Subsidy Design for Personal Protective Equipments (PPEs) Adoption

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1 Introduction

Since December 2019, the COVID-19 outbreak has spread in over 100 countries and regions at a stunning pace. To prevent humanitarian health hazards such as COVID-19, people are strongly suggested to purchase and use Personal Protective Equipments (PPEs) for self-protection. However, the fraction of the population who refused to comply with the PPEs is high (and also much higher in some regions than others). In this paper, we focus on an empirically tested behavioral explanation for the compliance obstacle (a lack of self-control) based on the *present-bias effect*, which means the trend to give a higher valuation to a present reward but a lower valuation to a future reward (O'Donoghue & Rabin, 2006). Since the utility of PPEs is realized in the future, a consumer may postpone his purchase decision but finally abandon his purchase plan in the future period due to this present-bias effect. The key take-away we focus on is that advance selling can be beneficial to the consumers as a *commitment device* (Bryan et al., 2010). However, the effect of advance selling may be limited, especially for consumers with low valuation, and

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can only encourage a part of consumers to purchase PPEs. Advance selling alone cannot fully address the compliance obstacles in PPEs.

To encourage more aggregate adoption in PPEs, we discuss a combination of advance selling and a subsidy policy. Our research question is how to design policy instruments, combining advance selling and subsidy programs, to resolve healthcare compliance obstacles and boost aggregate adoptions in PPEs? We propose a model consisting of a manufacturer of PPEs, consumers who suffer from *present-bias* and have heterogeneity in the awareness of their present-bias and a donor who provides a subsidy to boost the adoption of PPEs. We restrict ourselves to the manufacturer subsidy policy, where the subsidy is provided only to the manufacturer. The customer subsidy refers to the opposite one. It is because the consumer subsidy will be undercut by the manufacturer by charging a higher price, which makes the consumer subsidy less cost-effective than the manufacturer subsidy. In particular, when the budget is tight, the manufacturer subsidy should be only provided in the spot-period, because the spot-period subsidy reduces the effects of advance selling. In contrast, subsidy in both periods should be provided, when the budget constraint is relaxed. The results provide actionable insights towards overcoming healthcare compliance obstacles.

2 Literature Review

Our paper is related to the product/technology adoption puzzle. The first explanation of this puzzle is the lack of information. Conley and Udry (2010) study the effect of social learning in the knowledge diffusion and adoption of fertilizer in agricultural industry. Alternatively, Duflo et al. (2011) use present-bias to explain Kenya farmers' procrastination in fertilizer purchase. Present- bias is an important factor in explaining compliance obstacles. Following O'Donoghue and Rabin (2006), we model this effect using quasi-hyperbolic discounting framework.

Our paper is also related to the subsidy policy design. Burkart et al. (2016) point out the importance of carefully designed funding systems in the success of humanitarian organizations. Cohen and Dupas (2010) find affirmative evidence of subsidy by a randomized field experiment in Kenya, wherein malarial insecticide-treated nets are sold to pregnant women at some randomized prices. And our paper is closely related to Yu et al. (2018), which shows that manufacturer subsidy is more cost-effective than consumer subsidy.

3 Model

We consider a three-period model in which a manufacturer produces and sells PPEs to consumers. Let $t = 0$ denote the advance-period, $t = 1$ denote the spot-period and $t = 2$ denote the period when all the decisions are made and utilities are realized.

Consumers The population size of consumers (she) who get informed about PPEs is Λ_0 and Λ_1 in two periods, respectively. The utility of consuming PPEs is θV, which will be realized at $t = 2$. $V > 0$ refers to the intrinsic and deterministic value of the PPEs, while θ refers to a random valuation for the PPEs, which is privately observed by the consumer at $t = 1$. θ follows an uniform distribution on [0, 1].

Quasi-hyperbolic discounting Following O'Donoghue and Rabin (2001), we model the present-bias effect using quasi-hyperbolic discounting framework. A consumer' expected payoff at $t = 0$ is $u_0 = v_0 + \beta \sum_{t=1,2} \delta^t v_t$, where $\delta \in (0, 1]$ is the discount factor between two periods, and $\beta \in (0, 1]$ is the *present-bias* factor between the current period and future periods. Furthermore, consumers at $t = 0$ are heterogeneous in the awareness (unawareness) about her present-bias. Only a portion γ of customers are aware of their present-bias and know true β, while a portion $1 - \gamma$ are unaware and thus think their present-bias factor is 1 at $t = 0$.

Manufacturer The manufacturer (he) controls the production channel and dictates the prices. The manufacturer sets static prices P_0 and P_1 in the advance- and spot-period to maximize his profit as follows:

$$\max_{P_0} \pi_0 (P_0) = (P_0 - c)\, q_0,$$

$$\max_{P_1} \pi_1 (P_1) = \alpha (P_1 - c)\, q_1 + \pi_0 (P_0),$$

wherein q_0 and q_1 are adoption quantities in two periods, c is the unit production cost and the manufacturer's discount factor α is different from the consumers' in general.

Donor We also assume a donor who aims to incentivize compliance behaviors. The subsidy design is determined *a priori*, i.e., $t = -1$. The donor provides subsidy to the manufacturer in the form of $\mu_0 c$ and $\mu_1 c$ in advance- and spot-period, wherein μ_0, $\mu_1 \in [0, 1]$, and to consumers in the form of $\lambda_0 P_0$ and $\lambda_1 P_1$, where λ_0, $\lambda_1 \in [0, 1]$. The subsidy program is constrained by an exogenous dollar amount B. The donor's decision problem is as follows:

$$\max_{\mu_0, \mu_1; \lambda_0, \lambda_1} \mathrm{Q} = q_0 + q_1$$

$$\text{s.t.}\, q_0\ (\mu_0 c + \lambda_0 P_0) + \alpha\, q_1\ (\mu_1 c + \lambda_1 P_1) \le B$$

4 Analysis

To start with consumer behavior analysis, consumers are strategic, which implies that consumers make decisions by payoff calculations and comparison among different periods. For a clear demonstration, we do not consider the subsidy at this stage. A consumer's expected payoff is $u_1 = \beta\delta\theta V - P_1$, if she makes the purchase in period 1. Hence, she makes the purchase in period 1 if $\theta \geq \frac{P_1}{\beta\delta V}$. And the analysis is similar for period 0. A consumer will make purchase decisions to maximize her expected payoff.

Then we can characterize the manufacturer's pricing strategies as follows:

Proposition 1 *Three pricing strategies are sustained in equilibrium*[1] *:*

- *Equilibrium-D, "discount advance selling": All consumers who arrive in period* 0 *make purchases in period 0 (pooling equilibrium), denoted by the superscript D;*
- *Equilibrium-P, "premium advance selling": Among those who arrive in period* 0*, sophisticated consumers make purchases in period 0, while naive consumers do not (separating equilibrium), denoted by the superscript P;*
- *Equilibrium-N, "no advance selling": No consumers who arrive in the period* 0 *participate in the advance-selling market (pooling equilibrium), denoted by the superscript N.*

Furthermore, we have $Q^D > Q^P > Q^N$*, for the given subsidy.*

We define three different pricing strategies for the manufacturer. The divergent purchasing behaviors are driven by the heterogeneity in consumers' sophistication. Furthermore, since the total adoption quantities increase when more consumers make purchase in the advance period. It indicates that the advance pricing strategy is an effective instrument to stimulate the adoption quantity.

After characterizing consumer behaviors and manufacturer selling strategies, we start by investigating the donor's problem. We consider simplifying the general form of the subsidy program, as it is complicated to solve. We compare the manufacturer subsidy and the consumer subsidy and get:

Lemma 1 *The optimal subsidy design requires* $\lambda_0^* = \lambda_1^* = 0$.

Lemma 1 indicates that the donor should provide the subsidy only to the manufacturer. When given equal μ_1 or λ_1 (μ_0 or λ_0), it costs more to subsidize consumers than to subsidize the manufacturer. Moreover, any consumer subsidy will be undercut by the monopolistic manufacturer who is able to charge a higher price, which increases the cost for the donor to subsidize consumers. Hence, it is

[1]The terminology for different advance pricing strategies follows classic literature, e.g., Xie and Shugan (2001). The term "premium advance selling" speaks relatively to "discount advance selling", and does not imply a high price in absolute terms.

optimal for the donor to offer the subsidy only to the manufacturer. In the following discussion, it is sufficient to restrict ourselves to manufacturer subsidy policy.

Since the adoption quantity in the advance-period is dependent on the fraction of naive consumers, the advance-period subsidy will have no effect on the adoption quantity under any given selling strategy. Hence, we first pursue the analysis by investigating the spot-period subsidy effects on manufacturer profits. And we have:

Lemma 2

1. *Under the no advance pricing strategy, we have* $\frac{\partial \pi^N}{\partial \mu_1} > 0$.
2. *Under the premium advance pricing strategy, if and only if* $\frac{\Lambda_1}{\Lambda_0} > \frac{\beta^2 \delta[c\mu_1 - c + (2-\beta)\delta V]}{2\alpha(c\mu_1 - c + \beta\delta V)}$, *we have* $\frac{\partial \pi^D}{\partial \mu_1} > 0$.
3. *Under the discount advance pricing strategy, if and only if* $\frac{\Lambda_1}{\Lambda_0} > 2\alpha + \frac{\gamma\delta[c(\mu_1 - 1)(2\beta - 1) + \beta\delta V]}{2\alpha(c\mu_1 - c + \beta\delta V)}$, *we have* $\frac{\partial \pi^P}{\partial \mu_1} > 0$.

Interestingly, Lemma 2 indicates that the spot-period subsidy can reduce the manufacturer's profits when combining with advance selling strategies. The result is due to the inter-temporal cannibalization effect. The profit loss is generated when the increase in the spot-period subsidy forces the manufacturer to reduce the advance-period price and shift the sales from the advance period to the spot period. Thereby, only when the population ratio is relatively large, the profit increase in the spot-period outweighs the profit loss in the advance-period such that the spot-period subsidy benefits the manufacturer.

Finally, we go back to the donor's problem in Equation [equation-donor] and consider the optimal combination of subsidies in two periods.

Proposition 2 *Given the government budget* B*, there exists two thresholds* $\underline{B}$ *and* $\overline{B}$ *such that the donor provides subsidy only in the spot-period when* $B \leq \underline{B}$ *and distributes the subsidy in both advance- and spot-period when* $B \geq \overline{B}$*. When* $\underline{B} < B < \overline{B}$*, either policy is possible.*

Proposition 2 indicates that the optimal subsidy policy depends on the budget. Intuitively, the subsidy distributed in the advance-period will induce advance selling and thus a higher adoption quantity, but it incurs additional cost for the donor. When the budget is tight, it is not financially feasible to induce advance pricing strategies, so the donor should subsidize the manufacturer only in the spot-period. Conversely, when the budget gets relaxed, the donor has incentives to provide subsidy in the advance-period to induce advance selling. However, when the budget is intermediate, the optimal subsidy policy depends on the subsidy cost to induce advance selling and the advance-period subsidy is determined by profit loss for the manufacturer to choose advance selling. When the profit loss is small under advance pricing strategies, the donor will distribute the subsidy in both periods. Our results provide policy guidelines for designing such subsidy programs.

5 Conclusion

To prevent humanitarian health hazards such as COVID-19, we propose a stylized model with present-bias to understand a lack of compliance in Personal Protective Equipments (PPEs). Furthermore, we investigate the optimal subsidy policy when incorporating a donor. Advance selling strategies are effective in incentivizing the adoption quantity, but the increase in the spot-period subsidy discourages the manufacturer to adopt advance selling strategies. Finally, when the subsidy program is budget-constrained, the donor should provide subsidy only in the spot-period. In contrast, when the budget constraint is relaxed, subsidies should be provided in both periods. Our research is pioneering work in understanding and mitigating the adoption of preventive measures to prevent humanitarian health hazards. Future research is needed to further operationalize our actionable insights.

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