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Short Communication

Supply chain analysis under a price-discount incentive scheme for electric vehicles ☆

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ABSTRACT

We investigate an automobile supply chain where a manufacturer and a retailer serve heterogeneous consumers with electric vehicles (EVs) under a government's price-discount incentive scheme that involves a price discount rate and a subsidy ceiling. We show that the subsidy ceiling is more effective in influencing the optimal wholesale pricing decision of the manufacturer with a higher unit production cost. However, the discount rate is more effective for the manufacturer with a lower unit production cost. Moreover, the expected sales are increasing in the discount rate but may be decreasing in the subsidy ceiling. Analytic results indicate that an effective incentive scheme should include both a discount rate and a subsidy ceiling. We also derive the necessary condition for the most effective discount rate and subsidy ceiling that maximize the expected sales of EVs, and obtain a unique discount rate and subsidy ceiling that most effectively improve the manufacturer's incentive for EV production.

1. Introduction

The rapid development of the automobile industry in the past five decades has not only resulted in significant convenience to consumers but has also generated an increasingly serious air pollution problem. The environmental impact has pressured a number of governments to implement price-discount incentive schemes to promote the electric vehicle (EV). Under such schemes, each EV consumer can enjoy a price discount—calculated as a price discount rate times the retail price charged to the consumer—but limited to a subsidy ceiling. For example, the Spanish government provides a price discount equal to 25% of the purchase price, with a cap of €6000, to each consumer who purchases a new electric car. Similar price-discount schemes have been implemented in other countries, such as the United Kingdom and Romania. For more details, see online Appendix A.

Motivated by the above practices, we consider a price-discount incentive scheme that includes a price discount rate and a subsidy ceiling. We investigate an EV supply chain that involves a manufacturer and a retailer under such a scheme. In practice, the retail price of an automobile may differ among consumers because of the fact that the price for each consumer is not set by the retailer but is determined as a result of the negotiation between the consumer and the retailer. We use cooperative game theory to compute the negotiated retail price for each consumer and derive the expected sales function. To our knowledge, no government has implemented a price-discount scheme or a similar concept for any other market that involves price negotiation between the consumer and retailer. Thus, the bargaining analysis—which is our key modeling approach—and its results are only applicable to the sale of vehicles. We then develop the manufacturer's expected profit function and maximize it to obtain a unique optimal wholesale price for the manufacturer. Using these results, we investigate the effect of both the price discount rate and subsidy ceiling on the manufacturer's optimal wholesale price, the expected sales, and the manufacturer's maximum expected profit.

In this paper, we use the stimulated EV sales to measure the reduction in air pollution, because of the following fact: Stimulating the EV sales would induce more consumers to use EVs instead of fuel vehicles. As roughly calculated by Cuenca, Gaines, and Vyas (2000) and MacKay (2009), the use of an EV can help reduce carbon emissions by approximately 30 tons compared with the use of a fuel vehicle. Therefore, stimulating EV sales can be used as a surrogate measure for the reduction in air pollution. Accordingly, we examine the impact of the incentive scheme on the expected sales of EVs.

Very few EV-related publications exist in the operations management area. Chocteau, Drake, Kleindorfer, Orsato, and Roset (2011) developed a cooperative game model to investigate the

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effect of the collaboration among commercial fleets on the adoption of Avci, Girotra, and Netessine (2012) examined the adoption and environmental impact of EVs with battery swapping, and Mak, Rong, and Shen (2013) constructed robust optimization models for the planning of battery swapping infrastructures. Sioshansi (2012) investigated the incentives of consumers making charging decisions with different electricity tariffs.

Our paper is closely related to the recent publication by Huang, Leng, Liang, and Liu (2013) who examined a government subsidy scheme for EVs in a duopoly setting in which a fuel automobile supply chain and an electric-and-fuel automobile supply chain compete for consumers. The incentive scheme in Huang et al. (2013) only includes a fixed subsidy, whereas the price-discount scheme in our paper involves the retail price-dependent subsidy that cannot exceed a ceiling value. Moreover, Huang et al. (2013) drew most of their managerial insights from numerical experiments; in our paper we analytically investigate an EV supply chain under a price-discount scheme and examine the effectiveness of the scheme in stimulating EV sales. Since both fixed-subsidy and price-discount schemes exist in practice, our paper and Huang et al. (2013) complement each other in terms of research methodologies, contributions to literature, and findings for practitioners.

Unlike in Huang et al. (2013), we do not consider any fuel vehicle (FV) but only focus on an EV supply chain. This is reasonable because of the following two facts. First, in the automobile industry, there are a number of EV supply chains where the electric vehicles mainly include REVAi, Buddy, Citroën C1 eV'ie, Fisker Automotive, Tesla Roadster, Smart ED, Wheego Whip LiFe, and so on. Therefore, the EV supply chain in our model exists in practice. Second, the sales of all EVs account for only a tiny share of the current automobile market. For example, in the United States, the share of EV sales was only 0.53% during the first six months of 2013 (see hybridcars.com). Thus, any issue in the EV market is unlikely to significantly affect the FV market.

Price discount is a commonly-used promotion strategy and has been widely investigated in marketing and operations management fields. For publications regarding price-discount schemes applicable to supply chain members, see Bernstein, Chen, and Federgruen (2006), Klastorin, Moinzadeh, and Son (2002), and Wang (2005); for publications concerning price-discount schemes applicable to end consumers, see Gerstner and Hess (1995), Huchzermeier, Iyer, and Freheit (2002), Kurata and Liu (2007), and Sheu (2011). In the abovementioned publications, price-discount schemes are implemented by a manufacturer or retailer to increase sales or coordinate a supply chain. In addition, a few publications (e.g., Jørgensen & Zaccour, 1999; Ma, Zhao, & Ke, 2013) analyzed a government's subsidy. We examine the government's price-discount scheme for EVs that aims to reduce air pollution. Moreover, we consider the negotiation of retail price for each consumer, unlike in the abovementioned publications where retail price is determined by the firm.

2. Negotiated retail price

Under the government's price-discount incentive scheme, the government provides subsidy to the consumer who purchases an EV from a retailer. This subsidy is the minimum of the price discount (the discount rate α times the original retail price charged to the consumer) and subsidy ceiling A. To simplify our statement, we hereafter denote such a price-discount scheme by (α, A). In most practices in today's automobile market, the retail price for each consumer results from the negotiation between the consumer and the retailer. Accordingly, we apply the theory of cooperative game to determine the negotiated retail price for a consumer who is assumed to have valuation (consumption gain) θ on the EV.

A common solution to two-player games in cooperative game theory is "Nash bargaining scheme" (Nash, 1953). The consumer pays retail price p, enjoys the consumption gain θ, and obtains the subsidy amounting to $\min(\alpha p, A)$ from the government when he or she trades with the retailer. Thus, the consumer's net gain is calculated as $u_c \equiv \theta - p + \min(\alpha p, A)$. The retailer orders the EV from the manufacturer at wholesale price w; thus, the retailer's profit resulting from the trade with the consumer is computed as $u_r \equiv p - w$. Noting that neither the consumer nor the retailer will obtain any gain or profit if they cannot reach an agreement in their transaction, we construct a Nash bargaining model as follows:

$$\max_p \Lambda = [\theta - p + \min(\alpha p, A)](p - w) \quad \text{s.t. } \theta - p + \min(\alpha p, A) \geqslant 0 \quad \text{and } p - w \geqslant 0. \tag{1}$$

Therefore, if the manufacturer's wholesale price w is sufficiently high such that $w \geqslant A/\alpha$, then $p \geqslant A/\alpha$ because $p \geqslant w$; thus, $\min(\alpha p, A) = A$. This condition means that when $w \geqslant A/\alpha$, the consumer should obtain subsidy ceiling A from the government, and the discount rate α does not take effect in the incentive scheme. If $w < A/\alpha$, then the consumer obtains either price discount αp or subsidy ceiling A, depending on negotiated retail price p.

Theorem 1. *Given the manufacturer's wholesale price w, we find that under the incentive scheme* (α, A)*, the retail price for the consumer with the valuation* θ*, resulting from the negotiation between the consumer and the retailer, can be obtained as follows:*

1. *When* $w \leqslant A/\alpha$*, the consumer does not buy from the retailer if* $\theta < \underline{\theta} \equiv (1-\alpha)w$*; however, if* $\theta \geqslant \underline{\theta}$*, then the consumer trades with the retailer at negotiated price* p^* *as given below.*

$$p^* = \begin{cases} p_1^* \equiv [w + \theta/(1-\alpha)]/2, & \text{if } \underline{\theta} \leqslant \theta \leqslant \hat{\theta} \equiv 2(1-\alpha)A/\alpha - (1-\alpha)w; \\ p_2^* \equiv A/\alpha, & \text{if } \hat{\theta} \leqslant \theta \leq 2A/\alpha - A - w; \\ p_3^* \equiv (\theta + A + w)/2, & \text{if } \theta \geqslant 2A/\alpha - A - w. \end{cases} \tag{2}$$

If the consumer's valuation θ *is in the range* $[\underline{\theta}, \hat{\theta}]$*, then the amount of the subsidy awarded to the consumer is smaller than A; otherwise, if* $\theta \geqslant \hat{\theta}$*, then the consumer obtains a subsidy in amount of A.*

2. *When* $w \geqslant A/\alpha$*, the consumer may or may not buy from the retailer, depending on the consumer's valuation* θ*. Specifically, if* $\theta < w - A$*, then the consumer and the retailer would not reach an agreement on the retail price; however, if* $\theta \geqslant w - A$*, then the consumer and the retailer trade at the negotiated price* $p^* = p_3^*$*; the consumer can obtain subsidy A from the government.*

Proof. For the proof of this theorem and those for all subsequent theorems, see online Appendix B. □

In the above theorem, $\underline{\theta}$ denotes the after-discount payment made by consumers who buy from the retailer at wholesale price w. Since the wholesale price is the lowest retail price, $\underline{\theta}$ can be viewed as the smallest purchase cost for consumers. That is, if the discount for any purchase at the wholesale price does not exceed the subsidy ceiling, then a consumer's buying decision depends on whether his or her valuation is greater than the smallest purchase cost. If the consumer's valuation is less than the smallest purchase cost, then he or she cannot enjoy any positive net gain from buying an EV. Otherwise, the consumer should be willing to make a purchase. In Theorem 1, the threshold $\hat{\theta}$ represents the minimum valuation of consumers who obtain the maximum subsidy A. When a consumer's valuation is less than the minimum value, the consumer will receive subsidy αp, which is lower than subsidy ceiling A; otherwise, the consumer will receive the maximum subsidy.