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## CONTRACTING FOR PERSONALIZATION

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### Abstract

*This paper presents a stylized model based on the principal-agent framework in the absence of monetary instrument as a compensation device to agents with privately known production costs. Our results identify a new tradeoff that arises from alternative compensation devices, as well as the associated implications on firm's profitability and consumer welfare.*

*Keywords: Contract Design, Set-complement Instrument, Personalization.*

## 1 INTRODUCTION

This paper presents a stylized model based on the principal-agent framework in the absence of monetary instrument as a compensation device to agents with privately known production costs. This extension is motivated by both business and regulatory interests in personalized content deliveries in digital networks. In contrast with standard economic goods, personalization exhibits several unique characteristics. First, both the value (convenience) and cost (privacy concerns) that a user derives from consuming the goods is proportional to the amount of personal information shared, and thus are intrinsically correlated (Chellappa & Sin 2005). Second, price is not a strategic variable for the firm, as most personalization services are offered free of charge to the users. The wide array of web-based and mobile services offered by Microsoft (e.g. My MSNBC), Google (e.g. Google Health), Yahoo! (e.g. Yahoo! Sports), and most social networking sites (e.g. Facebook) displays similar features as the product being modeled in this paper.

We show that the challenge associated with the lack of external instruments can be tackled by transforming the compensation schedule into a set-complement of the production variable. Our results identify a new tradeoff that arises from complementary compensation devices, as well as the associated implications on firm's profitability and consumer welfare.

## 2 MODEL

The market is characterized by a monopolistic firm that offers free personalization services to a mass of consumers, who are heterogeneous in their privacy sensitivity, indexed by  $\theta \in \{\theta_1, \theta_2\}$ , unobservable to the firm. The respective portions of consumers belonging to each of the two types are  $v$  and  $1 - v$ , which is common knowledge.

The firm's objective is to optimally allocate personalization services to the two types of consumers to maximize profit. It collects information ( $I$ ) from users and incurs a constant variable cost<sup>1</sup> (normalized to 1) in generating the corresponding personalized services. The firm justifies this cost by designating a subset of the acquired information ( $i \subseteq I$ ) for commercial use. Its profit from serving each consumer is defined as:

$$\pi(i, I) = bi - \frac{1}{2}i^2 - I$$

where  $b \in \mathbb{R}^+$  represents the efficiency at which the firm is able to generate revenues from the acquired information. The quadratic term captures diminishing returns in revenue generation for a given set of information.

Consumers face a tradeoff between enjoying the convenience provided by personalization and suffering the privacy costs associated with sharing the necessary information:

$$U(I, i, \theta) = S(I) - \theta i$$

In this expression,  $S = aI$  represents the value that a consumer derives from consuming personalization.  $a$  denotes the marginal value that the service generates from each unit of information provided by the consumer, and can be interpreted as the technological efficiency of personalization deployed by the firm.<sup>2</sup> The cost component reflects privacy concerns of the consumers due to the

<sup>1</sup> This can be interpreted as a "resource cost" – the cost associated with the necessary computing resources in providing personalized content to a request (Liu et al. 2010).

<sup>2</sup>  $S(I)$  can also take a quadratic form, which implies a diminishing return of personal information on personalization convenience. With this specification, however, the basic intuition underlying results still holds.

firm’s exploitation of their information ( $i$ ). Consumers with higher values of  $\theta$  are more privacy sensitive and thus experience greater discomfort associated with secondary uses of their information.

Consistent with most industry practices, prior literature on personalization typically assumes that the firm fully exploits all information gathered from the consumers, i.e.  $i = I$  (Chellappa & Shivendu 2010). In this case, consumers’ decision on whether to subscribe the proposed personalization services depends on the relative magnitudes of the efficiency coefficient  $a$  against their type coefficient  $\theta$ . We label consumers with  $\theta_2 > a$  “privacy seekers”, and those with  $\theta_1 \leq a$  “convenience seekers”. Consumers of type  $\theta_2$  reject the personalization offer, whereas those of type  $\theta_1$  choose to disclose as much information as possible. From the firm’s perspective, the optimal level of information acquisition equals to  $I_1^{O*} = b - 1$  with profit equals to  $P^O = \frac{1}{2}v(b - 1)^2$  from serving only type  $\theta_1$  consumers, who enjoy a utility level of  $CS_1^O = (a - \theta_1)(b - 1)$ .

Consider the scenario where the firm can make an ex-ante credible commitment that a portion of the acquired information would be excluded from any secondary use, denoted as privacy preservation ( $\eta$ ), which is ex-post verifiable and enforceable through consumer auditing and government sanctions. Consumers’ privacy concerns thus arise only from its complement ( $i = I - \eta$ ); i.e. privacy seekers and convenience seekers are served by  $\{i_1^I, \eta_1^I\}$  and  $\{i_2^I, \eta_2^I\}$  respectively. The firm’s objective function can be represented by

$$\begin{aligned} \max_{\{i_1^I, \eta_1^I\}, \{i_2^I, \eta_2^I\}} & v \left( bi_1^I - \frac{1}{2}i_1^{I2} - (i_1^I + \eta_1^I) \right) + (1 - v) \left( bi_2^I - \frac{1}{2}i_2^{I2} - (i_2^I + \eta_2^I) \right) \\ \text{s.t. } & IRs, ICs, \text{ and } \eta_1^I, \eta_2^I \geq 0 \end{aligned}$$

where  $\eta_1^I, \eta_2^I \geq 0$  is referred to as the non-negative preservation constraint in the rest of this paper. Under complete information, the optimal contracting menu consists of  $\{\tilde{i}_1 = b - 1, \tilde{\eta}_1 = 0\}$  and  $\left\{ \tilde{i}_2 = b - \frac{\theta_2}{a}, \tilde{\eta}_2 = \frac{\theta_2 - a}{a} \left( b - \frac{\theta_2}{a} \right) \right\}$ .

### 3 RESULTS AND DISCUSSION

#### 3.1 Optimal contract under information asymmetry

We restrict our attention to the scenario where  $b\theta_1 \geq \theta_2 + \frac{v}{1-v}(\theta_2 - \theta_1)$ . This condition rules out information rent being the trivial explanation for market shutdown as observed in standard models. The following proposition characterizes the shape of the optimal menu under varying degrees of technology efficiency.

**Proposition 1.** There exists a unique  $\tilde{a} \in (\theta_1, \theta_2)$  that partitions the interval  $(\theta_1, \theta_2)$ , such that

$$\text{for } a \in (\theta_1, \tilde{a}), \begin{cases} i_1^{I*} = b - \frac{\theta_1}{a} \\ \eta_1^{I*} = \frac{1}{a} \left\{ (\theta_2 - \theta_1) i_2^{I*} - (a - \theta_1) i_1^{I*} \right\} \end{cases} \text{ and } \begin{cases} i_2^{I*} = b - \frac{1}{a} \left( \theta_2 + \frac{v}{1-v} (\theta_2 - \theta_1) \right) \\ \eta_2^{I*} = \frac{1}{a} (\theta_2 - a) i_2^{I*} \end{cases};$$

$$\text{for } a \in [\tilde{a}, \theta_2), \begin{cases} i_1^{II*} = i_1^{I*} - \frac{A(a - \theta_1)\frac{1}{v}}{(a - \theta_1)^2\frac{1}{v} + (\theta_2 - \theta_1)^2\frac{1}{1-v}} > \tilde{i}_1 \text{ and} \\ \eta_1^{II*} = 0 \end{cases}$$

$$\begin{cases} i_2^{II*} = i_2^{I*} + \frac{A(\theta_2 - \theta_1)\frac{1}{1-v}}{(a - \theta_1)^2\frac{1}{v} + (\theta_2 - \theta_1)^2\frac{1}{1-v}} < \tilde{i}_2, \\ \eta_2^{II*} = \frac{1}{a}(\theta_2 - a)i_2^{II*} \end{cases},$$

where  $A = (a - \theta_1)i_1^{I*} - (\theta_2 - \theta_1)i_2^{I*} \geq 0$  on  $[\tilde{a}, \theta_2)$ .

(All proofs are relegated to the Appendix).

Proposition 1 states that the form of the optimal contract varies depending on whether  $a$  falls below or beyond the critical value  $\tilde{a}$ . When technology efficiency is low (i.e.  $a \in (\theta_1, \tilde{a})$ ), the firm induces participation of both types of consumers and provide them with different levels of privacy preservation. The nonzero preservation for convenience seekers is surprising at the first glance, as preservation constitutes to pure cost for the firm, while it could have been substituted by  $i_1$  as compensation for this segment instead. Nonetheless, the firm finds it optimal to offer  $\eta_1$  because privacy preservation serves as a device that delivers the information rent (i.e.,  $(\theta_2 - \theta_1)i_2$ ) more efficiently. If no preservation is provided to the convenience seekers and information rent is solely delivered through  $i_1$ , then the firm will be faced with excessive overproduction. Therefore, incurring the additional cost in exchange for a less-severe distortion in the convenience-seeking segment is of the firm's best interest.

Another observation from this proposition is that commercial use of information on type  $\theta_1$  increases from  $\tilde{i}_1 = b - 1$  to  $i_1^{I*} = b - \frac{\theta_1}{a}$ . This ostensible overproduction is unfamiliar in standard models (Laffont & Martimort 2002), where the efficient segment always produces at the same level regardless of information asymmetry. This counter-intuitive result reflects the change that occurs in the firm's cost structure due to the need to incorporate preservation in maintaining incentive compatibility. In sum, serving the inefficient type not only imposes the conventional tradeoff between production efficiency of the inefficient type and information rent of the efficient type, but also induces the firm to deliberate on which compensation schedule to rely on when serving the efficient segment.

When technology efficiency is high (i.e.  $a \in (\tilde{a}, \theta_2)$ ), the utilitarian difference between the commercially used portion ( $i_1$ ) and the preserved portion ( $\eta_1$ ) of information becomes more subtle for convenience seekers. Even if the firm fully relies on  $i_1$  to deliver the required rent, the associated overproduction is less significant. Gradually, the substitution effect between  $i_1$  and  $\eta_1$  favors tolerating overproduction over incurring additional cost in serving the convenience seekers. When  $a$  exceeds  $\tilde{a}$  such that  $i_1 = b - \frac{\theta_1}{a}$  alone can generate sufficient information rent, the original incentive constraint of convenience seekers become slack and the optimal contract offers no preservation to this segment of consumers. The slackness in IC on one hand allows the firm to revert to the original cost structure when serving convenience seekers, while on the other enhances production efficiency of both types of consumers. Therefore, the conventional underproduction problem for the inefficient

type is moderated, while production of convenience seekers regresses toward  $\tilde{i}_1$ . The additive components in  $i_1^{II*}$  and  $i_2^{II*}$  reflect the corresponding production adjustments.

### 3.2 Welfare implications of privacy-preserving contract and improvements in personalization technology

The optimal set-complement contract engages the otherwise non-participating market segment (type  $\theta_2$  consumers), and enables the firm to attain higher profit levels than the original schedule  $\{I_1^O, 0\}$ . The following proposition quantifies the firm's profit under the new contract with varying degrees of technology efficiency.

**Proposition 2.** The firm's equilibrium profit: for  $a \in (\theta_1, \tilde{a})$ ,  $P^I = \frac{1}{2} \left( v(i_1^{I*})^2 + (1-v)(i_2^{I*})^2 \right)$ ; for  $a \in [\tilde{a}, \theta_2)$ ,  $P^{II} = P^I - \frac{1}{2} \frac{A^2}{(a - \theta_1)^2 \frac{1}{v} + (\theta_2 - \theta_1)^2 \frac{1}{1-v}}$ .

It can be verified that  $P^I > P^O$ . Such an increase in profit can be attributed to both inducing participation from the privacy seekers and adopting the more efficient cost structure in response to potential deviation of convenience-seeking consumers. Moreover, a privacy preserving contract also leaves larger consumer surplus to this segment (i.e.,  $CS_1^I > CS_1^O$ ), while consistently leaving privacy seekers with zero utility. For  $a \in (\theta_1, \tilde{a})$ , increasing technology efficiency ( $a$ ) improves the vendor's cost efficiency without exerting any impact on allocation efficiency.

The second part of Proposition 2 describes the relative magnitudes of  $P^I$  and  $P^{II}$ . The negative component reflects that the ability for the firm to realize benefits from improvements in technology efficiency is diminishing: once  $\eta_1$  degenerates to zero, the firm lacks an effective device to extract further increase in consumer surplus of the convenience-seeking segment (previously, extracting this improvement is implemented through substituting  $\eta_1$  for  $i_1$ ). The non-negativity of privacy preservation hence affects the allocation of surplus between the firm and consumers. This is illustrated in Figure 1, where the dotted lines in the interval  $(\tilde{a}, \theta_2)$  represent the firm's profit and surplus of type  $\theta_1$  consumers for the contract menu under the original trajectories.

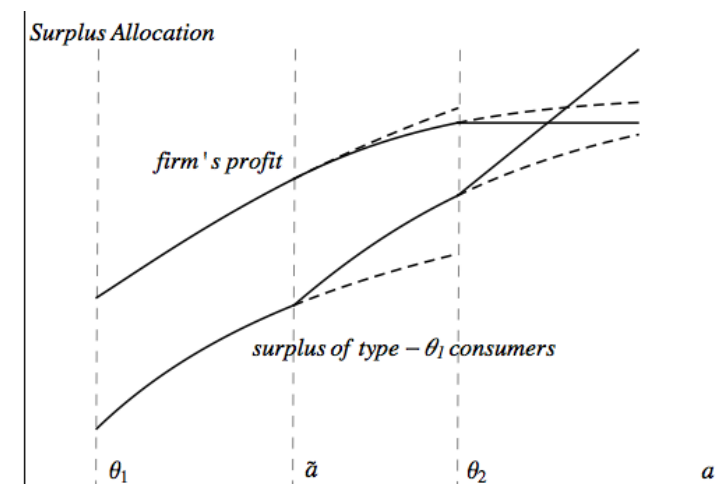


Figure 1. Surplus allocation with varying levels of technology efficiency

As technology efficiency exceeds  $\theta_2$ , both types exhibit characteristics of convenience seekers and are served by the same contract  $\{b - 1, 0\}$ . Incentive compatibility of the contracting menu is no longer a concern. Instead, the inability to extract the additional consumer surplus also pertains to the type  $\theta_2$  consumers. In this case, profit becomes independent of technology efficiency; additional investments bring no further improvement to the firm's profitability.

## 4 CONCLUSION

Improvements in technology efficiency not only affect the relative attractiveness of the two instruments as compensation devices, but may also change the distribution of consumer characteristics. In particular, our results show that technological improvements do not always enhance the firm's profitability, since technological improvements also associate with larger difficulty for the firm to extract the increased consumer surplus.<sup>3</sup> Ongoing work aims to refine the allocation of personalization under a continuous-type setup where the two aforementioned effects simultaneously influence the firm's optimal investment decision.

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<sup>3</sup> If "price" can be charged for personalization services, difficulty in extracting consumer surplus will never be an issue. Then improving the efficiency of personalization technology will be a more attractive strategy to the firm.

## Appendix

Proof of Proposition 1. We first assume  $\eta_1^I, \eta_2^I \geq 0$  to be inactive at the equilibrium. The solution process is similar to that for the standard discrete-type model. However, the following lemma indicates that  $\eta_1^{I*}$  does not always stay above zero.

**Lemma.** There exists a unique  $\tilde{a}$  in the interval  $(\theta_1, \theta_2)$  at which  $\eta_1^{I*}(a)$  intersect  $\eta = 0$ .

Proof: it can be verified that  $\eta_1^{I*}(\theta_1) > 0$  and  $\eta_1^{I*}(\theta_2) < 0$ . Moreover,  $\eta_1^{I*}(a)$  is strictly concave in  $a$ . The uniqueness of  $\tilde{a}$  follows from the concavity of  $\eta_1^{I*}(a)$ . Q.E.D.

This lemma implies that, for  $a \in [\tilde{a}, \theta_2)$ , ignoring the inequality  $\eta_1 \geq 0$  results in an incorrect specification for the equilibrium  $\eta_1$ . Instead, we impose the restriction that  $\eta_1^{II*} = 0$  at the equilibrium. In this case, the incentive constraint of convenience seekers and the participation constraint of privacy seekers still bind in equilibrium. Hence, the firm's objective is represented as follows:

$$\max_{i_2^{II}} v \left( b \left( \frac{(\theta_2 - \theta_1) i_2^{II}}{(a - \theta_1)} \right) - \frac{1}{2} \left( \frac{(\theta_2 - \theta_1) i_2^{II}}{(a - \theta_1)} \right)^2 - \frac{(\theta_2 - \theta_1) i_2^{II}}{(a - \theta_1)} \right) + (1 - v) \left( b i_2^{II} - \frac{1}{2} i_2^{II2} - \frac{\theta_2}{a} i_2^{II} \right).$$

It can readily verified that the solution corresponds to the second part of the proposition. Compared with production under complete information,

$$i_1^{II*} - \tilde{i}_1 = (a - \theta_1) \frac{1}{v} \frac{\left( b - \frac{\theta_2}{a} \right) (\theta_2 - \theta_1) - (a - \theta_1)(b - 1)}{\left( a - \theta_1 \right)^2 \frac{1}{v} + \left( \theta_2 - \theta_1 \right)^2 \frac{1}{1 - v}} \quad \text{and}$$

$$i_2^{II*} - \tilde{i}_2 = \frac{(b - 1)(a - \theta_1) - (\theta_2 - \theta_1) \left( b - \frac{\theta_2}{a} \right)}{\left( a - \theta_1 \right)^2 \frac{1}{v} + \left( \theta_2 - \theta_1 \right)^2 \frac{1}{1 - v}} \frac{1}{1 - v} (\theta_2 - \theta_1)$$

The respective inequalities in the proposition follow from  $\left( b - \frac{\theta_2}{a} \right) (\theta_2 - \theta_1) - (a - \theta_1)(b - 1) > 0$  for  $a \in [\tilde{a}, \theta_2)$ , which can be easily verified by a) its second derivative w.r.t.  $a$  is negative; b)  $\left( b - \frac{\theta_2}{a} \right) (\theta_2 - \theta_1) - (a - \theta_1)(b - 1) = 0$  at  $a = \theta_2$ ; and c)  $\left( b - \frac{\theta_2}{a} \right) (\theta_2 - \theta_1) - (a - \theta_1)(b - 1) > 0$  at  $a = \tilde{a}$ .

Since  $i_1^{II*} > b - 1 > b - \frac{\theta_2}{a} > i_2^{II*}$  for  $a \in (\tilde{a}, \theta_2)$ , the monotonicity condition holds.