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The Effects of Subsidies on Increasing Consumption through For-Profit and Not-For-Profit Newsvendors

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Subsidy programs are widely offered in both developing and developed countries to encourage consumption of products that generate positive social, health and environmental externalities. We study the effect of subsidies on product consumption under uncertain market demand. To reach a target consumer population, the program sponsor may subsidize a for-profit or a not-for-profit firm on each unit of the product purchased by the firm or on each unit of the sale generated by the firm. We show that subsidy programs provide stronger incentives to a not-for-profit firm than to its for-profit counterpart in inducing a large consumption whenever the sponsor is having a very limited budget or a very generous budget. When subsidizing a not-for-profit firm, the sponsor should always choose the purchase subsidy over the sales subsidy, because the former can induce a larger consumption than the latter with the same subsidy spending. However, this is not always true when the subsidy program is administered through a for-profit firm, unless the firm is a price taker in the market or the sponsor has a limited budget. Our analysis leads to new theoretical development of price-setting newsvendor problem for both the for-profit and not-for-profit operations under subsidy.

Key words: Newsvendor Model; Pricing; Not-for-profit operations; Subsidy.

1 Introduction

Subsidy programs are widely offered by governments and international agencies for many products, including food, health products, and green technology products. Many of such programs aim to increase product adoption by elevating the affordability of low socioeconomic populations and/or increasing the awareness of consumers. An effectively designed subsidy program would induce significantly increased product consumption, which often has positive social, health, and environmental effects on the community involved.

Subsidies on food and health products are common in developing countries to improve the living standard of the general population. Governments in these countries often subsidize food producers (e.g., cereal mills) to offer the commodities at a fixed price much below the market price (Tuck and Lindert 1996). These programs usually allow unrestricted access of local consumers who are willing to purchase the subsidized goods (Alderman 2002). Distributions of health products to low socioeconomic populations are often subsidized by governments and international agencies. Examples include the ready-to-use therapeutic food (Natarajan and Swaminathan 2014), contraceptives (Behrman 1989, Kearney and Levine 2009), recommended malaria drugs (Sabot et al. 2009), vaccines (Chick et al. 2008, Whittington et al. 2012), and eye glasses (Karnani et al. 2011). Subsidy programs are also offered to popularize products with improved social value even in developed countries. For example, subsidies are given to restaurants, both fast food and sit-down establishments, for offering vegetables, fruits and healthy beverages to entice consumers reducing the caloric intake which may contribute to obesity and other health problems (An 2012, Powell et al. 2013). Price subsidies are also offered to consumers to adopt new technological products (Kalish and Lilien 1983) or environmentally friendly products (Hirte and Tscharaktschiew 2013, Cohen et al. 2014).

A sponsor of a subsidy program (e.g., governments, non-governmental organizations, international agencies, or private donors) may support the product through a commercial channel or a non-commercial channel. The subsidies are usually offered in two forms, purchase subsidy (for, e.g., cereal, vegetable and fruit) and sales subsidy (for, e.g., drugs and electric vehicles). Take the non-traditional cookstove as an example. In the last decades, various entities have produced and promoted non-traditional cookstoves to replace wood-burning cooking for health and environmental improvement in developing countries. The most common sponsoring mechanism is based on the local government providing a sales subsidy to a not-for-profit organization who is in charge of the procurement, distribution and selling of these stoves to the households. Many of such projects

have been implemented in different developing countries such as Nepal¹, India² or Bolivia (Gaul 2009). Nonetheless, purchase and sale subsidies have also been offered to commercial for-profit manufacturers that run cooking programs. The most notable instances of such programs are in India for solar cookers (Knudson 2004) and improved chulhas (Rehman and Malhotra 2004).

When a subsidy is offered to a firm in a commercial channel, the sponsor must stimulate the firm to offer a high availability at an affordable price to allow consumer access of the product. A purchase subsidy directly reduces the firm's marginal cost of producing or acquiring the product and the sales subsidy compensates the firm on each consumption generated, both encouraging the firm to bring a large amount of the product to the market. In some cases (e.g., government food subsidy programs or some drug subsidy programs), the firm sells the product at a below market price set by the government (Tuck and Lindert 1996, Yadav et al. 2012) or suggested by the sponsor (Sabot et al. 2009), and the gap is made up by the subsidy. There are also occasions (e.g., subsidies on eye glasses, solar stoves, and some drugs) where the firm possesses significant pricing power (Taylor and Xiao 2014a).

Unlike a firm in the commercial channel, who targets profit maximization, a not-for-profit firm in a non-commercial channel strives to service the society. The not-for-profit firm needs to be consistent with the environment, resources and values that characterize the organization. Though they are not after profit maximization, the not-for-profit firms still have financial "survival" goals to meet. Survival to a not-for-profit firm usually means break-even in the long run and limited instances of below break-even in the short run (Hatten 1982). Subsidy programs offered to not-for-profit firms help them to alleviate the survival pressure and better achieve their societal goals.

On the one hand, the not-for-profit sector has grown rapidly in last decades, playing important roles in modern economy (Salamon 1994). On the other hand, some program sponsors have recently shifted their effort from non-commercial channels toward commercial channels (see, e.g., Gaul 2009, Simon et al. 2014). For example, the distribution of artemisinin combination therapies (ACTs) for malaria treatment is originally conducted by not-for-profit organizations. However, after observing low coverage rates, especially in rural areas, many international agencies start subsidizing retail sector drug shops to increase the distribution coverage (Cohen et al. 2014, Yadav et al. 2012). It is thus intriguing to understand the difference between the commercial and non-commercial channels in reaching the needy consumers under different subsidies. Our goal in this study is to explicitly

¹Social Cooker Review, March 2007, <http://solarcooking.org/newsletters/scrmar07.htm>.

²Social Cooker Review, March 2003, http://solarcooking.org/newsletters/scr_pdfs/scr_mar03.pdf.

compare different channel choices and different subsidy formats in effective implementation of subsidy programs. We take the perspective of a recipient firm and analyze his interaction with the subsidy program sponsor, who chooses a certain format of subsidy up to an available budget. The firm is modeled as a for-profit or a not-for-profit newsvendor, who determines the distribution quantity brought to the consumer market.

Though both for-profit and not-for-profit firms have their long-term strategic goals, our choice of newsvendor framework is due to the following considerations. Many of the food products sponsored by the subsidy programs are highly perishable and storage of inventory cannot be carried long. When introducing products like solar stoves and drugs, pilot subsidy programs are often used as a way of evaluating the local market needs (Sabot et al. 2009) or subsidy programs are rolled out sequentially at different regions (Knudson 2004). The implementation of these programs is often project based. Sponsors regularly conduct reviews and audits to ensure the appropriate use of funds and the performance of the programs (Wakolbinger and Toyasaki 2011). As Fine et al. (2000) point out, future funding from the sponsors are often based on evaluation of the extent to which the current program meets the specific need. As a result, the relatively short-term effects of the subsidy program on consumer adoption are expected.³ However, the future consumer demand can be highly instable and the sponsor’s funding availability is often subject to high unpredictability and frequent fluctuation (Natarajan and Swaminathan 2014). Possible nonstationary in the planning system would make it impossible to reduce a multiperiod problem to a newsvendor type model, making the analysis much involved.

When the recipient firm is a price taker, we show that purchase subsidy is always more effective in increasing consumption than sales subsidy. The driving force behind this observation is, however, different for the for-profit firm and the not-for-profit firm. The purchase subsidy is paid to the firm based on the quantity that he brings to the market, while the sales subsidy is paid on each realized sale. Because of demand uncertainty, the firm may not sell every product that he brings to the market. With the same subsidy funds, the profit-maximizing firm faces a lower risk to increase its distribution quantity under the purchase subsidy than under the sales subsidy. Consequently, the sponsor finds the purchase subsidy a more effective use of the limited budget—To meet a given consumption target, the sponsor needs less funds to subsidize the firm’s purchases than to

³Theoretically, the main insights obtained from a newsvendor framework are largely retained in a stationary multiperiod model which allows inventory carry over because the solution to the multiperiod is also a newsvendor type with the unit overage cost adjusted by the discount factor.

subsidize the sales. The firm in the purchase subsidy program, in turn, makes a lower profit than its counterpart in the sales subsidy program.

In contrast, profit maximization is not the intention of the not-for-profit firm. Subsidies alleviate the firm's financial survival pressure. It turns out that the purchase subsidy and the sales subsidy are equivalent in helping the firm to break even in the long term. However, purchase subsidy is more effective in mitigating the firm's risk of short-term loss than the sales subsidy. Therefore, the sponsor should choose to subsidize on the purchases, as opposed to the sales, of the not-for-profit firm.

When the recipient firm of the subsidy program possesses pricing power, the purchase subsidy continues to dominate the sales subsidy in incentivizing the not-for-profit firm to reach a high consumption. For the profit maximizing firm, however, this is not always true. The trade-off involved in the firm's quantity and pricing decisions becomes more subtle and it depends on the available funds offered by the sponsor. In particular, when the sponsor has a generous budget, the profit-maximizing firm can generate a higher consumption under the sales subsidy than under the purchase subsidy. This is because the firm would continue pushing the price down and thus increasing the market demand as the sales subsidy increases. In contrast, once the per-unit purchase subsidy exceeds the firm's marginal cost, further spending on the purchase subsidy would no longer induce the firm to lower the price and increase the affordability of the consumers.

To obtain some insights into the sponsor's choice between a commercial channel and a non-commercial channel, we compare a for-profit firm and a not-for-profit firm with the same cost structure and market access. Though the not-for-profit firm has more aligned incentive with the sponsor in raising consumption, its vulnerability to short-term financial loss may hinder him from bringing a large quantity to the market. This is particularly the case when the sponsor's budget is in an intermediate range. Sponsoring a for-profit firm, instead, leads to a higher consumption. The comparison is very different when the sponsor's budget is very high. In this case, the subsidy fund becomes substantial and the not-for-profit firm can easily meet its survival conditions. Consequently, the not-for-profit firm is free to choose a large distribution quantity, achieving a large consumption. The subsidy program should then be administered through the not-for-profit firm, as opposed to the for-profit firm.

The remainder of the paper is organized as follows. We review the related literature and discuss our contribution in the next section. Section 3 lays out the model and presents a benchmark case when no subsidy is offered to the firm. In Section 4, we analyze the incentive offered by subsidy

programs when the firm is a price taker. We extend this analysis to incorporate the firm’s pricing decision in Section 5. Section 6 concludes our study. The proofs of all formal results are relegated to the appendix.

2 Literature Review

There is a vast literature in economics that considers design of tax–subsidy policies to increase social welfare. We discuss several closely related papers, which concern the effect of subsidy program on increasing product adoption. Focusing on consumption stimulation, Ashraf et al. (2010) find empirically that the product price, which can be manipulated through tax or subsidy, may have a major impact on consumption of health products that have social externality. Nichols and Zeckhauser (1982) and Blackorby and Donaldson (1988) study efficient tax–subsidy policies to ensure that only the consumers belonging to the needy group in the population benefit from the subsidy. Kalish and Lilien (1983) examine the effect of subsidy on speeding up the new product diffusion. Hirte and Tscharaktschiew (2013), using an equilibrium analysis, conclude that electric vehicles should not be subsidized but be taxed to improve the social welfare in Germany. Ashraf et al. (2013) find that offering product information to the consumers can greatly enhance the effect of subsidy program in increasing the adoption of health product in developing countries. Taking the perspective of the producer firm, Bansal and Gangopadhyay (2003) and Gautier (2015) analyze how tax–subsidy policies impact competing firms’ output decisions. There are other related studies that analyze the interaction between the consumers and the private donors (e.g., Ben-Zion and Spiegel 1983). These studies, focusing on social welfare and consumption, do not consider the effect of subsidy on operational decisions.

There is a growing literature on analyzing subsidy programs in operations contexts. These studies attempt to understand the effect of subsidy in affecting the consumer choice on the subsidized product (e.g., Taylor and Xiao 2014a, Lobel and Perakis 2011), social externality of product adoption (e.g., Arifoglu et al. 2012), the firm’s decision of investing in new technology (e.g., Krass et al. 2013), or the coordination between the parties involved (e.g., Mamani et al. 2012, Chick et al. 2008, Raz and Ovchinnikov 2015).

Several recent papers in operations literature are most closely related to ours. Taylor and Xiao (2014b) study a model in which a sponsor may offer both purchase subsidy and sales subsidy to a profit-maximizing firm for distributing malaria drugs. They conclude that the sponsor should only

subsidize purchases for products with long life cycle, and should never offer sales subsidy alone for products with short life cycle. Our analysis for the case of the for-profit firm compliments their study. In particular, we do not assume explicit demand-price relation and thus generalize a number of observations made in their analysis. Also, they assume that the firm can postpone the pricing decision after the market uncertainty is fully resolved, while the firm in our model sets the price before observing the market condition, which makes the analysis much more involved. Cohen et al. (2014) consider a similar model as ours in which the government, with a fixed budget, provides a sales subsidy to induce a profit-maximizing firm to meet a target consumption level for products with green technology. They assume an additive demand noise. A similar model with an additive demand noise and a linear mean demand function is studied by Raz and Ovchinnikov (2015). While Cohen et al. (2014) focus on understanding the effect of demand uncertainty on the firm profit and the consumer surplus, Raz and Ovchinnikov (2015) focus on facilitating the coordination between the sponsor and the firm. The demand functions considered in these studies are special cases of that in our model. More importantly, the firms considered in the aforementioned studies are profit maximizers. As a major distinction to these studies, we aim to understand the incentive offered by different subsidies to induce the for-profit and not-for-profit firms to enlarge market consumption. Our analysis of not-for-profit firms, often critical players in subsidy programs, develops new understandings to this literature.

Though there is a significant body of research devoted to economic implications, performance evaluation, and organization of the not-for-profit sectors, the literature on operational decisions of not-for-profit firms is rather limited (Berenguer 2014, Feng and Shanthikumar 2016). Recent papers in this area analyze fundraising decisions (McCardle et al. 2009, Toyasaki and Wakolbinger 2014), budget allocation (Verheyen 1998), design of fund audit control (Privett and Erhun 2011), resource management (de Véricourt and Lobo 2009), and inventory management (Natarajan and Swaminathan 2014). Our study, aiming to understand the incentive offered by subsidy programs, complements this growing research of not-for-profit operations.

Our analysis of the for-profit firm's decision problem also contributes to the extensive literature on the newsvendor models with pricing. The problem for general demand function is very challenging because the expected profit function may not be unimodal in the pricing decision. We refer the reader to Petruzzi and Dada (1999) for a comprehensive survey on the developments of this problem by that time. Petruzzi and Dada (1999) also explicitly analyze two instances of the problem, one with an additive demand noise and a linear mean demand, and the other with multiplicative de-

mand noise and an iso-elastic mean demand. Assuming that the demand noise distribution has an increasing length-biased hazard rate, they show that the profit function is unimodal in the pricing decision and thus a unique solution can be obtained by solving the first-order conditions of the quantity and price. Song et al. (2008) extend the analysis for the case of multiplicative demand with general mean demand function. They characterize sufficient conditions on the elasticity of the mean demand under which the profit function is unimodal in price. Kocabiyıkoğlu and Popescu (2011) define a measure, called the lost sales elasticity. They derive conditions on this measure under which the firm’s pricing and quantity decisions exhibit desired monotone properties. Lu and Simchi-Levi (2013) study the problem with location-scale demand distributions. They find several sufficient conditions for the profit function to be log-concave in the price. Our model involving purchase or sales subsidy has added complexity compared with the classical price-setting newsvendor model. We show that the firm’s optimal decisions are monotone in the per-unit purchase subsidy when the demand is stochastically decreasing in the price in the hazard rate order, a condition equivalent to that derived by Kocabiyıkoğlu and Popescu (2011) to ensure the monotone response of the price to the quantity.⁴ In the case of sales subsidy, we show that the conditions needed for monotone decisions can be more general than what is derived by Lu and Simchi-Levi (2013) for unimodality of the profit function.

3 The Model

We consider a subsidy sponsor (she) who offers subsidies to a firm (him) on a product. The consumer demand $D(p)$ for the product is a nonnegative random variable with distribution $F_D(\cdot, p)$ and mean $\mu_D(p)$, depending on the price $p \in [\underline{p}, \bar{p}]$. We use $\bar{F}_D(\cdot, p) = 1 - F_D(\cdot, p)$ to denote the survival function of $D(p)$ and assume that the demand has a finite support, i.e., $\bar{d}(p) = \sup\{D(p)\} < \infty, p \in [\underline{p}, \bar{p}]$. The firm, who distributes the product to the consumers, incurs a marginal cost of c for each unit of product that he brings to the market. The sponsor, who may be a government or nongovernment agent, has a budget b to allocate as subsidies to the firm.

The forms of subsidy. The sponsor seeks to increase the consumption of the product under consideration (recall our earlier examples in §1). The product is not popularized due to various

⁴In the special case when the demand is additive (i.e., $D(p) = \mu_D(p) + Z$ where Z is a random variable with mean zero), this condition reduces to that the noise (i.e., Z) has an increasing hazard rate. In the special case when the demand is multiplicative (i.e., $D(p) = \mu_D(p)Z$, where Z is a random variable with mean one), this condition boils down to that the noise (i.e., Z) has a increasing length-biased hazard rate.

factors like consumer’s low awareness and affordability or the firm’s limited market access. Due to these concerns, the firm is reluctant to offer a large quantity at a low price to the market. To achieve her objective, the sponsor may offer either a *purchase subsidy* or a *sales subsidy*. Under the purchase subsidy, the firm receives r_P dollars for each unit of product that he brings (for distribution) to the market. When the firm’s distribution quantity is q and the market demand is d , the realized firm’s profit under the purchase subsidy is

$$\pi_P(q, p, d, r_P) = p(q \wedge d) - cq + r_P q, \quad (1)$$

where $x \wedge y = \min\{x, y\}$.

Under the sales subsidy, the firm receives r_S dollars for each unit of product sold to the consumer. When the firm’s distribution quantity is q and the market demand is d , the firm’s profit under the sales subsidy is

$$\pi_S(q, p, d, r_S) = p(q \wedge d) - cq + r_S(q \wedge d). \quad (2)$$

Because the amount of sales is ex ante uncertain, the total sales subsidy (i.e., the last term on the right-hand side) depends on the realized demand d and is random. We shall remark that some subsidy programs encourage consumer adoption by giving a discount on the product price. Our model of sales subsidy can be shown to be equivalent to that of price subsidy when the subsidy program allows unrestricted consumer access to the subsidized product (see a detailed discussion in §6).

The characterization of the firm. A subsidy program may be implemented through a commercial channel or a non-commercial channel. These two channels operate very differently. For the firm in the commercial channel, the profitability of the business is always a priority. When working with a for-profit firm in the subsidy program, the sponsor would normally choose a firm with healthy financial status and good credit. Therefore, it is reasonable to assume that the for-profit firm’s decision is aimed at maximizing his expected profit, $\mathbb{E}[\pi_i(q, p, D(p), r)]$, $i = P, S$.

A non-commercial channel, in contrast, works very differently. A not-for-profit firm in our context refers to either a non-governmental organization or a government agency, who aims to service the society. The firm’s goal is often aligned with that of the sponsor. This defines the firm’s objective as maximizing the product consumption, $\mathbb{E}[q \wedge D(p)]$. Though profitability is not his ultimate goal, the firm still needs to sustain the operations by ensuring both long-term and short-term financial survival (Hatten 1982, Bryce 2000). In the long term, the firm should make the ends

meet, which requires a nonnegative expected operating profit (i.e., $\mathbb{E}[\pi_i(q, p, D(p), r)] \geq 0, i = P, S$). In the short term, the not-for-profit firm often operates with limited cash and is thus vulnerable to the risk of loss. To limit such risk, the firm's decision should restrict the possibility of loss (i.e., $\Pr\{\pi_i(q, p, D(p), r) \geq 0\} \geq 1 - \beta$ for some $\beta \in [0, 1], i = P, S$).

The sequence of events. As discussed in §1, implementation and evaluation of subsidy programs are often project-based. We consider one project which concerns distributing a product to a target consumer group. The subsidy program is executed with the following event sequence.

1. The sponsor reviews a budget b up to which she can allocate funds to subsidize the firm. The sponsor may choose to subsidize the firm in two forms, either a per-unit purchase subsidy r_P or a per-unit sales subsidy r_S .
2. The firm makes his operating decision, i.e., the distribution quantity q , and incurs a cost of cq . If the firm has pricing power, he also chooses the product price p . Otherwise, p is exogenously determined.
3. The demand $D(p)$ materializes and the firm collects the revenue from the consumers and the subsidies from the sponsor.

In the base model analyzed in §4, we consider the case where the firm is a price taker. This applies to the situation when the sponsor has stringent price regulation or when the firm is a small player in the market. In §5, we extend the analysis to incorporate the firm's pricing flexibility.

We use subscripts F and N to denote the case of a for-profit firm and that of a not-for-profit firm, respectively. We also use P and S to denote the cases with purchase subsidy and sales subsidy, respectively.

3.1 Benchmark: The Firm's Decisions with No Subsidy

In this subsection, we briefly present the firm's decisions when no subsidy is provided. We will build on these results to analyze the effect of subsidy in the next section. Without any subsidy, the firm makes a profit of

$$\pi(q, p, d) = p(q \wedge d) - cq, \tag{3}$$

when the distribution quantity is q , the price is p , and the realized demand is d .

The **for-profit** firm attempts to maximize his expected profit $\mathbb{E}[\pi(q, p, D(p))]$. For a given p , the optimal distribution quantity is given by the standard newsvendor solution,

$$q_F(p) = \bar{F}_D^{inv}(c/p, p), \quad (4)$$

where $\bar{F}_D^{inv}(\cdot, p)$ is the inverse of $\bar{F}_D(\cdot, p)$. This leads to the expected sales of

$$s_F(p) = \int_0^{\bar{F}_D^{inv}(c/p, p)} \bar{F}_D(x, p) dx. \quad (5)$$

If, in addition, the firm has pricing power, then his optimal price is⁵

$$p_F = \operatorname{argmax}_{\underline{p} \leq p \leq \bar{p}} \left\{ p \int_{c/p}^1 \bar{F}_D^{inv}(\theta, p) d\theta \right\}. \quad (6)$$

In contrast, a **not-for-profit** firm seeks to maximize the expected product consumption, i.e., $\mathbb{E}[q \wedge D(p)]$, while sustaining his own operations, i.e.,

$$\mathbb{E}[\pi(q, p, D(p))] \geq 0, \quad (7)$$

$$\Pr\{\pi(q, p, D(p)) \geq 0\} \geq 1 - \beta, \quad (8)$$

The first condition ensures the *long-term* healthiness of the firm in the sense that the firm is not losing on average. A nonnegative expected profit from each project suggests that the firm may lose money in some projects and make money in others, while making the ends meet across all the projects in the long run. The second condition restricts the *short-term* risk so that the chance of a negative cash flow in a particular project is limited. With a fixed price p , the firm's optimal distribution quantity is determined by one of these conditions, whichever is more stringent, as suggested by the next lemma.

Lemma 1 (Not-for-profit firm: without subsidy) *The not-for-profit firm's optimal distribution quantity is $q_N(p) = q_{N1}(p) \wedge q_{N2}(p)$, where $q_{N1}(p) = \sup\{q : p \int_0^q \bar{F}_D(x, p) dx \geq cq\}$ and $q_{N2}(p) = \sup\{q : \bar{F}_D(cq/p, p) \geq 1 - \beta\}$.*

With the result in Lemma 1, we can calculate the expected sales of the not-for-profit firm as

$$s_N(p) = \int_0^{q_N(p)} \bar{F}_D(x, p) dx. \quad (9)$$

⁵Throughout this paper, if multiple optimal solutions exist, we always choose the smallest one.

If the firm also possesses pricing power, he should choose the following optimal price

$$p_N = \operatorname{argmax}_{p \leq \bar{p}} \{s_N(p)\}. \quad (10)$$

In our subsequent analysis, we will constantly refer to the results obtained from this benchmark case for our discussion on subsidies.

4 The Incentive from Subsidy under a Fixed Price

In this section, we focus on the case where the firm is a price taker in the market. Such a situation arises when the subsidized product price is regulated by the government or set by the program sponsor. For example, governments in developing countries often dictate the retail prices of subsidized food and drugs (Tuck and Lindert 1996). Pilot drug subsidy programs may be offered to some regions with suggested retail price (Sabot et al. 2009, Yadav et al. 2012).

When the firm's optimal decision leads to limited market reach of the product (i.e., when $s_F(p)$ and $s_N(p)$ are small), the sponsor may provide subsidies to the firm in order to increase the product adoption by the end consumers. When planning the budget of the subsidy program, the sponsor needs to understand the incentive offered by a certain subsidy to the firm—What level of subsidy spending $b(s)$ is sufficient to generate a target consumption level s ? To answer this question and to facilitate a comparison across different ways of offering subsidy, we define a measure $r(s) = b(s)/s$, called the *equivalent subsidy per consumption*. This measure represents the minimum spending on each unit of consumption generated to ensure a total consumption of s . For example, if the sponsor offers a purchase subsidy of \$4, the firm would choose a distribution quantity of 25 units and generate 20 units of sales in expectation. In this case, the subsidy spending is $b(20) = \$100$ and the equivalent subsidy per consumption is $b(20)/20 = \$5$.

For ease of exposition, we may transform the quantity decision into the expected sales based on the following observation. The expected sales under a quantity q and a price p is

$$\hat{s}(q, p) = \int_0^q \bar{F}_D(x, p) dx.$$

It is easy to check that $\hat{s}(\cdot, p)$ is increasing and concave in q . Therefore, its inverse $\hat{q}(s, p) = \inf\{q : \hat{s}(q, p) \geq s\}$, $s \in [0, \mu_D(p)]$ is increasing and convex in s . In other words, the additional quantity needed to increase one unit of expected sale is increasing in the level of expected sales.

4.1 The Equivalent Subsidies Per Consumption

We first analyze the case with the **for-profit firm**. With a per unit subsidy of r_P on the purchase, the firm's profit maximizing quantity in (4) increases to $q_{FP}(r_P, p) = \bar{F}_D^{inv}((c - r_P)/p, p)$, as his effective marginal cost reduces to $c - r_P$. To induce a quantity q , the per unit purchase subsidy is $r_P = c - p\bar{F}_D(q, p)$. Thus, the equivalent subsidy per consumption is

$$\rho_{FP}(s, p) = (c - p\bar{F}_D(\hat{q}(s, p), p)) \frac{\hat{q}(s, p)}{s}. \quad (11)$$

With a per unit subsidy of r_S on the sales, the firm's profit maximizing quantity in (4) becomes $q_{FS}(r_S, p) = \bar{F}_D^{inv}(c/(p + r_S), p)$, as his effective marginal revenue increases to $p + r_S$. To induce a quantity q , the per unit sales subsidy is $r_S = c/\bar{F}_D(q, p) - p$. Thus, the equivalent subsidy per consumption is

$$\rho_{FS}(s, p) = \frac{c}{\bar{F}_D(\hat{q}(s, p), p)} - p. \quad (12)$$

When a subsidy is offered to the **not-for-profit firm**, the firm is able to make more profit with the same quantity and price. In other words, both the long-term constraint (7) and the short-term constraint (8) are relaxed. We can modify the analysis for Lemma 1 to derive the equivalent subsidy per consumption in this case.

When the subsidy is given in the form of r_P dollars per unit of distribution quantity and there is a sufficient budget available, the firm's profit is $\pi_P(q, p, d, r_P)$ as defined in (1). To ensure the firm's long-term profit constraint $\mathbb{E}[\pi_P(q, p, D(p), r_P)] \geq 0$, the quantity must not exceed $q_{NP1}(r_P, p) = \sup\{q : p\hat{s}(q, p) \geq (c - r_P)q\}$. Therefore, the equivalent subsidy per consumption needed to induce a consumption level s that meets the firm's long-term profit constraint is

$$\rho_{NP1}(s, p) = c \frac{\hat{q}(s, p)}{s} - p. \quad (13)$$

To satisfy the firm's short-term profit constraint $\Pr\{\pi_P(q, p, D(p), r_P) \geq 0\} \geq 1 - \beta$, the quantity cannot be higher than $q_{NP2}(r_P, p) = \sup\{q : \bar{F}_D((c - r_P)q/p, p) \geq 1 - \beta\}$. Therefore, the equivalent subsidy per consumption needed to induce a consumption level s that meets the firm's short-term profit constraint is

$$\rho_{NP2}(s, p) = c \frac{\hat{q}(s, p)}{s} - p \frac{\bar{F}_D^{inv}(1 - \beta, p)}{s}. \quad (14)$$

Because both the expected profit and the chance of nonnegative profit are increasing in the subsidy for a fixed quantity, the equivalent subsidy per consumption for a not-for-profit firm is $\rho_{NP}(s, p) = \rho_{NP1}(s, p) \vee \rho_{NP2}(s, p)$, where $x \vee y = \max\{x, y\}$.

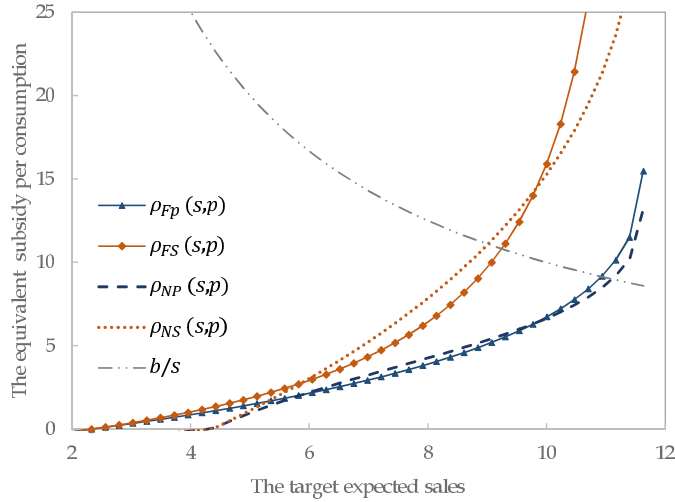
When the subsidy is given in the forms of r_S dollars per unit of sale and there is a sufficient budget, the firm's profit is $\pi_S(q, p, d, r_S)$ as defined in (2). The maximum quantity that satisfies the firm's long-term profit constraint $\mathbb{E}[\pi_S(q, p, D(p), r_S)] \geq 0$ is $q_{NS1}(r_S, p) = \sup\{q : (p + r_S)\hat{s}(q, p) \geq cq\}$. Thus, the corresponding equivalent subsidy per consumption is

$$\rho_{NS1}(s, p) = c \frac{\hat{q}(s, p)}{s} - p. \quad (15)$$

To meet the firm's short-term profit constraint $\Pr\{\pi_S(q, p, D(p), r_S) \geq 0\} \geq 1 - \beta$, the quantity cannot be higher than $q_{NS2}(r_S, p) = \sup\{q : \bar{F}_D(cq/(p + r_S), p) \geq 1 - \beta\}$. Thus, the corresponding equivalent subsidy per consumption is

$$\rho_{NS2}(s, p) = c \frac{\hat{q}(s, p)}{\bar{F}_D^{inv}(1 - \beta, p)} - p. \quad (16)$$

Taking together, the equivalent subsidy per consumption needed to induce a distribution quantity of q from the not-for-profit firm is $\rho_{NS}(s, p) = \rho_{NS1}(s, p) \vee \rho_{NS2}(s, p)$.



Notes. $D(p) = (1 - 0.1p)Z$ with Z following truncated $Normal(30, 10)$, $c = 5$, $p = 6$, $\beta = 0.18$, and $b = 50$.

Figure 1: The equivalent subsidies per consumption under a given target consumption s .

4.2 Comparisons

Having derived the equivalent subsidies per consumption in the previous subsection, we can now compare different scenarios to understand the incentives offered via subsidies on firm's output decisions. Figure 1 depicts an example that will aid our discussion of the formal results in the next two propositions.

Proposition 1 (Effectiveness of subsidies: purchase versus sales) *The sponsor can more effectively induce a target sales s by using purchase subsidy than using sales subsidy. That is, for $j \in \{F, N\}$ and $s_j(p) \leq s \leq \mu_D(p)$,*

$$\rho_{jP}(s, p) \leq \rho_{jS}(s, p).$$

Moreover, the firm makes a lower expected profit under the purchase subsidy than under the sales subsidy, i.e., $\mathbb{E}[\pi_P(\hat{q}(s, p), p, D(p), \rho_{jP}(s, p))] \leq \mathbb{E}[\pi_S(\hat{q}(s, p), p, D(p), \rho_{jS}(s, p))]$.

With a fixed market price p , the sponsor's subsidy offers both the for-profit firm and the not-for-profit firm an incentive to increase the distribution quantity, which in turn induces more consumption. This is reflected by the fact that $\rho_{jP}(s, p)$ and $\rho_{jS}(s, p)$, $j \in \{F, N\}$ are all increasing in s . However, the two types of subsidies work differently in consumption induction. A purchase subsidy is paid on the distribution quantity, while a sales subsidy is paid on the realized sales. Because not every unit distributed is guaranteed to be sold, the expected sales is always less than the distribution quantity. The for-profit, who aims toward expected profit maximization, would face less profit uncertainty when offered a purchase subsidy than when offered a sales subsidy with the same per unit dollar amount. As a result, the sponsor pays less to a for-profit firm on purchase subsidy than on sales subsidy to achieve the same consumption target. This observation is consistent with that obtained by Taylor and Xiao (2014b).

In the case of the not-for-profit firm, though the purchase subsidy is also more effective than the sales subsidy in general, the driving force is very different from that in the case of the for-profit firm. We note that when the not-for-profit firm is not much concerned about short-term risk (i.e., when β is large), the firm's decision essentially meets the long-term profit constraint, making the expected profit above zero. In this case, purchase subsidy and sales subsidy become equivalent to the not-for-profit firm, as $\rho_{NP1}(s, p) = \rho_{NS1}(s, p)$. The difference between the two subsidies arises only when the not-for-profit firm is highly vulnerable to short-term loss (i.e., when β is small). In this case a payment on the distribution quantity is more effective than one on the sales quantity in reducing the short-term loss.

The above observations are illustrated through an example in Figure 1, where we also plot the curve b/s . Facing a fixed budget b , the sponsor can spend up to b/s dollars per consumption if she intends to achieve a consumption target s . The intersection of b/s and $\rho_{jP}(s, p)$ ($\rho_{jS}(s, p)$), $j \in \{F, N\}$, determines the highest expected consumption that can be achieved with a budget b . It is clear from Figure 1 that the expected consumption under the purchase subsidy is higher than

under the sales subsidy with a given budget b for both the for-profit firm and the not-for-profit firm. In other words, the sponsor can use the limited budget more effectively by subsidizing the purchases than by subsidizing the sales.

Our next result summarizes the comparison between a for-profit firm and a not-for-profit firm. To incentivize a profit-maximizing firm to increase the distribution quantity and thus the sales, the sponsor needs to either reduce the marginal cost via the purchase subsidy or increase the marginal revenue via the sales subsidy. In contrast, a not-for-profit firm's objective is aligned with that of the sponsor. The subsidy helps to relax the constraints on the firm's operating profit and thus increase the distribution quantity. In reality for-profit firms and not-for-profit firms may differ in many dimensions including their cost structure, sourcing strategy, access to market, etc. Although these factors are important considerations for the sponsor when deciding a firm for the subsidy program, they are not the focus of our study. To isolate the effect of subsidy incentive on firms' behavior, we take two otherwise identical firms, a for-profit one and a not-for-profit one, and analyze the sponsor's preference in choosing a funding firm.

Proposition 2 (Effectiveness of subsidies: for-profit versus not-for-profit firms) *For $i \in \{P, S\}$, the comparison of the subsidy to a for-profit firm and that to a not-for-profit firm depends on $lh(q, p) = qf_D(q, p)/\bar{F}_D(q, p)$, the length-biased hazard rate of $D(p)$.*

- i) If $lh(\cdot, p)$ is decreasing, then $\rho_{Fi}(s, p) \geq \rho_{Ni}(s, p)$ for $0 \leq s \leq \mu_D(p)$.*
- ii) If $lh(\cdot, p)$ is increasing, then there exist $s_{i1}(p)$ and $s_{i2}(p)$ such that $\rho_{Fi}(s, p) \geq (\leq) \rho_{Ni}(s, p)$ for $s \leq s_{i1}(p)$ and $s \geq s_{i2}(p)$ (otherwise). Moreover, as β increases, $s_{i1}(p)$ is increasing and $s_{i2}(p)$ is decreasing so that for a sufficiently large β , $s_{i1}(p) = s_{i2}(p)$.*

The comparison between the for-profit firm and the not-for-profit firm depends on the consumer demand distribution, the sponsor's target consumption level and the loss vulnerability of the not-for-profit firm. When the demand distribution has a decreasing length-biased hazard rate, it is more effective to subsidize a not-for-profit firm than to subsidize a for-profit firm, regardless of the subsidy type. Most of the well-studied demand distributions, however, fall into the other category, i.e., with an increasing length-biased hazard rate. In this case, less spending is needed to induce a not-for-profit firm to reach a target consumption level than to induce a for-profit firm when the target consumption level is either very low or very high. This implies that the sponsor can allocate her funds more effectively by subsidizing a not-for-profit firm when her budget is very low or very

high, which can be directly observed from Figure 1. If the sponsor’s budget is in the intermediate range, however, she can use the funds more effectively by subsidizing a for-profit firm. This is consistent with the observation from Figure 1, in which $\rho_{Fi}(s, p)$ crosses $\rho_{Ni}(s, p)$ from the above and then from the below.

Intuitively, the not-for-profit firm would have a stronger incentive to increase consumption than the for-profit firm, because the former’s objective is aligned with that of the sponsor’s. In the example depicted in Figure 1, we observe that $s_F \leq s_N$. That is, with no subsidy, the not-for-profit firm reaches a higher consumption than the for-profit firm does. As the sponsor’s consumption target increases to an intermediate level, however, she needs to subsidize more on the not-for-profit firm than on the for-profit firm. This is because the not-for-profit firm may not have the ability to endure the short-term profit loss, which can significantly constrain his distribution quantity. Only when the consumption target becomes very high and a significant amount of subsidy is provided, the not-for-profit firm’s short-term loss can be easily avoided. In this case, the additional money needed for the not-for-profit firm to increase the consumption becomes much less than that for the for-profit firm. In summary, unless the not-for-profit firm is highly vulnerable to short-term loss (i.e., when β is small) and the sponsor’s target consumption level is in the intermediate range, it is more effective to administer the subsidy program through a not-for-profit firm.

5 Offering Subsidy to a Firm with Pricing Power

In the previous section, we discuss the situation where the product price is exogenously given. In this case, increasing consumption is equivalent to increasing the firm’s distribution quantity. When the firm has the ability to determine the product price, the sponsor’s subsidy can influence both the quantity and the price determined by the firm. A subsidy can either reduce the firm’s marginal cost or increase the firm’s revenue margin, which may induce an increased quantity under a fixed price and a reduced price under a fixed quantity. A reduced price, however, decreases the firm’s revenue margin, which can lead to a reduced quantity. Because of the intricate relationship between the quantity and the price, even the classical newsvendor pricing problem that does not involve subsidy decisions is known to be a challenging problem. The analysis on this problem dates back to Whitin (1955) and the developments so far are mostly limited to location-scale demands (see, Lu and Simchi-Levi 2013) or demand functions with restrictive assumptions (see, Kocabiyıkoğlu and Popescu 2011). The main task in this section is to characterize conditions under which the

expected consumption is monotone in the amount of subsidy. Then, we make comparisons of the effectiveness of different types of subsidies.

5.1 The For-Profit Firm

We first consider the situation when a *purchase subsidy* r_P is offered to the *for-profit firm*. Following the analysis in §3.1, we can modify the firm's optimal price in (6) to

$$p_{FP}^*(r_P) = \operatorname{argmax}_{p \in [\underline{p}, \bar{p}]} \left\{ p \int_{\frac{c-r_P}{p}}^1 \bar{F}_D^{inv}(\theta, p) d\theta \right\}.$$

The firm's optimal quantity in (4) becomes $q_{FP}^*(r_P) = \bar{F}_D^{inv}((c - r_P)/p_{FP}^*(r_P), p_{FP}^*(r_P))$.

Proposition 3 (Effects of purchase subsidy on for-profit firm's decisions) *Suppose $\{D(p), \underline{p} \leq p \leq \bar{p}\}$ is decreasing in the hazard rate order (i.e., $-\log \bar{F}_D(x, p)/dx$ is decreasing in p for any x). Then, for $0 \leq r_P \leq c$,*

- i) the optimal distribution quantity $q_{FP}^*(r_P)$ is increasing in r_P ,*
- ii) the optimal price $p_{FP}^*(r_P)$ is decreasing in r_P ,*
- iii) the optimal expected consumption $s_{FP}^*(r_P) = \hat{s}(q_{FP}^*(r_P), p_{FP}^*(r_P))$ is increasing in r_P , and*
- iv) the needed budget $b_{FP}(r_P) = r_P q_{FP}^*(r_P)$ is increasing in r_P .*

Proposition 3 states that the expected consumption is monotone increasing in the per-unit purchase subsidy when the demand is decreasing in the price in the hazard rate order. Kocabiyıkoğlu and Popescu (2011) show that optimal price is decreasing in the quantity in a version of our model with no subsidy (Theorem 1 (i) in their paper) under this condition. In our model with purchase subsidy, this condition ensures that a higher sponsor spending induces a stronger incentive for a profit-maximizing firm to increase consumption. Specifically, the purchase subsidy leads to an increased product supply via an increased distribution quantity and an increased market demand via a reduced price. Note that the condition of decreasing hazard rate is not restrictive. For additive demand model (i.e., $D(p) = \mu_D(p) + Z$ for some random variable Z), this condition boils down to Z having an increasing hazard rate, and for multiplicative demand model (i.e., $D(p) = \mu_D(p)Z$ for some random variable Z), this condition is equivalent to Z having an increasing length-biased hazard rate. These conditions are satisfied by most practical distributions, e.g., normal, exponential, uniform.

The sponsor determines the per-unit purchase subsidy by maximizing the expected consumption, i.e., $\max\{s_{FP}^*(r_P) : b_{FP}(r_P) \leq b\}$. When the conditions in Proposition 3 are satisfied, the more the sponsor spends, the larger is the expected consumption.

Next we analyze the situation where a *sales subsidy* r_S is offered to the *for-profit firm*. The firm's optimal price in (6) now becomes

$$p_{FS}^*(r_S) = \operatorname{argmax}_{p \in [\underline{p}, \bar{p}]} \left\{ (p + r_S) \int_{\frac{c}{p+r_S}}^1 \bar{F}_D^{inv}(\theta, p) d\theta \right\}. \quad (17)$$

The firm's optimal quantity in (4) is modified to $q_{FS}^*(r_S) = \bar{F}_D^{inv}(c/(p_{FS}^*(r_S) + r_S), p_{FS}^*(r_S))$.

Proposition 4 (Effects of sales subsidy on for-profit firm's decisions) *Suppose*

- (a) $\mu_D(p)$ is logconcave in p ,
- (b) $\{D(p), \underline{p} \leq p \leq \bar{p}\}$ is stochastically decreasing, and
- (c) $\log \psi(\alpha, p)$ is directionally concave (i.e., componentwise concave and submodular), where $\psi(\alpha, p) = (1/\mu_D(p)) \int_{1/\alpha}^1 \bar{F}_D^{inv}(x, p) dx, \alpha \geq 1$.

Then, for $r_S \geq 0$,

- i) the optimal critical fractile $c/(p_{FS}^*(r_S) + r_S)$ is decreasing in r_S ,
- ii) the optimal price $p_{FS}^*(r_S)$ is decreasing in r_S ,
- iii) the optimal expected consumption $s_{FS}^*(r_S) = \hat{s}(q_{FS}^*(r_S), p_{FS}^*(r_S))$ is increasing in r_S , and
- iv) the needed budget $b_{FS}(r_S) = r_S s_{FS}^*(r_S)$ is increasing in r_S .

Proposition 4 characterizes conditions under which the expected consumption is monotone in the per-unit sales subsidy. Condition (a) requires the expected demand to be logconcave and condition (b) requires the demand to be decreasing in the price in the first-order stochastic ordering. Both conditions are satisfied by most demand functions assumed in the literature. To understand condition (c), we note that $p \int_{1/\alpha}^1 \bar{F}_D^{inv}(x, p) dx$ is the expected firm profit when the product price is p and the critical fractile is $1/\alpha$. Thus $\psi(\alpha, p)$ is the ratio of the expected firm profit to the riskless firm profit (i.e., $p\mu_D(p)$). The requirement of this ratio being directional concave, though seems complex, is not restrictive. In the appendix, we demonstrate the result in the special case of location-scale demand functions (Proposition 8) and show that the needed conditions are in line

with those imposed by Lu and Simchi-Levi (2013), who provide the latest development on the newsvendor pricing problem for this class of demand functions.

According to Proposition 4, the profit-maximizing firm's incentive to increase consumption becomes stronger as the per-unit sales subsidy increases. The sponsor determines the sales subsidy by solving the following problem $\max\{s_{FS}^*(r_S) : b_{FS}(r_S) \leq b\}$. Because the sponsor's spending $b_{FS}(r_S)$ is increasing in the per-unit sales subsidy r_S and so does the sponsor's objective. It is easy to see that the sponsor should spend all that is available, i.e., making the budget constraint binding. When the sponsor has more funds available, she sets a higher per-unit subsidy r_S . The firm, in turn, reduces his price $p_{FS}^*(r_S)$ and increases his service level $1 - c/(p_{FS}^*(r_S) + r_S)$, according to Proposition 4.

5.2 The Not-For-Profit Firm

In this subsection, we examine the *not-for-profit firm's* decisions. Under the *purchase subsidy*, we can follow the analysis of Lemma 1 and define $q_{NP}(p, r_P) = q_{NP1}(p, r_P) \wedge q_{NP2}(p, r_P)$, where

$$\begin{aligned} q_{NP1}(p, r_P) &= \sup\{q : p\hat{s}(q, p) \geq (c - r_P)q\}, \\ q_{NP2}(p, r_P) &= \sup\{q : \bar{F}_D\left(\frac{c - r_P}{p}q, p\right) \geq 1 - \beta\}. \end{aligned}$$

Then, the firm's optimal price is $p_{NP}^*(r_P) = \arg \max\{s(q_{NP}(p, r_P), p), \underline{p} \leq p \leq \bar{p}\}$, which leads to the optimal quantity $q_{NP}^*(r_P) = q_{NP}(p_{NP}^*(r_P), r_P)$ and the optimal expected sales $s_{NP}^*(r_P) = \hat{s}(q_{NP}^*(r_P), p_{NP}^*(r_P))$. The required budget spending is $b_{NP}(r_P) = q_{NP}^*(r_P)r_P$. The sponsor, in turn, solves the following problem $\max\{s_{NP}^*(r_P) : b_{NP}(r_P) \leq b\}$.

Similarly, under the *sales subsidy*, we define $q_{NS}(p, r_S) = q_{NS1}(p, r_S) \wedge q_{NS2}(p, r_S)$, where

$$\begin{aligned} q_{NS1}(p, r_S) &= \sup\{q : (p + r_S)\hat{s}(q, p) \geq cq\}, \\ q_{NS2}(p, r_S) &= \sup\{q : \bar{F}_D\left(\frac{c}{p + r_S}q, p\right) \geq 1 - \beta\}. \end{aligned}$$

Then, the firm's optimal price is $p_{NS}^*(r_S) = \arg \max\{s(q_{NS}(p, r_S), r_S), \underline{p} \leq p \leq \bar{p}\}$, which leads to the optimal quantity $q_{NS}^*(r_S) = q_{NS}(p_{NS}^*(r_S), r_S)$ and the optimal expected sales $s_{NS}^*(r_S) = \hat{s}(q_{NS}^*(r_S), p_{NS}^*(r_S))$. The required budget spending is $b_{NS}(r_S) = s_{NS}^*(r_S)r_S$. The sponsor, in turn, solves the following problem $\max\{s_{NS}^*(r_S) : b_{NS}(r_S) \leq b\}$.

In general, the not-for-profit firm's optimal quantity and price may not be monotone in the per-unit purchase or sales subsidy offered to him. Nevertheless, a higher per-unit subsidy always leads to a higher expected consumption, whether the firm is subsidized on purchases or on sales, as suggested by the next proposition.

Proposition 5 (Effects of subsidies on not-for-profit firm's decisions) $s_{NP}^*(r_P)$ is increasing in r_P and $s_{NS}^*(r_S)$ is increasing in r_S .

From the sponsor's perspective, Proposition 5 suggests that she should spend all the available funds to help the not-for-profit firm to reach the maximum consumption. This is because the firm and the sponsor have the same objective.

5.3 Comparisons

When the firm possesses pricing power, the comparison among different scenarios turns out to be challenging. We provide some characterizations in the next two propositions to highlight the effect of pricing on the subsidy decisions.

Proposition 6 (Effectiveness of subsidies: purchase versus sales) For a give budget b , the following results hold:

- i) A for-profit firm achieves a higher expected sales under sales subsidy than under purchase subsidy when b is sufficiently large;*
- ii) A not-for-profit firm always achieves a higher expected sales under purchase subsidy than under sales subsidy.*

The distinction between purchase and sales subsidy is mainly driven by the demand uncertainty. One can easily show that, when the demand becomes deterministic, these two subsidies become equivalent regardless of the nature of the subsidized firm. When the demand is uncertain, the firm's pricing decision can influence the dispersion of the demand distribution, inducing complex response to subsidies. Proposition 6(ii) suggests that the purchase subsidy is more effective to incentivize a not-for-profit firm to increase sales than the sales subsidy does. This observation is similar to its counterpart in Proposition 1 where the firm is a price taker. The difference is that a price taker's distribution quantity always increases with the subsidy, while a price setter's may not be.

The comparison is generally challenging when the firm is for profit. Proposition 6(i) suggests that the sales subsidy can be more effective than purchase subsidy, a situation that would never arise if the firm does not have pricing power (recall Proposition 1). To see this result, we note that with purchase subsidy, the sponsor can induce the firm to choose the highest distribution quantity $\bar{d}(p)$ by making the product free for the firm (i.e., $r_P = c$). In this case, the firm would choose a price $p_\mu \in [\underline{p}, \bar{p}]$ to maximize the expected revenue $p\mu_D(p)$. Any additional spending on purchase

subsidy would not affect the firm's decision and increase the firm's expected sales beyond $\mu_D(p_\mu)$. With sales subsidy, in contrast, the sponsor can potentially push the firm's price to get as low as \underline{p} and achieve an expected sales of $\mu_D(\underline{p})$. As a result, the sales subsidy can work more effectively than the purchase subsidy when a large budget is spent on a firm with pricing power.

Taylor and Xiao (2014b) provide a comparison between purchase and sales subsidies in the context of for-profit channels. With the assumption of linear demand and multiplicative demand noise, they find that the purchase subsidy is more (less) effective than sales subsidy when the sponsor's budget is below (above) a certain threshold. Our result in Proposition 6(i) is in line with their conclusion. As we work with general stochastic demand functions, characterizing the comparison for all budget levels is analytically challenging, though an extensive numerical analysis confirms the threshold structure derived by Taylor and Xiao (2014b).

Proposition 7 (Effectiveness of subsidies: for-profit versus not-for-profit firms) *When the budget b is sufficiently large and both firm's are given the same type of subsidy, a not-for-profit firm achieves a higher expected consumption than a for-profit firm does if*

- i) $lh(\cdot, p)$ is decreasing for $p \in [\underline{p}, \bar{p}]$,*
- ii) $lh(\cdot, p)$ is increasing for $p \in [\underline{p}, \bar{p}]$, and b is sufficiently large, or*
- iii) $lh(\cdot, p)$ is increasing for $p \in [\underline{p}, \bar{p}]$, $s_N(p_N) > s_F(p_F)$, and b is sufficiently small.*

When comparing the performance across the for-profit and not-for-profit firm, the property of demand distribution also plays an important role. When the demand has a decreasing length-biased hazard rate, the sponsor always finds the not-for-profit firm more effective in achieving a high consumption level than the for-profit firm. When the demand has an increasing length-biased hazard rate, the same observation holds when the sponsor's budget is either very small or very large. These observations are consistent with the corresponding ones made in Proposition 2, where the firm does not have pricing power. When the firm has pricing power, however, it is challenging to characterize the conditions under which the for-profit firm outperforms the not-for-profit one.

6 Concluding Remark

We analyze the effectiveness of subsidy programs administered through a for-profit or a not-for-profit firm to increase product consumption (see the summary in Table 1). When the firm is a

price taker, we show that the purchase subsidy is always more effective in increasing consumption than the sales subsidy. When the firm possesses pricing power, the purchase subsidy continues to dominate the sales subsidy in incentivizing the not-for-profit firm to reach a high consumption level. However, this is not always true for the for-profit firm, for which the sales subsidy can provide higher consumption level than the purchase subsidy when the sponsor has a generous budget.

Table 1: Purchase versus sales subsidies in effectively inducing consumption

Firm	Not-for-profit	For-profit
Price-taker	$Purchase \succcurlyeq Sales$	
Price-setter	$Purchase \succcurlyeq Sales$	$Purchase \preccurlyeq Sales$ (with large budget)

Whether the sponsor prefers a for-profit or a not-for-profit recipient firm depends on the characteristics of the consumer demand and the sponsor's budget level. For most commonly used demand distributions (i.e., those with increasing length-biased hazard rates), the subsidy program can be more effectively administered through a not-for-profit firm than a for-profit firm when the sponsor has a very limited or very generous funding budget (see the summary in Table 2).

Table 2: For-profit versus not-for-profit firms in effectively administering subsidy program

Firm	High or low budget	Medium budget
Price-taker	$For-Profit \preccurlyeq Not-for-profit$	$For-Profit \succcurlyeq Not-for-profit$
Price-setter		$Undetermined$

On the theoretical front, our analysis also leads to new development of the price-setting newsvendor model by identifying conditions for the monotonicity and uniqueness of the optimal decisions when the newsvendor seeks profit maximizing under subsidies. Our results for the not-for-profit newsvendor provide new understandings of the subsidized not-for-profit operations.

There are several important avenues for future studies. Understanding the operational decisions of not-for-profit firms has gained increasing attentions recently. In addition to obtaining subsidies, not-for-profit firms may have other source of funds (e.g., funds from private donors without specified use). Unrestricted donations generate a highly uncertain cash flow, which on the one hand can alleviate the financial pressure and on the other hand can induce additional uncertainties in the planning. The effect of uncertain donations on the design of effective subsidy programs is yet to be understood. In practice, the program sponsor may offer a price subsidy on a product. The consumers who purchase the products pay the product price less the subsidy. When the subsidy

program does not restrict access to the subsidized product, the price subsidy can be shown to be equivalent to sales subsidy.⁶ In some occasions, the price subsidy program may restrict the access of the local consumers by their income level, social status (e.g., student only), or amount of purchase (e.g., at most one item at the subsidized price per household). In these cases, one needs to model the characteristics of different consumer groups and their buying behavior to understand the effect of price subsidy on the consumption. Moreover, positive social externalities among consumers may be obtained via increased consumption. For example, it is beneficial for the entire local population to increase the awareness of the disease control (Taylor and Xiao 2014a) or to increase adoption of drugs to control contagious disease (Arifoglu et al. 2012). Understanding such externality can help the firm to make effective decisions and the sponsors appropriately access the performance of subsidy programs.

Appendix: Proofs

Proof of Lemma 1. Let $\phi(q, p) = p \int_0^q \bar{F}_D(x, p) dx - cq$. Then $\phi(\cdot, p)$ is concave with $\phi(0, p) = 0$ and $\phi(\infty, p) = -\infty$. Therefore, $q_{N1}(p) = \sup\{q : \phi(q, p) \geq 0\}$ is well defined. It is clear that $\phi(q, p) \geq 0$ for any $q \leq q_{N1}(p)$.

Note that when $d \geq q$, $\pi(q, p, d) = (p - c)q \geq 0$. Hence, $\pi(q, p, d) < 0$ indicates $d < cq/p$. Let $q_{N2}(p) = \sup\{q : \bar{F}_D(cq/p, p) \geq 1 - \beta\}$. Then, $\Pr\{\pi(q, p, D(p)) > 0\} \geq 1 - \beta$ for any $q \leq q_{N2}(p)$.

Comparing $q_{N1}(p)$ and $q_{N2}(p)$, we obtain the result. \square

Proof of Proposition 1. We first prove the result for the *for-profit firm*, i.e., $j = F$. Define $\phi(q) = \int_0^q \bar{F}_D(x, p) dx - q\bar{F}_D(q, p)$. We have $\phi(0) = 0$ and

$$\phi'(q) = \bar{F}_D(q, p) - \bar{F}_D(q, p) + qf_D(q, p) = qf_D(q, p) \geq 0.$$

Hence, $\int_0^q \bar{F}_D(x, p) dx \geq q\bar{F}_D(q, p)$ for all $q \geq 0$ or $s \geq \hat{q}(s, p)\bar{F}_D(\hat{q}(s, p), p)$. From (11) and (12), observe that

$$\rho_{FP}(s, p) = \frac{\hat{q}(s, p)}{s} \bar{F}_D(\hat{q}(s, p), p) \rho_{FS}(s, p).$$

Also, $s = \int_0^{\hat{q}(s, p)} \bar{F}_D(x, p) dx$. It follows that $\rho_{FP}(s, p) \leq \rho_{FS}(s, p)$ for any $s_F(p) \leq s \leq \mu_D(p)$.

⁶Specifically, under a per-unit price subsidy r_x , the firm's profit is $\pi(q, p, d) = (p - r_x)(q \wedge d) - cq$. However, the product demand becomes $D(p - r_x)$. One can take $\hat{p} = p - r_x$ and transform the firm's decision into (q, \hat{p}) . Then it is easy to see that the problem under the price subsidy is equivalent to that under the sales subsidy.

Next we prove the result for the *not-for-profit firm*. We note from (13) and (15) that $\rho_{NP1}(s, p) = \rho_{NS1}(s, p)$. Also, from (13) and (14), $\rho_{NP1}(s, p) \leq (>) \rho_{NP2}(s, p)$, when $s \geq (<) \bar{F}_D^{inv}(1 - \beta, p)$. In this case, we have from (14) and (16),

$$\rho_{NS2}(s, p) = \frac{s}{\bar{F}_D^{inv}(1 - \beta, p)} \rho_{NP2}(s, p) \geq (<) \rho_{NP2}(s, p) \geq (<) \rho_{NP1}(s, p).$$

Thus, $\rho_{NS}(s, p) = \rho_{NS1}(s, p) \vee \rho_{NS2}(s, p) = \rho_{NP1}(s, p) \vee \rho_{NS2}(s, p) \geq \rho_{NP1}(s, p) \vee \rho_{NP2}(s, p) = \rho_{NP}(s, p)$.

Finally, we compare the firm's profits. For any $s > s_j(p), j \in \{F, N\}$ we have from (1) and (2)

$$\begin{aligned} & \mathbb{E}[\pi_P(\hat{q}(s, p), p, D(p), \rho_{jP}(s, p)s/\hat{q}(s, p))] - \mathbb{E}[\pi_S(\hat{q}(s, p), p, D(p), \rho_{jS}(s, p))] \\ &= ps - c\hat{q}(s, p) + \rho_{jP}(s, p)s - (ps - c\hat{q}(s, p) + \rho_{jS}(s, p)s) \\ &= s(\rho_{jP}(s, p) - \rho_{jS}(s, p)) \\ &\leq 0. \end{aligned}$$

Thus, we conclude the proof. \square

Proof of Proposition 2. We first consider the case of purchase subsidy. From the proof of Proposition 1, $s \geq \hat{q}(s, p)\bar{F}_D(\hat{q}(s, p), p)$. Then, from (11) and (13), we have

$$\rho_{FP}(s, p) = c\frac{\hat{q}(s, p)}{s} - p\frac{\hat{q}(s, p)\bar{F}_D(\hat{q}(s, p), p)}{s} = \rho_{NP1}(s, p) + p\left(1 - \frac{\hat{q}(s, p)\bar{F}_D(\hat{q}(s, p), p)}{s}\right) \geq \rho_{NP1}(s, p).$$

Also note from (13) and (14) that $\rho_{NP}(s, p) = \rho_{NP2}(s, p) > \rho_{NP1}(s, p)$ if and only if $s > \bar{F}_D^{inv}(1 - \beta, p)$. We have from (11) and (14)

$$\rho_{NP2}(s, p) - \rho_{FP}(s, p) = \frac{p}{s}\phi(\hat{q}(s, p), p),$$

where $\phi(q, p) = q\bar{F}_D(q, p) - \bar{F}_D^{inv}(1 - \beta, p)$ is decreasing in β . Note $\phi(\bar{d}(p), p) < 0$, and $\phi(q, p)$ is quasi-concave (quasi-convex) in q if $lh(\cdot, p)$ is increasing (decreasing). Hence, we conclude the result for purchase subsidy.

Next we examine the case of sales subsidy. By Proposition 1, $\rho_{FS}(s, p) \geq \rho_{FP}(s, p)$. Then $\rho_{FS}(s, p) \geq \rho_{NP1}(s, p) = \rho_{NS1}(s, p)$. Also note that $\rho_{NS2}(s, p) = c\hat{q}(s, p)/\bar{F}_D^{inv}(1 - \beta, p) - p$ is decreasing in β . From (12) and (16), we have

$$\rho_{NS2}(s, p) - \rho_{FS}(s, p) = \frac{c}{\bar{F}_D(\hat{q}(s, p), p)\bar{F}_D^{inv}(1 - \beta, p)}\phi(\hat{q}(s, p), p).$$

Applying a similar argument as that for the purchase subsidy, we conclude the result for sales subsidy. \square

Proof of Proposition 3. We first show that the firm's optimal price $\tilde{p}(q)$ for a given quantity q is decreasing. To see that let $\psi(p, q) = p \int_0^q \bar{F}_D(x, p) dx$. Then,

$$\frac{\partial \ln(\psi(p, q))}{\partial q} = \frac{\bar{F}_D(q, p)}{\int_0^q \bar{F}_D(x, p) dx}.$$

When $\{D(p), \underline{p} \leq p \leq \bar{p}\}$ is decreasing in the hazard rate order, $\bar{F}_D(x, p)/\bar{F}_D(q, p)$ is increasing in p for any $x < q$. This implies that the right-hand side of the above is decreasing in p . Thus, $\psi(p, q)$ is submodular in (p, q) . Consequently, $\tilde{p}(q) = \arg \max\{\psi(p, q) : \underline{p} \leq p \leq \bar{p}\}$ is decreasing in q .

Let $\phi(p, q, r_P) = p \int_0^q \bar{F}_D(x, p) dx - (c - r_P)q$. We have

$$\frac{\partial \phi(\tilde{p}(q), q, r_P)}{\partial r_P} = q,$$

and thus $\phi(\tilde{p}(q), q, r_P)$ is supermodular in (q, r_P) . Therefore, $q_{FP}^*(r_P)$ is increasing in r_P and $p_{FP}^*(r_P) = \tilde{p}(q_{FP}^*(r_P))$ is decreasing in r_P . \square

Proof of Proposition 4. We first show that $p_{FS}^*(r_S) + r_S$ is increasing in r_S under the following conditions:

- (a) $\mu_D(p)$ is logconcave in p , and
- (c-1) $\log \psi(\alpha, p)$ is concave in p .
- (c-3) $\log \psi(\alpha, p)$ is submodular in (α, p) .

From (17), the profit of the firm, after optimizing the quantity, is

$$\phi(p, r_S) = (p + r_S) \int_{\frac{c}{p+r_S}}^1 \bar{F}_D^{inv}(x, p) dx.$$

Observe that

$$\log \phi(p, r_S) = \log(p + r_S) + \log \mu_D(p) + \log \psi\left(\frac{p + r_S}{c}, p\right).$$

Define $v = p + r_S$ and

$$\tilde{\phi}(v, r_S) = \log \phi(p, r_S) = \log v + \log \mu_D(v - r_S) + \log \psi(v/c, v - r_S).$$

The logconcavity of $\mu_D(p)$ in p implies the supermodularity of $\log \mu_D(v - r_S)$ in (v, r_S) . Now the supermodularity of $\log \psi(v/c, v - r_S)$ in (v, r_S) follows from the observation

$$\frac{\partial^2}{\partial v \partial r_S} \log \psi\left(\frac{v}{c}, v - r_S\right) = -\left(\frac{1}{c} \frac{\partial^2}{\partial \alpha \partial p} \log \psi(\alpha, p) + \frac{\partial^2}{\partial p^2} \log \psi(\alpha, p)\right) \Bigg|_{\substack{\alpha=v \\ p=v-r_S}}.$$

Because $\log \psi(\alpha, p)$ is submodular in (α, p) by condition (c-3) and $\log \psi(\alpha, p)$ is concave in p by condition (c-1), we have $\partial^2 \log \psi(v/c, v - r_S) / \partial v \partial r_S \geq 0$. Hence, we conclude that $\tilde{\phi}(v, r_S)$ is supermodular in (v, r_S) . It is now easy to see that the smallest value of v that maximizes $\tilde{\phi}(v, r_S)$ with the constraint $v \geq r_S$, $v^*(r_S)$ is increasing in r_S . In other words, $v^*(r_S) = p_{FS}^*(r_S) + r_S$ is increasing in r_S .

Next we show that $p_{FS}^*(r_S)$ is decreasing in r_S when the following conditions hold:

(c-2) $\log \psi(\alpha, p)$ is concave in α , and

(c-3) $\log \psi(\alpha, p)$ is submodular in (α, p) .

Observe that

$$\frac{\partial^2 \log \phi(p, r_S)}{\partial p \partial r_S} = \frac{\partial^2}{\partial p \partial r_S} \log \psi\left(\frac{p + r_S}{c}, p\right) = \frac{1}{c^2} \frac{\partial^2}{\partial \alpha^2} \log \psi(\alpha, p) \Big|_{\alpha = \frac{p+r_S}{c}} + \frac{1}{c} \frac{\partial^2}{\partial \alpha \partial p} \log \psi(\alpha, p) \Big|_{\alpha = \frac{p+r_S}{c}}.$$

By conditions (c-2) and (c-3), it is immediate that $\log \phi(p, r_S)$ is submodular in (p, r_S) . Hence, $p_{FS}^*(r_S)$ is decreasing in r_S .

Finally we show that $s_{FS}^*(r_S)$ is increasing in r_S under the following conditions (a), (b), and (c). Observe that

$$s_{FS}^*(r_S) = \int_0^{\bar{F}_D^{inv}\left(\frac{c}{p_{FS}^*(r_S) + r_S}, p_{FS}^*(r_S)\right)} \bar{F}_D(x, p_{FS}^*(r_S)) dx.$$

Since $p_{FS}^*(r_S) + r_S$ is increasing in r_S , $\bar{F}_D^{inv}\left(\frac{c}{p_{FS}^*(r_S) + r_S}, p\right)$ is increasing in r_S for any p . Since $p_{FS}^*(r_S)$ is decreasing in r_S and $D(p)$ is stochastically decreasing in p , $\bar{F}_D(x, p_{FS}^*(r_S))$ is increasing in r_S for any x . Hence, $s_{FS}^*(r_S)$ is increasing in r_S . \square

Proposition 8 (For-profit firm: sales subsidy—The Location-Scale Case) *Suppose $D(p) = \mu_D(p) + \sigma_D(p)Z$, where Z is a random variable with survival function $\bar{F}_Z(\cdot)$, mean zero and standard deviation one. The results i)-iv) in Proposition 4 hold when*

(a) $\mu_D(p)$ is logconcave in p ,

(b) the coefficient of variation $C_D(p) = \sigma_D(p)/\mu_D(p)$ is decreasing and convex in p , and

(c) $g(\alpha) = \frac{1}{1-1/\alpha} \int_{1/\alpha}^1 \bar{F}_Z^{inv}(u) du$ is convex in α .

Proof of Proposition 8. When $D(p) = \mu_D(p) + \sigma_D(p)Z$, we have

$$\psi(\alpha, p) = \int_{1/\alpha}^1 (1 + C_D(p) \bar{F}_Z^{inv}(u)) du = (1 - 1/\alpha)(1 - C_D(p)g(\alpha)).$$

It is clear that the assumption of $C_D(p)$ being convex in p and the observation $g(\alpha) \geq 0$ imply that $\psi(\alpha, p)$ is concave in p and thus logconcave in p .

Next we show that under the assumption of $C_D(p)$ being increasing in p , $\log \psi(\alpha, p)$ is submodular in (α, p) . Observe that $\partial^2 \log \psi / \partial \alpha \partial p \leq 0$ is equivalent to

$$\begin{aligned} 0 &\geq \psi(\alpha, p) \frac{\partial^2 \psi(\alpha, p)}{\partial \alpha \partial p} - \frac{\partial \psi(\alpha, p)}{\partial \alpha} \frac{\partial \psi(\alpha, p)}{\partial p} \\ &= \left(1 - \frac{1}{\alpha}\right) (1 - C_D(p)g(\alpha)) \left(-\frac{1}{\alpha^2} C'_D(p)g(\alpha) - \left(1 - \frac{1}{\alpha}\right) C'_D(p)g'(\alpha)\right) \\ &\quad + \left(1 - \frac{1}{\alpha}\right) C'_D(p)g(\alpha) \left(\frac{1}{\alpha^2} (1 - C_D(p)g(\alpha)) - \left(1 - \frac{1}{\alpha}\right) C_D(p)g'(\alpha)\right) \\ &= -\left(1 - \frac{1}{\alpha}\right)^2 C'_D(p)g'(\alpha). \end{aligned}$$

It is easy to check that $d \log g(\alpha) / d\alpha \leq 0$ and thus $g'(\alpha) \leq 0$. Therefore, the above inequality holds when $C'_D(p) \leq 0$.

Finally, it is easy to see that $\log \psi(\alpha, p)$ is concave in α when $g(\alpha)$ is convex in α . From the proof of Proposition 4, we conclude that (i) and (ii) hold. Now the expected consumption can be written as

$$s_{FS}^*(r_S) = \mu_D(p_{FS}^*(r_S)) \left(1 + C_D(p_{FS}^*(r_S)) \int_0^{\bar{F}_Z^{inv}\left(\frac{c}{p_{FS}^*(r_S) + r_S}\right)} \bar{F}_Z(x) dx\right).$$

Because $p_{FS}^*(r_S) + r_S$ is increasing in r_S , $p_{FS}^*(r_S)$ is decreasing in r_S and $C_D(p)$ is decreasing in p , we conclude that $s_{FS}^*(r_S)$ is increasing in r_S . \square

Proof of Proposition 5. In the case of purchase subsidy, it is easy to see that the feasible set of (q, p) defined by constraints $p\hat{s}(q, p) \geq (c - r_P)q$ and $\bar{F}_D\left(\frac{c - r_P}{p}q, p\right) \geq 1 - \beta$ becomes larger as r_P increases. Thus, the objective is increasing in r_P . A similar argument proves the result in the case of sales subsidy. \square

Proof of Proposition 6. To see part (i), we first consider the purchase subsidy. Note that the for-profit firm's objective $pE[\min D(p), q] - (c - r_P)q$ is increasing in q if $r_P \geq c$. In this case, the firm's optimal distribution quantity becomes $q_{FP}^*(r_P) = \bar{d}(p)$. Then, the firm's optimal price should be $p_{FP}^*(r_P) = p_\mu \equiv \arg \max\{p\mu_D(p) : \underline{p} \leq p \leq \bar{p}\}$. In other words, the firm's decision becomes independent of r_P once $r_P \geq c$ and in this case the firm achieves the highest expected consumption $s_{FP}^*(c) = \mu_D(p_\mu)$ under purchase subsidy. The minimum budget the sponsor needs to induce the highest consumption is $b_{FP}(c) = c\bar{d}(p_\mu)$.

Now we look at the sales subsidy. Note that the highest possible consumption under sales subsidy is $\mu_D(\underline{p})$, which is finite. Thus, when B goes to infinity, ρ_{FS} also goes to infinity. Thus,

a large enough ρ_{FS} would induce the firm to set the price as close to \underline{p} as possible to make the highest profit. As a result, with a large enough budget, the firm's expected sales can get as close as possible to $\mu_D(\underline{p}) \geq \mu_D(p_\mu)$. We obtain part (i).

Now we prove part (ii). Note that when the firm is not-for-profit, his objective is the same as the sponsor's objective. The result would follow if we can show that under a given budget spending, the feasible set for the firm under the purchase subsidy is larger than that under the sales subsidy. If a budget of b is spent, then the firm's expected profit under a price p and a quantity q becomes $p\hat{s}(q, p) - cq + b$, regardless of the format of the subsidy. Hence, the long-term profit constraint is the same under both forms of subsidy. From the proof of Proposition 1, the short-term constraint under the purchase subsidy requires $Pr\{D(p) \geq (cq - b)/p\} \geq 1 - \beta$ and that under the sales subsidy requires $Pr\{D(p) \geq cq/(p + b/\hat{s}(q, p))\} \geq 1 - \beta$. Because the long-term constraint requires $p\hat{s}(q, p) + b \geq cq$, we have

$$\frac{cq - b}{p} - \frac{cq}{p + b/\hat{s}(q, p)} = \frac{b}{p} \left(-1 + \frac{cq}{p\hat{s}(q, p) + b} \right) \leq 0.$$

Therefore, the feasible set for the problem under the purchase subsidy is larger than that under the sales subsidy. \square

Proof of Proposition 7. To prove part (i), we note that for a fixed price p , the for-profit firm's optimal decisions always lead to a lower expected sales than those of the not-for-profit firm by Proposition 2. When both firms also optimize p , the not-for-profit firm must achieve a higher expected sales than the for-profit one because the former's objective is to maximize the expected sales.

To see part (ii), we note from the proof of Proposition 2 that, in this case, there exists a finite threshold on the budget $\bar{b}_j(p)$ for each price p , such that when the budget is higher than $\bar{b}_j(p)$, the not-for-profit firm achieves a larger expected sales than the for-profit one when both price at p . Let $\bar{\bar{b}}_j = \max_{\underline{p} \leq p \leq \bar{p}} \bar{b}_j(p)$. Then it is clear that when $b \geq \bar{\bar{b}}_j$, the not-for-profit firm's optimal decisions must lead to a higher expected sales than those of the for-profit firm.

Part (iii) follows from a similar argument as that for part (ii). We only need to note that when $s_N(p_N) > s_F(p_F)$, there exists a $\underline{b}_j(p) > 0$ for each p such that when the budget is lower than $\underline{b}_j(p)$, the not-for-profit firm achieves a larger expected sales than the for-profit one when both price at p . \square

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