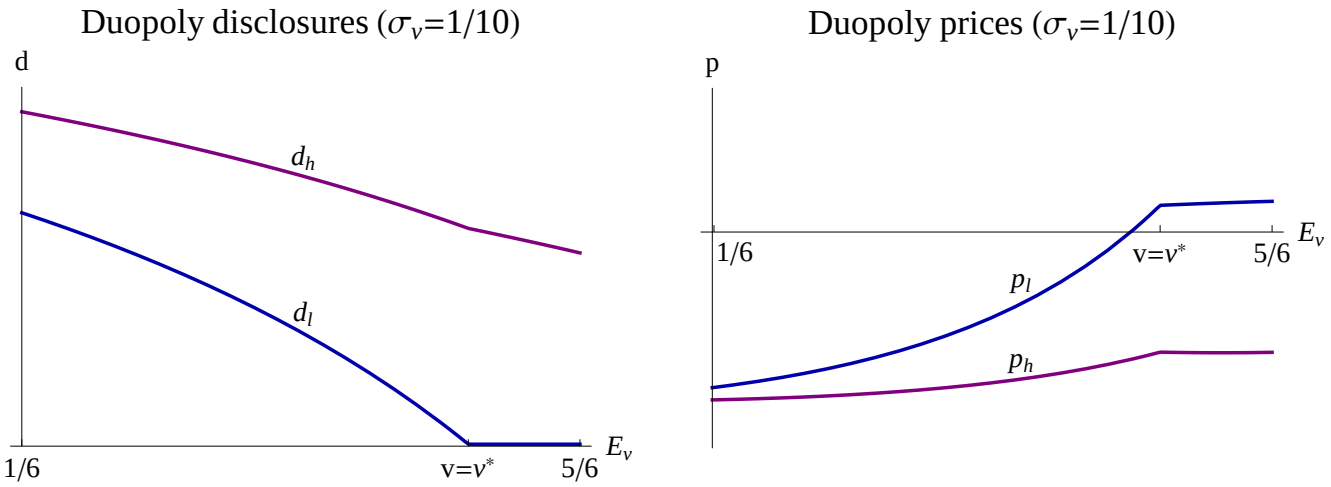

Figure 3: Duopoly disclosures (left) and prices (right) as a function of the consumer population's valuation mean.

which is inversely related to quality.[10]

Having characterized the duopoly solution, our next proposition establishes the qualitative impact of competition in the marketplace.

Proposition 3. *Comparison of the duopoly and monopoly solutions reveals that competition has two main effects on the marketplace: the introduction of a low-disclosure (high-quality) service, $d_l < d_h \approx d_m$, and subsidization of the high-disclosure (low-quality) service, $p_h < 0 < p_m$.*

The first part of the proposition follows from the fact that the high-disclosure duopolist sets a level of disclosure which is approximately equivalent to that of the monopolist, though marginally higher. The low-disclosure duopolist, however, serves a disclosure level which is qualitatively different from that of the monopolist. This can be verified by inspection of monopoly disclosure d_m in Figure 1 and duopoly disclosures d_h and d_l in Figures 2 and 3 (note that disclosures are plotted over the same range in all cases). Our model therefore predicts that low-disclosure services which are sustained exclusively by price revenues only arise under competition.

Regarding the second part of the proposition, note that the monopolist quotes a positive price and the duopolist supplying the high-disclosure service quotes a negative price in order to subsidize consumers. Clearly, the difference in pricing is due to the competitive pressure faced by the duopolist, as in both cases consumers exhibit positive willingness to pay for the service. It can be shown that the price differential under both regimes, $p_m - p_h$, is decreasing in consumer heterogeneity, which determines the intensity of competition all other factors being equal. Thus our model predicts that consumer subsidization in the presence of disclosure revenues is a direct consequence of competition.

[10]See Wauthy (1996) for a detailed characterization of equilibrium profits in the standard vertical differentiation model.

It should be clear that both of the above effects of competition benefit consumers, subsidizing them under high levels of disclosure and allowing them to select into lower disclosure alternatives. In the next section we disentangle the effect of competition on consumer surplus and on the stock of information disclosed in the marketplace.

5 Policy implications

We next examine in more detail the implications of competition on consumer welfare. The surplus derived by consumers depends on the informational quality of the services as well as prices; consumer surplus increases when firms reduce prices or when they reduce their level of disclosure. The total volume of information disclosed by firms also provides a useful metric of consumer privacy in the marketplace.

We define the *information stock* of firm j, denoted by Y_j, as the total stock of consumer information accumulated by the firm in the marketplace. If consumers $v_i \in (\underline{v}, \overline{v})$ sign up for firm j's service, then the information stock of firm j is given by

$$Y_j = \frac{1}{V - v} \int_{\underline{v}}^{\overline{v}} y_j \, \mathrm{d}v_i.$$

The *information disclosed* by firm j, denoted by Y_j^d, is then given by $Y_j^d = d_j Y_j$.

The surplus enjoyed by consumers signed up with firm j can be written as

$$CS_j = \frac{1}{V - v} \int_{\underline{v}}^{\overline{v}} u_{i,j} \, \mathrm{d}v_i.$$

Inspection of Y_j^d and CS_j under the monopoly and duopoly regimes yields the following result.

Proposition 4. *Consumer information disclosed under duopoly is always lower than under monopoly, $Y_h^d + Y_l^d < Y_m^d$, and consumer surplus is always higher, $CS_h + CS_l > CS_m$. Furthermore, consumer information disclosed and consumer surplus under duopoly are generally increasing in the consumer population's valuation spread (intensity of competition).*

To understand the result, consider first the determinants of the information stock accumulated by firms in the marketplace. The total information stock obtained by a firm is a function of both its userbase and its level of disclosure — on how many consumers provide it with information and how much information each consumer provides. In the interior duopoly equilibrium, both duopolists obtain the same information stock because asymmetries in their userbases and disclosure levels even out. In the corner duopoly equilibrium where $d_l = 0$, the low-disclosure firm obtains a larger information stock. And taken together, both duopolists always obtain a larger information stock than the monopolist, because their average disclosure level is lower and consumer information

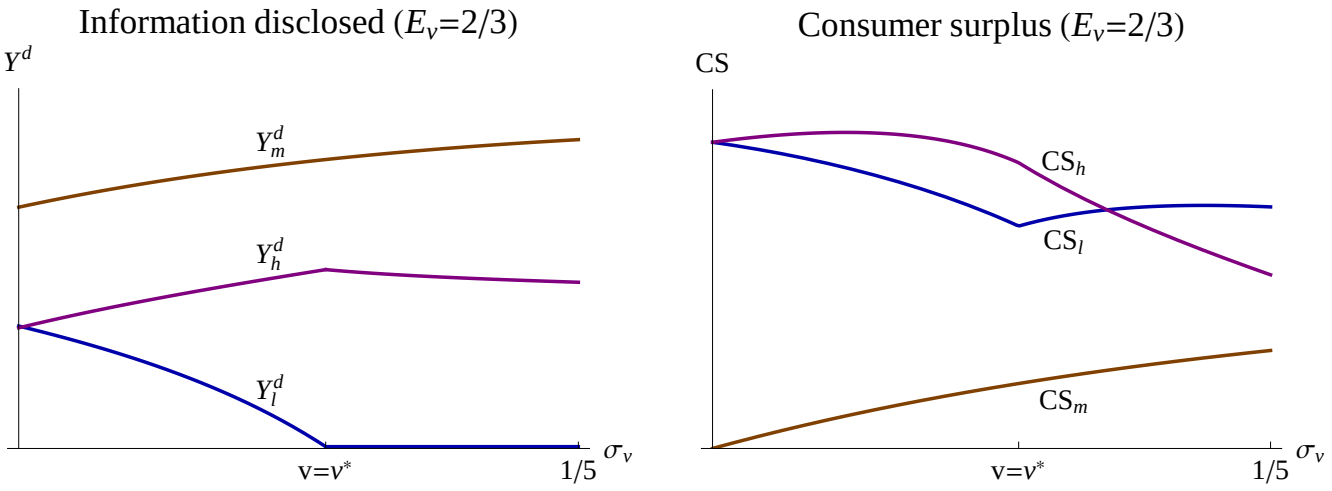

Figure 4: Information disclosed (left) and consumer surplus generated by each firm (right) as a function of the consumer population's valuation spread.

provision is linear in disclosure. Thus, across covered market equilibria, $Y_l + Y_h > Y_m > Y_l \geq Y_h$, with the latter inequality being strict whenever $v < v^*$.

Consider next the effective stock of information disclosed, as depicted in Figure 4. Total information disclosed is always lower under duopoly than under monopoly. Thus, competition drives firms to accumulate a larger information stock but to disclose a smaller part of it. However, it is important to stress that the effective stock of information disclosed under duopoly is inversely related to consumer heterogeneity. That is, a reduction in the spread of consumers' valuation distribution, which intensifies competition, tends to increase information disclosed as given by $Y_h^d + Y_l^d$ rather than decrease it (with the exception of a small parameter range when $v \to 1$). In other words, the more intense is competition in the marketplace, the larger the stock of information disclosed and the closer it is to the monopoly outcome. The intuition for this result lies in the fact that firms translate competitive pressure to prices rather than to disclosure levels. Therefore, despite reducing consumer utility, our analysis reveals that a high volume of disclosed information should be expected in a competitive marketplace.

Consumer surplus decreases with consumer heterogeneity (that is, increases with the intensity of competition) and is always higher under duopoly, as expected. Moreover, the high-disclosure duopolist generates the higher level of consumer surplus in the market for a large subset of the parameter space, as depicted in Figure 4. Recall that the high-disclosure duopolist sets a higher disclosure level than that of the monopolist, $d_h > d_m$. It can also be shown that the effective stock of information it discloses in equilibrium Y_h^d is largely unaffected by its disclosure level d_h, because consumers account for it when selecting which service to patronize and how much information to provide it with. The result underscores the fact that informed rational consumers stand to benefit from the presence of high levels of disclosure in the marketplace.

6 Conclusion

Consumers are unable to control the disclosure practices of services that collect their personal information, but can decide which services to trust and how much information to provide. Our analysis explains how this disciplines the disclosure and pricing strategies of firms under competition. Firms engaging in disclosure choose to share the benefits with consumers by subsidizing them, and firms charging positive prices choose not to engage in disclosure. Therefore, we should expect competition to increase the supply of both subsidized and no-disclosure services. Moreover, subsidized services have the potential to remain highly profitable under competition despite the fact that disclosure generates consumer disutility.

Our results contribute to explain recent developments in the business models of online services. Initiatives to subsidize consumers in order to sustain disclosure revenues, such as Amazon's *Special Offers* program, are prone to become more widespread. We expect such subsidization schemes to also tie consumers into services. For instance, Amazon's initiative applies to Kindle devices which keep consumers inside Amazon's service ecosystem. Analysts have long expected Google to follow this path with its expanding line of hardware devices.[11] But our results also suggest that there is scope for no-disclosure services to compete. Services such as Microsoft's Office 365 are well positioned to attract customers weary of disclosure practices, and their success will rely on attracting the high-valuation consumer segment. More generally, we also expect such services to attract consumers with larger stocks of personal information or those whose information is more sensitive to disclosure.

We expect increasing consumer awareness of disclosure practices and familiarity with its implications to reinforce the relevance of our analysis. Recent surveys of consumer attitudes towards privacy underscore this trend. Alan Westin, a pioneering scholar in the field of privacy, noted in a recent consumer survey that "offering online users free email or free searches did not seem to a majority of our respondents to be a sufficient set of benefits or valued services to overcome the instinctive feeling of not wanting to be tracked and marketed to based on their online transactions and surfs. Web sites wanting to have users not opt out of customized marketing may well have to up the benefits ante to persuade online users that benefits promised outweigh perceived privacy and data security risks."[12]

Our formal analysis should be understood to provide a benchmark for informed and rational consumers. From a policy perspective, we expect transparency to play an important role in informing consumer decisions and delivering a competitive supply of services, and efforts to make disclosure practices salient and understandable for consumers are clearly desirable. But our results recommend caution on restricting disclosure practices. We have shown that high-disclosure services should be expected to play an important role in a competitive marketplace. We have also

[11] See 'Google heightens rivalry with iPad,' *Wall Street Journal*, March 2012.

[12] See Alan Westin's report 'How online users feel about behavioral marketing and how adoption of privacy and security policies could affect their feelings,' Privacy Consulting Group, March 2008.

shown that such services can outperform their no-disclosure counterparts in generating consumer surplus, ensuring that lower valuation consumers participate in the market. Informed consumers are smart and adjust their information provision accordingly when using these services.

The interactions present in our model suggest additional avenues for empirical research. The drivers of consumer information provision under different disclosure regimes merit further attention. Our analysis considers a single instance of consumer information and firm disclosure, but different types of services command different types of information to which different disclosure regimes may be applicable. Better understanding of the implications of these differences, which for example may include categories such as product preferences, social connections, or geographical location, could explain variations in consumer behavior and firm strategies across different services. The viability of disclosure and the intensity of subsidization across these services should be expected to vary accordingly.

Innovation in the provision of information-intensive services and disclosure intermediation can also be understood in the context of our framework. Social networking, for instance, can be understood as a service innovation that generates utility for users willing to provide information that would otherwise remain private. In the mobile app ecosystem, new applications are flourishing that help consumers store and share snippets of their personal information. New instances of such services will continue to emerge with future hardware and software developments. In addition, innovation in services generates new disclosure opportunities. New industry players are specializing in the aggregation of consumer information originating from different sources, allowing such services to monetize consumer information snippets by contributing to broader profiling. The tensions surrounding consumer information provision and disclosure will remain for the foreseeable future.

Appendix

We characterize the conditions for the covered market solution derived in Proposition 2 to constitute an equilibrium. We analyze unilateral deviations to uncovered market configurations by each firm in order to establish a sufficient condition for such deviations not to pay off. A unilateral deviation by firm j to an uncovered market configuration consists of a disclosure-price pair d_j^u and p_j^u which satisfies $v_f > v$ (ensures that low-valuation consumers prefer not to purchase) taking the other firm's strategy as fixed and given by d_{-j} and p_{-j} characterized in Proposition 2. We consider unilateral deviations by firms in the first and second stages of the game that satisfy $d_l < d_h$ and $p_h < p_l$, and evaluate their impact on consumer demand and information provision y_j^u in the third and fourth stages.

Consider first a deviation by the low-disclosure firm. A unilateral deviation by firm l will yield an uncovered market if $v_f > v$ as a result of the deviation. Recall that consumers with higher valuation $v_i \geq v_f$ always prefer to participate in the market given that $\partial u_{i,j}/\partial v_i > 0$, so an uncovered market configuration implies that low valuation consumers choose not to participate. Note however that the indifferent consumer v_f is determined by the strategy of firm h, because consumer $v_i = v$ purchases from firm h in the solution derived in Proposition 2. Therefore, given that $\partial u_{i,j}/\partial v_i > 0$, all consumers in the population prefer to sign up with firm h rather than to stay out of the market, and no unilateral deviation by firm l can yield an uncovered market.

Consider next a deviation by the high-disclosure firm. Such a deviation will yield an uncovered market configuration if $v_f > v$ so that low-valuation consumers prefer to stay out of the market. Three different cases can arise in this market configuration. Both firms derive positive demand after the deviation if the indifferent and pivot consumers satisfy $V > v_p > v_f > v$. Firm h takes over the market and serves all participating consumers if $v_p \geq V > v_f > v$. And firm h derives no demand after the deviation if $v_f > v_p$. We can dismiss the latter case because such a deviation will never payoff for firm h.

Consider first the case where both firms derive positive demand. The deviation profits of firm h, to be denoted by π_h^u, can then be written as

$$\pi_h^u(p_h^u, p_l, d_h^u, d_l) = \frac{v_p - v_f}{V - v}(p_h^u + d_h^u y_h^u)$$

where the pivot consumer v_p is given by (8), the indifferent consumer v_f by (3), and consumer information provision for the deviating firm y_h^u by (2), accounting for firm h's deviation disclosure d_h^u and price p_h^u. In order to identify the most profitable deviation we next solve for the optimal deviation price of firm h,

$$p_h^u = \frac{(1 - d_h^u)(2(1 - d_h)p_l - d_h(1 - d_l)^2)}{4\,(1 - d_l)^{\,2}}. \tag{11}$$

We next argue that it is optimal for firm h to take over the market and serve all participat-

ing consumers when deviating to an uncovered market configuration. Plugging d_l and p_l from Proposition 2 and optimal deviation price p_h^u in (11) into the pivot consumer v_p in (8) as well as the indifferent consumer v_f in (3), it can be shown that $v_p(p_h^u, p_l, d_h^u, d_l) - v_f(p_h^u, d_h^u) > V - v$ across the solution space characterized in Proposition 2. This implies that it is always optimal for firm h to take over the market when deviating, because the optimal price in an uncovered market configuration where $v_f > v$ always ensures that all participating consumers purchase from firm h given that $v_p > V$.

The deviation profits of firm h in an uncovered takeover configuration (where it takes over the market) are given by

$$\pi_h^{u,t}(p_h^u, p_l, d_h^u, d_l) = \frac{V - v_f}{V - v}(p_h^u + d_h^u y_h^u).$$

The optimal deviation price of firm h is then the highest price that ensures that all participating consumers sign up to its service. The pivot consumer must then be given by $v_p = V$. Denote this deviation price by $p_h^{u,t}$. Equating $u_V(d_l, p_l) = u_V(d_h^u, p_h^{u,t})$ and solving for $p_h^{u,t}$ yields

$$p_h^{u,t} = \frac{1}{4}(4p_l - V(d_h^u - d_l)(2 - d_h^u - d_l).$$

We next determine the disclosure range for d_h^u to yield an uncovered market given optimal deviation price $p_h^{u,t}$. Denoted the upper boundary of this disclosure range by $\overline{d}_h^u$. Solving for $v_f(p_h^{u,t}, d_h^u) = v$ obtains two candidate solutions. It can be shown by plugging d_l and p_l from Proposition 2 (both for the interior and corner cases) into both candidate solutions that only the following one is well defined within the feasible disclosure range $d_h \in [0, 1]$,

$$\overline{d}_h^u = \frac{v - V - \sqrt{(V - v)\left(V\left(1 - d_l\right)^2 - 4p_l\right)}}{v - V}. \tag{12}$$

We have established that a unilateral deviation by firm h to an uncovered market configuration can only be profitable in the disclosure range $d_h^u < \overline{d}_h^u$ and entails firm h setting a price to take over the market. Outside this disclosure range, the optimal pricing strategy of firm h implies covering the market, and therefore cannot yield higher profits than those derived in the solution characterized in Proposition 2.

A sufficient condition to ensure that no unilateral deviation pays off for firm h is $\overline{d}_h^u \leq d_l$. Plugging d_l and p_l from Proposition 2 into $\overline{d}_h^u$ in (12) reveals that $\overline{d}_h^u$ always attains a larger value for the corner case where $d_l = 0$. Therefore, $\overline{d}_h^u(d_l = 0) < 0$ ensures that $\overline{d}_h^u \leq d_l$ across the solution space characterized in Proposition 2. It can be shown that $\overline{d}_h^u(d_l = 0) < 0$ holds whenever $v > v_{min}$ where v_{min} is given by the first root of the following polynomial:

$$24v_{min}^4 + (-36V - 64)v_{min}^3 + (18V^2 + 48V + 110)v_{min}^2 + (3V^3 - 86V - 44)v_{min} + (-4V^3 + 20V^2 + 16V - 8) = 0.$$

The following figure depicts the parameter space implied by $v > v_{min}$ and $V \leq 1$.

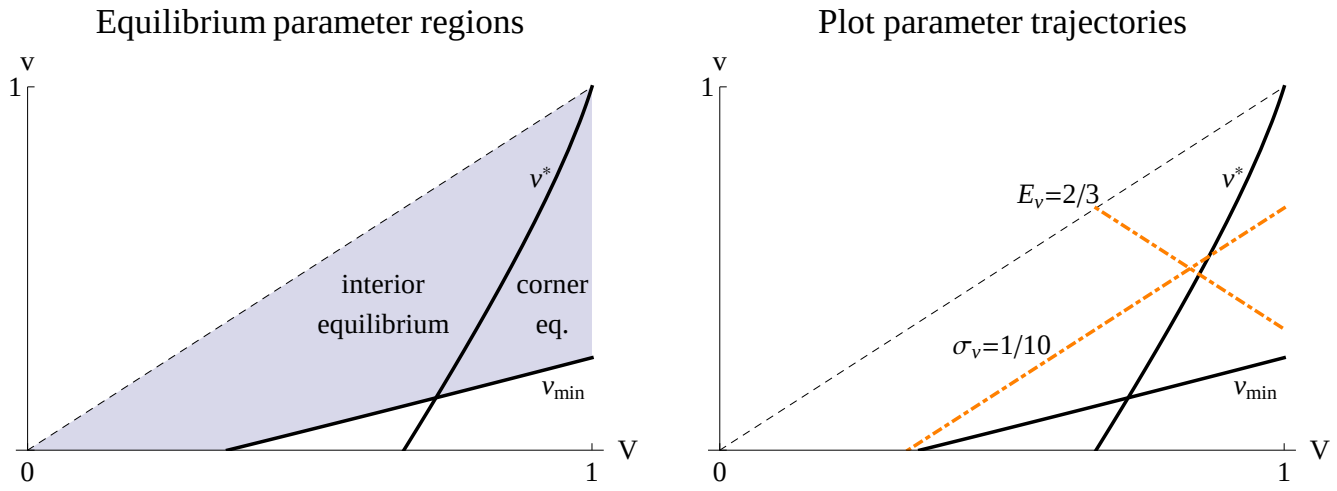

Figure 5: The plot on the left identifies parameter regions where the interior and corner solutions derived in Proposition 2 constitute an equilibrium; note that firm h may have incentives to deviate to an uncovered market configuration when $v < v_{min}$. The plot on the right identifies the parameter trajectories used in Figures 1-4.

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