Competing for Information: A Duopoly of Personalized Service Provision under Privacy Concerns

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Abstract

There is "no free disposal" (NFD) in the consumption of online personalization services, as this activity inherently involves sharing of personal and preference information that creates disutilities to the consumer. Not only are more services *not* necessarily better for the consumer, but these services are also provided for free as firms extract value from the usage of consumer information rather than from directly pricing the services. Firms may offer personalization through a "take-it or leave-it" approach (the fixed-services strategy) or allow consumers to choose a subset of the portfolio of services offered (the variable-services strategy). We model a duopoly of firms that are heterogeneous in their marginal value for consumer information (MVI) and interact through a two-stage dynamic game, where the firms choose a fixed- or variable-services strategy in the first stage and the corresponding level of services in the second. Our findings suggest that when the MVIs of competing firms are sufficiently different, there is a unique subgame-perfect Nash equilibrium (SPNE) in pure strategies where both firms offer fixed-services such that they segment the market. As the difference in their MVIs increase, the high MVI firm continues to offer fixed-services while the low MVI firm enjoys the option of offering variable services. A duopoly of high MVI firms results in both firms offering variable services as long as one firm has very large MVI, and both offering fixed-services otherwise. Interestingly, while the former is consumer welfare maximizing, the latter results in a third of the market (consisting of privacy seekers) not being served. Our results lead to important managerial and policy implications, as well as interesting extensions to extant location models.

Key words: personalization, privacy, spatial competition, Nash-equilibrium, welfare analysis

1. Introduction

Personalizing services and recommendations to the specific taste and preferences of individuals has become an integral part of competitive strategies for many online companies. Interestingly, while firms incur investment costs in developing these services, they are generally offered for free by portals like iGoogle and MyYahoo!; the operational basis for these online firms that rely on consumer information is unique. Portal-like firms rely on their ability to sell browsing profiles to advertisers and targeted marketers (Dewan et al. 1999), while many e-tailers use information acquired for personalization to manage their own inventory, marketing goals, and to enhance customer satisfaction and loyalty (Shankar et al. 2002). Differences in firms' abilities to exploit the acquired consumer information are known as their different marginal values for information (MVIs). There are two primary revenue models; large firms such as Yahoo!, AOL, MSN and others maintain their own advertising networks that stretch across multiple sites. These firms can directly serve and place advertisements for clients based on profiles that they construct from the acquired user information. On the other hand, many smaller portals that offer identical personalization services rely on cooperating with third-party advertising networks. Their revenues come largely from reselling information and profiles, and they often act as carriers of other advertising networks such as DoubleClick in the pre-Google era, and Atlas (Atlas Suite), thus enjoying a lower MVI compared to that of larger firms who have their own advertising networks.

Besides differences in their ability to generate revenues from customer information, firms also make different strategic choices in their delivery of personalization. Chellappa and Shivendu (2010) observe that companies adopt one of two approaches in delivering personalization services: a "fixed-services" approach, where consumers are required to subscribe the full set of services being offered and sharing all corresponding information; and a "variable-services" approach, where consumers enjoy the freedom of choosing only a subset of the offered services. Apple's "Genius Recommendation" on iTunes is an example of the former strategy. Once the "Genius" feature is enabled, the user implicitly agrees to sharing her entire music and video libraries with Apple, as well as her browsing and purchase history on iTunes' store. Apple then uses this information to offer personalized recommendation on movies and songs to the user. In other words, a user cannot choose to have only her music preferences to be shared with Apple while not sharing what movies she had watched or rented. Another example is Google's dictionary plug-in for Chrome; once a user installs this plugin for the browser, the service provides definition to words appear on any website that a user visits, hence collecting the user's browsing history as well as the actual contents of all visited websites. Since a user cannot opt to have the service being activated only on a subset of the websites she visits, this is considered a "take-it-or-leave-it" (fixed-services approach) service offered by Google. On the other hand, several restaurant and game recommendation services, such as Ness and Decide-o-tron, allow a user to selectively share her preferences of particular types of cuisine/game, hence allowing the firm to tailor recommendations for the user on the relevant dishes/genres alone. Further, many toolbars, such as those offered by Yahoo! and Microsoft, allow consumers to turn on and off features and fine-tune which components of the toolbar to activate, allowing for personalization at a more granular level. These latter cases are considered to belong to the variable-services approach. While the above examples illustrate how the fixed- and variable-services approaches are manifested differently in a variety of contexts, it is important to note that our research concerns not the competition between specific technology artifacts or applications, but rather the underlying strategic options available to firms in acquiring customer information and delivery of personalization.

Firms competing in the personalization market face many unique challenges. First, while there is no monetary usage cost, an important cost intrinsically related to the usage of personalization services is the privacy costs that individuals incur when sharing their preference and usage information needed for tailoring services to their tastes (Volokh 2000). Hence unlike monetary costs that can be extracted as surplus by the firm, privacy costs suffered by the consumer only affect the number services that she may use (and hence the amount of information she might share) and thus disallowing the firm from efficiently deploying all related services. Second, the non-price nature of this market implies the lack of fiscal instrument for firms in discriminating consumers and in competing against rival firms. Third, most data acquisition and personalization technologies are not only widely available but also standardized; the resulting personalization services are often indistinguishable to the consumer, hence cannot be used by the firm to differentiate itself from the competitors. Competition in these regards have largely been unexplored in extant research.

In this research we seek to provide insights into three important aspects of competition for customer information in the personalization market. First, we are interested in formulating the strategic interaction between firms competing for customer information so as to provide insights into firm strategies. Should firms adopt a fixed- or variable-services approach and what is the optimal size of the corresponding services-set? Investments in personalization services and data acquisition technologies may be capital intensive, hence answer to this question sheds light on the relationship between firms' marginal value for information and their optimal investment decision in order to provide guidelines for their personalization strategies. Second, given that extant research observe that a monopoly may not serve the whole market even if it is costless – due to negligible versioning and marginal costs – to do so (Bhargava and Choudhary (2008); Jones and Mendelson (2011); Chellappa and Shivendu (2010)), will competitive forces shift this result and lead to full market coverage? Finally, we wish to investigate the regulatory implications regarding the allowance of data acquisition technologies used during personalization. Should FTC proscribe usage at all or if it should perhaps intervene in the firm's service strategy (fixed vs. variable)? While the FTC acknowledges the legitimate use of consumer information by businesses, they are also concerned that such usage should be beneficial to consumers without excessive intrusion to their privacy (See FTC workshop report (2003)). Hence answer to this question allows us to offer important guidelines to the policy makers interested in balancing the interests between for-profit firms and the general public in light of privacy concerns.

To answer these questions, we study a duopolistic competition in the personalization market, where firms are differentiated by their marginal values for information (MVI) and engage in a two-stage dynamic game. In the first stage, firms choose their technological infrastructure to decide between pursuing a fixed-services personalization approach or a variable one. In the second stage, having observed the rival's chosen strategy in the first stage, firms simultaneously decide on the specific levels of personalization service to offer.

The contributions of our work are two-fold. At the theoretical level, our model incorporates elements of both horizontal and vertical differentiations that prevail in the personalization market, while taking into account the unique characteristics of information goods (zero marginal cost, costless degradation), thus offering important extensions to standard spatial competition models that are widely used in IS research. Further, research on the impacts of information privacy on online business at the societal level is severely lacking (Belanger et al. 2011), while IS literature on privacy from the regulator's perspective is also very limited; our research represents a first step towards bridging these gaps. At the managerial level, we prescribe the firm's optimal response given its competitor's strategy and their respective abilities to generate revenues from customer information. Results from our analysis provides a comprehensive characterization of possible market outcomes, with detailed descriptions of firms' personalization approaches, service levels, market coverable and the resulting consumer surplus. Finally, we offer specific guidelines for regulatory body such as the FTC with regards to improving consumer welfare through protecting their privacy online while preserving the business viability of personalization providers.

2. Literature Review

Our study is informed by, and contributes to, two streams of literature: the literature on information privacy and personalization, and spatial competition models.

Privacy and Personalization

Of the many conceptualizations and definitions of privacy (see Belanger and Crossler 2011 and Smith et al. 2011 for a comprehensive review), the one that is most relevant to our context of study is information privacy. Information privacy has been referred to as moral, legal, or property rights (Chellappa et al. 2008; Clarke 1999), a commodity (Campbell et al. 2002; Davies 1997; Garfinkel 2000), a state of limited access to information (Smith et al. 2011), an individual's ability to control information about herself (Stone et al. 1983), control (or lack of such) over secondary uses (Belanger et al. 2011; Belanger et al. 2002), and the ability to choose the extent and contexts under which information about oneself is shared with or withheld from others (Duncan et al. 1993). Recent surveys show that privacy is considered highly important by a majority of Internet users (Belanger et al. 2011; Chellappa et al. 2008; Madden et al. 2007; Smith et al. 2011). Concern for privacy arises when a consumer shares her personal information with a third party, thus forgoing control over the shared information. Note that this concern represents a consumer's belief regarding his or her (dis)comfort in sharing personal information, and is independent of what the firm may actually do with this information. It is because of this perception of risk of information disclosure that privacy concern is subjective and unique to an individual (Chellappa et al. 2008). In other words, different consumers incur different disutilties or costs from information disclosure; other things being equal, the higher the privacy concern, the less likely is a consumer to share her personal information, and vice versa.

Prior research has shown that Internet users' privacy concerns influence not only the individuals' attitudes towards the overall regulatory environments and their willingness to share information, but also their acceptance of technology (Malhotra et al. 2004; McGinity 2000; Milberg et al. 2000; Smith et al. 1996; Stewart et al. 2002; Van Slyke et al. 2006) and intention to use online services (Belanger et al. 2002; Chellappa et al. 2005; Eastlick et al. 2006; Resnick et al. 2003). The underlying reason is that consumers assess the costs versus benefits associated with divulging personal information, a concept known as the "privacy calculus" (Culnan et al. 1999; Culnan et al. 2003), and consumers are willing to disclose their personal information in exchange for economic and social benefits (Chellappa et al. 2005; Hann et al. 2008; Laufer et al. 1977). In the context of personalization, consumers decide whether or not and to what extent to adopt personalized services by balancing the perceived benefits of disclosing information required for these services with the associated risks (Awad et al. 2006; Chellappa et al. 2008; Chellappa et al. 2010; Chellappa et al. 2005); Culnan et al. (2003); (Derlega et al. 1993; White 2004). This observation finds resonance in a recent Accenture's survey, which observes that a majority of Internet users are willing to share personal information with online retailers if they are provided with personalized services and recommendations in exchange (Accenture 2012).

Despite the rich literature on privacy in information systems, there are two important areas that have not received adequate attention. Extant research observes that most companies fail to deliver sufficient privacy protection to the consumers (Belanger et al. 2011; Peslak 2005; Peslak 2006; Ryker et al. 2002; Sheehan 2005), pointing towards the inadequacy of industry self-regulation and the need to consider legislative options (Culnan 2000; Tang et al. 2008; Xu et al. 2012). However, there is somewhat a limited number of papers in information systems that provides an understanding of issues surrounding consumer's privacy from a regulator's perspective. Chellappa and Shivendu (2008) observe that, in the context of personalization, a regulator should disallow the use of enforcement technologies (i.e. a take-it or leave-it offer) by Internet firms if no private contract is in place. Tang et al. (2008) suggest that even though government regulations can enhance consumer trust, legislative options may not be socially optimal due to their negative effects on firms' profit margins, resulting in higher prices for the consumers. Lee et al. (2011), on the other hand, find that enforcement of the fair information practice by a regulatory body can be welfare enhancing, due to its ability to limit firms' incentives to exploit the competition-mitigation effects of privacy protection. Xu et al. (2012) find that industry self-regulation and government legislation can be substitutes for each other. These diverse findings in the role and effects of government regulation point towards the need to investigate the role of regulation in the specific context in which consumers engage in information exchange with online companies. Further, the impact of privacy on online business at the societal level is also severely lacking (Belanger et al. 2011; Smith et al. 2011); most of the extant research focuses on individual-level analysis with results that may not be generalizable beyond the specific contexts of the studies. Our work investigates competition in the market for information under a general setting, and analyzes the welfare implications at the societal-level offer important insights for regulators on protecting consumer privacy online; in particular, ours is one of the first attempts in addressing regulatory implications of the personalization-privacy tradeoffs in a competitive and non-price context. Our study, therefore, contributes to the stream of privacy literature by bridging these gaps.

Spatial Competition

Internet portals and companies have long been capitalizing on this tradeoff and created an active market for consumers' personal and preference information, where customer information is bought and sold, and is being exploited to gain competitive advantages and to increase sales (Taylor 2004). For example, information resellers such as Acxiom have collected online behavioral information of nearly all American adults and sell the acquired information to advertisers for profit. Other companies such as eBureau specializes in helping companies analyze the value of individual Internet users to achieve more effective promotions and targeted advertising. The interactions among these various types of companies are not merely restricted to trading information with existing clients, but they can auction off online access to Internet users that they have profiled in ad-trading platforms (e.g. Rubicon). More recently, a new type of intermediary in the market for information has emerged; companies such as Reputation.com serve as a "vault" for personal data, a third-party that collect customers' preferences and allow them to decide with whom and the extent to which to share their personal information in exchange for monetary (e.g. coupons) and non-monetary (e.g. status upgrade) benefits.

Through the provision of personalized services and recommendations that are free of charge, firms offer incentives to the consumers to divulge personal information. Their personalization strategies fall largely into one of the two categories: a) a fixed-services strategy whereby consumers are offered a "take-it or leave-it" choice, and are required to share all information prescribed by the usage or these services; b) a variable-services strategy whereby consumers are offered an array of services, but are given choices as to the extent to which they use them. Under the variable-services strategy, consumers can opt-out from using certain components of the offered services, thus sharing only the personal information relevant for the chosen services (Chellappa et al. 2008; Chellappa et al. 2010). Chellappa and Shivendu (2008; 2010) are among the first to investigate these particular personalization approaches in a monopolistic setting. They find that, surprisingly, the monopoly may not want to serve the entire market even when it is costless to do so through a variable-services approach. They call for investigations of a competitive setting and generalizing discrete consumer types to a continuum so as to gain more insights into market outcome and welfare implications under competition in the personalization market. Our research offers an initial attempt towards this important direction.

Extant location-based competition models provide a good starting point for the development of our theoretical framework; primarily due to its tractability and robustness in analyzing competitive outcomes when consumer preferences are diverse. There are, however, a few unique characteristics of the personalization market that raise challenges to adopting existing model in our investigation: First, at the product level, personalization services belong to a class of economic goods with a "no-free-disposal" property; i.e. more is not necessarily better (Chellappa et al. 2010; Nahata et al. 2003). This is due to the inherit tradeoff between values that a consumer derives from personalization and the privacy costs associated with sharing the corresponding information. As a result, consumer's utility is non-monotonic concave; each consumer has an ideal preference point, and there are satiation points on both sides of this point beyond which the utility becomes negative. Second, personalization services are information goods, and are characterized by zero marginal cost and costless degradation; once a particular level of services is being offered, it is costless for the firm to serve additional customers and to serve customers who desire only a subset of the offered services. Third, at the firm level, the costs of investing in personalization technologies are increasing in service level; more sophisticated personalization are more costly, which implies that it is more costly to serve consumers who desire more services. Finally, unlike in a price-quantity competition where firms can undercut each other to gain market share, or in a quality-competition where firms can differentiate themselves along the lines of different quality, the personalization market is characterized by non-price competition with products (services) that are virtually identical. In other words, firms are restricted in the available instruments compete upon and to discriminate consumers. While the non-monotonic consumer utility resembles the characterization of consumers having "ideal points" in the horizontal differentiation models, the fact that firms cannot costlessly locate themselves anywhere along the consumer continuum is akin to the quality competition/vertical segmentation models. Thus our model exhibits aspects of both horizontal and vertical segmentation.

Findings in purely vertically segmented markets are well known in economics, marketing and information systems (where it is called versioning), where segmentation is generally superior except under shutdown conditions. On the other hand, findings in horizontally segmented markets are diverse and highly dependent on specific assumptions on transport costs and reservation prices (Hotelling 1929; Salop 1979). Equilibria may or may not exist, and the real source of non-existence of equilibrium in such markets is often the non-quasiconcavity (caused by infinite reservation prices) as well as the discontinuity of the payoff functions (Economides 1984).

There is a limited number of papers that consider aspects of both vertical and location-based competition. For example, Gabszewicz and Thisse (1986) consider a market where there are vertical and horizontal differentiations with quadratic transport costs albeit with infinite reservation prices for consumers. Research in marketing has also considered cases where consumers vary both in their marginal value for quality as well as in their taste preferences, although these attributes are assumed to be independent of each other (Desai 2001). While closer to our model in spirit, it is to be noted that aspects of horizontal and vertical differentiation in our case emerge endogenously from the NFD utility and consumer heterogeneity. The above differences combined with the non-price, zero marginal cost and zero versioning cost of services in our market require us to re-examine any extant segmentation findings. In addition, while pricing models from marketing (Moorthy 1988) partially relate to fixed-services competition in our model, there is no extant work in this genre that investigates variable strategies (where each consumer gets his preferred service level) in a competitive setting. It is also important to note that we make no a priori assumptions on market coverage or relative firm characteristics, as we endogenously determine these for various equilibria. These fundamental differences between ours and extant models, combined with the information goods nature of personalization, are likely to lead to equilibrium strategies and market outcomes that are very different from those observed in existing literature. Our model, therefore, offer important extensions to standard spatial competition models that are widely used in IS research.

3. Model

3.1. Consumers' tradeoff

Consumers decide whether and to what extent to use personalization services, based on balancing their perceived benefits of disclosing information required for these services with the associated risks (Culnan et al. 2003; Derlega et al. 1993). Such a tradeoff has been modeled by prior research (Chellappa et al. 2010) as a function of consumers' marginal value for personalization p and their coefficient of information privacy concerns r. The benefit from services is ps while the cost is convex in the amount of information (i) shared, i.e. ri^2. Consumers' privacy costs increase at an increasing rate as the information that they share is increasingly personal. It is assumed that one unit of information is required for the creation of one personalized service (i.e., $s = i$); hence along the lines of Chellappa and Shivendu (2008), we express a consumer c's utility as a function of personalization services consumed:

$$u(s,p,r) = ps - rs^2 \tag{1}$$

Observe that the utility function is non-monotonic concave (inverted-U), capturing no-free-disposal in services consumed. Consumers vary in their value for personalization and concerns for privacy (Chellappa et al. 2005), hence we consider a market where consumers are uniformly distributed in their personalization to privacy (p4p) ratio, given by $\theta \triangleq \frac{p}{r} \sim U[0,b]$. A summary explanation of key notations used in this paper is presented in Table 1.

Table 1: Key Notations

SYMBOL	DEFINITION	SYMBOL	DEFINITION
p	Consumer's marginal value for personalization services	r	Consumer's privacy cost coefficient
σ_i	Marginal value for information (MVI) of firm i	$\pi_i\left(\sigma_i, s_i\right)$	Firm i's profit function with respect to the MVI and level of services offered
s_i	Personalization services of firm i (s^* - consumer's surplus-maximizing service level; s^o - consumer's break-even service level)	F	Superscript denoting fixed-services
$u\left(p, r, s\right)$	Consumers' utility from personalization services	V	Superscript denoting variable-services

3.2. Firms' strategies

Firms gather customer information through offering personalization services. Firms vary in their ability to use consumer information by virtue of the extent to which this information can be exploited to their own purposes, and either invest in building their own personalization services, or incur licensing and technology costs of buying from firms such as BestToolBars.net and ezToolbar.com. We assume that the cost for the one time creation of services by firm i to be quadratic (given by s_i^2). In other words, it is more costly to provide services that increasingly address the individual than those that generically fit a large group of consumers. Further, our setup suggests that this cost increases at a faster rate than the values derived from the associated customer information. This assumption rules out the trivial conclusion that a firm's optimal strategy is to offer infinite amounts of personalization services if benefits outweigh costs. Also, note that once the firm has invested in creating a set of services, both the marginal cost of serving an additional consumer, as well as the costs of serving the needs of consumers who consume fewer services than those created, are zero.

Firms pursue a fixed- or variable-services personalization approach when offering personalization services. Under the fixed-services approach, the consumer is faced with a take-it or leave-it offer where they will use the full set of services as long as the utility is non-negative. For a given type of consumers, there exists a satiation service level (denoted by s^o) beyond which consumption of additional services result in negative utility; this level is a solution to $u\left(s,\theta\right)=0$, i.e. $s^o\left(\theta\right)=\theta$. In order to ensure a nonnegative demand for its services, when a firm (firm i) employs the fixed-services approach, its choice of the level of services s_i^F is constrained in the interval $\left[0,b\right]$. Under the variable-services approach, the firm offers its full list of services to the market (denoted by s_i^V), and allows consumers to opt out from certain components of the services. Due to zero costs of degrading levels of services (i.e., zero versioning costs), consumers with varying degrees of the p4p tradeoffs will use her optimal level of services (denoted by s^*), which is a solution to $\max_{s\le s_i^V} u\left(s,\theta\right)$, i.e., $s^*\left(\theta\right)=\frac{\theta}{2}$. It can be observed that when the firm employs the variable-services approach, it has no incentive to provide $s_i^V>\frac{b}{2}$, as the market is already fully covered for $s_i^V=\frac{b}{2}$; additional services has no positive effects on its revenue. As a result, the firm constrains its choice of the level of services in the interval $\left[0,\frac{b}{2}\right]$.

Given the different implications of personalization approaches on firms' action set, we investigate the service-investment decision of a *capacity constrained* firm. We assume a quadratic cost for the one time creation of services (a kind of fixed cost but endogenized in the optimization problem), and construct the objective function when the firm adopts the fixed-services strategy as

$$\max_{s_i^F} \sigma_i s_i^F \int_0^b 1_{s^o(\theta)\geq s_i^F}(\theta) f(\theta) d\theta - \left(s_i^F\right)^2 \tag{2}$$

and that when it adopts the variable-services strategy as

$$\max_{s_i^V} \sigma_i \int_0^b 1_{s^*(\theta)<s_i^V}(\theta) \frac{\theta}{2} f(\theta) d\theta + \sigma_i s_i^V \int_0^b 1_{s^*(\theta)\geq s_i^V}(\theta) f(\theta) d\theta - \left(s_i^V\right)^2 \tag{3}$$

where σ_i is the marginal value for information (MVI) of firm i. The density function of $f(\theta)$ describes the distribution of p4p ratios in the market, and is assumed to be uniform $[0, b]$. The marginal cost of serving an additional consumer is zero.

The indicator function $1_{s^o(\theta)\geq s_i^F}(\theta)$ describes whether a consumer of type θ will subscribe the personalization services s_i^F deployed by firm i if it adopts the fixed-services strategy. The indicator function of $1_{s^*(\theta)<s_i^V}(\theta)$ characterizes the market segment in which customers consume their desired levels of personalization given that firm i adopts the variable-services strategy.

In this paper, we consider a duopoly where the two firms may or may not differ in their marginal value for information $\sigma_i \mid_{i\in\{1,2\}}$ with identical costs of producing personalization services. The identical cost function not only rules out a trivial explanation that any difference in firm strategies is due to differences in costs, but is also consistent with the ubiquitous availability and open-standard nature of personalization technologies. The ability to use information, however, is indeed a function of firms' business strategies and endowments that may affect their overall personalization offerings. No assumption is made on the relative values of the two MVIs.

4. Competition in a Duopoly

We model the duopolistic competition as a two-stage game with complete but imperfect information. In the first stage, firms simultaneously decide whether to follow a fixed- or a variable-services approach. Having observed the rival's choice of personalization approach, firms simultaneously choose their respective service levels $s_1 \in S_1$ and $s_2 \in S_2$ in the second stage. Note that the strategy spaces are bounded by b $\left(S_1, S_2 = \left[0, b\right]\right)$, as no consumer would use beyond this level; hence no firm will ever consider a strategy of offering services beyond this limit. We solve for the subgame-perfect Nash equilibria (SPNEs) in pure strategies through backward induction based on the series of possible subgame equilibria attained in the second stage.

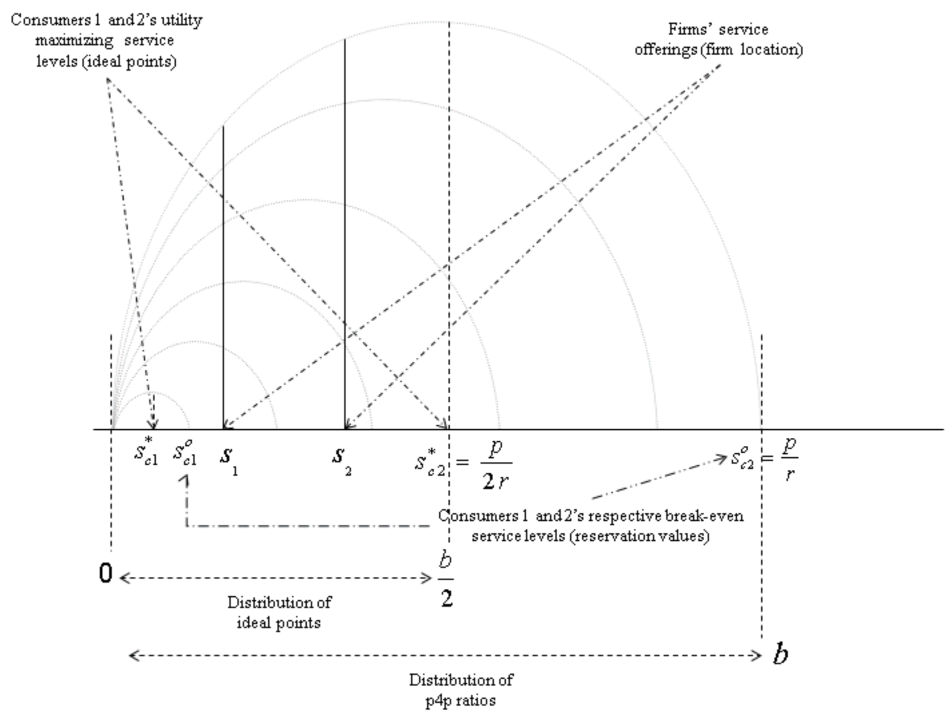

Figure 1: Distribution of consumer preferences and firm locations on a line

Figure 1 characterizes our personalization market as a linear one where each consumer's location or ideal service level s^* is uniformly distributed from 0 to $\frac{b}{2}$. If a firm offers a certain service level s_1 at some distance x from the ideal point of a consumer, the disutility given by $|\, u\left(p, r, s^*\right) - u\left(p, r, s_1\right) \,|$ will be rx^2. Hence consumers suffer a convex transportation cost, along the lines of D'Aspremont et al. (1979), for which equilibrium in locations exists under certain condition. While firms incur convex costs of locating themselves on the line (normally ignored in spatial models), the zero-marginal costs and zero versioning costs of services combined with the NFD property create unique competitive situations non-existent in physical goods markets. i.e. a firm adopting a variable-services strategy with service level s_1 can costlessly serve all consumers with $s^*(\theta) < s_1$ at their respective ideal levels. This can be considered as the firm costless creating a franchise at each consumer location to his left. Also note that since consumers do not have infinite reservation, no assumption is made *a priori* as to whether or not the market is covered.

We now proceed to solving for equilibria using backward induction. In the service-level subgames, firms know whether the competitor has adopted a fixed- or a variable-services approach in the previous stage. There are four possible subgames, namely fixed-fixed, fixed-variable, variable-fixed and variable-variable. Before identifying the SPNEs, we shall first characterize all possible subgame equilibria.

4.1. Subgame when both firms pursue the fixed-services approach

We first consider the case when both firms pursue the fixed-services approach. The individual rationality constraint requires that a consumer picks a service where her utility is non-negative, while the incentive compatibility condition requires that she chooses the firm that offers her the highest utility, i.e., she will choose Firm 1 if $u(s_1,\theta) > u(s_2,\theta)$. This can be written as

$$\theta(s_1 - s_2) > s_1^2 - s_2^2 \tag{4}$$

And if $s_1 < s_2$ (case a), equation (4) implies $\theta < s_1 + s_2$. Notice that consumers with $\theta < s_1$ would not use any services at all, therefore consumers given by $\theta \in [s_1, s_1 + s_2)$ would use Firm 1's services and the remaining consumers given by $\theta \in [s_1 + s_2, b]$ would use Firm 2's services.

By symmetry, we know that if Firm 1 offers more services than Firm 2 ($s_1 > s_2$, case "c"), consumers with $\theta \in \left[s_1 + s_2, b\right]$ will use Firm 1's services. If both firms offer the same level of service level ($s_1 = s_2$, case "b"), then given that consumers are indifferent between the two firms, Firm 1 will get half the market of all consumers using the services, i.e. half of the consumers whose break-even service level are $\theta \in \left[s_1, b\right]$. We can formally write Firm 1's profit functions in the second stage when both firms pursue a fixed-services approach (we use superscripts F and V for fixed- and variable-services approaches, respectively) as

$$\pi_1^F = \begin{cases} \pi_{1a}^F = \sigma_1 \int_{s_1}^{s_1+s_2} s_1 f\left(\theta\right) d\theta - s_1^{\,2} & \text{if } \left(s_1 < s_2\right) \\ \pi_{1b}^F = \frac{1}{2}\sigma_1 \int_{s_1}^{b} s_1 f\left(\theta\right) d\theta - s_1^{\,2} & \text{if } \left(s_1 = s_2\right) \\ \pi_{1c}^F = \sigma_1 \int_{s_1+s_2}^{b} s_1 f\left(\theta\right) d\theta - s_1^{\,2} & \text{if } \left(s_1 > s_2\right) \end{cases}$$

By symmetry, we can construct Firm 2's profit function. Notice that the payoff functions of both firms are discontinuous in the service space; such a discontinuity raises the concern of whether pure-strategy equilibrium exists. However, for our analyses, we consider only pure-strategy equilibria for two reasons: First, mixed strategies severely limit the explanatory power of the model; second, Dasgupta and Maskin (1986) suggest that it is not the discontinuity itself, but rather failure of the payoff functions to be quasi-concave that is the reason for the non-existence of equilibrium in pure-strategies. They propose that under certain conditions (quasi-concavity, upper semi-continuity and graph continuity of the payoff functions), even a game with functions that have limited continuity can possess a pure-strategy Nash equilibrium. Later work has argued that these conditions are still too restrictive, and that pure strategy equilibrium exists as long as the aggregator function alone possesses certain properties[1] (Baye et al. 1993).

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[1] The sufficient conditions are *Diagonal Transfer Continuity* and *Diagonal Transfer Quasiconcavity.*

Lemma 1[2]**.** *In a subgame where both firms adopt a fixed-services strategy, a subgame equilibrium* $\left(s_i^{F*}, s_{-i}^{F*}\right) = \left(\frac{b\sigma_i\sigma_{-i}}{4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}}, \frac{2b^2\sigma_{-i}}{4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}}\right)$ *in the second stage exists if and only if* $\sigma_i \in \left[0, 2b\right)$ *and* $\sigma_{-i} \in \left[\frac{8b^2\sigma_i}{4b^2-\sigma_i^2}, \infty\right)$ ■

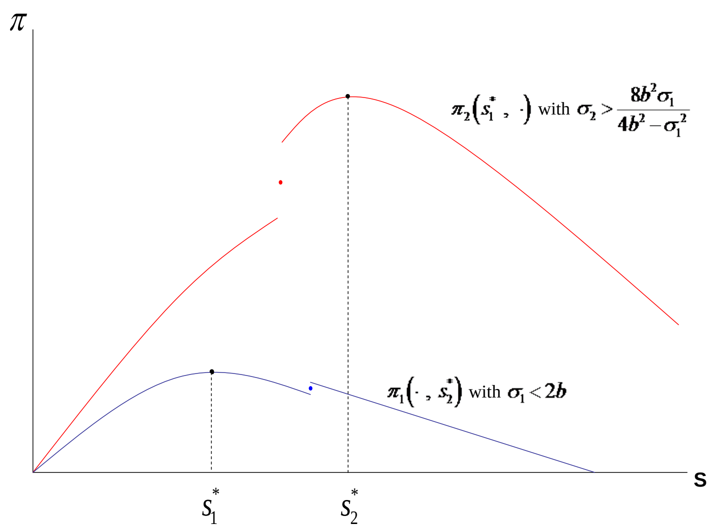

Figure 2: Profit functions under equilibrium when both firms pursue the fixed-services approach with different service levels

Without loss of generality, assume Firm 2 to be the firm with larger MVI throughout the paper. Note that while the equilibrium services offered by both firms are increasing in σ_2, the services offered by high MVI firm $\left(s_2^{F*}\right)$ is decreasing in σ_1 and the low MVI firm's services $\left(s_1^{F*}\right)$ continue to increase in its own MVI. The intuition behind this is that if the MVIs are sufficiently far apart, firms will make themselves attractive to very distinct segments; however, as σ_1 ap-

[2] Due to the symmetric nature of the equilibria, we use i and $-i$ to denote the two different firms in lemmas and propositions. In the corresponding discussions, we use Firm 1 and Firm 2 for clarity of exposition.

proaches $2b$, the low MVI firm will begin to offer services that are now attractive to some consumers (who were using more than their optimal levels) of its competitor. For the large MVI firm, the cost of offering higher number of services is not offset by the demand captured and will therefore lower his service level. Further, we know that the number of consumers who are not served $\left(\theta < s_1^{F*}\right)$ increases in MVI, while on the other hand some consumers (with high p4p ratio) might receive services closer to their optima. This portends interesting consumer (and hence social) welfare implications that we shall explore later. In fact, since $\lim_{\sigma_1 \to 2b} s_1^{F*} = s_2^{F*}$, we not only know that the 2b threshold is important in maintaining the equilibrium with different service levels but also that there is potentially an equilibrium of identical service level if the MVIs of both firms are sufficiently high (no smaller than $2b$).

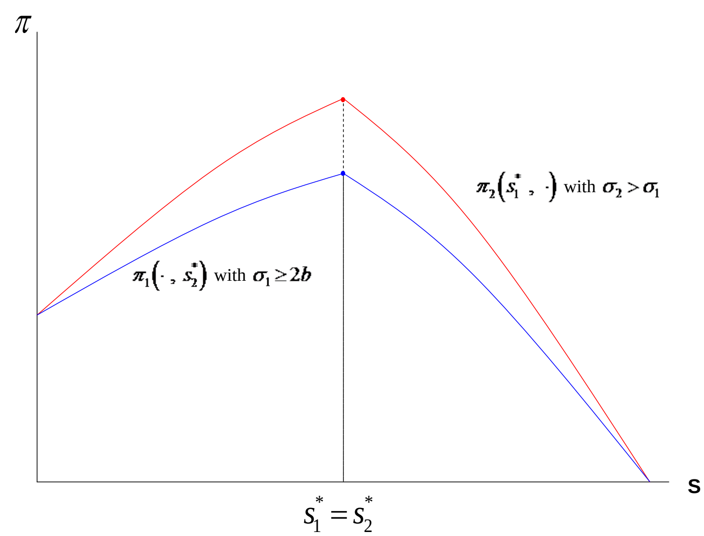

Figure 3: Profits of firms under subgame equilibrium when both firms pursue the fixed-services approach with identical service level

Lemma 2. *In the subgame where both firms employ a fixed-services strategy, an equilibrium* $\left(s_i^{F*}, s_{-i}^{F*}\right) = \left(\frac{b}{3}, \frac{b}{3}\right)$ *exists if and only if* $\left\{\sigma_i, \sigma_{-i}\right\} \in \left[2b, \infty\right)$ ■

Lemma 2 suggests that when firms with relatively high MVIs both pursue a fixed-services approach, the only feasible equilibrium is characterized by firms offering the same level of services and sharing the market equally (see Figure 3 for a graphical representation of profits of the high MVI firms with respect to services offered). The equilibrium service level $\left(s_1^{F*}, s_2^{F*}\right) = \left(\frac{b}{3}, \frac{b}{3}\right)$ should be interpreted along with the NFD property of personalization. The firm that marginally increases its service level (e.g., a small amount δ) attracts all consumers from $\left[2s^F + \delta, b\right]$, but at the price of forgoing all consumers from the market segment $\left[s^F, 2s^F + \delta\right]$ to its rival because the utilities for these consumers become negative by staying with this firm. The similar tradeoff also applies to the one that considers a marginally decrease in its services level to attract the lower-end segment of the market $\left[s^F - \delta, 2s^F - \delta\right]$. Therefore, both firms face the tradeoffs between serving the upper segment and lower segment of the covered market. The credible threat that the competitor would undercut the focal firm's sales from either above or below makes $s_1^{F*} = s_2^{F*} = \frac{b}{3}$ the only equilibrium that survives the two-side deviation check. Note that firms need not be characterized by identical MVIs for the equilibrium with identical service level to exist; it is both necessary and sufficient for the existence of this equilibrium that both firms have MVIs that are no smaller than a threshold $\left(2b\right)$.

4.2 Subgame when both firms pursue the variable-services approach

When firms pursue the variable-services approach, the NFD property plays an important role in that with the option of choosing their own service levels, consumers choose only their optimal service level $\frac{\theta}{2}$ if available. Since consumers are indifferent between services offered by the two firms, both firms share the consumer segment with $\theta \le \min\left\{2s_1, 2s_2\right\}$. The remaining consumers use services from the firm offering a higher service level, because they can no longer be satisfied by the other firm. Note also that only consumers given by $\min\left\{2s_1, 2s_2\right\} < \theta \le \max\left\{2s_1, 2s_2\right\}$

have the option of choosing their ideal level of services; consumers with $\theta > \max\{2s_1, 2s_2\}$ can only use the exact amount that is offered. Thus, we can formally write Firm 1's profit functions as

$$\pi_1^V = \begin{cases} \pi_{1a}^V = \frac{1}{2}\sigma_1 \int_0^{2s_1} \frac{\theta}{2} f(\theta)\, d\theta - s_1^2 & \text{if } (s_1 < s_2) \\ \pi_{1b}^V = \frac{1}{2}\sigma_1 \left[\int_0^{2s_1} \frac{\theta}{2} f(\theta)\, d\theta + s_1 \int_{2s_1}^{b} f(\theta)\, d\theta \right] - s_1^2 & \text{if } (s_1 = s_2) \\ \pi_{1c}^V = \frac{1}{2}\sigma_1 \int_0^{2s_2} \frac{\theta}{2} f(\theta)\, d\theta + \sigma_1 \left[\int_{2s_2}^{2s_1} \frac{\theta}{2} f(\theta)\, d\theta + s_1 \int_{2s_1}^{b} f(\theta)\, d\theta \right] - s_1^2 & \text{if } (s_1 > s_2) \end{cases}$$

For some firm parameters, offering a service level lower than that of the competitor is a strictly *dominated* strategy; when $\sigma_1 < 2b$, π_{1a}^V is negative regardless of the service level offered by Firm 2. The intuition is that when both firms pursue the variable-services approach, the firm offering a lower service level incurs the full cost of offering the services while being assured of only half the corresponding market. However, if $\sigma_1 > 2b$, π_{1a}^V is still increasing as s_1 approaches s_2, implying that this firm will prefer to offer the same or higher number of services compared to his competitor. Extending this logic to Firm 2 and by symmetry we can preclude the possibility of an equilibrium with different service levels when variable services define the market.

Lemma 3. *In the subgame where both firms pursue a variable-services approach, an equilibrium* $\left(s_i^{V*}, s_{-i}^{V*}\right) = \left(\frac{b}{2}, \frac{b}{2}\right)$ *exists if and only if* $\{\sigma_i, \sigma_{-i}\} \in [2b, \infty)$.

It can be observed that both firms create the highest level of services in their action set, i.e. $\left[0, \frac{b}{2}\right]$, even with <u>*finite*</u> σ. The intuition is that, as long as the firms can earn a non-negative profit by providing the same level of services, both of them have the incentive to offer a service level that is infinitesimally higher than its competitors; because this small deviation allows the firm to capture all consumers lying within $(2s^V, b]$ (who were originally split equally between the two firms) while still maintaining the half of the market that overlaps its competitor, i.e., $\left[0, 2s^V\right]$, since both firms allow consumers to freely choose their individual desired levels of personalized services within the set of $\left[0, s^V\right]$. The tie-up effect drives the service investment of both firms to the extent that the surplus of all consumers in the market is maximized. Hence, if the MVIs are high enough for firms to offset the cost of offering such a high level of personalization, both firms would offer the maximum level of services desired by the consumers in equilibrium. Moreover, there exists no equilibrium where firms deploy different levels of personalization services, as the firm that deploys the lower level (nonzero) of services always gains from increasing its services level.

An important reason as to why firms need to possess sufficiently high MVIs (no smaller than $2b$) for this equilibrium to exist is that when one firm is below the threshold, there is always the tendency for firms to serve different portions of the market as posited in Proposition 1. On the other hand, two small firms never find it optimal to share the market. The intuition is that since consumers are indifferent between services offered by the two firms as long as the levels of services are the same, both firms incur the full infrastructure costs while only getting half of the market; firms can always increase their market share by offering slightly more or fewer number of services.

4.3. Subgame when one firm pursues fixed- while the other pursues variable-services approach

Without loss of generality, assume Firm 2 to be the one that pursues the fixed-services approach, while Firm 1 allows consumers to choose services in a variable fashion. First consider the case when both firms offer different levels of services $\left(s_1 \neq s_2\right)$. If Firm 1 offers fewer number of services than 2 $\left(s_1 < s_2\right)$, then all consumers with surplus maximizing number of services lower than that offered by Firm 1 $\left(\theta \leq 2s_1\right)$ would choose Firm 1, because they can freely choose their ideal level to consume. The remaining consumers would choose Firm 1 if $u\left(\theta, s_1\right) > u\left(\theta, s_2\right)$. We can see that consumers with p4p ratio $\theta \in [2s_1, s_1 + s_2)$ still use Firm 1's services. However, if Firm 1 offers more services than Firm 2 $(s_1 > s_2)$, all consumers will choose Firm 1 and use their individual utility-maximizing number of services. If both firms offer the same level of services $(s_1 = s_2)$, Firm 1 will capture all consumers whose $\theta \leq 2s_1$ and half the market of all remaining consumers. Thus the profit function of the firm offering variable services can be written as

$$\pi_1^{\widetilde{V}} = \begin{cases} \pi_{1a}^{\widetilde{V}} = \sigma_1 \left[\int_0^{2s_1} \frac{\theta}{2} f(\theta)\, d\theta + \int_{2s_1}^{s_1+s_2} s_1 f(\theta)\, d\theta \right] - s_1^2 & \text{if } (s_1 < s_2) \\ \pi_{1b}^{\widetilde{V}} = \sigma_1 \left[\int_0^{2s_1} \frac{\theta}{2} f(\theta)\, d\theta + \frac{1}{2} \int_{2s_1}^{b} s_1 f(\theta)\, d\theta \right] - s_1^2 & \text{if } (s_1 = s_2) \\ \pi_{1c}^{\widetilde{V}} = \sigma_1 \left[\int_0^{2s_1} \frac{\theta}{2} f(\theta)\, d\theta + \int_{2s_1}^{b} s_1 f(\theta)\, d\theta \right] - s_1^2 & \text{if } (s_1 > s_2) \end{cases}$$

And the profit function of the firm offering fixed-services can be written as

$$\pi_2^{\widetilde{F}} = \begin{cases} \pi_{2a}^{\widetilde{F}} = \sigma_2 \int_{s_1+s_2}^{b} s_2 f(\theta)\, d\theta - s_2^2 & \text{if } (s_1 < s_2) \\ \pi_{2b}^{\widetilde{F}} = \frac{\sigma_2}{2} \int_{2s_2}^{b} s_2 f(\theta)\, d\theta - s_2^2 & \text{if } (s_1 = s_2) \\ \pi_{2c}^{\widetilde{F}} = -s_2^2 & \text{if } (s_1 > s_2) \end{cases}$$

Let the Nash equilibrium pair be given by $s_1^{\widetilde{V}*}$ and $s_2^{\widetilde{F}*}$. We can immediately observe that when the firm offering higher number of services allows consumers to choose their preferred level, it is never optimal for the firm offering a lower service level to pursue a fixed-services approach, as itresults in a negative profit for the firm (i.e., $s_1^{\widetilde{F}} < s_2^{\widetilde{V}}$ is never an equilibrium possibility). Hence the only possible equilibrium with different levels of services will be characterized by $s_1^{\widetilde{V}*} < s_2^{\widetilde{F}*}$.

Lemma 4. *In the subgame where one firm pursues the fixed-services approach while the other pursues the variable-services approach, there exists an equilibrium characterized by different* *service levels* $\left(s_i^{\widetilde{V}*}, s_{-i}^{\widetilde{F}*}\right) = \left(\dfrac{b\sigma_i\sigma_{-i}}{4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}}, \dfrac{2b^2\sigma_{-i}}{4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}}\right)$, *where* $\sigma_i \in \left[0, \dfrac{2b}{1+\sqrt{2}}\right)$

and $\sigma_{-i} \in \left[\dfrac{8b^2\sigma_i}{4b^2 - 4b\sigma_i - \sigma_i^2}, \infty\right)$ ■

4.4. Subgame-perfect Nash Equilibria (SPNEs) for the full game

Having characterized all equilibria for the second stage subgame, we now proceed to determine the SPNEs for the full game. Note that similar to a traditional price-location game where price and location are the two strategic variables, the two strategic variables available to the firms here are their choices regarding fixed- versus variable-services approach and the actual number of services to offer. However, the MVI-related conditions from within the possible subgame equilibria tell us about the relative MVIs of the firms that allow for an equilibrium to exist. In verifying that any or all of the second-stage equilibria are subgame-perfect, we need not only to consider the strategies and service space, but also the bounds within which these are valid. We shall first focus on the case where two firms have sufficiently different MVIs.

PROPOSITION 1. *When two firms are sufficiently differentiated in their MVIs, i.e.,* $\sigma_i < 2b$ *and* $\sigma_{-i} \geq \dfrac{8b^2\sigma_i}{4b^2 - \sigma_i^2}$, *there exists a pure-strategy SPNE where both firms pursue the fixed-services approach and segment the market. As the difference in MVIs between the two firms further increases to satisfy* $\sigma_{-i} \geq \dfrac{8b^2\sigma_i}{4b^2 - 4b\sigma_i - \sigma_i^2}$, *a second pure-strategy SPNE emerges, where the low MVI firm adopts a variable-services approach while maintaining the same service levels and profits.* ■

Proposition 1 characterizes competition when firms are sufficiently differentiated in MVIs. The two firms share the market in such a way that the low MVI firm serves mainly consumers with low p4p ratios and the high MVI firm caters to consumers with high p4p ratios. Note that when both firms offer fixed-services, it does not matter what the ideal points of consumers are, consumers select a given service-level as long as their individual rationality (IR) constraints are satisfied, and their choice of firm depends on the individual's incentive compatibility (IC) constraint. The condition on the separation of MVIs essentially ensures that the firm with low MVI will not attempt to undercut the higher MVI competitor due to the tradeoff between its costs and marginal value for information.

When the difference in MVI between the two firms increases, an additional equilibrium where the low MVI firm pursues the variable-services approach emerges. By offering variable services, the low MVI firm essentially serves those consumers who would have been left out of the market by both firms had they offered fixed services (i.e., those with very low p4p ratios such that $\theta < s_1^{F*}$). At the same time, the firm loses some of the surplus that it could have extracted from consumers with $\theta \in \left(s_1^{F*}, 2s_1^{F*}\right]$, as these consumers now only use their respective ideal service level $\left(\frac{\theta}{2}\right)$. However, under the uniform distribution, both the equilibrium service levels and profits remain the same when the low MVI firm pursues this strategy.

The condition ensuring that the firm with low MVI will not attempt to undercut the higher MVI competitor is more stringent when the former employs the variable-service strategy. Although the fixed-vs.-fixed equilibrium and the fixed-vs.-variable equilibrium produce the same profits for both firms, they are different in attractiveness of potential deviations. Compared with the case where it pursues a fixed-services approach, the low MVI firm is more likely to deviate when it instead adopts a variable-services approach at the first stage, since undercutting the higher MVI competitor does not lead to surrendering consumers with low p4p ratios to its competitor, which is the case had it offered fixed services. Thus the corresponding equilibrium requires a larger separation in MVIs so that the high MVI firm's equilibrium service level is intimidatingly high to prevent the low MVI firm from undercutting its service level.

An important result to note is that in equilibrium, whenever at least one firm offers variable services, the market is *always fully covered*, and that consumer surplus is unambiguously higher compared to the case where both firms offer fixed services. Whenever one firm allows consumers to choose their desired service level, every consumer can find a service level that guarantees a non-zero utility; consumers with low p4p ratios are allowed to pick up their ideal levels of services from the variable-services firm and derive the maximum attainable surplus from personalization, while consumers with high p4p ratios choose between this firm and the competitor with a higher service level by selecting $s_1^{\widetilde{V}*}$ or $s_2^{\widetilde{F}*}$. Next we turn to the scenario when the market is served by two firms with sufficiently high MVIs.

PROPOSITION 2. *The competition between firms with high MVIs* $(\sigma_i, \sigma_{-i} \geq 2b)$ *is characterized by pure-strategy SPNEs with the same level of services.*

a) Both firms pursuing a fixed-services approach if MVIs of <u>both</u> firms are large but within a threshold value $(10b)$*. One-third of the market will be left out in this equilibrium.*

b) When MVIs of both firms exceed the threshold value given in (a), both firms pursue a variable-services approach. The market is fully covered in this equilibrium.

c) Both the fixed-v.s.-fixed equilibrium in a) and the variable-v.s.-variable equilibrium in b) can exist if <u>either</u> firm has an MVI that exceeds a threshold value $(10b)$*.* ■

Proposition 2 tells us that, when both firms have relatively high MVIs $(\sigma_1, \sigma_2 \geq 2b)$, they cannot credibly differentiate themselves with each other in both service strategies and levels of services. As a result, only that both firms pursue the same personalization approach with identical service level can be the equilibrium outcomes.

The discussion following Lemma 3 suggests that both firms adopting the variable-services approach in stage 1 would induce a tie-up effect for services investment, which incentivizes both firms to create the highest level of services in the action set (i.e., $\frac{b}{2}$) even with *a finite* σ. Thus the equilibrium service level is independent of the firms' own MVIs (as long as they are above the threshold), and all consumers enjoy their ideal level of personalization services. In this case, the market is fully covered, and all consumers are able to tailor personalization to their ideal levels. Alternatively, if both firms pursue the fixed-services approach in stage 1, the NFD property of personalization enables the competitor to undercut the focal firm's sales by lowering the level of services. Our analysis shows that $s^{F^*} = \frac{b}{3}$ is the only level of services that prevents the competitor from undercutting the focal firm's sales either from above or below, and hence is chosen by both firms in the equilibrium. Again, the equilibrium service level is independent of the firms' own MVIs (as long as they fall in some ranges). In this case, both firms end up serving and sharing the upper two-thirds of the market and leaving the rest (consumers with $\theta < \frac{b}{3}$) uncovered; at the same time some consumers $\left(\frac{2b}{3} < \theta \leq b\right)$ are left without being fully satisfied.

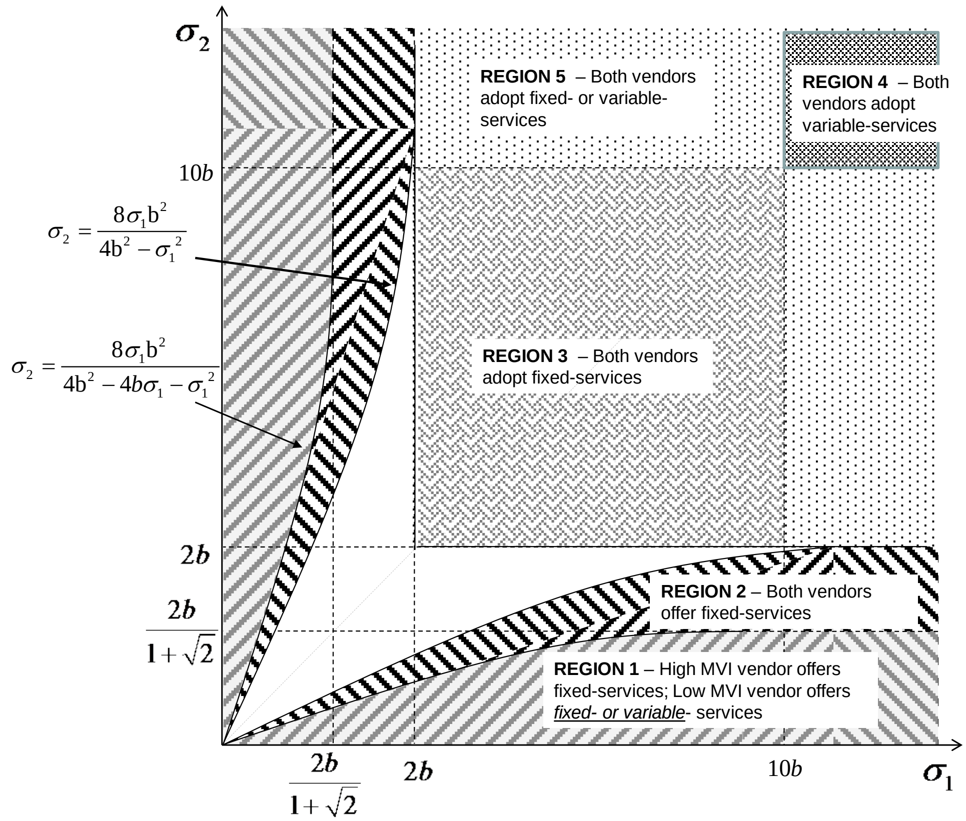

Figure 4: SPNE regions

Figure 4 characterizes the equilibrium regions of competition between firms with different MVIs where SPNEs exist in pure strategies. In Table 2 below, we provide a summary of all equilibrium strategies and profits as discussed in Propositions 1 and 2. Note that firm types refer to the characterization of the duopolies as defined by their respective MVIs. Also observe that from Figure 4, the region in white corresponds to the scenario where no pure-strategy equilibrium exists. This suggests that in a duopoly where firms' MVIs fall in this region, the firms might continue to undercut each other or randomize their service strategies.

Table 2: SPNE strategies and profits

Firm Types	Strategies	Profits
Two equilibria: (Region 1 in Figure 4) $\sigma_i \in \left[0, \frac{2b}{1+\sqrt{2}}\right)$ $\sigma_{-i} \in \left[\frac{8\sigma_i b^2}{4b^2 - 4b\sigma_i - \sigma_i^2}, +\infty\right)$	$\left\{\left(s_i^F, \frac{b\sigma_i\sigma_{-i}}{4b(b+\sigma_{-i})+\sigma_i\sigma_{-i}}\right); \left(s_{-i}^F, \frac{2b^2\sigma_{-i}}{4b(b+\sigma_{-i})+\sigma_i\sigma_{-i}}\right)\right\}$ $\left\{\left(s_i^V, \frac{b\sigma_i\sigma_{-i}}{4b(b+\sigma_{-i})+\sigma_i\sigma_{-i}}\right); \left(s_{-i}^F, \frac{2b^2\sigma_{-i}}{4b(b+\sigma_{-i})+\sigma_i\sigma_{-i}}\right)\right\}$	$\pi_i^{F*} = \pi_i^{V*} = \frac{b^2\sigma_i^2\sigma_{-i}^2}{\left[4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}\right]^2}$ $\pi_{-i}^{F*} = \frac{4b^3\sigma_{-i}^2\left(b+\sigma_{-i}\right)}{\left[4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}\right]^2}$
Unique Equilibrium: (Region 2 in Figure 4) $\sigma_i \in \left[0, 2b\right)$ $\sigma_{-i} \in \left[\frac{8\sigma_i b^2}{4b^2 - \sigma_i^2}, \frac{8\sigma_i b^2}{4b^2 - 4b\sigma_i - \sigma_i^2}\right)$	$\left\{\left(s_i^F, \frac{b\sigma_i\sigma_{-i}}{4b(b+\sigma_{-i})+\sigma_i\sigma_{-i}}\right), \left(s_{-i}^F, \frac{2b^2\sigma_{-i}}{4b(b+\sigma_{-i})+\sigma_i\sigma_{-i}}\right)\right\}$	$\pi_i^{F*} = \frac{b^2\sigma_i^2\sigma_{-i}^2}{\left[4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}\right]^2}$ $\pi_{-i}^{F*} = \frac{4b^3\sigma_{-i}^2\left(b+\sigma_{-i}\right)}{\left[4b\left(b+\sigma_{-i}\right)+\sigma_i\sigma_{-i}\right]^2}$
Unique Equilibrium: (Region 3 in Figure 4) $\sigma_{i,-i} \in \left[2b, 10b\right)$	$\left\{\left(s_i^F, \frac{b}{3}\right); \left(s_{-i}^F, \frac{b}{3}\right)\right\}$	$\pi_i^{F*} = \frac{b\left(\sigma_i - b\right)}{9}$ $\pi_{-i}^{F*} = \frac{b\left(\sigma_{-i} - b\right)}{9}$
Unique Equilibrium: (Region 4 in Figure 4) $\sigma_{i,-i} \in \left[10b, +\infty\right)$	$\left\{\left(s_i^V, \frac{b}{2}\right); \left(s_{-i}^V, \frac{b}{2}\right)\right\}$	$\pi_i^{V*} = \frac{b\left(\sigma_i - 2b\right)}{8}$ $\pi_{-i}^{V*} = \frac{b\left(\sigma_{-i} - 2b\right)}{8}$
Two Equilibria: (Region 5 in Figure 4) $\sigma_i \in \left[2b, 10b\right)$, $\sigma_{-i} \in \left[10b, +\infty\right)$	$\left\{\left(s_i^F, \frac{b}{3}\right); \left(s_{-i}^F, \frac{b}{3}\right)\right\}$; $\left\{\left(s_i^V, \frac{b}{2}\right); \left(s_{-i}^V, \frac{b}{2}\right)\right\}$	$\left\{\pi_i^{F*} = \frac{b\left(\sigma_i - b\right)}{9}; \pi_{-i}^{F*} = \frac{b\left(\sigma_{-i} - b\right)}{9}\right\}$; $\left\{\pi_i^{V*} = \frac{b\left(\sigma_i - 2b\right)}{8}; \pi_{-i}^{V*} = \frac{b\left(\sigma_{-i} - 2b\right)}{8}\right\}$

Another important implication is one that hints towards reducing consumer privacy concerns. We can see that profits of both firms are increasing in consumers' p4p ratios, and prior research (Chellappa et al. 2005) suggests that engendering trust in a personalization context may reduce privacy concerns. While it is beyond the scope of this paper, one could observe that even if service offerings are indistinguishable, firms may better their profits by differentiating themselves on the basis of consumer trust.

4.5. Welfare analyses

Welfare analysis is an important part of any research on privacy, for the simple reason that many rules and regulations governing consumers' online privacy concerns are the domain of regulatory bodies. Hence in our research we are interested not only in the competitive outcomes but also in the resulting consumer and social welfare. In this subsection, we examine welfare under the different SPNEs to provide managerial and regulatory recommendations.

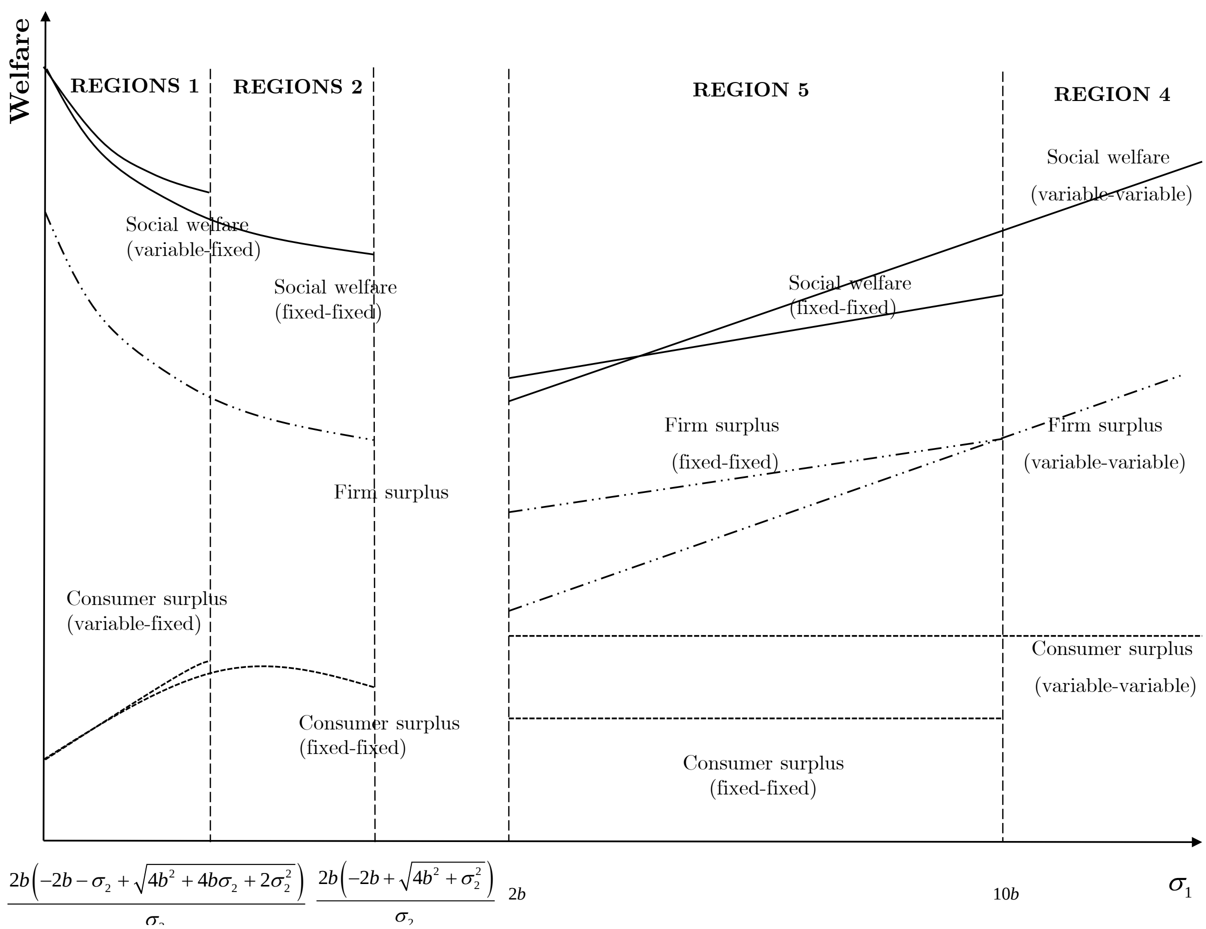

Figure 5: Welfare comparison when $\sigma_2 \geq 10b$

Proposition 3. *The provision of variable-services even by one firm always improves consumer welfare, compared to when both firms pursue the fixed-services approach. Consumer and social welfare is maximized in the case when two firms have very large MVIs (exceeding 10b).* ■

The 4 regions depicted in Figure 5 can be understood as 3 different market conditions; while regions 1 and 2 are perhaps representative of a nascent market where not all firms have figured out how to use consumer information effectively, region 4 represents the case where firms have fully matured in this capability. Comparing consumer surpluses in different equilibria described in regions 1 and 5 (Figure 5) reveals that consumers are always better off when variable services are offered by at least one firm. This observation can be attributed to the fact that, when at least one firm pursues the variable-services approach, some (if not all) consumers can enjoy their surplus-maximizing service levels; further, the market is fully served.

However, how consumer surplus and firms' profits change with respect to varying degrees of firms' capability of exploiting customer information within each of the equilibria is less straightforward. In region 1 where firms' MVIs are sufficiently differentiated $\left(\sigma_1 \leq \frac{2b\left(-2b+\sqrt{4b^2+\sigma_2^2}\right)}{\sigma_2} < 2b,\ \sigma_2 \geq 10b\right)$, the equilibrium is characterized by both firms pursuing the fixed-services approach; which results in a partially covered market segmented by the two firms (Proposition 1). In this equilibrium, and for a given σ_2, consumer surplus is not monotonically increasing in the marginal value for information of the low MVI firm $\left(\sigma_1\right)$ (see Figure 5). To unveil the underlying rationale of this non-monotonic nature of consumer surplus, observe that the equilibrium level of services of firm 1 $\left(s_1^{F*} = \frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)$ is increasing in σ_1, while that of firm 2 $\left(s_2^{F*} = \frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)$ is *decreasing* in σ_1. Therefore, a reduction in the differentiation in firms' MVIs (i.e. σ_1 increases while σ_2 remains constant) leads to the convergence of firms' equilibrium service levels. This convergence bring forward two counter-acting effects on the overall consumer surplus: first, the surplus of consumers with medium p4p ratios (those around the market partition point) approaches the maximum attainable levels; second, the surplus of those with highest p4p ratios decreases and consumers with the lowest p4p ratios start to exit the market. The latter (negative) effect gradually dominates the former as σ_1 increases, leading to reduction in consumer surplus. Firm surplus, on the other hand, is uniformly decreasing in the marginal value for information of the low MVI firm $\left(\sigma_1\right)$; this is due to the intensified competition resulting from reduced differentiation in the service levels of the two firms. The resulting monotonic decrease in social welfare suggests that the loss from firm surplus always dominates any possible increase in consumer surplus discussed above.

In region 5 we again observe some interesting dynamics in firm and consumer surplus with regards to the particular personalization approach that firms choose in equilibrium. Compared with the fixed-vs.-fixed equilibrium, when firms pursue the variable-services approach, consumer surplus is unambiguously higher (due to reasons discussed before). However, firm surplus is lower in the latter case. This can be attributed to two reasons: first, firms incur higher investment costs in offering higher service levels ($\frac{b}{2}$ in variable-variable vs. $\frac{b}{3}$ in fixed-fixed); second, consumers now choose service levels that maximize their individual utilities while such levels are lower than that required by the firms in the former case, hence providing less information to firms for revenue-generating purposes. The difference in firm surplus under the two equilibria decreases as firms' MVIs increase (i.e. the negative effects of investment cost and reduction in revenue-generating ability on profits are less pronounced for firms with higher MVIs), hence we observe the social welfare under the variable-vs.-variable equilibrium first lag behind and then exceed that under the fixed-vs.-fixed equilibrium.

Table 3: Welfare under different models of firm competition

Personalization Approach	Welfare
Both firms offer fixed services	Consumer surplus $= \dfrac{2b^4\sigma_2\left(8b^3+4b\left(2b+\sigma_1\right)\sigma_2+\left(2b+3\sigma_1\right)\sigma_2^2\right)}{\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3}$ Social welfare $= \dfrac{16b^5+\sigma_2\left(32b^4+4b^2\sigma_1\left(2b+\sigma_1\right)\right)+\left(36b^3+10b^2\sigma_1+4b\sigma_1^2+\sigma_1^3\right){\sigma_2}^2+4b\left(4b+\sigma_1\right)\sigma_2^3}{\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3}b^2\sigma_2$
Both firms offer fixed services	Consumer surplus $=\dfrac{2b^2}{27}$ Social welfare $=\dfrac{3\sigma_1+3\sigma_2-4b}{27}b$
Both firms offer variable services	Consumer surplus $=\dfrac{b^2}{12}$ Social welfare $=\dfrac{3\sigma_1+3\sigma_2-10b}{24}b$
Firm 1 offers variable services & Firm 2 offers fixed services	Consumer surplus $= \dfrac{b^2\sigma_2\left(96b^5+48b^3\left(2b+\sigma_1\right)\sigma_2+\left(24b^3+36b^2\sigma_1+\sigma_1^3\right)\sigma_2^2\right)}{6\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3}$ Social welfare $= \dfrac{96b^5+\left(192b^4+48b^3\sigma_1+24b^2\sigma_1^2\right)\sigma_2+\left(216b^3+60b^2\sigma_1+24b\sigma_1^2+7\sigma_1^3\right)\sigma_2^2+\left(96b^2+24b\sigma_1\right)\sigma_2^3}{6\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3}b^2\sigma_2$

A final but perhaps the most important observation is that consumer surplus is maximized when both firms have very high MVIs $\left(\geq 10b\right)$, and the market is characterized by both firms pursuing the variable-services approach. This result implies that, counter to intuition, a regulator should perhaps be concerned about competition among smaller players, while allowing larger firms to play out their respective strategies; as competitive forces will drive high MVI firms to not only serve the entire market and offer the largest set of services, but also allow consumers to freely choose the extent of personalization that best fits them. We summarize the quantitative findings from the welfare analysis in Table 3.

5. Managerial and policy implications

An important motivation for our problem is the emergence of new personalization delivery technologies that provide firms with greater control over how information about consumers' online usage is acquired. The fixed-services approach – the option to acquire a fixed-amount of information through delivering a given set of personalized services – was hitherto non-existent as early forms of personalization was largely restricted to user controlled, Web-based static mechanisms. It is in fact the fixed-services contract that a user agrees to, often with little or no control subsequently, that has gotten the attention of the media and privacy groups that compare these services to spyware technologies (e.g., the campaign against Ask Jeeves (Stone 2005)), and has become the main subject of ongoing FTC investigations into the legitimate and illegitimate data acquisition technologies (FTC 2004).

From a managerial perspective, since firms' profits are increasing in consumers' p4p ratio, our results suggest that firms should employ significant trust building and other reassuring services known to help allay privacy concerns and therefore increase the p4p ratios. Since firms with large MVIs have strong incentives to move towards variable-services offering, it is evident that smaller independent firms that solely depend on third-party advertising networks for generating value from information will find it hard to continue sustaining in this market. Perhaps these smaller firms will distinguish themselves by going the niche services route or will be absorbed into some larger firms. It is also interesting to note that while in the highly competitive marketplace firms adopt the variable-services approach, Apple and Google are currently persisting with the fixed-services approach. This could perhaps be attributed to their near monopoly status in the area of retail personalization, although our model would suggest that with increasing number of firms occupying this space, these firms will eventually allow consumers the option to turn off certain features of their services.

5.1. Policy implications

Our results suggest that consumer welfare is increasing in the firms' ability to use information. Further, when a market is mature with firms already having figured out effective usage of customer information, the competitive dynamics dictate that firms offer the maximum possible number of services that the market would consume at each consumer's preferred level, thus maximizing consumer surplus. This is perhaps one of those unique markets where an oligopoly of a few large players might indeed be beneficial to the consumers.

There could potentially be two responses to addressing the concerns of privacy advocates; one that bars information acquisition itself and a second that bars the usage of the information acquired. Our findings suggest that if the regulator can encourage effective use of information by firms (such that they are able to increase their marginal value for information), there is then no need prevent information acquisition since competition will ensure that firms act in a fashion that is favorable to the consumers. Indeed it is only in nascent markets with small firms where primarily the fixed-services approach is being pursued. These observations from our model have found support in a recent case where FTC accuses UPromise of its "deceptive" data collection practice through a toolbar that delivers personalization services to its members (FTC 2012). Unlike those toolbars offered by Yahoo! or MSN, users of the UPromise toolbar are required to employ its full functionality, thus allowing the company to monitor their browsing and transaction history, or to uninstall it and forgo any personalization that the toolbar provides. As a result, UPromise is ordered to destroy all data that it has collected from its members, to explicitly disclose its data collection practices, and to obtain consent from consumers before installing or re-enabling its toolbar on users' computers.

5.2 Implications to theory

From a theoretical point of view, our research adds to the literature on privacy, as well as competition in NFD goods and services markets. Despite the rich literature on privacy in information systems, there are two important areas that have not received adequate attention. First, there is a limited number of papers in information systems that provides an understanding of issues surrounding consumer's privacy from a regulator's perspective. Second, the impact of privacy on online business at the societal level is also severely lacking (Belanger et al. 2011; Smith et al. 2011); most of the extant research focuses on individual-level analysis with results that may not be generalizable beyond the specific contexts of the studies. Our work investigates competition in the market for information under a general setting, and analyzes the welfare implications at the societal-level offer important insights for regulators on protecting consumer privacy online; in particular, ours is one of the first attempts in addressing regulatory implications of the personalization-privacy tradeoffs in a competitive and non-price context. Our study, therefore, contributes to the stream of privacy literature by bridging these gaps.

Our model incorporates elements of both horizontal and vertical differentiations that emerge endogenously from the NFD property and cost characteristics of personalization services, and heterogeneity among consumers and firms. These attributes, combined with the non-price, zero marginal cost and zero versioning cost of personalization have been unexplored in extant research. Hence our modeling approach offers important extensions to standard spatial competition models that are widely used in IS research.

5.3. Limitations and future research

As with any first model of a real-world context, we are limited in the number of issues we can explore in the current paper. One first such limitation is perhaps the assumption that firms only vary in their MVIs and have common cost coefficients. It is quite possible that firms may differ in their ability to personalize and also in the liability costs of the information they acquire, process and store. Further, we have assumed a simple personalization technology where a unit of personalized service can be generated for a given unit of personal information; with rapid advances in technology perhaps more services can be produced for a single unit of information. Indeed, it would be interesting to explore how firms can differentiate themselves on the basis of the amount of services they can offer for a single piece of information, rather than only the total number of indistinguishable services. Finally, existing privacy protection policies are severely inadequate and a majority of Internet users feel that their privacy is not protected by current laws (Chellappa et al. 2008; Sharton et al. 2001; Sheehan 2004). In response, the FTC has recently introduced a "Do Not Track" initiative; an online version of the "Do Not Call" proposal, whereby Internet users are granted complete autonomy with regards to whether or not to allow (and if so, which) firms to track their online behavior. Investigations of whether this policy indeed induces welfare-improving effects, and the specific extent to which the FTC should restrict data collection versus its subsequent usage, would be fruitful research avenues.

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Appendix: Proof of Propositions (Proof of Lemmas in Companion Appendix)

Proof of Propositions 1 and 2:

Propositions 1 and 2 can be derived from comparing the equilibria conditions and the respective profits for the firms under different equilibria in the service-level subgames given in the lemmas. For example, by comparing the conditions under which equilibria in the full game is possible (please refer to lemmas 1 and 4 for detail), we observe that two equilibria, i.e. $\left\{\left(s_1^F, \frac{b\sigma_1\sigma_2}{4b(b+\sigma_2)+\sigma_1\sigma_2}\right);\left(s_2^F, \frac{2b^2\sigma_2}{4b(b+\sigma_2)+\sigma_1\sigma_2}\right)\right\}$ and $\left\{\left(s_1^V, \frac{b\sigma_1\sigma_2}{4b(b+\sigma_2)+\sigma_1\sigma_2}\right);\left(s_2^F, \frac{2b^2\sigma_2}{4b(b+\sigma_2)+\sigma_1\sigma_2}\right)\right\}$, are possible candidates as equilibria in the full game when $\sigma_1 < \frac{2b}{1+\sqrt{2}}$ and $\sigma_2 \geq \frac{8b^2\sigma_1}{4b^2 - 4b\sigma_1 - \sigma_1^2}$. Since firms' profit functions are the same in the two cases (i.e. firms are indifferent between fixed-fixed/variable-fixed strategies in the first stage), both equilibria are SPNEs. On the other hand, when $\sigma_1 < 2b$ and $\frac{8b^2\sigma_1}{4b^2 - \sigma_1^2} \leq \sigma_2 < \frac{8b^2\sigma_1}{4b^2 - 4b\sigma_1 - \sigma_1^2}$, only one equilibrium $\left(\left\{\left(s_1^F, \frac{b\sigma_1\sigma_2}{4b(b+\sigma_2)+\sigma_1\sigma_2}\right);\left(s_2^F, \frac{2b^2\sigma_2}{4b(b+\sigma_2)+\sigma_1\sigma_2}\right)\right\}\right)$ is possible; hence contributing to a unique SPNE. When the MVIs of both firms are sufficiently large, two equilibria emerge: $\left\{\left(s_1^F, \frac{b}{3}\right);\left(s_2^F, \frac{b}{3}\right)\right\}$ and $\left\{\left(s_1^V, \frac{b}{2}\right);\left(s_2^V, \frac{b}{2}\right)\right\}$ (lemmas 2 and 3). Upon comparing profits of the firms, we notice that the former (latter) equilibrium dominates when $\sigma_i \in [2b, 10b),\ i \in \{1,2\}$ $\left(\sigma_i \in [10b, +\infty),\ i \in \{1,2\}\right)$; hence resulting in a unique SPNE in the respective regions.

For a given σ_2, $s_1^{F*} = \frac{b\sigma_1\sigma_2}{4b\left(b + \sigma_2\right) + \sigma_1\sigma_2}$ is increasing in σ_1, while $s_2^{F*} = \frac{2b^2\sigma_2}{4b\left(b + \sigma_2\right) + \sigma_1\sigma_2}$ is decreasing in σ_1. When $\sigma_1 < 2b$ and $\sigma_2 \geq \frac{8b^2\sigma_1}{4b^2 - \sigma_1^2}$, the maximum σ_1 that retains the fixed-v.s.-fixed equilibrium is $\frac{2b\left(-2b+\sqrt{4b^2+\sigma_2^2}\right)}{\sigma_2}$. Substituting it into $s_1^{F*} = \frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}$

yields $\frac{-2b+\sqrt{4b^2+\sigma_2^2}}{2\sigma_2+\sqrt{4b^2+\sigma_2^2}}b < \frac{1}{3}b$. ■

<u>Proof of Proposition 3:</u>

The maximum attainable consumer surplus is $\int_0^b \frac{\theta^2}{4} f\left(\theta\right) d\theta = \frac{b^2}{12}$, which is attained when all consumers are served their ideal levels of personalization.

In the case of fixed services, both firms offer $s_1^{F*} = s_2^{F*} = \frac{b}{3}$. Consumers with p4p ratios less than the equilibrium service level $\left(\theta < \frac{b}{3}\right)$, would not use any service. The total consumer surplus is given by:

$$\int_{\frac{b}{3}}^{b} \left(\frac{b}{3}\theta - \frac{b^2}{9}\right) f\left(\theta\right) d\theta = \frac{2}{27}b^2 \tag{A.1}$$

Since firm surplus is given by $\pi_1^{F*} + \pi_2^{F*}$, the total welfare under fixed services is:

$$\int_{\frac{b}{3}}^{b} \left(\frac{b}{3}\theta - \frac{b^2}{9}\right) f\left(\theta\right) d\theta + \frac{b\left(\sigma_1 - b\right)}{9} + \frac{b\left(\sigma_2 - b\right)}{9} \tag{A.2}$$

$$= \frac{3\sigma_1 + 3\sigma_2 - 4b}{27}b \tag{A.3}$$

In the case of fixed services where the two firms offer either $s_1^{F*} = \frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}$ or $s_2^{F*} = \frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}$. The total consumer surplus is given by:

$$\int_{s_1^{F*}}^{s_1^{F*}+s_2^{F*}}\left(\theta s_1^{F*}-\left(s_1^{F*}\right)^2\right)f\left(\theta\right)d\theta+\int_{s_1^{F*}+s_2^{F*}}^{b}\left(\theta s_2^{F*}-\left(s_2^{F*}\right)^2\right)f\left(\theta\right)d\theta$$

$$=\frac{1}{b}\left[\int_{\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}}^{\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}+\frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}}\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\left(\theta-\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)d\theta\right]$$

$$+\frac{1}{b}\left[\int_{\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}+\frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}}^{b}\frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\left(\theta-\frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)d\theta\right], \quad \text{(A.4)}$$

$$=\frac{2b^4\sigma_2\left(8b^3+4b\left(2b+\sigma_1\right)\sigma_2+\left(2b+3\sigma_1\right)\sigma_2^2\right)}{\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3}$$

where the first term represents the surplus of consumers served by firm 1 whereby the second term represents that served by firm 2.

The firm's profits are $\pi_1^{F*}=\frac{b^2\sigma_1^2\sigma_2^2}{\left[4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right]^2}$ $\pi_2^{F*}=\frac{4b^3\sigma_2^2\left(b+\sigma_2\right)}{\left[4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right]^2}$

Social welfare =

$$\frac{16b^5+\sigma_2\left(32b^4+4b^2\sigma_1\left(2b+\sigma_1\right)\right)+\left(36b^3+10b^2\sigma_1+4b\sigma_1^2+\sigma_1^3\right){\sigma_2}^2+4b\left(4b+\sigma_1\right)\sigma_2^3}{\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3}b^2\sigma_2\,.$$

In the case of variable services, both firms offer $s_1^{V*}=s_2^{V*}=\frac{b}{2}$. The service level offered by the firms satisfies even the consumer with the highest demand for personalization. Since consumers are free to choose the level of personalization to adopt and all consumers enjoy their respective optimal level of services, all consumers attain their highest utilities $\left(w^*\right)$.

Since firm surplus is $\pi_1^{V*}+\pi_2^{V*}$, and the total welfare under variable services is:

$$\int_0^b\frac{\theta^2}{4}f\left(\theta\right)d\theta+\frac{b\left(\sigma_1-2b\right)}{8}+\frac{b\left(\sigma_2-2b\right)}{8} \quad \text{(A.5)}$$

$$=\frac{3\sigma_1+3\sigma_2-10b}{24}b \quad \text{(A.6)}$$

In the case of variable-vs.-fixed services scenario, $s_1^{\widetilde{V}*} = \dfrac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}$ and

$s_2^{\widetilde{F}*} = \dfrac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}$.

The total consumer surplus is given by:

$$\int_0^{2s_1^{\widetilde{V}*}} \frac{\theta^2}{4} f\left(\theta\right)d\theta + \int_{2s_1^{\widetilde{V}*}}^{s_1^{\widetilde{V}*}+s_2^{\widetilde{F}*}} \left(\theta s_1^{\widetilde{V}*} - \left(s_1^{\widetilde{V}*}\right)^2\right) f\left(\theta\right)d\theta + \int_{s_1^{\widetilde{V}*}+s_2^{\widetilde{F}*}}^{b} \left(\theta s_2^{\widetilde{F}*} - \left(s_2^{\widetilde{F}*}\right)^2\right) f\left(\theta\right)d\theta$$

$$= \frac{1}{12}\frac{1}{b}\left(\frac{2b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)^3$$

$$+\frac{1}{b}\left[\int_{\frac{2b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}}^{\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}+\frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}} \frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\left(\theta - \frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)d\theta\right] \quad , \text{(A.7)}$$

$$+\frac{1}{b}\left[\int_{\frac{b\sigma_1\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}+\frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}}^{b} \frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\left(\theta - \frac{2b^2\sigma_2}{4b\left(b+\sigma_2\right)+\sigma_1\sigma_2}\right)d\theta\right]$$

$$= \frac{96b^5 + 48b^3\left(2b+\sigma_1\right)\sigma_2 + \left(24b^3 + 36b^2\sigma_1 + \sigma_1^3\right)\sigma_2^2}{6\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3} b^2\sigma_2$$

where the first two terms indicate the surplus of consumers served by firm 1 whereby the second term represents that served by firm 2.

The firm's profits are $\pi_1^{\widetilde{V}*} = \dfrac{b^2\sigma_1^2\sigma_2^2}{\left[4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right]^2}$ and $\pi_2^{\widetilde{F}*} = \dfrac{4b^3\sigma_2^2\left(b+\sigma_2\right)}{\left[4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right]^2}$.

Social welfare =

$$\frac{96b^5 + \left(192b^4 + 48b^3\sigma_1 + 24b^2\sigma_1^2\right)\sigma_2 + \left(216b^3 + 60b^2\sigma_1 + 24b\sigma_1^2 + 7\sigma_1^3\right)\sigma_2^2 + \left(96b^2 + 24b\sigma_1\right)\sigma_2^3}{6\left(4b\left(b+\sigma_2\right)+\sigma_1\sigma_2\right)^3} b^2\sigma_2$$

.

Suppose $\sigma_1 < \sigma_2$, the second derivative of (A.4) w.r.t. σ_1 is

$12b^4\sigma_2^4 \frac{-12b^2 + 4b\sigma_1 + \left(-8b + 3\sigma_1\right)\sigma_2}{\left(4b^2 + 4b\sigma_2 + \sigma_1\sigma_2\right)^5}$ in which $-12b^2 + 4b\sigma_1 + \left(-8b + 3\sigma_1\right)\sigma_2 < 0$ for $\sigma_1 < 2b$. Therefore, for a given σ_2, consumer welfare is strictly concave in σ_1.

The first order derivative of (A.4) w.r.t. σ_1 is $4b^4\sigma_2^2 \frac{-4b^3 + 2b\left(b - 2\sigma_1\right)\sigma_2 + 3\left(b - \sigma_1\right)\sigma_2^2}{\left(4b^2 + 4b\sigma_2 + \sigma_1\sigma_2\right)^4}$.

The maximum σ_1 that retains the fixed-vs.-fixed equilibrium is $\frac{2b\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\sigma_2}$. Substituting it into the first order derivative above yields

$$\frac{3\sigma_2^2 + \sigma_2\left(14b - 6\sqrt{4b^2 + \sigma_2^2}\right) + 4b\left(3b - 2\sqrt{4b^2 + \sigma_2^2}\right)}{4\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^4} b\sigma_2^2 < 0 .$$

When $\sigma_1 = \frac{2b\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\sigma_2}$, consumer surplus in the fixed-vs.-fixed equilibrium is

$$\frac{\sigma_2^2 + 4b\left(-b + \sqrt{4b^2 + \sigma_2^2}\right) + \sigma_2\left(-2b + 3\sqrt{4b^2 + \sigma_2^2}\right)}{2\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^3} b^2\sigma_2 .$$

For $\sigma_2 \geq 2b$, $\frac{\sigma_2^2 + 4b\left(-b + \sqrt{4b^2 + \sigma_2^2}\right) + \sigma_2\left(-2b + 3\sqrt{4b^2 + \sigma_2^2}\right)}{2\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^3}\sigma_2 b^2 - \frac{2}{27}b^2 > 0$, implying that consumer surplus under the maximum σ_1 that retains the fixed-vs.-fixed equilibrium with different levels of services is always larger than that in the fixed-vs.-fixed equilibrium where both firms offer the same level of services.

Moreover, $\lim_{\sigma_2 \to \infty} \frac{\sigma_2^2 + 4b\left(-b + \sqrt{4b^2 + \sigma_2^2}\right) + \sigma_2\left(-2b + 3\sqrt{4b^2 + \sigma_2^2}\right)}{2\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^3}\sigma_2 b^2 = \frac{2}{27}b^2$.

The second order derivative of (A.7) w.r.t. σ_1 is

$$-4b^3\sigma_2^3 \frac{-4b^3\sigma_1 + \left(36b^3 - 20b^2\sigma_1 + b\sigma_1^2\right)\sigma_2 + \left(24b^2 - 13b\sigma_1 + \sigma_1^2\right)\sigma_2^2}{\left(4b^2 + 4b\sigma_2 + \sigma_1\sigma_2\right)^5},$$

in which $-4b^3\sigma_1 + \left(36b^3 - 20b^2\sigma_1 + b\sigma_1^2\right)\sigma_2 + \left(24b^2 - 13b\sigma_1 + \sigma_1^2\right)\sigma_2^2 > 0$ for $\sigma_1 < 2b$ and

$\sigma_2 \geq \dfrac{8b^2\sigma_1}{4b^2 - {\sigma_1}^2}$ (because for $\sigma_1 < 2b$, $24b^2 - 13b\sigma_1 + \sigma_1^2 > 0$ and $36b^3 - 20b^2\sigma_1 + b\sigma_1^2 > 0$,

and

$-4b^3\sigma_1 + \left(36b^3 - 20b^2\sigma_1 + b\sigma_1^2\right)\sigma_2 + \left(24b^2 - 13b\sigma_1 + \sigma_1^2\right)\sigma_2^2 > 0$ when $\sigma_2 = \dfrac{8b^2\sigma_1}{4b^2 - {\sigma_1}^2}$).

Therefore, for a given σ_2, consumer welfare is strictly concave in σ_1.

the industry profits of the equilibria in region 1 and region 2 of Figure 5 are all

$\dfrac{b^2\sigma_1^2\sigma_2^2}{\left[4b\left(b + \sigma_2\right) + \sigma_1\sigma_2\right]^2} + \dfrac{4b^3\sigma_2^2\left(b + \sigma_2\right)}{\left[4b\left(b + \sigma_2\right) + \sigma_1\sigma_2\right]^2}$, the first order derivative of which w.r.t. σ_1 is

$\dfrac{8b^3\left(\sigma_1 - \sigma_2\right)\sigma_2^2(b + \sigma_2)}{\left(4b^2 + 4b\sigma_2 + \sigma_1\sigma_2\right)^3} < 0$ for $\sigma_1 < 2b$ and $\sigma_2 \geq \dfrac{8b^2\sigma_1}{4b^2 - {\sigma_1}^2}$. It implies that, given σ_2, the

industry profit is decreasing in the low MVI firm's MVI $\left(\sigma_1\right)$.

When $\sigma_1 = \dfrac{2b\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\sigma_2}$, $\dfrac{2b\sigma_2^2 + \sigma_2^3 - 4b^2\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^2}b$

When $\sigma_1 = 2b$, $\pi_1^{F*} + \pi_2^{F*} = \dfrac{b\left(\sigma_1 - b\right)}{9} + \dfrac{b\left(\sigma_2 - b\right)}{9} = \dfrac{b\sigma_2}{9}$

For $\sigma_2 \geq 2b$, $\dfrac{2b\sigma_2^2 + \sigma_2^3 - 4b^2\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^2}b - \dfrac{b\sigma_2}{9} > 0$.

$$\frac{2b\sigma_2^2 + \sigma_2^3 - 4b^2\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\left(2\sigma_2 + \sqrt{4b^2 + \sigma_2^2}\right)^2} b = \frac{2b + \sigma_2 - \frac{1}{{\sigma_2}^2} 4b^2\left(-2b + \sqrt{4b^2 + \sigma_2^2}\right)}{\left(2 + \sqrt{\frac{4b^2}{\sigma_2^2} + 1}\right)^2} b$$

Since social welfare in the fixed-vs.-fixed equilibrium where the two firms offer different levels of services is

$$\frac{16b^5 + \sigma_2\left(32b^4 + 4b^2\sigma_1\left(2b + \sigma_1\right)\right) + \left(36b^3 + 10b^2\sigma_1 + 4b\sigma_1^2 + \sigma_1^3\right){\sigma_2}^2 + 4b\left(4b + \sigma_1\right)\sigma_2^3}{\left(4b\left(b + \sigma_2\right) + \sigma_1\sigma_2\right)^3} b^2\sigma_2$$

the first order derivative of it w.r.t. σ_1 is

$$4b^3\sigma_2^2 \frac{-4b^3(b - 2\sigma_1) + 2b(-3b^2 + 6b\sigma_1 + \sigma_1^2)\sigma_2 + (-13b^2 + 3b\sigma_1 + 2\sigma_1^2)\sigma_2^2 - 2(4b + \sigma_1)\sigma_2^3}{\left(4b\left(b + \sigma_2\right) + \sigma_1\sigma_2\right)^4} < 0$$

for $\sigma_1 < 2b$ and $\sigma_2 \geq \frac{8b^2\sigma_1}{4b^2 - {\sigma_1}^2}$ (region 1 and 2 in Figure 5), implying that social welfare is decreasing in σ_1.

In the variable-vs.-fixed equilibrium, social surplus is represented by

$$\frac{96b^5 + \left(192b^4 + 48b^3\sigma_1 + 24b^2\sigma_1^2\right)\sigma_2 + \left(216b^3 + 60b^2\sigma_1 + 24b\sigma_1^2 + 7\sigma_1^3\right)\sigma_2^2 + \left(96b^2 + 24b\sigma_1\right)\sigma_2^3}{6\left(4b\left(b + \sigma_2\right) + \sigma_1\sigma_2\right)^3} b^2\sigma_2$$

,

the first order derivative of it w.r.t. σ_1 is

$$\frac{-8b^3\left(b - 2\sigma_1\right) + b\left(-12b^2 + 24b\sigma_1 + 5\sigma_1^2\right)\sigma_2 + \left(-26b^2 + 6b\sigma_1 + 5\sigma_1^2\right)\sigma_2^2 - 4\left(4b + \sigma_1\right)\sigma_2^3}{\left(4b\left(b + \sigma_2\right) + \sigma_1\sigma_2\right)^4} 2b^3\sigma_2^2$$

the nominator is

$$-8b^3\left(b - 2\sigma_1\right) + b\left(-12b^2 + 24b\sigma_1 + 5\sigma_1^2\right)\sigma_2 + \left(-26b^2 + 6b\sigma_1 + 5\sigma_1^2\right)\sigma_2^2 - 4\left(4b + \sigma_1\right)\sigma_2^3 < 0$$

for $\sigma_1 < \dfrac{2b}{1+\sqrt{2}}$ and $\sigma_2 \geq \dfrac{8b^2\sigma_1}{4b^2 - 4b\sigma_1 - \sigma_1^2}$. Therefore, social welfare in the variable-vs.-fixed equilibrium is also decreasing in σ_1.■