Promoting Electric Automobiles: Supply Chain Analysis under a Government's Subsidy Incentive Scheme

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Abstract

We analyze a fuel automobile (FA) supply chain and an electric-and-fuel automobile (EA-FA) supply chain in a duopoly setting, under a government's subsidy incentive scheme that is implemented to promote the electric automobile (EA) for the control of air pollution. Benefiting from such a scheme, each EA consumer can enjoy a subsidy from the government. We show that the incentive scheme is more effective in increasing the sales of the EA when consumers' bargaining power is stronger. The impact of the incentive scheme on consumers' net surplus is the largest among all components in the social welfare. A higher subsidy may not result in a greater reduction in the environmental hazard. Moreover, a larger number of service and charging stations can reduce the negative impact of the incentive scheme on the FA market while enhancing its positive impact on the EA market. We also compare the incentive scheme with the centralized control with no subsidy, and find that the incentive scheme is more effective in promoting the EA and protecting the environment.

Key words: Electric automobile; supply chain; government subsidy; incentive scheme; social welfare.

1 Introduction

The past two decades have witnessed an increasing concern over the air pollution generated by traditional fuel automobiles (FAs). As a response for environmental protection, many governments have recently implemented incentive schemes to stimulate consumers' purchases of electric automobiles (EAs). A common incentive scheme is to directly award a fixed amount of subsidy to each consumer who purchases a qualifying EA. Hereafter, such an incentive scheme is simply called the "subsidy incentive scheme." In the United States, each electric vehicle purchased in or after 2010 may be eligible for a federal subsidy of up to \$7,500 in the form of income tax credit. In addition, a number of state governments in the United States have already adopted the subsidy incentive scheme to promote the EAs. For example, the state of California provides each consumer with a subsidy of up to \$5,000 for his or her purchase of an all-electric or battery electric vehicle (BEV), and a subsidy of up to \$3,000 for the purchase of a plug-in hybrid vehicle. The state of Georgia promotes BEVs by offering an amount of \$5,000 to each consumer who buys a unit of BEV.

In addition to the United States, some other governments (in, e.g., France and Japan) also execute similar subsidy incentive schemes, which have successfully, and dramatically, increased the sales of EAs in those countries. From the above practices, we find that the subsidy incentive scheme has been playing a significant role in stimulating the sales of EAs. Thus, it should be important to investigate such a scheme from the academic perspective.

We begin by briefly reviewing recent theoretic research papers regarding sustainable operations under a government's incentive scheme or environmental policy; for a review on the publications before 2005, see Kleindorfer, Singhal, and van Wassenhove (2005). Krass, Nedorezov, and Ovchinnikov (2012) investigated an environmental-protection problem where an environmental regulator uses environmental taxes or pollution fines to motivate the choice of innovative and "green" emissions-reducing technologies. Ovchinnikov and Raz (2010) developed a newsvendor model involving a pricing decision variable to investigate a government's interventions (e.g., rebates, subsidies, and buyback guarantees) for public interest goods with the aims of improving the affordability of the good, increasing the accessability to the good, and maximizing the social welfare. Drake, Kleindorfer, and van Wassenhove (2012) developed a two-stage stochastic model to investigate the impact of emissions cap-and-trade and emissions tax regulation on a firm's technology choice and capacity decisions. Apart from the above papers, several scholars investigated the impact of environmental legislations on product take-back and recovery; see a review by Atasu and van Wassenhove (2010). For example, Atasu, van Wassenhove, and Sarvary (2009) constructed an economic model to examine the extended producer responsibility from a social planner's (government's) perspective. Toyasaki, Boyaci, and Verter (2011) analyzed and compared monopolistic and competitive take-back schemes for recycling waste electrical and electronic equipment.

Different from extant papers regarding sustainable operations, we consider a government's subsidy incentive scheme aiming at promoting the sales of the EA for the purpose of environmental protection. Chocteau et al. (2011) developed a cooperative game model to investigate the collaboration on the adoption of the EA among commercial fleets, but they did not consider the impact of any scheme implemented by a government. In addition to our above review regarding sustainable operations, a number of papers—e.g., Aydin and Porteus (2009), Chen et al. (2007), Dogan (2010), Gilpatric (2009), and Khouja and Zhou (2010)—have investigated various incentive schemes that are used by manufacturers and/or retailers to increase the sales.

Our above review shows that very few research papers are concerned with a government's subsidy incentive scheme for promoting the EA. In this paper, we investigate the impact of a government's subsidy incentive scheme on two supply chains, which include an FA supply chain only making an FA and an EA-FA supply chain producing both an EA and an FA. This should be realistic because of the following reason: As online Table A (in online Appendix A) indicates, many major FA producers (e.g., Toyota, Honda, Ford, etc.) also sell a significant number of EAs, thus being regarded as the manufacturers making both the EA and the FA. However, we also note from Table A that the EA sales of some major FA manufacturers (e.g., Mazda, BMW, Porsche, and Chrysler) are negligibly small compared with their FA sales; therefore, these firms can be reasonably viewed as those only making the FA. It thus follows from the evidence in Table A that both the FA and the EA-FA supply chains should exist in practice.

Under the government's incentive scheme, the FA and the EA-FA supply chains compete for consumers in a market of a finite size. Each consumer buys an FA from the FA or the EA-FA supply chain, or purchases an EA from the EA-FA supply chain, or does not buy any automobile. In Section 2, we first investigate the bargaining between a consumer and each retailer in two supply chains. Using consumers' (strategic) choice decisions, we derive the demand function for each automobile, and develop the profit functions for two manufacturers, who make their wholesale pricing decisions in Nash equilibrium. We also perform a sensitivity analysis, and find that a larger subsidy can generate a greater demand for the EA, but may not result in a greater reduction in the demand for the FAs. Moreover, when consumers have stronger bargaining power, the incentive scheme is more effective in increasing the sales of the EA.

In Section 3, we construct a social welfare function, and perform a sensitivity analysis to explore the impact of the subsidy, the number of service and charging stations, and the mean value of consumers' relative bargaining power on the social welfare and its major components. In the decentralized setting in which two manufacturers make their wholesale pricing decisions in a non-cooperative game, we find that the incentive scheme does not significantly increase the negative impact on the profit in the FA market. The impact of the incentive scheme on consumers' net surplus is the largest among all components in the social welfare. A larger subsidy may not result in a greater reduction in the environmental hazard. Moreover, a better infrastructure condition for the EA (i.e., a larger number of service and charging stations) can reduce the negative impact of the incentive scheme on the FA market while enhancing its positive impact on the EA market.

The centralized control with a wholesale price ceiling for each automobile can result in globally optimal wholesale prices that maximize the social welfare. We find that the centralized setting with no subsidy always benefits the FA market but the subsidy scheme always results in more benefits in the EA market. A subsidy incentive scheme is more helpful in reducing the environmental hazard than the centralized setting. This paper ends with a summary of major managerial insights and a comparison with two other relevant papers in Section 4.

2 Supply Chain Analysis in the Duopoly Setting

We consider the competition between the FA and the EA-FA supply chains in a market where B potential consumers may buy during the period of implementing the subsidy incentive scheme. In the FA supply chain, the manufacturer M_1 produces its fuel automobile FA_1 at the quantity-dependent unit cost $c(D_1)$ (where D_1 denotes the sales of the FA_1), determines its wholesale price w_1 for FA_1, and then sells its products to the retailer R_1. In the EA-FA supply chain, the manufacturer M_2 produces its fuel automobile FA_2 at the unit cost $c(D_2)$ and its electric automobile EA at the unit cost $\hat{c}(\hat{D})$, where D_2 and $\hat{D}$ represent the sales of the FA_2 and the EA, respectively. The manufacturer M_2 determines its wholesale prices w_2 and $\hat{w}_2$ for its FA_2 and EA, respectively, and sells its products to the retailer R_2, who then serves consumers with both FA_2 and EA.

Note that in practice, the retail price of an automobile may differ among different consumers, which is mainly attributed to the fact that the price for each consumer is not set by a retailer itself but is determined as a result of the negotiation between the consumer and the retailer. Accordingly, for each automobile in the two supply chains, we compute a negotiated retail price for each consumer rather than an optimal retail price that maximizes a retailer's expected profit.

According to the above, we investigate the following two-stage decision problem in the duopoly setting.

1. In the first stage, the manufacturer M_1 and the manufacturer M_2 make optimal wholesale pricing decisions to maximize their individual profits. We model the wholesale pricing decision problem as a two-player non-cooperative game and solve the game to find the wholesale prices in Nash equilibrium. The manufacturers M_1 and M_2 then announce their wholesale prices to the retailers R_1 and R_2, respectively.
2. In the second stage, each consumer in the market bargains with R_1 over the retail price of the FA_1 and with R_2 over the retail prices of the FA_2 and the EA. According to the three negotiations, the consumer may buy an FA_1 or FA_2, may buy an EA, or may not buy any automobile.

2.1 Negotiated Retail Prices and Consumers' Purchase Choices

We construct a two-player cooperative game model to analyze the bargaining process between a consumer and each retailer, investigate consumers' purchase choices, and find negotiated retail prices of the FA_1, the FA_2, and the EA.

2.1.1 Consumers' Net Surpluses and Retailers' Profits

We begin by computing a consumer's net surplus and the retailer R_1's profit generated from the consumer's purchase of an FA_1 at the negotiated retail price p_1. The consumer has a valuation θ_1 on the FA_1; that is, the consumer can enjoy the utility ("gross gain") θ_1 from using the FA_1 over its lifetime. To calculate the net surplus for the consumer, we should estimate his or her total relevant cost k_1 during the FA_1's lifespan, which mainly includes the lifecycle sum of the fuel cost, maintenance cost, running cost, etc., as discussed by Cuenca, Gaines, and Vyas (2000). We also learn from this paper that the lifecycle cost (excluding the purchase cost) for an FA under *normal* conditions can be estimated using the following method: In practice, each FA's lifespan is usually measured in miles. For a specific type of FA, all consumers incur very similar cost for each unit of lifetime miles; and thus, the total lifecycle cost can be simply calculated as the corresponding unit cost per mile times the lifetime miles. According to the cost estimation by the U.S. Department of Energy (2011), the average annual cost for a fuel automobile in the United States is $4,005.

Therefore, the consumer's net surplus from purchasing an FA_1 can be calculated as his or her valuation θ_1 minus the lifecycle cost k_1 and the negotiated retail price p_1, i.e., $u_1(\eta_1, p_1) = \theta_1 - k_1 - p_1 = \eta_1 - p_1$, where $\eta_1 \equiv \theta_1 - k_1$ represents the consumer's net consumption gain. In practice, consumers usually have different valuation θ_1 and incur different lifecycle cost k_1, thus obtaining different net gain η_1. Accordingly, we assume that η_1 is a random variable. Since the retailer R_1 buys the FA_1 from the manufacturer M_1 at the wholesale price w_1 and sells it to the consumer with the net consumption gain η_1 at the retail price p_1, the retailer's profit $\pi_1(\eta_1, p_1)$ from the transaction is calculated as, $\pi_1(\eta_1, p_1) = p_1 - w_1$.

Using the above arguments, for the FA_2 in the EA-FA supply chain, we can compute the profit of the retailer R_2 and the net surplus of the consumer as $\pi_2(\eta_2, p_2) = p_2 - w_2$ and $u_2(\eta_2, p_2) = \eta_2 - p_2$, respectively, where η_2 is the consumer's net consumption gain—which is a random variable, and p_2 is the retail price of the FA_2. Similarly, for the EA, the profit of the retailer R_2 and the net surplus of the consumer are calculated as $\hat{\pi}(\hat{\eta}, \hat{p}) = \hat{p} - \hat{w}$ and $\hat{u}(\hat{\eta}, \hat{p}) = \hat{\eta} - \kappa(n) - \hat{p} + s$, where $\hat{\eta}$ means the consumer's net consumption gain from using the EA, and is a random variable; n denotes the number of service and charging stations; $\kappa(n)$ is consumers' average $n-$dependent cost of using the EA; $\hat{p}$ is the retail price of the EA; and s denotes the subsidy awarded by the government to each EA consumer. We incorporate the cost function $\kappa(n)$ into each consumer's net surplus function, because Avci, Girotra, and Netessine (2012) have shown that the battery switching stations can reduce the driving cost and thus increase the adoption of electric vehicles. Accordingly, it is reasonable to assume that $\kappa(n)$ is a decreasing, convex function of n. For a detailed discussion regarding the above calculation, see online Appendix B.

Since, in practice, the random variables η_i $(i = 1, 2)$ and $\hat{\eta}$ should be correlated with each other but may not be perfectly dependent, we reasonably assume that η_i $(i = 1, 2)$ and $\hat{\eta}$ are jointly distributed with the trivariate probability density function $f(\eta_1, \eta_2, \hat{\eta})$ and the trivariate cumulative distribution function $F(\eta_1, \eta_2, \hat{\eta})$ on the support $\{(\eta_1, \eta_2, \hat{\eta}) \mid \eta_1, \eta_2, \hat{\eta} \geq 0\}$.

2.1.2 The Bargaining Models and Analysis

We now construct two-player game models to characterize the bargaining processes for the retail prices of three automobiles. Since the negotiation over the price of an automobile involves two players (i.e., a consumer and a retailer), we solve the bargaining problem using the cooperative-game solution concept of "generalized Nash bargaining (GNB) scheme" (Nash 1953, Roth 1979). The GNB scheme represents a unique bargaining solution that can be obtained by solving the following maximization problem: $\max_{y_1, y_2}(y_1 - y_1^0)^\beta (y_2 - y_2^0)^{1-\beta}$, s.t. $y_1 \geq y_1^0$ and $y_2 \geq y_2^0$, where β and $1 - \beta$ denote players 1's and 2's relative bargaining powers; y_i and y_i^0 correspond to player i's profit and disagreement payoff, respectively, for $i = 1, 2$. The concept of GNB has been used to analyze various problems in supply chain management; see, for example, Nagarajan and Bassok (2008). In the bargaining between a consumer and the retailer R_1, we, w.l.o.g., assume that the consumer and the retailer R_1 are players 1 and 2, respectively. Since consumers may have heterogeneous bargaining power in their price negotiations, we accordingly assume that each consumer's bargaining power β is a non-negative random variable with the p.d.f. $g(\beta)$ and the c.d.f. $G(\beta)$ on the support $[\beta_1, \beta_2]$, where β_1 and β_2 represent the minimum and maximum values of consumers' bargaining power in negotiating with the retailer R_1, respectively, i.e., $0 \leq \beta_1 \leq \beta_2 \leq 1$.

According to our discussion in online Appendix C, we find that, when a consumer with the net consumption gain η_1 on the FA_1 bargains with the retailer R_1, the GNB model can be constructed as,

$$\max_{p_1} \Lambda_1 \equiv (\eta_1 - p_1 - u_1^0)^\beta (p_1 - w_1)^{1-\beta}, \text{ s.t. } \eta_1 - p_1 \geq u_1^0 \text{ and } p_1 - w_1 \geq 0, \tag{1}$$

where $u_1^0 \equiv \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2), 0\}$ is the consumer's disagreement payoff for the FA_1. To find the retail price of the FA_2, we build the following GNB model for the bargaining problem between a consumer with the net consumption gain η_2 on the FA_2 and the retailer R_2 as,

$$\max_{p_2} \Lambda_2 \equiv (\eta_2 - p_2 - u_2^0)^{\hat{\beta}} (p_2 - w_2 - v_2^0)^{1-\hat{\beta}}, \text{ s.t. } \eta_2 - p_2 \geq u_2^0 \text{ and } p_2 - w_2 \geq v_2^0. \tag{2}$$

In (2), $\hat{\beta} \equiv r\beta$ represents the consumer's bargaining power relative to the retailer R_2 with the constant parameter $r > 0$ differentiating between the retailers R_1 and R_2; $u_2^0 \equiv \max\{\hat{u}(\hat{\eta}, \hat{p}), u_1(\eta_1, p_1), 0\}$

is the consumer's disagreement payoff for the FA_2; v_2^0 is the retailer R_2's disagreement payoff for the FA_2, i.e.,

$$v_2^0 \equiv \max\{(\hat{p} - \hat{w}) \times \mathbf{1}_{\hat{u}(\hat{\eta},\hat{p}) \geq u_1(\eta_1,p_1)}, 0\} = \begin{cases} \max\{\hat{p} - \hat{w}, 0\}, & \text{if } \hat{u}(\hat{\eta},\hat{p}) \geq u_1(\eta_1,p_1), \\ 0, & \text{if } \hat{u}(\hat{\eta},\hat{p}) < u_1(\eta_1,p_1), \end{cases} \tag{3}$$

where $\mathbf{1}_{\hat{u}(\hat{\eta},\hat{p}) \geq u_1(\eta_1,p_1)} = 1$ if $\hat{u}(\hat{\eta},\hat{p}) \geq u_1(\eta_1,p_1)$, but $\mathbf{1}_{\hat{u}(\hat{\eta},\hat{p}) \geq u_1(\eta_1,p_1)} = 0$ if $\hat{u}(\hat{\eta},\hat{p}) < u_1(\eta_1,p_1)$.

To compute the retail price of the EA, we construct the following GNB model to characterize the bargaining between a consumer with $\hat{\eta}$ on the EA and the retailer R_2 as,

$$\max_{\hat{p}} \hat{\Lambda} \equiv (\hat{\eta} - \kappa(n) - \hat{p} + s - \hat{u}^0)^{\hat{\beta}}(\hat{p} - \hat{w} - \hat{v}^0)^{1-\hat{\beta}}, \text{ s.t. } \hat{\eta} - \kappa(n) - \hat{p} + s \geq \hat{u}^0 \text{ and } \hat{p} - \hat{w} \geq \hat{v}^0, \tag{4}$$

where $\hat{u}^0 \equiv \max\{u_1(\eta_1,p_1), u_2(\eta_2,p_2), 0\}$ is the consumer's disagreement payoff for the EA, and the retailer R_2's disagreement payoff for the EA is $\hat{v}^0 \equiv \max\{(p_2 - w_2) \times \mathbf{1}_{u_2(\eta_2,p_2) \geq u_1(\eta_1,p_1)}, 0\}$. Note that $\hat{v}^0$ can be explained similar to v_2^0 in (3).

Our above GNB models incorporate the consumer's purchase choice. Such a bargaining modeling approach has been widely considered in the business and economics fields. For similar models, see, e.g., Davidson (1988), Dukes, Gal-Or, and Srinivasan (2006), Horn and Wolinsky (1988), Iyer and Villas-Boas (2003), Lommerud et al. (2005), Symeonidis (2008), etc. We next solve the optimization problems in (1), (2), and (4), and find the negotiated retail prices of the FA_1, the FA_2, and the EA.

Theorem 1 Given two manufacturers' wholesale prices $(w_1, w_2, \hat{w})$ under the subsidy incentive scheme for the EA, the consumer with the net consumption gain η_i for the FA_i $(i = 1, 2)$ and $\hat{\eta}$ for the EA negotiates with two retailers. The negotiated FA_i retail price p_i^* and EA retail price $\hat{p}^*$ are computed as follows.

1. If $(\eta_1, \eta_2, \hat{\eta}) \in \mathbf{\Omega}_0 \equiv \{(\eta_1, \eta_2, \hat{\eta}) : \tau_1 < 0, \tau_2 < 0, \hat{\tau} < 0\}$, where $\tau_1 \equiv \eta_1 - w_1$, $\tau_2 \equiv \eta_2 - w_2$, and $\hat{\tau} \equiv \hat{\eta} - \kappa(n) + s - \hat{w}$, then the consumer does not buy any automobile.
2. If η_1 is no less than w_1 (i.e., $\tau_1 \geq 0$), then the consumer may decide to buy an FA_1 from the retailer R_1. The price p_1^* depends on the values of η_1, η_2, and $\hat{\eta}$, as shown in Table 1.

Case	Conditions	Negotiated Retail Price p_1^*
1	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{11} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq \hat{\beta}\tau_2, \tau_2 \geq \hat{\tau} \geq 0\}$	$p_1^* = p_{11}^* \equiv \beta w_1 + (1-\beta)(\eta_1 - \hat{\beta}\tau_2)$
2	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{12} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq \hat{\beta}\hat{\tau}, \hat{\tau} \geq \tau_2 \geq 0\}$	$p_1^* = p_{12}^* \equiv \beta w_1 + (1-\beta)(\eta_1 - \hat{\beta}\hat{\tau})$
3	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{13} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq \hat{\beta}\tau_2, \tau_2 \geq 0, \hat{\tau} \leq 0\}$	$p_1^* = p_{13}^* \equiv \beta w_1 + (1-\beta)(\eta_1 - \hat{\beta}\tau_2)$
4	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{14} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq \hat{\beta}\hat{\tau}, \hat{\tau} \geq 0, \tau_2 \leq 0\}$	$p_1^* = p_{14}^* \equiv \beta w_1 + (1-\beta)(\eta_1 - \hat{\beta}\hat{\tau})$
5	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{15} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq 0, \tau_2 \leq 0, \hat{\tau} \leq 0\}$	$p_1^* = p_{15}^* \equiv \beta w_1 + (1-\beta)\eta_1$

Table 1: The negotiated retail price p_1^* for the consumer who buys an FA_1.

In addition, we find that p_1^* is decreasing in the subsidy s but is increasing in w_1.

3. If η_2 is no less than w_2 (i.e., $\tau_2 \geq 0$), then the consumer may decide to buy an FA_2 from the retailer R_2. The price p_2^* depends on the values of η_1, η_2, and $\hat{\eta}$, as shown in Table 2.

Case	Conditions	Negotiated Retail Price p_2^*
1	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{21} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq \hat{\beta}\hat{\tau}, \tau_2 \geq \beta\tau_1 + (1-\beta)\hat{\beta}\hat{\tau}, \hat{\tau} \geq 0\}$	$p_2^* = p_{21}^* \equiv \hat{\beta}w_2 + (1-\hat{\beta}) \times\{\eta_2 - [\beta\tau_1 + (1-\beta)\hat{\beta}\hat{\tau}]\}$
2	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{22} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq 0, \hat{\tau} \geq \beta\tau_1, \tau_2 \geq \beta\tau_1\}$	$p_2^* = p_{22}^* \equiv \hat{\beta}w_2 + (1-\hat{\beta})(\eta_2 - \beta\tau_1)$
3	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{23} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq 0, \hat{\tau} \leq 0, \tau_2 \geq \beta\tau_1\}$	$p_2^* = p_{23}^* \equiv \hat{\beta}w_2 + (1-\hat{\beta})(\eta_2 - \beta\tau_1)$
4	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{24} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \hat{\tau} \geq 0, \tau_1 \leq 0, \tau_2 \geq 0\}$	$p_2^* = p_{24}^* \equiv \hat{\beta}w_2 + (1-\hat{\beta})\eta_2$
5	$(\eta_1,\eta_2,\hat{\eta}) \in \mathbf{\Omega}_{25} \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \leq 0, \hat{\tau} \leq 0, \tau_2 \geq 0\}$	$p_2^* = p_{25}^* \equiv \hat{\beta}w_2 + (1-\hat{\beta})\eta_2$

Table 2: The negotiated retail price p_2^* for the consumer who buys an FA_2.

We find that p_2^* is decreasing in the subsidy s but is increasing in w_2.

4. If $\hat{\eta}$ is no less than $\hat{w} + \kappa(n) - s$ (i.e., $\hat{\tau} \geq 0$), then the consumer may decide to buy an EA from the retailer R_2. The negotiated retail price $\hat{p}^*$ depends on the values of η_1, η_2, and $\hat{\eta}$, as shown in Table 3.

Case	Conditions	Negotiated Retail Price $\hat{p}^*$
1	$(\eta_1,\eta_2,\hat{\eta}) \in \hat{\mathbf{\Omega}}_1 \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq \hat{\beta}\tau_2, \tau_2 \geq 0, \hat{\tau} \geq \beta\tau_1 + \hat{\beta}(1-\beta)\tau_2\}$	$\hat{p}^* = \hat{p}_1^* \equiv \hat{\beta}\hat{w} + (1-\hat{\beta})\{\hat{\eta} - \kappa(n) + s - [\beta\tau_1 + \hat{\beta}(1-\beta)\tau_2]\}$
2	$(\eta_1,\eta_2,\hat{\eta}) \in \hat{\mathbf{\Omega}}_2 \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq 0, \tau_2 \geq \beta\tau_1, \hat{\tau} \geq \beta\tau_1\}$	$\hat{p}^* = \hat{p}_2^* \equiv \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s - \beta\tau_1]$
3	$(\eta_1,\eta_2,\hat{\eta}) \in \hat{\mathbf{\Omega}}_3 \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \geq 0, \tau_2 \leq 0, \hat{\tau} \geq \beta\tau_1\}$	$\hat{p}^* = \hat{p}_3^* \equiv \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s - \beta\tau_1]$
4	$(\eta_1,\eta_2,\hat{\eta}) \in \hat{\mathbf{\Omega}}_4 \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \leq 0, \tau_2 \geq 0, \hat{\tau} \geq 0\}$	$\hat{p}^* = \hat{p}_4^* \equiv \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s]$
5	$(\eta_1,\eta_2,\hat{\eta}) \in \hat{\mathbf{\Omega}}_5 \equiv \{(\eta_1,\eta_2,\hat{\eta}) : \tau_1 \leq 0, \tau_2 \leq 0, \hat{\tau} \geq 0\}$	$\hat{p}^* = \hat{p}_5^* \equiv \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s]$

Table 3: The negotiated retail price $\hat{p}^*$ for the consumer who buys an EA.

We find that $\hat{p}^*$ is increasing in both the subsidy s and the wholesale price $\hat{w}$.

Proof. For a proof of this theorem, see online Appendix D. ■

2.2 Demand and Profit Functions in Two Supply Chains

Using Theorem 1, we can derive the expected sales for the FA_i $(i = 1, 2)$ and the EA as,

$$D_i(\mathbf{w}) = B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\mathbf{\Omega}_{ij}} f(\eta_1,\eta_2,\hat{\eta})d\hat{\eta}d\eta_2 d\eta_1\right)\right]g(\beta)d\beta\right\}, \tag{5}$$

$$\hat{D}(\mathbf{w}) = B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\hat{\mathbf{\Omega}}_{j}} f(\eta_1,\eta_2,\hat{\eta})d\hat{\eta}d\eta_2 d\eta_1\right)\right]g(\beta)d\beta\right\}, \tag{6}$$

where $\mathbf{w} \equiv (w_1, w_2, \hat{w})$. Hereafter, we let $D(\mathbf{w})$ denote the total demand for two FAs, i.e., $D(\mathbf{w}) \equiv \sum_{i=1}^{2} D_i(\mathbf{w})$. Then, we can compute the manufacturers' and the retailers' expected profits in two supply chains. Specifically, the manufacturer M_1's and the retailer R_1's expected profits are obtained as,

$$\Pi_{M1}(\mathbf{w}) = [w_1 - c(D_1(\mathbf{w}))]D_1(\mathbf{w}), \tag{7}$$

and

$$\Pi_{R1}(\mathbf{w}) = B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\mathbf{\Omega}_{1j}} (p_{1j}^* - w_1) f(\eta_1,\eta_2,\hat{\eta})d\hat{\eta}d\eta_2 d\eta_1\right)\right]g(\beta)d\beta\right\}. \tag{8}$$

For the EA-FA supply chain, the manufacturer M_2's and the retailer R_2's expected profits are calculated as,

$$\Pi_{M2}(\mathbf{w}) = [w_2 - c(D_2(\mathbf{w}))]D_2(\mathbf{w}) + [\hat{w} - \hat{c}(\hat{D}(\mathbf{w}))]\hat{D}(\mathbf{w}), \tag{9}$$

and

$$\begin{aligned}\Pi_{R2}(\mathbf{w}) &= B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\mathbf{\Omega}_{2j}}(p_{2j}^* - w_2)f(\eta_1,\eta_2,\hat{\eta})d\hat{\eta}d\eta_2 d\eta_1\right)\right]g(\beta)d\beta\right\}\\ &\quad + B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\hat{\mathbf{\Omega}}_j}(\hat{p}_j^* - \hat{w})f(\eta_1,\eta_2,\hat{\eta})d\hat{\eta}d\eta_2 d\eta_1\right)\right]g(\beta)d\beta\right\}. \end{aligned}\tag{10}$$

The manufacturers M_1 and M_2 compete in the market by determining their wholesale prices w_1 and $(w_2, \hat{w})$, respectively. Such a pricing decision problem can be described as a "simultaneous-move" game. In practice, a manufacturer should determine a production quantity under its capacity constraint. Thus, in the game, the manufacturer M_1 maximizes its expected profit $\Pi_{M1}(\mathbf{w})$ subject to $D_1(\mathbf{w}) \leq D_1^0$, and the manufacturer M_2 maximizes $\Pi_{M2}(\mathbf{w})$ subject to $D_2(\mathbf{w}) \leq D_2^0$ and $\hat{D}(\mathbf{w}) \leq \hat{D}^0$, where D_i^0 $(i = 1, 2)$ denotes the capacity for FA$_i$ and $\hat{D}^0$ is the capacity for the EA. Solving the game we can find a Nash equilibrium. Due to the intractable complexity of two manufacturers' profit functions in (7) and (9), we cannot analytically find the wholesale prices in Nash equilibrium $\mathbf{w}^N \equiv (w_1^N, w_2^N, \hat{w}^N)$. We next provide an example to illustrate our game analysis.

Example 1 Suppose that a market has $B = 10,000$ potential consumers during the period of a government's incentive scheme with the subsidy $s = \$7,000$, which applies to the U.S. market because the federal government provides each consumer who purchases an electric vehicle in or after 2010 with a subsidy of up to $7,500 in the form of income tax credit. Each consumer's net consumption gains η_i $(i = 1, 2)$ and $\hat{\eta}$ are jointly distributed as a trivariate normal with the joint probability density function,

$$f(\eta_1, \eta_2, \hat{\eta}) = \frac{1}{(2\pi)^{3/2}\sqrt{|\mathbf{V}|}} \exp\left(-\frac{1}{2}(\boldsymbol{\eta} - \boldsymbol{\mu})^T \mathbf{V}^{-1}(\boldsymbol{\eta} - \boldsymbol{\mu})\right),$$

where $\boldsymbol{\eta} \equiv [\eta_1, \eta_2, \hat{\eta}]^T$ denotes a random vector; $\boldsymbol{\mu} \equiv [\mu_1, \mu_2, \hat{\mu}]^T \equiv [E(\eta_1), E(\eta_2), E(\hat{\eta})]^T$ is the vector of the consumers' average net consumption gains on three automobiles; and $|\mathbf{V}|$ is the determinant of the 3×3 covariance matrix $\mathbf{V}$. The matrix $\mathbf{V}$ is written as,

$$\mathbf{V} \equiv \begin{bmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \hat{\rho}_1\sigma_1\hat{\sigma} \\ \rho_{12}\sigma_1\sigma_2 & \sigma_2^2 & \hat{\rho}_2\sigma_2\hat{\sigma} \\ \hat{\rho}_1\sigma_1\hat{\sigma} & \hat{\rho}_2\sigma_2\hat{\sigma} & \hat{\sigma}^2 \end{bmatrix},$$

where σ_i $(i = 1, 2)$ and $\hat{\sigma}$ denote the standard deviations of η_i and $\hat{\eta}$, respectively; ρ_{12} is the correlation coefficient between η_1 and η_2, and $\hat{\rho}_i$ is the correlation coefficient between η_i and $\hat{\eta}$. For this numerical example, we use the parameter values as follows: $\mu_1 = \mu_2 = 30,000$, $\hat{\mu} = 36,000$; $\sigma_1 = \sigma_2 = 4,000$, $\hat{\sigma} = 5,000$; $\rho_{12} = 0.7$, $\hat{\rho}_1 = 0.3$, and $\hat{\rho}_2 = 0.4$. The mean value and standard deviation for two fuel automobiles are selected as above because of the following reason: As reported by Markiewicz (2012), the average transaction price of new fuel cars in April 2012 is \$30,748. This means that the average value of consumers' net consumption gains can roughly approximate around \$30,748; hence, $\mu_1 = \mu_2 = 30,000$. Note from `Jiskha.com` (2010) that, in 2010, the transaction prices of new fuel cars roughly satisfy a normal distribution with mean \$23,000 and standard deviation \$3,500. In our numerical example, it should be reasonable to assume that consumers' net consumption gains from fuel cars are normally distributed with mean \$30,000 and standard deviation \$4,000 (i.e., $\sigma_1 = \sigma_2 = 4,000$). Similarly, noting from Grünig et al. (2011) that the average transaction price of all-electric vehicles in 2011 is around \$36,000, we can assume the values of the parameters $\hat{\mu}$ and $\hat{\sigma}$ as given above. Moreover, we assume that $\rho_{12} = 0.7$, because consumers' net consumption gains from the two fuel automobiles (i.e., FA_1 and FA_2) should be similar. We also assume that $\hat{\rho}_1 = 0.3$ and $\hat{\rho}_2 = 0.4$, because the correlation between the FA_i ($i = 1, 2$) and the EA should be small, and the correlation between the FA_2 and the EA should be higher than that between the FA_1 and the EA, since the FA_2 and the EA are both produced by the manufacturer M_2.

Moreover, to use the EA, each consumer incurs the average $n-$dependent cost $\kappa(n) = an^{-b}$, where the parameters $a, b > 0$ describe the dependence of each EA user's cost on the facility availability. In this example, $n = 100$, $a = 3500$, and $b = 0.5$. The parameter values should be reasonable, because the U.S. Department of Energy (2012a) reported that, as of May 17, 2012, the average number of charging stations in each state in the U.S. is around 100. For the distribution of charging stations in the U.S., see Figure A in online Appendix E. Moreover, from the Alternative Fuels & Advanced Vehicles Data Center of the U.S. Department of Energy (`http://www.afdc.energy.gov/afdc/`), we roughly assume the values of the parameters a and b as given above.

According to the empirical study by Chen, Yang, and Zhao (2008), we assume that each consumer's bargaining power β (for the FA_1) is normally distributed on the support $[0.1, 0.9]$, with the mean value $\mu_\beta = 0.4$ and the standard deviation $\sigma_\beta = 0.1$. Each consumer's power in bargaining with the retailer R_2 over the retail prices of the FA_2 and the EA is $r\beta$, where $r = 0.8$, which reflects the fact that most consumers still prefer an FA to an EA in today's automobile market. Because of economies of scale, the unit production cost for each automobile is usually decreasing in the production quantity. Accordingly, the manufacturer M_1's unit production cost for the FA_1 [i.e., $c(D_1(\mathbf{w}))$] and the manufacturer M_2's unit production cost for the FA_2 [i.e., $c(D_2(\mathbf{w}))$] are assumed to be $c(D_i(\mathbf{w})) = c + \lambda_1[D_i(\mathbf{w})]^{-\lambda_2}$, for $i = 1, 2$; and that for the EA is assumed to be $\hat{c}(\hat{D}(\mathbf{w})) = \hat{c} + \hat{\lambda}_1[\hat{D}(\mathbf{w})]^{-\hat{\lambda}_2}$. According to Cuenca, Gaines, and Vyas (2000), we assume that

$c = 25,000$, $\lambda_1 = 3,000$, $\lambda_2 = 0.5$; $\hat{c} = 29,000$, $\hat{\lambda}_1 = 2,300$, and $\hat{\lambda}_2 = 0.7$. Note that $\hat{c}$ is larger than c, which is in line with the fact that the unit production cost for an EA is usually much higher than that for an FA, mainly because the EA battery is costly.

We construct a "simultaneous-move" game in which the manufacturer M_1 maximizes its expected profit $\Pi_{M1}(\mathbf{w})$ in (7) subject to $D_1(\mathbf{w}) \leq D_1^0$, where the capacity D_1^0 (for FA_1) is assumed to be 6,000, and the manufacturer M_2 maximizes its expected profit $\Pi_{M2}(\mathbf{w})$ in (9) subject to $D_2(\mathbf{w}) \leq D_2^0$ and $\hat{D}(\mathbf{w}) \leq \hat{D}^0$, where $D_2^0 = 6,000$ and $\hat{D}^0 = 1,000$. We assume that $D_1^0 = D_2^0 = 6,000$, because the market data center of The Wall Street Journal shows that, for the top 20 FAs in the U.S. market, the average state-wide sales in 2012 are expected to vary from 3647 to 8800. In addition, $\hat{D}^0$ is assumed to be $1,000$, because, from the statistics provided by American International Automobile Dealers Association, we learn that, for the top 10 brands, the average state-wide sales in 2012 will be around 1,000.

We solve the above game, and obtain Nash equilibrium as $\mathbf{w}^N = (w_1^N, w_2^N, \hat{w}^N) = (\$26,633.48, \$27,451.29, \$32,612.43)$. The corresponding expected sales for the FA_1 and the FA_2 are 3,570 and 4,935, respectively. The total sales of two FAs are thus 8,505, i.e., $D(\mathbf{w}^N) = 8,505$; and the expected sales for the EA are 454, i.e., $\hat{D}(\mathbf{w}^N) = 454$. We then calculate the corresponding expected profits for the manufacturers M_1 and M_2 as $\Pi_{M1}(\mathbf{w}^N) = \$1.01 \times 10^7$ and $\Pi_{M2}(\mathbf{w}^N) = \$3.21 \times 10^7$. We also find the retailers R_1's and R_2's expected profits as $\Pi_{R1}(\mathbf{w}^N) = \$0.318 \times 10^7$ and $\Pi_{R2}(\mathbf{w}^N) = \$2.39 \times 10^7$.

In order to examine the impact of the subsidy s on two supply chains, we consider the case when the government does not implement such a scheme (i.e., $s = 0$), and calculate the corresponding wholesale prices in Nash equilibrium as $\mathbf{w}^N = (w_1^N, w_2^N, \hat{w}^N) = (\$27,351.66, \$28,312.11, \$30,972.23)$. We note that the government's incentive scheme with the subsidy $s = \$7,000$ increases the wholesale price of the EA but decreases the wholesale prices of two FAs. When $s = 0$, the expected sales for the FA_1, the FA_2, and the EA are 4380, 4656, and 347, respectively. The total sales of two FAs are 9,036. Comparing the demands with those when $s = \$7,000$, we find that, as a result of executing the incentive scheme for the EA, the expected sales of two fuel automobiles are reduced by 531 units—which account for 5.88% of the total expected sales when $s = 0$, and the expected sales of the EA are increased by 107 units—which are 30.84% of the expected sales of the EA when $s = 0$. Though, we note that the expected sales of the EA are significantly lower than those of two fuel automobiles, mainly because the expensive battery in an EA increases the production cost and thus the price of the EA.

In addition, we learn that, with no subsidy incentive scheme, $\Pi_{M1}(\mathbf{w}^N) = \$1.535 \times 10^7$, $\Pi_{R1}(\mathbf{w}^N) = \$0.438 \times 10^7$; and, $\Pi_{M2}(\mathbf{w}^N) = \$3.095 \times 10^7$, $\Pi_{R2}(\mathbf{w}^N) = \$1.452 \times 10^7$, which demonstrates that the incentive scheme could improve the profitability of the EA-FA supply chain. □

2.3 Sensitivity Analysis

Using the parameter values in Example 1 as the base values, we perform sensitivity analyses to investigate the impact of the government's subsidy s, the number of service and charging stations for the EA (i.e., n), and the mean value of consumers' relative bargaining power β (i.e., μ_β) on (i) the wholesale prices in Nash equilibrium, (ii) the demands for the FA$_i$ ($i = 1, 2$) and the EA, and (iii) the system-wide profits of two supply chains. We present our numerical results in online Appendix F, where the results for s, n, and μ_β are provided in Tables E, F, and G, respectively. In Table F, for each value of n, the percentage increase or decrease is calculated for the case when $s = \$7,000$ compared with the case of no subsidy ($s = 0$). Similar comparison is made for each value of μ_β, as presented in Table G.

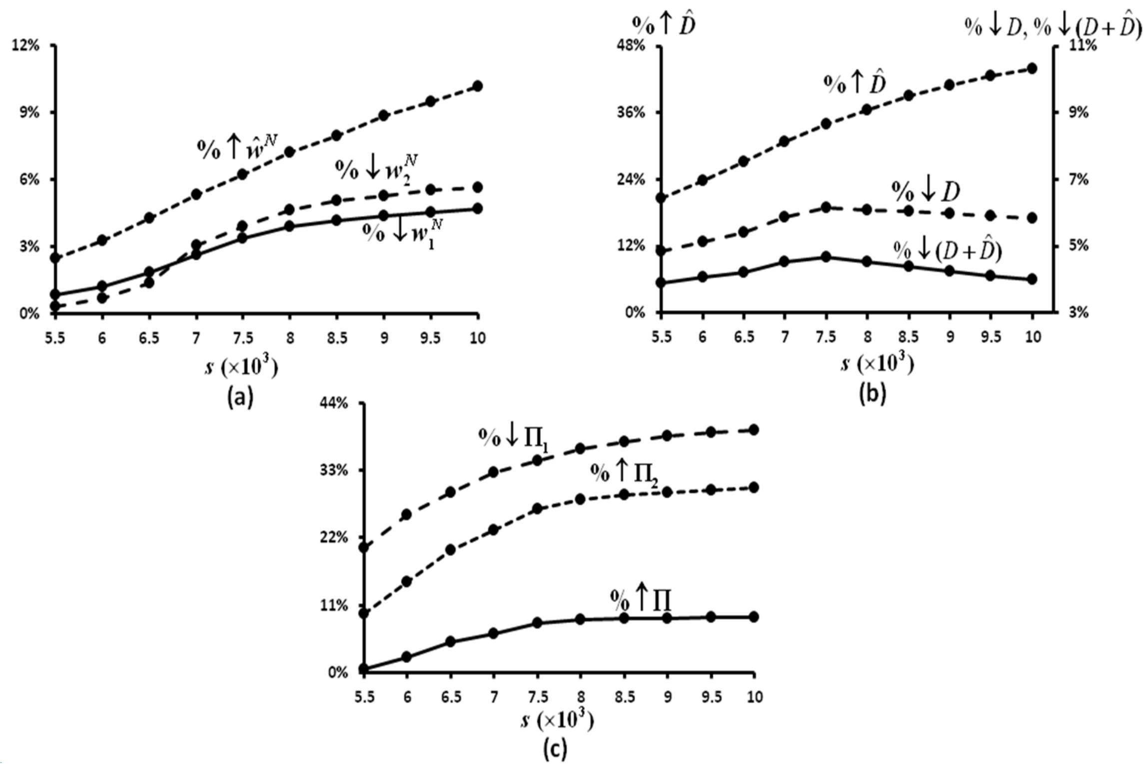

Figure 1: The percentage changes in the wholesale prices [as shown in (a)], demands [as shown in (b)], and profits in two supply chains [as shown in (c)]. Note that the mark "%↑" ("%↓") represents the percentage increase (percentage decrease) compared with the case of no subsidy ($s = 0$). In (c), the subscripts "1" and "2" represent the FA and the EA-FA supply chains, respectively. Moreover, Π_1, Π_2, and Π denote the profits of the FA and the EA-FA supply chains, and the total profit of two supply chains, respectively.

Using online Table E, we draw Figure 1(a) to show the percentage changes in the wholesale prices of two FAs and the EA when the subsidy s changes from \$5,500 to \$10,000. We find that, as the government increases its subsidy s, the manufacturer M_2 increases its wholesale price $\hat{w}^N$ for the EA, possibly because the manufacturer intends to benefit from the incentive scheme by "sharing" a portion of the subsidy from consumers. In order to mitigate the impact of the scheme on the sales of two FAs, the manufacturers M_1 and M_2 reduce the wholesale price for the FA_1 (w_1^N) and that for the FA_2 (w_2^N), respectively. Noting from Theorem 1 that each consumer's negotiated retail price for each FA is decreasing in s but is increasing in the wholesale price for the FA, whereas each consumer's negotiated retail price for the EA is increasing in both s and the wholesale price for the EA. It thus follows that, when two manufacturers determine their wholesale prices in Nash equilibrium, each consumer's negotiated retail price for each FA is decreasing in s and that for the EA is increasing in s.

We also use online Table E to plot Figure 1(b) to indicate the percentage decrease in the total demand for two FAs (i.e., $\% \downarrow D$) and the percentage increase in the demand for the EA (i.e., $\% \uparrow \hat{D}$). We note that the demand for the EA increases significantly as the subsidy s rises. Since the total demand for two FAs is reduced under the incentive scheme, we can conclude that the scheme may help stimulate the sales of the EA while discouraging consumers from buying the FAs. We also find that $\% \downarrow D$ is increasing in s when $s \leq \$7,500$ but is decreasing in s when $s > \$7,500$. In addition, Figure 1(c) shows that an increase in the subsidy s may reduce the profit of the FA supply chain but greatly increase the profit of the EA-FA supply chain. Such a result may imply that the incentive scheme should be helpful in improving the profitability of the supply chain involving the production of an EA. We also find that the total profit of two supply chains is slightly increasing in s.

As online Table F indicates, with a larger number of service and charging stations, the incentive scheme (with $s = \$7,000$) will result in a greater percentage increase in the wholesale price of the EA but also a greater percentage reduction in the wholesale prices of two FAs. Moreover, the percentage decrease in the total demand for two FAs will be smaller while the percentage increase in the demand for the EA will be larger. We also note that, as the value of n increases, both the reduction in the profit of the FA supply chain and the increase in the profit of the EA-FA supply chain are increasing; and, the total profit of two supply chains rises at an increasing rate. We learn from online Table G that, when consumers have a higher relative bargaining power, the wholesale price for each automobile will be lower; moreover, as the value of μ_β increases, the increase in the EA sales will significantly rise, and the reduction in the total sales of two FAs will decrease when $\mu_\beta \leq 0.50$ but increase when $\mu_\beta > 0.50$. It could follow that the incentive scheme is more effective in promoting the sales of the EA when consumers' bargaining power is stronger. In addition, when consumers are stronger in negotiating retail prices, the incentive scheme (with $s = \$7,000$) will result in a larger reduction in the profit of the FA supply chain and a smaller increase in the profit of the EA-FA supply chain. It thus follows that both supply chains will benefit less from the scheme when consumers are stronger in their price negotiations.

3 The Social Welfare

In the preceding section, we analyzed the FA and the EA-FA supply chains given the government's subsidy s. A realistic question may arise as follows: How does the government determine its subsidy? Similar to Krass, Nedorezov, and Ovchinnikov (2012) and Ovchinnikov and Raz (2010) who considered the social welfare for a technology choice problem and a pricing problem for public interest goods, respectively, we find that, in our problem, we should investigate the impact of the subsidy on the social welfare and the environmental protection, because the government's subsidy incentive scheme for the EA should be ascribed to its societal value and public interest.

3.1 The Social Welfare Function

We now compute the social welfare that results from the implementation of an EA incentive scheme. Our analysis in Section 2 indicates that such a scheme affects the manufacturers' and the retailers' profits in the FA and the EA-FA supply chains. Thus, a term in the social welfare function should be the total profit of two supply chains. Moreover, since the incentive scheme applies to each EA consumer and also affects each FA consumer, we should include the net surplus of both the FA and the EA consumers into the social welfare function. Because the primary goal of the scheme is to reduce the environmental hazard, we should consider the negative impacts of two FAs (FA_i, $i = 1, 2$) and the EA on the environment in the social welfare function. The government's total expense for the subsidies awarded to the EA consumers and the total installation cost of charging stations should also be included.

According to the above, we find that the social welfare $\Phi(s)$—generated by the incentive scheme with the subsidy s—can be written as,

$$\Phi(s) = \Pi(s) + \Pi_C(s) - I(s) - U(s) - A, \tag{11}$$

where $\Pi(s)$ is the total profit of two supply chains; $\Pi_C(s)$ denotes the total net surplus of both the FA and the EA consumers; $I(s)$ is the environmental hazard of two FAs and the EA; $U(s) = s\hat{D}(\mathbf{w}^N)$ denotes the government's total subsidy expense; and A represents the total installation cost of n charging stations. Note that $A = \alpha \times n$, where α denotes the installation cost per charging station. We learn from the U.S. Department of Energy's handbook (2012b) that the installation cost for a charging station varies from \$15,000 [i.e., the cost for the stations equipped with the 240-volt (level 2) "slow" chargers] to \$70,000 [i.e., the cost for the stations with the 480-volt "fast" chargers], and the average installation cost is around \$40,000. Accordingly, for our numerical experiments we set $\alpha = \$40,000$.

Next, we compute the terms $\Pi(s)$, $\Pi_C(s)$, and $I(s)$ in (11).

3.1.1 Supply Chain Profits

From Section 2.2 we find two manufacturers' total profit as $\Pi_M(s) \equiv \sum_{i=1}^{2} \Pi_{Mi}(\mathbf{w}^N)$, where the manufacturer M_1's profit $\Pi_{M1}(\mathbf{w}^N)$ and the manufacturer M_2's profit $\Pi_{M2}(\mathbf{w}^N)$ can be obtained by substituting the Nash equilibrium-based wholesale prices $\mathbf{w}^N$ into the two manufacturers' profit functions in (7) and (9), respectively. Similarly, we can compute two retailers' total profit as $\Pi_R(s) \equiv \sum_{i=1}^{2} \Pi_{Ri}(\mathbf{w}^N)$, where the retailer R_1's profit $\Pi_{R1}(\mathbf{w}^N)$ and the retailer R_2's profit $\Pi_{R2}(\mathbf{w}^N)$ can be found by substituting $\mathbf{w}^N$ into the two retailers' profit functions in (8) and (10), respectively. Therefore, $\Pi(s) = \Pi_M(s) + \Pi_R(s)$.

3.1.2 Consumers' Net Surpluses

We now compute the total net surplus of the consumers who buy an FA_1 (from the retailer R_1), an FA_2, or an EA (from the retailer R_2). Using Theorem 1, we can find that, when two manufacturers adopt the wholesale prices in Nash equilibrium, the total net surplus $\Pi_{C1}(s)$ of the consumers who purchase an FA_1 from the retailer R_1 can be calculated as follows:

$$\Pi_{C1}(s) \equiv B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\mathbf{\Omega}_{1j}}(\eta_1 - p_{1j}^N) f(\eta_1,\eta_2,\hat{\eta})\,d\hat{\eta}\,d\eta_2\,d\eta_1\right)\right] g(\beta)\,d\beta\right\}, \tag{12}$$

where $\mathbf{\Omega}_{1j}$ $(j = 1,\ldots,5)$ is defined as in Table 1, and p_{1j}^N $(j = 1,\ldots,5)$ can be found as p_{1j}^* in Table 1 where w_i $(i = 1,2)$ and $\hat{w}$ are replaced by w_i^N $(i = 1,2)$ and $\hat{w}^N$, respectively. The total net surplus $\Pi_{C2}(s)$ of the consumers who purchase an FA_2 from the retailer R_2 and the total net surplus $\hat{\Pi}_C(s)$ of the consumers who purchase an EA are computed as,

$$\Pi_{C2}(s) = B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\mathbf{\Omega}_{2j}}(\eta_2 - p_{2j}^N) f(\eta_1,\eta_2,\hat{\eta})\,d\hat{\eta}\,d\eta_2\,d\eta_1\right)\right] g(\beta)\,d\beta\right\}, \tag{13}$$

$$\hat{\Pi}_C(s) = B\left\{\int_{\beta_1}^{\beta_2}\left[\sum_{j=1}^{5}\left(\iiint_{\hat{\mathbf{\Omega}}_j}(\hat{\eta} - \kappa(n) - \hat{p}_j^N + s) f(\eta_1,\eta_2,\hat{\eta})\,d\hat{\eta}\,d\eta_2\,d\eta_1\right)\right] g(\beta)\,d\beta\right\}, \tag{14}$$

where $\mathbf{\Omega}_{2j}$ and $\hat{\mathbf{\Omega}}_j$ $(j = 1,\ldots,5)$ are defined as in Tables 2 and 3, respectively; and, p_{2j}^N and $\hat{p}_j^N$ $(j = 1,\ldots,5)$ are p_{2j}^* in Table 2 and $\hat{p}_j^*$ in Table 3, where w_i $(i = 1,2)$ and $\hat{w}$ are replaced by w_i^N $(i = 1,2)$ and $\hat{w}^N$, respectively. Thus, the total net surplus of all consumers is $\Pi_C(s) = \sum_{i=1}^{2} \Pi_{Ci}(s) + \hat{\Pi}_C(s)$.

3.1.3 Environmental Hazards

From Section 1 we find that a government's main objective of implementing its subsidy incentive scheme is to reduce the number of FAs on the road, as the carbon emission of the FA is a major source of air pollution. However, we learn from a number of reports (e.g., Lewis 2011, MacKay 2009, and Weed 1998) that using an EA instead of an FA may not help reduce air pollution because of the following three facts: First, the production of an EA involves the assembly of an expensive battery, which requires a much higher copper content than the production of an FA (Weed 1998). That is, the production of an EA may generate more pollutants than that of an FA. Secondly, the use of an EA produces significantly fewer emissions than the use of an FA; but, an EA runs on electricity produced by a power plant (possibly through the burning of fossil fuels). Therefore, an EA cannot be claimed to be "emissions free." Nevertheless, as Lewis (2011) and MacKay (2009) discussed, the total emission resulting from the use of an EA is much smaller than that from the use of an FA. Thirdly, the disposal of an EA at the end of its life cycle may generate more pollutants than the disposal of an FA, mainly because of the battery disposal; see, e.g., MacKay (2009).

Our above discussion implies that stimulating the sales of the EA may not help reduce carbon emissions. However, MacKay (2009) approximately calculated the emissions generated by an EA and those by an FA, and concluded that the EA is neck and neck with the most fuel efficient FA. It would thus follow that, in our paper, the EA should be "greener" than two FAs. Letting γ_i $(i = 1, 2)$ and $\hat{\gamma}$ measure the degrees of environmental hazard of the FA$_i$ and the EA, respectively, we can calculate the environmental impact of the FA$_i$ and that of the EA bought by consumers as $I_i(s) \equiv \gamma_i D_i(w^N)$ and $\hat{I}(s) \equiv \hat{\gamma}\hat{D}(w^N)$, where $D_i(w^N)$ and $\hat{D}(w^N)$ are obtained as in (5) and (6), respectively. The total environmental impact is thus $I(s) = \sum_{i=1}^{2} I_i(s) + \hat{I}(s)$. According to the calculation by MacKay (2009), we can reasonably assume that $\hat{\gamma} < \gamma_1$ and $\hat{\gamma} < \gamma_2$. However, we *cannot* immediately draw any conclusion that the total environmental footprint will be reduced as a result of implementing the subsidy incentive scheme, because we need to consider the impact of the scheme on the sales of both the EA and two FAs.

3.2 Numerical Experiments and Managerial Implications

We now perform numerical experiments to explore the impact of the government's incentive scheme on the social welfare $\Phi(s)$ in (11). In all subsequent experiments with the parameter values as in Example 1, we set the values of the parameters in environmental hazard as $\gamma_1 = \gamma_2 = \$2000$ per FA and $\hat{\gamma} = \$1200$ per EA, which are estimated according to the following facts: As roughly calculated by Cuenca, Gaines, and Vyas (2000) and MacKay (2009), the total carbon emissions from an FA and those from an EA (from their productions to end-of-life disposals) are around 70 tons and 40 tons, respectively. Serchuk (2009) reported that the Investor Responsibility Research Center Institute—which is a not-for-profit organization serving as a funder of environmental, social, and corporate governance research—prices carbon at \$28.24 per ton in the year 2012. Therefore, we can estimate the environmental hazard per FA and that per EA as above.

Note that the government could implement its scheme to affect automobile supply chains in a "decentralized" or "centralized" manner. Similar to Krass, Nedorezov, and Ovchinnikov (2012), in the decentralized setting, the manufacturers M_i $(i = 1, 2)$ can independently make their wholesale pricing decisions in response to a subsidy set by the government; in the centralized setting, the government can control the wholesale prices of three automobiles without implementing a subsidy scheme. We learn from Section 2 that, in the decentralized setting, for a given value of the subsidy s, the manufacturers M_1 and M_2 determine their wholesale prices in Nash equilibrium $\mathbf{w}^N = (w_1^N, w_2^N, \hat{w}^N)$ to maximize their profits in (7) and (9). As a specific value of the subsidy s results in a corresponding social welfare, we can investigate the impact of s on the social welfare for the decentralized setting. In the centralized setting, the government may influence two manufacturers' wholesale pricing decisions (by, e.g., setting a wholesale price ceiling or a wholesale price floor for each automobile) to improve the social welfare. That is, the government may maximize the social welfare $\Phi(s)$ by inducing the manufacturers to choose the globally-optimal wholesale prices.

Next, we begin by investigating the decentralized setting, and then examine the centralized setting. In order to analyze the effect of the incentive scheme on the social welfare, we need to compare the social welfare $\Phi(s)$ under a scheme with a positive value of the subsidy s (i.e., $s > 0$) with that in the case of no subsidy [i.e., $\Phi(0)$], which can be regarded as the "baseline" social welfare for the measurement of the incentive scheme. Using the parameter values in Example 1, we can calculate the baseline social welfare $\Phi(0)$ as,

$$\begin{aligned} \Phi(0) &= \Pi(0) + \Pi_C(0) - I(0) - U(0) - A \\ &= \$6.520 \times 10^7 + \$1.289 \times 10^7 - \$1.849 \times 10^7 - \$0 - \$40,000 \times 100 \\ &= \$5.560 \times 10^7. \end{aligned} \tag{15}$$

3.2.1 Social Welfare Analysis in the Decentralized Setting

In Section 2.3, we have calculated the wholesale prices in Nash equilibrium, given different values of the subsidy s, the number of service and charging stations for the EA (i.e., n), and the mean value of consumers' relative bargaining power β (i.e., μ_β). Those numerical results are used to examine the social welfare in the decentralized setting; for our calculation results, see online Appendix G.

The Impact of the Subsidy s We consider the impact of the subsidy s on the social welfare and its components. Noting from Section 2.3 that the incentive scheme affects both the FA and the EA markets, we should explore the impact of the scheme on the supply chain profit, consumers' net surplus, environmental hazard, and social welfare in the FA market and those in the EA market, which are presented as in online Tables H and K.

We first calculate the social welfare and its major components for the problem in Example 1 where $s = \$7000$. Our results are presented in Table 4, where (i) the percentage increase [decrease] in the social welfare is calculated by using $\%\!\uparrow \Phi(s) \equiv (\Phi(s) - \Phi(0))/\Phi(0)$ [$\%\!\downarrow \Phi(s) \equiv (\Phi(0) - \Phi(s))/\Phi(0)$]; (ii) the percentage increase [decrease] in the supply chain profit is computed by using

Market	Supply Chain Profit ($\times 10^7$)	Consumers' Net Surplus ($\times 10^7$)	Environmental Hazard ($\times 10^7$)	Social Welfare ($\times 10^7$)
FA	5.354 (↓ 5.613%)	0.629 (↓ 13.241%)	1.701 (↓ 5.878%)	4.282 (↓ 6.714%)
EA	1.574 (↑ 85.701%)	1.120 (↑ 98.582%)	0.055 (↑ 30.880%)	1.922 (↑ 98.128%)
Total	6.928 (↑ 6.258%)	1.749 (↑ 35.687%)	1.756 (↓ 5.051%)	6.204 (↑ 11.576%)

Table 4: The impact of the incentive scheme with the subsidy $s = \$7,000$ on supply chain profits, consumers' net surpluses, environmental hazards, and social welfares in the FA and the EA markets. Note that the mark "↑" or "↓" represents the percentage increase or percentage decrease compared with the case of no subsidy ($s = 0$).

$\%\!\uparrow \Pi(s) \equiv (\Pi(s) - \Pi(0))/\Pi(0)$ [$\%\!\downarrow \Pi(s) \equiv (\Pi(0) - \Pi(s))/\Pi(0)$]; (iii) the percentage increase [decrease] in the consumers' net surplus is $\%\!\uparrow \Pi_C(s) \equiv (\Pi_C(s) - \Pi_C(0))/\Pi_C(0)$ [$\%\!\downarrow \Pi_C(s) \equiv (\Pi_C(0) - \Pi_C(s))/\Pi_C(0)$]; and (iv) the percentage increase [decrease] in the environmental hazard is $\%\!\uparrow I(s) \equiv (I(s) - I(0))/I(0)$ [$\%\!\downarrow I(s) \equiv (I(0) - I(s))/I(0)$]. Note that $\Phi(0)$, $\Pi(0)$, $\Pi_C(0)$, and $I(0)$ are the social welfare, the supply chain profit, the consumers' net surplus, and the environmental hazard for the case of no subsidy (i.e., $s = 0$), as given in (15).

We find that, compared with the baseline social welfare $\Phi(0) = 5.560 \times 10^7$, the social welfare can be increased by 11.576% when the government implements its incentive scheme with $s = \$7,000$. Note that the social welfare in the EA market is increased by 98.128% but that in the FA market is reduced by 6.714%. Since the total social welfare is increased, we may conclude that, when $s = \$7000$, from the social welfare perspective, the (positive) impact of the scheme on the EA market is greater than the (negative) impact of the scheme on the FA market. In addition, we learn from Table 4 that the incentive scheme with $s = \$7,000$ increases the total profit of two supply chains by 6.258% and the total net surplus of consumers by 35.687%, and decreases the environmental hazard by 5.051%.

Next, we examine the impact of the subsidy s on the percentage increases or decreases in the social welfare and major components of the social welfare as well as their allocation between the FA and the EA markets. Our results are presented in online Tables H and K, from which we can find the percentage changes in the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in the FA and the EA markets. For convenience, we provide the percentage changes in Table 5, from which we learn that, when the subsidy incentive scheme is implemented, the percentage change in the total net surplus of all consumers is the largest among all major components of the social welfare. Thus, the impact of the scheme on consumers' net surplus is the greatest, which is mainly because the incentive scheme designed for the EA consumers also significantly influences the FA consumers.

Using Table 5, we plot Figure 2 to show how the above percentage increases or decreases change as the subsidy is increased from \$5,500 to \$10,000. From Figure 2(a), we find that the total social welfare is increased under the subsidy incentive scheme. Thus the scheme should be useful in improving the social welfare. In addition, the percentage increase in the social welfare in the EA market [i.e., $\%\!\uparrow \Phi(s)_{EA}$] is increasing in the subsidy s, whereas the percentage decrease in the social

s ($\times 10^3$)	Percentage Change in Social Welfare			Percentage Change in Supply Chain Profit		
	$\Phi(s)_{FA}$	$\Phi(s)_{EA}$	$\Phi(s) = \Phi(s)_{FA}$ $+\Phi(s)_{EA}$	$\Pi(s)_{FA}$	$\Pi(s)_{EA}$	$\Pi(s) = \Pi(s)_{FA}$ $+\Pi(s)_{EA}$
5.5	↓ 6.463%	↑ 57.893%	↑ 4.764%	↓ 5.031%	↑ 37.683%	↑ 0.521%
6.0	↓ 6.511%	↑ 71.665%	↑ 7.127%	↓ 5.172%	↑ 53.728%	↑ 2.485%
6.5	↓ 6.651%	↑ 88.625%	↑ 9.970%	↓ 5.402%	↑ 74.398%	↑ 4.972%
7.0	↓ 6.714%	↑ 98.128%	↑ 11.576%	↓ 5.613%	↑ 85.701%	↑ 6.258%
7.5	↓ 6.827%	↑ 110.583%	↑ 13.655%	↓ 5.825%	↑ 101.286%	↑ 8.100%
8.0	↓ 7.346%	↑ 116.260%	↑ **14.217%**	↓ 6.265%	↑ 108.943%	↑ 8.712%
8.5	↓ 8.019%	↑ 119.302%	↑ 14.192%	↓ 6.847%	↑ 113.308%	↑ 8.773%
9.0	↓ 8.746%	↑ 121.612%	↑ 13.995%	↓ 7.482%	↑ 117.909%	↑ 8.819%
9.5	↓ 9.576%	↑ 124.398%	↑ 13.795%	↓ 8.187%	↑ 123.572%	↑ 8.942%
10.0	↓ 10.284%	↑ 126.624%	↑ 13.599%	↓ 8.804%	↑ 127.938%	↑ 8.972%

s ($\times 10^3$)	Percentage Change in Consumers' Net Surplus			Percentage Change in Environmental Hazard		
	$\Pi_C(s)_{FA} \equiv \sum_{i=1}^{2} \Pi_{Ci}(s)$	$\Pi_C(s)_{EA} \equiv \hat{\Pi}_C(s)$	$\Pi_C(s) = \Pi_C(s)_{FA}$ $+\Pi_C(s)_{EA}$	$I(s)_{FA} \equiv \sum_{i=1}^{2} I_i(s)$	$I(s)_{EA} \equiv \hat{I}(s)$	$I(s) \equiv I(s)_{FA}$ $+I(s)_{EA}$
5.5	↓ 13.655%	↑ 85.284%	↑ 29.635%	↓ 4.854%	↑ 20.703%	↓ 4.279%
6.0	↓ 13.517%	↑ 89.894%	↑ 31.730%	↓ 5.121%	↑ 23.701%	↓ 4.473%
6.5	↓ 13.379%	↑ 93.440%	↑ 33.359%	↓ 5.430%	↑27.162%	↓ 4.696%
7.0	↓ 13.241%	↑ 98.582%	↑ 35.687%	↓ 5.878%	↑ 30.880%	↓ 5.051%
7.5	↓ 12.966%	↑ 102.305%	↑ 37.471%	↓ 6.144%	↑ 34.057%	↓ 5.239%
8.0	↓ 12.690%	↑ 106.028%	↑ 39.255%	↓ 6.098%	↑ 36.438%	↓ 5.141%
8.5	↓ 12.276%	↑ 110.461%	↑ 41.427%	↓ 6.049%	↑ 39.063%	↓ 5.033%
9.0	↓ 11.724%	↑ 112.943%	↑ 42.824%	↓ 5.973%	↑ 40.896%	↓ 4.917%
9.5	↓ 11.310%	↑ 114.716%	↑ 43.832%	↓ 5.911%	↑ 42.659%	↓ 4.818%
10.0	↓ 10.759%	↑ 117.199%	↑ 45.229%	↓ 5.829%	↑ 43.862%	↓ 4.710%

Table 5: The sensitivity analysis for the impact of the subsidy s on the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in the decentralized setting. Note that the mark "↑" or "↓" represents the percentage increase or percentage decrease compared with the case of no subsidy ($s = 0$).

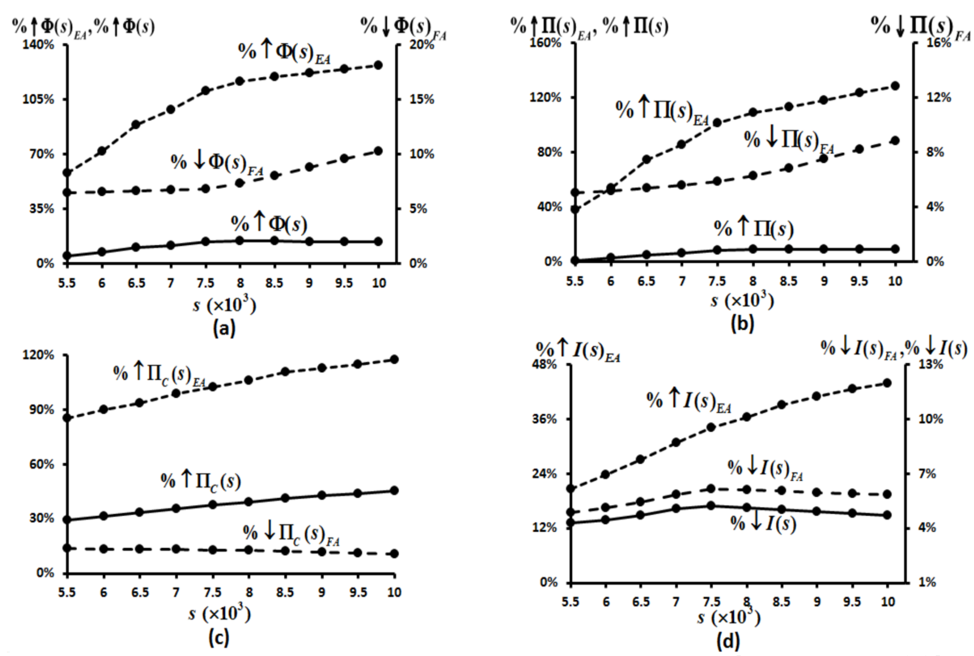

Figure 2: The percentage increases or decreases in the social welfare [as shown in (a)], supply chain profit [as shown in (b)], consumers' net surplus [as shown in (c)], and environmental hazard [as shown in (d)] in the FA and the EA markets for the decentralized setting. Note that the mark "%↑" ("%↓") represents the percentage increase (percentage decrease) compared with the case of no subsidy ($s = 0$). The subscripts "FA" and "EA" denote the FA and the EA markets, respectively.

welfare in the FA market [i.e., $\%\downarrow \Phi(s)_{FA}$] increases slightly when $s \leq \$7,500$ but significantly when $s > \$7,500$. The percentage increase in the total social welfare is increasing in s when $s \leq \$8,000$ but is decreasing in s when $s > \$8,000$. Therefore, a higher subsidy may not result in a larger total social welfare. In our numerical experiment, *ceteris paribus*, the *optimal* subsidy that maximizes the total social welfare in the decentralized setting is around $7,810.

We learn from Figure 2(b) (and also Table 5) that, when the incentive scheme with $s \in [5500, 10000]$ is implemented, the supply chain profit generated in the FA market is reduced whereas that in the EA market is increased. Nevertheless, as s is increased in the range $[5500, 8000]$, the reduction in $\Pi(s)_{FA}$ increases slightly; but, as s is increased in the range $(8000, 10000]$, the reduction in $\Pi(s)_{FA}$ rises significantly. This may imply that raising a small subsidy does not significantly increase the negative impact on the profitability in the FA market. Overall, the total profit of two supply chains is increasing in s.

From Figure 2(c) (and also Table 5), we find that the implementation of the subsidy incentive scheme benefits the EA consumers (i.e., $\%\uparrow \Pi_C(s)_{EA} > 0$) but makes the FA consumers worse off (i.e., $\%\downarrow \Pi_C(s)_{FA} > 0$). The total surplus of all consumers is increased under the incentive scheme, and the percentage increase ($\%\uparrow \Pi_C(s)$) is increasing in the subsidy s. This means that the incentive scheme can, in general, deliver benefits to consumers.

Figure 2(d) (and Table 5) shows that the incentive scheme is useful in reducing the environmental hazard. Although increasing the sales of the EA generates a higher environmental hazard in the EA market, the hazard in the FA market is more significantly reduced and the total environmental hazard is thus decreased. When s is smaller than $7,500, the environmental hazard resulting from the FAs is reduced at a rate that is increasing in s. Since the total increase in $I(s)_{EA}$ is smaller than the total reduction in $I(s)_{FA}$, the total environmental hazard is decreasing in $s \in [5500, 7500)$. However, the incentive scheme with $s \geq \$7,500$ cannot *further* reduce the total environmental hazard because $\%\downarrow I(s)_{FA}$ is decreasing in s and $\%\uparrow I(s)_{EA}$ is increasing in s. Therefore, a subsidy in amount of around $7,500 should be more effective in reducing the total environmental hazard.

Remark 1 According to the above discussion, we conclude that, from the social welfare perspective, the positive impact of an incentive scheme with a subsidy in the range $[5500, 7500]$ on the EA market is greater than the negative impact on the FA market; but the impact of a subsidy in the range $(7500, 10000]$ is greater in the FA market. Implementing an incentive scheme will greatly improve the supply chain profit in the EA market but reduce the supply chain profit in the FA market. However, when the subsidy s is sufficiently small (i.e., $s \leq \$8,000$), increasing the subsidy does not greatly increase the negative impact of the scheme on the supply chain profit in the FA market. But, if $s > \$8,000$, then increasing the subsidy significantly increases the negative impact of the scheme on the supply chain profit in the FA market.

We also find that the impact of the incentive scheme on the total net surplus of all consumers is the largest among all components in the social welfare. An incentive scheme with a larger subsidy may not result in a further reduction in the environmental hazard. Thus, in order to effectively reduce the environmental hazard, the government should set the subsidy s to be around \$7,500. $\triangleleft$

The Impact of the Number of Service and Charging Stations We increase the number of service and charging stations (i.e., n) from 30 to 120 in steps of 10, and for each value of n, we calculate the changes in the social welfare and its major components, resulting from the scheme with $s = \$7,000$ (compared with the case of no subsidy). Using online Tables I and K, we provide the percentage changes in the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in Table 6.

n	**Percentage Change in Social Welfare**			**Percentage Change in Supply Chain Profit**		
	$\Phi(s)_{FA}$	$\Phi(s)_{EA}$	$\Phi(s) = \Phi(s)_{FA}$ $+\Phi(s)_{EA}$	$\Pi(s)_{FA}$	$\Pi(s)_{EA}$	$\Pi(s) = \Pi(s)_{FA}$ $+\Pi(s)_{EA}$
30	↓ 6.225%	↑ 83.502%	↑ 9.428%	↓ 6.131%	↑ 42.331%	↑ 0.169%
40	↓ 6.409%	↑ 84.100%	↑ 9.380%	↓ 6.087%	↑ 46.520%	↑ 0.752%
50	↓ 6.539%	↑ 85.444%	↑ 9.507%	↓ 6.042%	↑ 51.994%	↑ 1.503%
60	↓ 6.603%	↑ 88.633%	↑ 10.011%	↓ 5.973%	↑ 59.674%	↑ 2.561%
70	↓ 6.637%	↑ 92.510%	↑ 10.659%	↓ 5.918%	↑ 67.567%	↑ 3.635%
80	↓ 6.665%	↑ 98.132%	↑ 11.617%	↓ 5.869%	↑ 78.327%	↑ 5.077%
90	↓ 6.705%	↑ 99.505%	↑ **11.823%**	↓ 5.828%	↑ 84.096%	↑ 5.862%
100	↓ 6.714%	↑ 98.128%	↑ 11.576%	↓ 5.613%	↑ 85.701%	↑ 6.258%
110	↓ 6.753%	↑ 98.075%	↑ 11.534%	↓ 5.560%	↑ 89.995%	↑ 6.862%
120	↓ 6.796%	↑ 97.820%	↑ 11.454%	↓ 5.523%	↑ 94.066%	↑ 7.423%

n	**Percentage Change in Consumers' Net Surplus**			**Percentage Change in Environmental Hazard**		
	$\Pi_C(s)_{FA} \equiv$ $\sum_{i=1}^{2} \Pi_{Ci}(s)$	$\Pi_C(s)_{EA} \equiv$ $\hat{\Pi}_C(s)$	$\Pi_C(s) = \Pi_C(s)_{FA}$ $+\Pi_C(s)_{EA}$	$I(s)_{FA} \equiv$ $\sum_{i=1}^{2} I_i(s)$	$I(s)_{EA} \equiv$ $\hat{I}(s)$	$I(s) \equiv I(s)_{FA}$ $+I(s)_{EA}$
30	↓ 6.814%	↑ 86.720%	↑ 34.112%	↓ 6.168%	↑ 26.438%	↓ 5.434%
40	↓ 8.234%	↑ 88.865%	↑ 34.251%	↓ 6.132%	↑ 27.070%	↓ 5.384%
50	↓ 9.297%	↑ 90.443%	↑ 34.344%	↓ 6.083%	↑ 27.867%	↓ 5.319%
60	↓ 10.041%	↑ 92.057%	↑ 34.631%	↓ 6.005%	↑ 29.014%	↓ 5.217%
70	↓ 10.579%	↑ 94.238%	↑ 35.283%	↓ 5.962%	↑ 29.574%	↓ 5.162%
80	↓ 11.007%	↑ 95.124%	↑ 35.431%	↓ 5.909%	↑ 30.161%	↓ 5.097%
90	↓ 11.531%	↑ 96.099%	↑ 35.562%	↓ 5.888%	↑ 30.543%	↓ 5.068%
100	↓ 13.241%	↑ 98.582%	↑ 35.687%	↓ 5.878%	↑ 30.880%	↓ 5.051%
110	↓ 13.807%	↑ 99.415%	↑ 35.733%	↓ 5.839%	↑ 31.446%	↓ 4.999%
120	↓ 14.331%	↑ 100.213%	↑ 35.787%	↓ 5.823%	↑ 31.966%	↓ 4.973%

Table 6: The sensitivity analysis for the impact of the number of service and charging stations (i.e., n) on the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in the decentralized setting. Note that the mark "↑" or "↓" represents the percentage increase or percentage decrease compared with the case of no subsidy ($s = 0$).

We learn from Table 6 that, when there are a larger number of service and charging stations (i.e., the value of n is increased), the subsidy incentive scheme will generate a greater reduction in the social welfare in the FA market. When $n \leq 90$, the scheme will also result in greater percentage increases in both the total social welfare and the social welfare in the EA market; but, when $n > 90$, the two percentage increases will decrease in n. This happens mainly because of the following fact: if the number of charging stations is higher (when $n > 90$), then the greater installation cost (of the charging stations) cannot be offset by the benefits resulting from the increase in n—i.e., the increases in the supply chain profit and the consumers' net surplus. We find that, *ceteris paribus*, the number of charging stations, with which the scheme is the most effective in improving the total social welfare, is 90.

In addition, Tables 5 and 6 indicate that the impact of n on the total supply chain profit and the expected profit in the EA supply chain is similar to but less sensitive than that of the subsidy s. We also find that, as the number of service and charging stations is increasing, the decrease in the expected profit in the FA supply chain is reduced, which differs from the impact of the subsidy s. The above results imply that a better infrastructure condition for the EA (i.e., a higher value of n) can reduce the negative impact of the incentive scheme on the profit in the FA market while enhancing its positive impact on the profit in the EA market.

We find from Table 6 that, as the value of n is higher, the subsidy incentive scheme will result in greater percentage increases in both the EA consumers' net surplus and consumers' total net surplus. However, with a larger n, the scheme will generate a greater percentage decrease in the FA consumers' net surplus, which differs from the relevant impact of the subsidy s.

The Impact of the Mean Value of Consumers' Relative Bargaining Power We vary the mean value of consumers' relative bargaining power (i.e., μ_β) from 0.3 to 0.75 in increments of 0.05, and for each value of μ_β, we compute the changes in the social welfare and its major components, generated as a result of implementing the scheme with $s = \$7,000$ (compared with the case of no subsidy). Our numerical results are provided in online Tables J and K, where we can find the changes in the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in the FA and the EA markets. The percentage changes are summarized in Table 7.

We find from Table 7 that the value of μ_β has a greater impact on the total supply chain profit and the total consumers' net surplus than the values of s and n. When consumers are stronger in bargaining with retailers (i.e., the value of μ_β is larger), the percentage increase in consumers' total net surplus under the incentive scheme is greater, whereas the profits of two supply chains are more likely to deteriorate. The scheme with $s = \$7,000$ can raise the FA consumers' net surplus [i.e., $\%\!\uparrow \Pi_C(s)_{FA} > 0$] when $\mu_\beta \geq 0.45$, even though the scheme aims at encouraging consumers to buy the EAs. When consumers' bargaining power is higher, the scheme results in a smaller reduction in the environmental hazard, thereby being less effective in reducing the total environmental hazard.

Moreover, when consumers are not strong in negotiating retail prices (i.e., $\mu_\beta \leq 0.60$), the subsidy scheme can generate a larger percentage increase in the social welfare [i.e., $\%\!\uparrow \Phi(s)$] if the value of μ_β is higher. However, the percentage increase in the social welfare is decreasing in μ_β when consumers are strong in negotiation (i.e., $\mu_\beta > 0.60$). We also note that when consumers are slightly stronger than two retailers—i.e., the value of μ_β is around 0.60, the percentage increase in the social welfare under the scheme reaches its maximum value.

μ_β	Percentage Change in Social Welfare			Percentage Change in Supply Chain Profit		
	$\Phi(s)_{FA}$	$\Phi(s)_{EA}$	$\Phi(s) = \Phi(s)_{FA} + \Phi(s)_{EA}$	$\Pi(s)_{FA}$	$\Pi(s)_{EA}$	$\Pi(s) = \Pi(s)_{FA} + \Pi(s)_{EA}$
0.30	↓ 6.297%	↑ 51.644%	↑ 3.811%	↓ 3.621%	↑ 89.948%	↑ 8.543%
0.35	↓ 6.679%	↑ 71.686%	↑ 6.992%	↓ 5.352%	↑ 87.353%	↑ 6.699%
0.40	↓ 6.714%	↑ 98.128%	↑ 11.576%	↓ 5.613%	↑ 85.701%	↑ 6.258%
0.45	↓ 8.969%	↑ 109.456%	↑ 11.690%	↓ 9.088%	↑ 85.583%	↑ 3.219%
0.50	↓ 10.860%	↑ 121.120%	↑ 12.164%	↓ 12.275%	↑ 84.639%	↑ 0.324%
0.55	↓ 12.190%	↑ 127.559%	↑ 12.189%	↓ 15.066%	↑ 83.931%	↓ 2.196%
0.60	↓ 13.078%	↑ 134.689%	↑ **12.700%**	↓ 17.397%	↑ 82.633%	↓ 4.393%
0.65	↓ 13.721%	↑ 135.458%	↑ 12.303%	↓ 19.454%	↑ 81.689%	↓ 6.305%
0.70	↓ 14.287%	↑ 136.072%	↑ 11.943%	↓ 21.259%	↑ 80.274%	↓ 8.060%
0.75	↓ 15.243%	↑ 137.867%	↑ 11.466%	↓ 23.295%	↑ 80.156%	↓ 9.847%

μ_β	Percentage Change in Consumers' Net Surplus			Percentage Change in Environmental Hazard		
	$\Pi_C(s)_{FA} \equiv \sum_{i=1}^{2} \Pi_{Ci}(s)$	$\Pi_C(s)_{EA} \equiv \hat{\Pi}_C(s)$	$\Pi_C(s) = \Pi_C(s)_{FA} + \Pi_C(s)_{EA}$	$I(s)_{FA} \equiv \sum_{i=1}^{2} I_i(s)$	$I(s)_{EA} \equiv \hat{I}(s)$	$I(s) \equiv I(s)_{FA} + I(s)_{EA}$
0.30	↓ 29.103%	↑ 1.418%	↓ 15.749%	↓ 7.048%	↑ 9.389%	↓ 6.678%
0.35	↓ 16.552%	↑ 45.567%	↑ 10.628%	↓ 6.476%	↑ 20.853%	↓ 5.861%
0.40	↓ 13.241%	↑ 98.582%	↑ 35.687%	↓ 5.878%	↑ 30.880%	↓ 5.051%
0.45	↑ 0.552%	↑ 122.908%	↑ 54.088%	↓ 5.523%	↑ 40.136%	↓ 4.495%
0.50	↑ 14.345%	↑ 146.277%	↑ 72.071%	↓ 5.191%	↑ 43.884%	↓ 4.086%
0.55	↑ 26.897%	↑ 168.333%	↑ 88.782%	↓ 5.536%	↑ 63.554%	↓ 3.981%
0.60	↑ 38.897%	↑ 189.539%	↑ 104.810%	↓ 5.782%	↑ 77.424%	↓ 3.909%
0.65	↑ 50.069%	↑ 201.773%	↑ 116.447%	↓ 6.125%	↑ 96.253%	↓ 3.820%
0.70	↑ 59.310%	↑ 219.858%	↑ 129.558%	↓ 6.645%	↑ 125.806%	↓ 3.663%
0.75	↑ 68.690%	↑ 251.241%	↑ 148.565%	↓ 6.844%	↑ 181.572%	↓ 2.603%

Table 7: The sensitivity analysis for the impact of the mean value of consumers' relative bargaining power (i.e., μ_β) on the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in the decentralized setting. Note that the mark "↑" or "↓" represents the percentage increase or percentage decrease compared with the case of no subsidy ($s = 0$).

3.2.2 Social Welfare Analysis in the Centralized Setting

We now investigate the centralized setting in which the government would not implement the subsidy incentive scheme but induce two manufacturers to make the globally-optimal wholesale pricing decisions (that maximize the total social welfare) by setting upper or lower limits for the wholesale prices of two FAs and the EA. That is, when there is no subsidy for the EA (i.e., $s = 0$), under the centralized control two manufacturers choose the globally-optimal wholesale prices that maximize the social welfare. Next, using the parameter values in Example 1, we derive the globally-optimal solution (for the subsidy $s = 0$), and compute the upper or lower limits for the wholesale prices of three automobiles, which can induce the maximization of the total social welfare. Then, we compare the social welfare and its major components resulting from the centralized control with those generated when the government implements a subsidy scheme.

Globally Optimal Wholesale Prices and the Maximum Social Welfare We first solve the numerical problem in Example 1 to obtain the globally optimal wholesale prices $\mathbf{w}^* = (w_1^*, w_2^*, \hat{w}^*)$ when the subsidy $s = 0$. Maximizing the social welfare in (11), we find that $w_1^* = \$26,247.56$, $w_2^* = \$26,918.37$, and $\hat{w}^* = \$29,903.56$. Comparing $\mathbf{w}^*$ and $\mathbf{w}^N$ (which was obtained in Example 1 for $s = 0$), we find that, in order to improve the social welfare, the wholesale prices for the FA_1, the FA_2, and the EA in the centralized setting are decreased by 4.037%, 4.923%, and 3.450%, respectively.

As a result of adopting the globally optimal solution $\mathbf{w}^*$, the expected sales of two FAs are 9,008, which is reduced by 0.31% from the "baseline" total demand—i.e., the total demand when the government does not "control" two supply chains; but, the expected sales of the EA are 416, which are higher than the corresponding baseline demand by 19.88%. We calculate the corresponding social welfare and its major components in the FA and the EA markets, as presented in Table 8. We learn that, compared with the case of no control, when the globally optimal solution $\mathbf{w}^*$ is adopted, the supply chain profits in both the FA and the EA markets are increased; as a result, the total profit is increased by 10.215%. In addition, the FA consumers would obtain a less total surplus but the EA consumers can enjoy a higher total surplus. The total surplus of all consumers is increased by 12.956%. The "centralized" decisions can also reduce the total environmental hazard by 0.162%, and increase the total social welfare by 14.928%.

Market	**Supply Chain Profit** ($\times 10^7$)	**Consumers' Net Surplus** ($\times 10^7$)	**Environmental Hazard** ($\times 10^7$)	**Social Welfare** ($\times 10^7$)
FA	5.900 ($\uparrow$ 4.012%)	0.683 ($\downarrow$ 5.793%)	1.802 ($\downarrow$ 0.305%)	4.781 ($\uparrow$ 4.164%)
EA	1.286 ($\uparrow$ 51.770%)	0.773 ($\uparrow$ 37.057%)	0.050 ($\uparrow$ 20.024%)	1.609 ($\uparrow$ 65.926%)
Total	7.186 ($\uparrow$ 10.215%)	1.456 ($\uparrow$ 12.956%)	1.852 ($\downarrow$ 0.162%)	6.390 ($\uparrow$ 14.928%)

Table 8: The social welfare and its major components in the FA and the EA markets for the centralized setting, and the percentage changes compared with those for the baseline case (i.e., the decentralized setting with the subsidy $s = 0$).

The Centralized Analysis and Its Comparison with the Subsidy Scheme We examine the centralized setting in which the government sets a wholesale price ceiling (an upper limit for the wholesale price) or a wholesale price floor (a lower limit for the wholesale price) for each automobile, which is a common (easy-to-implement) centralized control. Note that, as discussed in, e.g., Chapter 4 of the book written by Krugman, Wells, and Graddy (2007), price ceiling and price floor are a government's *legal* restrictions on the maximum price that sellers are allowed to charge for a good and the minimum price that buyers are required to pay for a good, respectively.

Since the wholesale price of each automobile is decreased in the centralized setting, we assume that the government sets wholesale price ceilings for the FA_1, the FA_2, and the EA as $\omega_1^* = \$26,247.56$, $\omega_2^* = \$26,918.37$, and $\hat{\omega}^* = \$29,903.56$, respectively. Thus, the manufacturers M_1's and M_2's constrained maximization problems are developed as (i) $\max_{w_1} \Pi_{M1}(\mathbf{w})$, s.t. $w_1 \leq \omega_1^*$ and $D_1(\mathbf{w}) \leq D_1^0$; and (ii) $\max_{w_2,\hat{w}} \Pi_{M2}(\mathbf{w})$, s.t. $w_2 \leq \omega_2^*$, $\hat{w} \leq \hat{\omega}^*$, $D_2(\mathbf{w}) \leq D_2^0$, and $\hat{D}(\mathbf{w}) \leq \hat{D}^0$. Note that $\Pi_{M1}(\mathbf{w})$ and $\Pi_{M2}(\mathbf{w})$ are given as in (7) and (9), respectively; and D_i^0 $(i = 1, 2)$ and $\hat{D}^0$ are the capacities for the FA_i and the EA, respectively. Under the centralized control, we find that two manufacturers choose the globally optimal wholesale prices $w_1^* = \$26,247.56$, $w_2^* = \$26,918.37$, and $\hat{w}^* = \$29,903.56$.

Next, we compare the centralized setting with the decentralized setting under the subsidy incentive scheme. For such a comparison, we use Table 8 and online Tables H and K to compute the percentage increases or decreases by which the social welfare and its major components generated in the centralized setting deviate from those under the subsidy incentive scheme. Our results are presented in Table 9, where we find that the centralized control can result in an increase or a decrease in the social welfare, supply chain profit, consumers' net surplus, and environmental hazard, compared with the decentralized setting under different subsidy incentive schemes. For example, when we compare the centralized setting (with no subsidy) and the incentive scheme with $s = \$5500$, we find that the globally-optimal solution can result in 11.341% more social welfare in the FA market and 5.026% more social welfare in the EA market, and increase the total social welfare by 9.700%.

s	**Percentage Change in Social Welfare**			**Percentage Change in Supply Chain Profit**		
$(\times 10^3)$	$\Phi(s)_{FA}$	$\Phi(s)_{EA}$	$\Phi(s) = \Phi(s)_{FA} + \Phi(s)_{EA}$	$\Pi(s)_{FA}$	$\Pi(s)_{EA}$	$\Pi(s) = \Pi(s)_{FA} + \Pi(s)_{EA}$
5.5	↑ 11.341%	↑ 5.026%	↑ 9.700%	↑ 9.523%	↑ 10.197%	↑ 9.643%
6.0	↑ 11.419%	↓ 3.363%	↑ 7.269%	↑ 9.686%	↓ 1.305%	↑ 7.543%
6.5	↑ 11.575%	↓ 12.077%	↑ 4.497%	↑ 9.952%	↓ 12.991%	↑ 4.997%
7.0	↑ 11.653%	↓ 16.285%	↑ 2.998%	↑ 10.198%	↓ 18.297%	↑ 3.724%
7.5	↑ 11.784%	↓ 21.243%	↑ 1.108%	↑ 10.446%	↓ 24.619%	↑ 1.958%
8.0	↑ 12.415%	↓ 23.308%	↑ 0.614%	↑ 10.965%	↓ 27.386%	↑ 1.383%
8.5	↑ 13.240%	↓ 24.354%	↑ 0.646%	↑ 11.658%	↓ 28.872%	↑ 1.325%
9.0	↑ 14.132%	↓ 25.163%	↑ 0.820%	↑ 12.424%	↓ 30.374%	↑ 1.283%
9.5	↑ 15.177%	↓ 26.091%	↑ 0.996%	↑ 13.287%	↓ 32.137%	↑ 1.169%
10.0	↑ 16.100%	↓ 26.797%	↑ 1.172%	↑ 14.054%	↓ 33.437%	↑ 1.140%
s	**Percentage Change in Consumers' Net Surplus**			**Percentage Change in Environmental Hazard**		
$(\times 10^3)$	$\Pi_C(s)_{FA} \equiv \sum_{i=1}^{2} \Pi_{Ci}(s)$	$\Pi_C(s)_{EA} \equiv \hat{\Pi}_C(s)$	$\Pi_C(s) = \Pi_C(s)_{FA} + \Pi_C(s)_{EA}$	$I(s)_{FA} \equiv \sum_{i=1}^{2} I_i(s)$	$I(s)_{EA} \equiv \hat{I}(s)$	$I(s) \equiv I(s)_{FA} + I(s)_{EA}$
5.5	↑ 9.105%	↓ 26.029%	↓ 12.867%	↑ 4.828%	↓ 0.398%	↑ 4.633%
6.0	↑ 8.931%	↓ 27.824%	↓ 14.252%	↑ 5.073%	↓ 2.913%	↑ 4.870%
6.5	↑ 8.758%	↓ 29.148%	↓ 15.300%	↑ 5.442%	↓ 5.482%	↑ 5.108%
7.0	↑ 8.585%	↓ 30.982%	↓ 16.752%	↑ 5.938%	↓ 8.257%	↑ 5.467%
7.5	↑ 8.241%	↓ 32.252%	↓ 17.833%	↑ 6.250%	↓ 10.394%	↑ 5.708%
8.0	↑ 7.899%	↓ 33.477%	↓ 18.886%	↑ 6.187%	↓ 11.972%	↑ 5.587%
8.5	↑ 7.390%	↓ 34.878%	↓ 20.132%	↑ 6.125%	↓ 13.644%	↑ 5.467%
9.0	↑ 6.719%	↓ 35.637%	↓ 20.913%	↑ 6.062%	↓ 14.676%	↑ 5.347%
9.5	↑ 6.221%	↓ 36.168%	↓ 21.467%	↑ 6.000%	↓ 15.825%	↑ 5.227%
10.0	↑ 5.564%	↓ 36.898%	↓ 22.222%	↑ 5.875%	↓ 16.528%	↑ 5.108%

Table 9: The percentage increase or decrease in the social welfare, supply chain profit, consumers' net surplus, and environmental hazard in the centralized setting. Note that "↑" or "↓" represents the percentage increase or percentage decrease resulting from the centralized control with no subsidy, compared to the decentralized setting with a subsidy.

Table 9 also indicates that the centralized control benefits the FA supply chain but the subsidy incentive scheme in general improves the profit of the EA supply chain. The total profit of two supply chains in the centralized setting is always higher than that under any subsidy incentive scheme. Moreover, we find that the FA consumers can obtain a higher total surplus in the centralized setting, whereas the EA consumers can enjoy more under the subsidy scheme. The total surplus of all consumers is reduced in the centralized setting compared with the decentralized setting. We also note from Table 9 that the subsidy scheme can reduce more environmental hazard than the centralized control with no subsidy.

Remark 2 From the perspectives of the social welfare, supply chain profit, and consumers' net surplus, the centralized control with $s = 0$ benefits the FA market but the subsidy incentive scheme generally results in more benefits in the EA market. In the centralized setting, two supply chains can attain more profits than in the decentralized setting where the government implements the subsidy incentive scheme. Compared with the centralized setting, the subsidy scheme not only generates a greater total consumer surplus but also results in a lower environmental hazard. According to our above findings, we can conclude that the subsidy incentive scheme is more effective in promoting the EA and protecting the environment than the centralized setting. $\lhd$

4 Summary and Concluding Remarks

In this paper we analyze two supply chains (i.e., the FA and the EA-FA supply chains) each involving a manufacturer and a retailer, when a government implements a subsidy incentive scheme to promote the EA in a market. The FA supply chain only produces an FA whereas the EA-FA supply chain makes both an FA and an EA. We develop a two-stage approach to investigate the duopoly setting in which two supply chains compete for consumers. We derive the demand function for each automobile, develop expected profit functions of the manufacturers in two supply chains, and perform a numerical study to calculate the wholesale prices in Nash equilibrium. Then, we construct a social welfare function, and investigate a decentralized setting in which two manufacturers determine their wholesale prices in a non-cooperative game. For this setting, we consider the impact of the subsidy, the number of service and charging stations, and the mean value of consumers' bargaining power on the social welfare and its major components. Furthermore, we investigate the centralized setting in which, with no subsidy, the government can set a wholesale price ceiling for each automobile to achieve the maximization of the total social welfare.

Our major managerial insights are summarized as follows. In addition, we compare our results with two relevant papers concerning the impact of governments' environmental policies on the adoption of green technologies. The two papers are (i) Drake, Kleindorfer, and van Wassenhove (2012) who examined the impact of emissions cap-and-trade and emissions tax regulation on a firm's green technology choice and capacity decisions, and (ii) Krass, Nedorezov, and Ovchinnikov (2012) who investigated the impact of a regulator's environmental tax on a firm's decision on the adoption of a green technology.

1. When the subsidy s is increased, the wholesale price for the EA is increased but that for each FA is decreased. In addition, consumers' negotiated retail prices for each FA are decreasing in s and those for the EA are increasing in s. In this paper, we use generalized Nash bargaining scheme to investigate the negotiated retail price for each consumer, derive the demand function for each automobile, and reveal the impact of consumers' bargaining powers on the effectiveness

of the subsidy scheme. This significantly distinguishes our paper from Drake, Kleindorfer, and van Wassenhove (2012) and Krass, Nedorezov, and Ovchinnikov (2012).

2. The subsidy incentive scheme can increase the demand for the EA but reduce the total demand for two FAs. This implies that a subsidy incentive scheme should be effective in promoting the EA. In addition, such an effectiveness is higher when consumers are stronger in negotiating retail prices with retailers.

   Similar to the above, Drake, Kleindorfer, and van Wassenhove (2012) found that (i) a firm's capacity for a dirty technology—which is equivalent to the total demand for two FAs in our paper—is decreasing in the regulator's subsidy that is granted to the firm, and (ii) the firm's capacity for a green technology—which is equivalent to the demand for the EA in our paper—is increasing in the subsidy. But, different from Drake, Kleindorfer, and van Wassenhove (2012) who showed that the total demand is increasing in the subsidy (provided to the firm), we find that, under the subsidy scheme, the total demand for all automobiles may not be increasing in the subsidy (provided to each EA consumer).

3. A subsidy incentive scheme can improve the profit of the supply chain involving the production of both an FA and an EA but reduce the profit of the supply chain producing only an FA. That is, the incentive scheme encourages manufacturers to produce both automobile types rather than only the FA.

4. The implementation of a subsidy scheme is helpful in improving the social welfare. The impact of the scheme on consumers' net surplus is the largest among all components in the social welfare. However, an incentive scheme with a larger subsidy may not result in a further reduction in the environmental hazard. That is, a sufficiently high subsidy may result in an increasing environmental hazard, which is similar to the corresponding major insights found by Drake, Kleindorfer, and van Wassenhove (2012) and Krass, Nedorezov, and Ovchinnikov (2012). Specifically, Drake, Kleindorfer, and van Wassenhove (2012) found that the investment and production subsidies for a firm may increase the emissions potential of the firm's optimal capacity portfolio, and Krass, Nedorezov, and Ovchinnikov (2012) showed that increasing the environmental tax to a sufficiently high level may discourage a firm from adopting a greener technology.

5. More service and charging stations can reduce the negative impact of the scheme on the FA market while enhancing its positive impact on the EA market. In addition, the effectiveness of the subsidy scheme on environmental protection is small in the market where consumers are strong in bargaining with retailers.

6. When there is no subsidy incentive scheme, the centralized control with a wholesale price ceiling for each automobile can result in globally optimal wholesale prices that maximize the social welfare. Krass, Nedorezov, and Ovchinnikov (2012) shows that a combination of the

environmental tax, the subsidy granted to a firm, and the consumer rebate can maximize the social welfare.

7. From the perspectives of social welfare, supply chain profit, and consumers' net surplus, the centralized control with no subsidy always benefits the FA market but the subsidy incentive scheme generally results in more benefits in the EA market.
8. A subsidy incentive scheme is more helpful in decreasing the environmental hazard than the centralized control with no subsidy. This result is somewhat different from Krass, Nedorezov, and Ovchinnikov (2012), who found that the socially optimal tax level in the centralized setting may induce the choice of the green technology.

In conclusion, we find that a subsidy incentive scheme can help improve the social welfare, increase the sales of the EA, and reduce the environmental hazard. More service and charging stations can help improve the positive impact of the subsidy scheme on the EA market and also reduce its negative impact on the FA market. An incentive scheme is more effective in promoting the EA and protecting the environment than the centralized control.

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Online Supplements

"Promoting Electric Automobiles: Supply Chain Analysis under a Government's Subsidy Incentive Scheme"

J. Huang, M. Leng, L. Liang, J. Liu

Appendix A Hybrid Electric Vehicle Sales by Model

From the statistics provided by the U.S. Department of Energy (2011), we can find the total sales of major hybrid electric vehicles in the United States from 1999 to 2010. For a summary, see Table A, where we list all vehicle manufacturers in the descending order of their total sales.

No	Manufacturer	Vehicle	Total Sales (1999–2010)	No	Manufacturer	Vehicle	Total Sales (1999–2010)
1	**Toyota**	Prius	955,101	5	**Nissan**	Altima	**33,274**
		Highlander	109,509	6	**GM**	Saturn Vue	10,029
		Camry	169,564			Saturn Aura	1,638
		Total	**1,234,174**			GMC Yukon	4,764
2	**Honda**	Insight	55,452			Cadillac Escalade	3,969
		Civic	204,513			Sierra/Silverado	3,991
		Accord	27,086			*Total*	**24,391**
		CR-Z	5,249	7	**Chevrolet**	Chevy Tahoe	8,471
		Total	**292,300**			Chevy Malibu	6,660
3	**Ford**	Escape	106,467			*Total*	**15,131**
		Fusion	36,370	8	**Benz**	Mercedes ML450	627
		Lincoln MKZ	1,192			Mercedes S400	801
		Mercury Mariner	12,806			*Total*	**1,428**
		Mercury Milan	2,884	9	**Mazda**	Tribute	**570**
		Total	**159,719**	10	**BMW**	ActiveHybrid 7	102
4	**Lexus**	RX400h	102,909			X6	205
		GS 450h	4,881			*Total*	**307**
		LS600hL	2,231	11	**Porsche**	Cavenne	**206**
		HS 250h	17,362	12	**Chrysler**	Aspen	79
		Total	**127,383**			Dodge Durango	9
						Total	**88**

Table A: The sales of major hybrid electric vehicles from 1999 to 2010.

Appendix B Calculation of a Consumer's Net Surplus and Retailer R_2's Profit in the EA-FA Supply Chain

We now consider the EA-FA supply chain which serves the market with both the FA_2 and the EA. Under a subsidy incentive scheme each EA consumer can obtain a fixed subsidy s. Similar to the FA supply chain, we can find that as a result of bargaining over the retail price p_2 for the FA_2, the retailer R_2 and a consumer with the valuation θ_2 on the FA_2 enjoy the net surplus $u_2(\eta_2, p_2) = \eta_2 - p_2$ (where $\eta_2 \equiv \theta_2 - k_2$) and the profit $\pi_2(\eta_2, p_2) = p_2 - w_2$, respectively. Note that η_2 is the consumer's net consumption gain, k_2 is the lifecyle cost of the FA_2, and w_2 is the wholesale price determined by the manufacturer M_2. Similar to the FA_1, η_2 is a random variable.

In addition, the retailer R_2 bargains with the consumer over the retail price $\hat{p}$ for the EA. In order to distinguish the notations for the EA from those for the FA_i $(i = 1, 2)$, we, hereafter, use the hat symbol ($\hat{}$) to indicate the EA. In order to assure a reasonable and effective subsidy for the incentive scheme, we assume that the subsidy s should be no higher than the wholesale price $\hat{w}$, i.e., $0 \leq s < \hat{w}$. The consumer's valuation on the EA is usually different from that of the FA. A recent survey (Giffi, Hill, Gardner & Hasegawa 2010) indicates that, in practice, young, high-income, and environmentally-sensitive consumers are likely to buy the EAs, since they treat an EA as a green, clean, and affordable automobile. However, many consumers are unfamiliar with the EA and are thus unwilling to purchase such automobiles. Different from consumers' valuations θ_i on the FA_i $(i = 1, 2)$, we characterize each consumer's valuation on the EA as $\hat{\theta}$, which is a random variable.

Since each consumer buying the EA can get the subsidy s from the government, we find that, similar to our above discussion for the FA_i $(i = 1, 2)$, the net surplus of a consumer with the valuation $\hat{\theta}$ can be calculated as $\hat{\theta} - \hat{k} - \hat{p} + s$, where $\hat{k}$ denotes the EA's lifecycle cost including the electricity cost, maintenance cost, and running cost, etc. (Cuenca, Gaines & Vyas 2000). As discussed by Skerlos and Winebrake (2010), the accessibility of the facility (e.g., service centers, charging stations) used for electric vehicles is an important factor that impacts the magnitude of plug-in electric vehicles benefits; and as reported by an expert panel at Indiana University (2011), consumers' costs for using electric vehicles are highly associated with the facility accessibility. We learn from the U.S. Department of Energy (2011) that electric vehicle users in the United States incur the average annual cost \$2,802, including the maintenance cost \$663 and the electricity cost \$372—which are dependent on the number of service and charging centers, the insurance, license, and registration cost \$1,616, and other cost (e.g., the fuel cost for hybrid vehicles) \$151. To consider the important role of the facility, in this paper we assume that $\hat{k} = \kappa(n) + \varepsilon$, where n denotes the number of service and charging centers, $\kappa(n)$ is the average $n-$dependent cost, and ε is the $n-$independent cost that may differ among consumers. We incorporate the cost function $\kappa(n)$ into each consumer's net surplus function, because Avci, Girotra, and Netessine (2012) have shown that the battery switching stations can reduce the driving cost and thus increase the adoption of electric vehicles. Accordingly, it is reasonable to assume in our paper that $\kappa(n)$ is a decreasing, convex function of n. It thus follows that a consumer's net surplus $\hat{u}(\hat{\theta}, \hat{p})$ can be re-written as $\hat{u}(\hat{\eta}, \hat{p}) = \hat{\eta} - \kappa(n) - \hat{p} + s$, where $\hat{\eta} \equiv \hat{\theta} - \varepsilon$ simply means the consumer's net consumption gain from using the EA, and can be assumed as a random variable. In addition, from the transaction with the consumer on the EA, the retailer R_2 can attain the profit $\hat{\pi}(\hat{\eta}, \hat{p}) = \hat{p} - \hat{w}$.

Appendix C Generalized Nash Bargaining Models

We first construct a two-player cooperative game model to characterize the bargaining process for the consumer with the net consumption gain η_1 (from the FA_1) and the retailer R_1. The GNB scheme represents a unique bargaining solution that can be obtained by solving the following maximization problem: $\max_{y_1, y_2} (y_1 - y_1^0)^\beta (y_2 - y_2^0)^{1-\beta}$, s.t. $y_1 \geq y_1^0$ and $y_2 \geq y_2^0$, where β and $1 - \beta$ denote players 1's and 2's relative bargaining powers; y_i and y_i^0 correspond to player i's profit and disagreement payoff, respectively, for $i = 1, 2$.

We find that, in the GNB model, $y_1 = u_1(\eta_1, p_1) = \eta_1 - p_1$ and $y_2 = \pi_1(\eta_1, p_1) = p_1 - w_1$. Next, we discuss the calculation of the disagreement payoffs y_1^0 and y_2^0 for the consumer and the retailer R_1, respectively. If the consumer cannot trade with the retailer R_1, then he or she may decide to instead buy an EA or an FA_2 from the retailer R_2, or may not buy any automobile, which depends on whether or not the consumer can draw a positive net surplus from trading with the retailer R_2. Therefore, when the consumer negotiates a retail price with the retailer R_1, his or her disagreement payoff should be the maximum value of the net surplus obtained from purchasing the EA, that from purchasing the FA_2, and zero, i.e., $y_1^0 = u_1^0 \equiv \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2), 0\}$, where $\hat{u}(\hat{\eta}, \hat{p}) = \hat{\eta} - \kappa(n) - \hat{p} + s$ and $u_2(\eta_2, p_2) = \eta_2 - p_2$ denote the consumer's net surplus from purchasing an EA and that from buying an FA_2, respectively, as discussed in Section 2.1.1. If $\hat{u}(\hat{\eta}, \hat{p}) > 0$ and $u_2(\eta_2, p_2) > 0$, then the consumer should decide to purchase the FA_1 when $u_1(\eta_1, p_1) \geq \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2)\}$; but, he or she should buy the FA_2 or the EA from the retailer R_2 when $u_1(\eta_1, p_1) < \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2)\}$. However, if $\hat{u}(\hat{\eta}, \hat{p}) > 0$ and $u_2(\eta_2, p_2) \leq 0$, then the consumer's disagreement payoff is $\hat{u}(\hat{\eta}, \hat{p})$, and the consumer will buy the FA_1 from the retailer R_1 or buy the EA from the retailer R_2, which depends on the comparison between $u_1(\eta_1, p_1)$ and $\hat{u}(\hat{\eta}, \hat{p})$. Similarly, if $\hat{u}(\hat{\eta}, \hat{p}) \leq 0$ and $u_2(\eta_2, p_2) > 0$, then the consumer will buy the FA_1 from the retailer R_1 or buy the FA_2 from the retailer R_2. If $\hat{u}(\hat{\eta}, \hat{p}) \leq 0$ and $u_2(\eta_2, p_2) \leq 0$, then the consumer's decision depends on whether or not his or her net surplus (generated from buying an FA_1) $u_1(\eta_1, p_1)$ is larger than zero. If $u_1(\eta_1, p_1) > 0$, then the consumer would complete a transaction with the retailer R_1; otherwise, the consumer would leave without buying any automobile. Note that, for each transaction, the retailer R_1's security point is zero, i.e., $y_2^0 = 0$. The retailer R_1 is willing to sell the FA_1 only when its profit $\pi_1(\eta_1, p_1)$ is non-negative, i.e., $\pi_1(\eta_1, p_1) = p_1 - w_1 \geq 0$.

According to the above discussion, we find that, when a consumer with the net consumption gain η_1 bargains with the retailer R_1, the GNB model can be constructed as,

$$\begin{aligned} \max_{p_1} \Lambda_1 &\equiv [\eta_1 - p_1 - \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2), 0\}]^\beta (p_1 - w_1)^{1-\beta}, \\ \text{s.t.} \quad & \eta_1 - p_1 \geq \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2), 0\} \quad \text{and} \quad p_1 - w_1 \geq 0. \end{aligned}$$

Similarly, when a consumer negotiates with the retailer R_2 over the retail price p_2 of the FA_2, his or her disagreement payoff should be $u_2^0 = \max\{\hat{u}(\hat{\eta}, \hat{p}), u_1(\eta_1, p_1), 0\}$; when the consumer bargains with R_2 over the EA retail price $\hat{p}$, his or her disagreement payoff should be $\hat{u}^0 = \max\{u_1(\eta_1, p_1), u_2(\eta_2, p_2), 0\}$. Since the price negotiations for both the FA_2 and the EA occur between the consumer and the retailer R_2, the consumer's relative bargaining powers for the two negotiations are the same. Noting that the consumer's power in bargaining with the retailer R_1 is β, we assume that his or her power in bargaining with the retailer R_2 is $\hat{\beta} \equiv r\beta$, where the parameter r differentiates between the retailers R_1 and R_2. If $r \geq 1$, then the consumer's bargaining power relative to the retailer R_2 is greater than or equal to that relative to the retailer R_1; otherwise, if $r < 1$, then the consumer is stronger in negotiating with R_1 than in negotiating with R_2. Noting that the consumer's bargaining power should be smaller than or equal to 1, we assume the value of r such that $\hat{\beta} \leq 1$ for $\beta \in [\beta_1, \beta_2]$.

Note that, different from the retailer R_1 in the FA supply chain, the retailer R_2 sells both the FA_2 and the EA. This means that the retailer's disagreement payoff for the FA_2 may be zero or the unit profit from the EA (i.e., $\hat{p}-\hat{w}$), which depends on the comparison between $\hat{p}-\hat{w}$ and zero. Therefore, the retailer R_2's disagreement payoff for the FA_2 is v_2^0, as given in (3). Similarly, the retailer R_2's disagreement payoff for the EA should be obtained as $\hat{v}^0 \equiv \max\{(p_2 - w_2) \times \mathbf{1}_{u_2(\eta_2,p_2)\geq u_1(\eta_1,p_1)}, 0\}$, which can be explained similar to v_2^0 in (3).

To find the retail price of the FA_2, we build the following GNB model for the bargaining problem between the consumer and the retailer R_2 as,

$$\max_{p_2} \Lambda_2 \equiv (\eta_2 - p_2 - u_2^0)^{\hat{\beta}}(p_2 - w_2 - v_2^0)^{1-\hat{\beta}}, \text{ s.t. } \eta_2 - p_2 \geq u_2^0 \text{ and } p_2 - w_2 \geq v_2^0.$$

To compute the retail price of the EA, we construct the following GNB model to characterize the bargaining between the consumer and the retailer R_2 as,

$$\max_{\hat{p}} \hat{\Lambda} \equiv [\hat{\eta} - \kappa(n) - \hat{p} + s - \hat{u}^0]^{\hat{\beta}}(\hat{p} - \hat{w} - \hat{v}^0)^{1-\hat{\beta}}, \text{ s.t. } \hat{\eta} - \kappa(n) - \hat{p} + s \geq \hat{u}^0 \text{ and } \hat{p} - \hat{w} \geq \hat{v}^0.$$

Appendix D Proof of Theorem 1

We learn from our discussion in Section 2.1.2 that the negotiated retail price p_1 for a consumer buying an FA_1, the price p_2 for a consumer buying an FA_2, and the price $\hat{p}$ for a consumer buying an EA are determined by solving (1), (2), and (4), respectively. Next, we begin by computing p_1 that results from the bargaining between the consumer with the net consumption gain η_1 and the retailer R_1.

D.1 The Negotiated Retail Price p_1 for the Consumer Buying an FA_1

The consumer with the net consumption gain η_1 decides to buy an FA_1 if and only if his or her net surplus $u_1(\eta_1, p_1)$ is non-negative and no less than that drawn from purchasing an FA_2 or an EA, i.e., $u_1(\eta_1, p_1) \geq \max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2), 0\}$. That is, to find the retail price p_1 for the consumer, we should solve the constrained maximization problem in (1), where we need to compare $u_2(\eta_2, p_2)$, $\hat{u}(\hat{\eta}, \hat{p})$, and 0 so as to decide on the disagreement payoff $\max\{\hat{u}(\hat{\eta}, \hat{p}), u_2(\eta_2, p_2), 0\}$. Thus, we should analyze the following five possible cases: (i) $u_2(\eta_2, p_2) \geq \hat{u}(\hat{\eta}, \hat{p}) \geq 0$, (ii) $\hat{u}(\hat{\eta}, \hat{p}) \geq u_2(\eta_2, p_2) \geq 0$, (iii) $u_2(\eta_2, p_2) \geq 0 \geq \hat{u}(\hat{\eta}, \hat{p})$, (iv) $\hat{u}(\hat{\eta}, \hat{p}) \geq 0 \geq u_2(\eta_2, p_2)$, and (v) $u_2(\eta_2, p_2) \leq 0$ and $\hat{u}(\hat{\eta}, \hat{p}) \leq 0$.

D.1.1 The Negotiated Retail Price p_1 when $u_2(\eta_2, p_2) \geq \hat{u}(\hat{\eta}, \hat{p}) \geq 0$

In the case that $u_2(\eta_2, p_2) \geq \hat{u}(\hat{\eta}, \hat{p}) \geq 0$, the consumer's disagreement payoff for his or her bargaining with the retailer R_1 is $u_2(\eta_2, p_2)$. That is, if the consumer cannot trade with R_1, then he or she will bargain with the retailer R_2 over the price p_2 for the FA_2. Note that, for the negotiation with R_2 for p_2, the disagreement payoff should be $\hat{u}(\hat{\eta}, \hat{p})$, because, if the consumer does not buy an FA_2 from R_2, then he or she should then bargain with R_2 over the retail price $\hat{p}$ for the EA. Furthermore, if the consumer cannot reach any agreement with R_2 upon the price $\hat{p}$, then the consumer will not buy any automobile, which means that the disagreement payoff for the bargaining over the EA price should be zero.

Summarizing the above, we should use the backward approach to find the negotiated retail price p_1 for the FA_1 and derive the condition assuring the completion of the FA_1 trade between the consumer and the retailer R_1. Specifically, we should take the following three steps to solve our problem.

Step 1: Determine the disagreement payoff for the FA_2 bargaining problem. We learn from our above argument that, if the consumer does not buy an FA_2 from the retailer R_2, then the consumer may buy an EA from the retailer R_2. That is, the disagreement payoff for the FA_2 bargaining problem is the consumer's net surplus $\hat{u}(\hat{\eta}, \hat{p})$ that results from purchasing an EA. To find $\hat{u}(\hat{\eta}, \hat{p})$, we should analyze the EA bargaining problem in which, as discussed above, the disagreement payoff for the consumer is zero. Therefore, the generalized Nash bargaining (GNB) model for the negotiation of the EA price can be developed as,

$$\max_{\hat{p}} \hat{\Lambda} = [\hat{\eta} - \kappa(n) - \hat{p} + s]^{\hat{\beta}} (\hat{p} - \hat{w})^{1-\hat{\beta}}, \text{ s.t. } \hat{\eta} - \kappa(n) - \hat{p} + s \geq 0 \text{ and } \hat{p} - \hat{w} \geq 0, \tag{16}$$

where $\hat{\beta} = r\beta$, as defined in Section 2.1.2. Solving the above, we can find $\hat{p}$ and then compute $\hat{u}(\hat{\eta}, \hat{p})$.

Step 2: Determine the disagreement payoff for the FA_1 bargaining problem. As discussed previously, the consumer who does not buy an FA_1 from the retailer R_1 should instead buy an FA_2 from the retailer R_2. This implies that the disagreement payoff for the FA_1 bargaining problem is the consumer's net surplus $u_2(\eta_2, p_2)$ that is determined as a result of purchasing an FA_2. Similar to Step 1, we find that, to find p_2 and compute $u_2(\eta_2, p_2)$, we need to solve the following GNB problem:

$$\max_{p_2} \Lambda_2 = [\eta_2 - p_2 - \hat{u}(\hat{\eta}, \hat{p})]^{\hat{\beta}} [p_2 - w_2 - (\hat{p} - \hat{w})]^{1-\hat{\beta}}, \text{ s.t. } \eta_2 - p_2 \geq \hat{u}(\hat{\eta}, \hat{p}) \text{ and } p_2 - w_2 \geq \hat{p} - \hat{w}. \tag{17}$$

Step 3: Find the negotiated retail price p_1. Using $u_2(\eta_2, p_2)$ (that is calculated in Step 2), we can obtain the negotiated retail price p_1 for the consumer, by solving the GNB problem as follows:

$$\max_{p_1} \Lambda_1 = [\eta_1 - p_1 - u_2(\eta_2, p_2)]^{\beta} (p_1 - w_1)^{1-\beta}, \text{ s.t. } \eta_1 - p_1 \geq u_2(\eta_2, p_2) \text{ and } p_1 - w_1 \geq 0. \tag{18}$$

Next, we follow the three steps to determine the negotiated price p_1.

The Disagreement Payoff for the FA_2 Bargaining Problem We now solve the constrained problem in (16). First, temporarily ignoring the constraints, we differentiate $\hat{\Lambda}$ once and twice with respect to $\hat{p}$, and find that

$$\begin{aligned}
\frac{\partial \hat{\Lambda}}{\partial \hat{p}} &= \{-\hat{\beta}[\hat{\eta} - \kappa(n) - \hat{p} + s]^{-1} + (1 - \hat{\beta})(\hat{p} - \hat{w})^{-1}\}\hat{\Lambda}, \\
\frac{\partial^2 \hat{\Lambda}}{\partial \hat{p}^2} &= -\{\hat{\beta}[\hat{\eta} - \kappa(n) - \hat{p} + s]^{-2} + (1 - \hat{\beta})(\hat{p} - \hat{w})^{-2}\}\hat{\Lambda} + \left(\frac{\partial \hat{\Lambda}}{\partial \hat{p}}\right)^2 \Big/ \hat{\Lambda}.
\end{aligned}$$

We find that $\partial^2\hat{\Lambda}/\partial\hat{p}^2 < 0$ at any point satisfying the first-order condition that $\partial\hat{\Lambda}/\partial\hat{p} = 0$. This implies that $\hat{\Lambda}$ is a unimodal function of the price $\hat{p}$ with a unique maximizer $\hat{p} = \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s]$. The consumer's corresponding net surplus from buying an EA is thus calculated as $\hat{u}(\hat{\eta}, \hat{p}) = \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]$. Note that the two constraints are satisfied when $\hat{\eta} \geq \kappa(n) + \hat{w} - s$.

The Disagreement Payoff for the FA$_1$ Bargaining Problem To calculate $u_2(\eta_2, p_2)$, we need to solve the constrained problem in (17). Using lines similar to those in our computation of $\hat{u}(\hat{\eta}, \hat{p})$, we find that the optimal price maximizing Λ_2 is uniquely determined as $p_2 = (1-\hat{\beta})\eta_2 + \hat{\beta}w_2$; as a result, $u_2(\eta_2, p_2) = \hat{\beta}(\eta_2 - w_2)$. It follows that $u_2(\eta_2, p_2) \geq \hat{u}(\hat{\eta}, \hat{p})$ and $p_2 - w_2 \geq \hat{p} - \hat{w}$ when $\eta_2 \geq w_2 + [\hat{\eta} - \kappa(n) + s - \hat{w}]$.

The Negotiated Retail Price p_1 for the FA$_1$ We now compute the retail price p_1 that is determined as a consequence of the bargaining between the retailer R_1 and the consumer with the disagreement payoff $u_2(\eta_2, p_2)$. We need to solve the constrained maximization problem in (18). Similar to the above analysis, we attain the negotiated retail price as,

$$p_1 = \beta w_1 + (1-\beta)[\eta_1 - \hat{\beta}(\eta_2 - w_2)],$$

and compute the consumer's net surplus as $u_1(\eta_1, p_1) = u_2(\eta_2, p_2) + \beta[\eta_1 - w_1 - u_2(\eta_2, p_2)]$, which is greater than or equal to $u_2(\eta_2, p_2)$ when $\eta_1 - w_1 \geq u_2(\eta_2, p_2)$. Note that $p_1 - w_1 = (1-\beta)[\eta_1 - w_1 - u_2(\eta_2, p_2)]$, which is non-negative when $\eta_1 - w_1 \geq u_2(\eta_2, p_2)$.

From our above analysis, we find the sufficient conditions—for the case that $u_2(\eta_2, p_2) \geq \hat{u}(\hat{\eta}, \hat{p}) \geq 0$—as (i) $\hat{\eta} \geq \kappa(n) + \hat{w} - s$; (ii) $\eta_2 \geq w_2 + [\hat{\eta} - \kappa(n) + s - \hat{w}]$; and (iii) $\eta_1 \geq w_1 + \hat{\beta}(\eta_2 - w_2)$.

D.1.2 The Negotiated Retail Price p_1 when $\hat{u}(\hat{\eta}, \hat{p}) \geq u_2(\eta_2, p_2) \geq 0$

We now assume that the consumer can enjoy a higher net surplus from buying an EA than from buying an FA$_2$. For this case, in Step 1 we should find the disagreement payoff for the EA bargaining problem by solving the following GNB problem:

$$\max_{p_2} \Lambda_2 = (\eta_2 - p_2)^{\hat{\beta}}(p_2 - w_2)^{1-\hat{\beta}}, \text{ s.t. } \eta_2 - p_2 \geq 0 \text{ and } p_2 - w_2 \geq 0. \tag{19}$$

Then, in Step 2, we should compute the disagreement payoff for the FA$_1$ bargaining problem by solving,

$$\begin{aligned} \max_{\hat{p}} \hat{\Lambda} = &\quad [\hat{\eta} - \kappa(n) - \hat{p} + s - u_2(\eta_2, p_2)]^{\hat{\beta}}[\hat{p} - \hat{w} - (p_2 - w_2)]^{1-\hat{\beta}}, \\ \text{s.t.} &\quad \hat{\eta} - \kappa(n) - \hat{p} + s \geq u_2(\eta_2, p_2) \text{ and } \hat{p} - \hat{w} \geq p_2 - w_2. \end{aligned}$$

In Step 3, we can obtain the negotiated retail price p_1 as the optimal solution of the following problem:

$$\max_{p_1} \Lambda_1 = [\eta_1 - p_1 - \hat{u}(\hat{\eta}, \hat{p})]^{\beta}(p_1 - w_1)^{1-\beta}, \text{ s.t. } \eta_1 - p_1 \geq \hat{u}(\hat{\eta}, \hat{p}) \text{ and } p_1 - w_1 \geq 0.$$

Similar to our analysis in Appendix D.1.1, we can obtain the negotiated retail price for the FA_1 as

$$p_1 = \beta w_1 + (1-\beta)\{\eta_1 - \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]\}.$$

The conditions assuring the case that $\hat{u}(\hat{\eta}, \hat{p}) \geq u_2(\eta_2, p_2) \geq 0$ are thus found as (i) $\eta_2 \geq w_2$; (ii) $\hat{\eta} \geq \kappa(n) + \hat{w} - s + (\eta_2 - w_2)$; and (iii) $\eta_1 \geq w_1 + \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]$.

D.1.3 The Negotiated Retail Price p_1 when $u_2(\eta_2, p_2) \geq 0 \geq \hat{u}(\hat{\eta}, \hat{p})$

For this case, the consumer will not buy an EA from the retailer R_2. We thus only need to consider the following two steps: In Step 1, we compute the disagreement payoff for the consumer in his or her bargaining with the retailer R_1 over the price p_1, by solving the GNB problem in (19). Then, in Step 2, we solve the constrained maximization problem in (18) to obtain the negotiated retail price p_1. Similar to our previous analyses, we find that

$$p_1 = \beta w_1 + (1-\beta)[\eta_1 - \hat{\beta}(\eta_2 - w_2)],$$

and the sufficient conditions for this case are (i) $\eta_2 \geq w_2$, (ii) $\eta_1 \geq w_1 + \hat{\beta}(\eta_2 - w_2)$, and (iii) $\hat{\eta} \leq \kappa(n) + \hat{w} - s$. Note that, under the condition (iii), $\hat{u}(\hat{\eta}, \hat{p}) \leq 0$.

D.1.4 The Negotiated Retail Price p_1 when $\hat{u}(\hat{\eta}, \hat{p}) \geq 0 \geq u_2(\eta_2, p_2)$

Following our arguments in Appendix D.1.3, we can use two similar steps to find that the negotiated retail price of the FA_1 is

$$p_1 = \beta w_1 + (1-\beta)\{\eta_1 - \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]\};$$

and the sufficient conditions for this case are (i) $\hat{\eta} \geq \kappa(n) + \hat{w} - s$, (ii) $\eta_1 \geq w_1 + \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]$, and (iii) $\eta_2 \leq w_2$. Note that, under condition (iii), $u_2(\eta_2, p_2) \leq 0$.

D.1.5 The Negotiated Retail Price p_1 when $u_2(\eta_2, p_2) \leq 0$ and $\hat{u}(\hat{\eta}, \hat{p}) \leq 0$

For this case, we can find the price p_1 by only considering a single GNB problem, which is given as follows:

$$\max_{p_1} \Lambda_1 = (\eta_1 - p_1)^{\beta}(p_1 - w_1)^{1-\beta}, \text{ s.t. } \eta_1 - p_1 \geq 0 \text{ and } p_1 - w_1 \geq 0.$$

Solving the above yields that

$$p_1 = \beta w_1 + (1-\beta)\eta_1.$$

We also find that the sufficient conditions assuring the case are (i) $\eta_1 \geq w_1$, (ii) $\eta_2 \leq w_2$, and (iii) $\hat{\eta} \leq \kappa(n) + \hat{w} - s$. Note that $u_2(\eta_2, p_2) \leq 0$ under condition (ii) and $\hat{u}(\hat{\eta}, \hat{p}) \leq 0$ under condition (iii).

We summarize our analyses for the above five cases, and find the conditions and the negotiated price p_1^*, as shown in Table B, where we can simply write our solution as follows:

Case	Conditions			Negotiated Retail Price p_1^*
	η_1	η_2	$\hat{\eta}$	
1	$\eta_1 \geq w_1 + \hat{\beta}(\eta_2 - w_2)$	$\eta_2 \geq w_2 + [\hat{\eta}$ $-\kappa(n) + s - \hat{w}]$	$\hat{\eta} \geq \kappa(n)$ $+\hat{w} - s$	$p_1^* = \beta w_1 + (1-\beta)$ $\times[\eta_1 - \hat{\beta}(\eta_2 - w_2)]$
2	$\eta_1 \geq w_1 + \hat{\beta}[\hat{\eta} - \kappa(n)$ $+s - \hat{w}]$	$\eta_2 \geq w_2$	$\hat{\eta} \geq \hat{w} + \kappa(n) - s$ $+(\eta_2 - w_2)$	$p_1^* = \beta w_1 + (1-\beta)$ $\times\{\eta_1 - \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]\}$
3	$\eta_1 \geq w_1 + \hat{\beta}(\eta_2 - w_2)$	$\eta_2 \geq w_2$	$\hat{\eta} \leq \kappa(n)$ $+\hat{w} - s$	$p_1^* = \beta w_1 + (1-\beta)$ $\times[\eta_1 - \hat{\beta}(\eta_2 - w_2)]$
4	$\eta_1 \geq w_1 + \hat{\beta}[\hat{\eta} - \kappa(n)$ $+s - \hat{w}]$	$\eta_2 \leq w_2$	$\hat{\eta} \geq \kappa(n)$ $+\hat{w} - s$	$p_1^* = \beta w_1 + (1-\beta)$ $\times\{\eta_1 - \hat{\beta}[\hat{\eta} - \kappa(n) + s - \hat{w}]\}$
5	$\eta_1 \geq w_1$	$\eta_2 \leq w_2$	$\hat{\eta} \leq \kappa(n)$ $+\hat{w} - s$	$p_1^* = \beta w_1 + (1-\beta)\eta_1$

Table B: The negotiated retail price p_1^* for the consumer who buys an FA_1.

D.2 The Negotiated Retail Price p_2 for the Consumer Buying an FA_2

Similar to Appendix D.1, we find that the consumer with the net consumption gain η_2 for the FA_2 decides to buy an FA_2 if and only if his or her net surplus $u_2(\eta_2, p_2) \geq \max\{\hat{u}(\hat{\eta}, \hat{p}), u_1(\eta_1, p_1), 0\}$. That is, to find the retail price p_2 for the consumer, we should solve the constrained maximization problem in (2), where we need to compare $u_1(\eta_1, p_1)$, $\hat{u}(\hat{\eta}, \hat{p})$, and 0 in order to decide on the consumer's disagreement payoff $u_2^0 = \max\{\hat{u}(\hat{\eta}, \hat{p}), u_1(\eta_1, p_1), 0\}$ and the retailer R_2's disagreement profit $v_2^0 = \max\{(\hat{p} - \hat{w}) \times \mathbf{1}_{\hat{u}(\hat{\eta},\hat{p}) \geq u_1(\eta_1,p_1)}, 0\}$. Using similar lines as those in Appendix D.1, we analyze five possible cases, and obtain the negotiated retail price p_2^* and corresponding conditions, as shown in Table C.

Case	Conditions			Negotiated Retail Price p_2^*
	η_1	η_2	$\hat{\eta}$	
1	$\eta_1 \geq w_1 + \hat{\beta}$ $\times[\hat{\eta} - \kappa(n)$ $+s - \hat{w}]$	$\eta_2 \geq w_2 + \beta$ $\times[\eta_1 - w_1 + r(1-\beta)$ $\times(\hat{\eta} - \kappa(n) + s - \hat{w})]$	$\hat{\eta} \geq \kappa(n)$ $+\hat{w} - s$	$p_2^* = \hat{\beta} w_2 + (1-\hat{\beta})$ $\times\{\eta_2 - \beta[\eta_1 - w_1 + r$ $\times(1-\beta)(\hat{\eta} - \kappa(n) + s - \hat{w})]\}$
2	$\eta_1 \geq w_1$	$\eta_2 \geq w_2 + \beta(\eta_1 - w_1)$	$\hat{\eta} \geq \hat{w} + \kappa(n) - s$ $+\beta(\eta_1 - w_1)$	$p_2^* = \hat{\beta} w_2 + (1-\hat{\beta})$ $\times[\eta_2 - \beta(\eta_1 - w_1)]$
3	$\eta_1 \geq w_1$	$\eta_2 \geq w_2$ $+\beta(\eta_1 - w_1)$	$\hat{\eta} \leq \kappa(n)$ $+\hat{w} - s$	$p_2^* = \hat{\beta} w_2 + (1-\hat{\beta})$ $\times[\eta_2 - \beta(\eta_1 - w_1)]$
4	$\eta_1 \leq w_1$	$\eta_2 \geq w_2$	$\hat{\eta} \geq \kappa(n)$ $+\hat{w} - s$	$p_2^* = \hat{\beta} w_2 + (1-\hat{\beta})\eta_2$
5	$\eta_1 \leq w_1$	$\eta_2 \geq w_2$	$\hat{\eta} \leq \kappa(n)$ $+\hat{w} - s$	$p_2^* = \hat{\beta} w_2 + (1-\hat{\beta})\eta_2$

Table C: The negotiated retail price p_2^* for the consumer who buys an FA_2.

D.3 The Negotiated Retail Price $\hat{p}$ for the Consumer Buying an EA

Similar to Appendices D.1 and D.2, we calculate the negotiated retail price $\hat{p}$ as shown in Table D.

Case	Conditions η_1	η_2	$\hat{\eta}$	Negotiated Retail Price $\hat{p}^*$
1	$\eta_1 \geq w_1 + \hat{\beta} \times(\eta_2 - w_2)$	$\eta_2 \geq w_2$	$\hat{\eta} \geq \kappa(n) + \hat{w} - s + \beta[\eta_1 - w_1 + r \times(1-\beta)(\eta_2 - w_2)]$	$\hat{p}^* = \hat{\beta}\hat{w} + (1-\hat{\beta}) \times\{\hat{\eta} - \kappa(n) + s - \beta \times[\eta_1 - w_1 + r(1-\beta)(\eta_2 - w_2)]\}$
2	$\eta_1 \geq w_1$	$\eta_2 \geq w_2 + \beta(\eta_1 - w_1)$	$\hat{\eta} \geq \kappa(n) + \hat{w} - s + \beta(\eta_1 - w_1)$	$\hat{p}^* = \hat{\beta}\hat{w} + (1-\hat{\beta}) \times[\hat{\eta} - \kappa(n) + s - \beta(\eta_1 - w_1)]$
3	$\eta_1 \geq w_1$	$\eta_2 \leq w_2$	$\hat{\eta} \geq \kappa(n) + \hat{w} - s + \beta(\eta_1 - w_1)$	$\hat{p}^* = \hat{\beta}\hat{w} + (1-\hat{\beta}) \times[\hat{\eta} - \kappa(n) + s - \beta(\eta_1 - w_1)]$
4	$\eta_1 \leq w_1$	$\eta_2 \geq w_2$	$\hat{\eta} \geq \kappa(n) + \hat{w} - s$	$\hat{p}^* = \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s]$
5	$\eta_1 \leq w_1$	$\eta_2 \leq w_2$	$\hat{\eta} \geq \kappa(n) + \hat{w} - s$	$\hat{p}^* = \hat{\beta}\hat{w} + (1-\hat{\beta})[\hat{\eta} - \kappa(n) + s]$

Table D: The negotiated retail price $\hat{p}^*$ for the consumer who buys an EA.

D.4 Summary of Analytic Results

From our above analyses, we find that the consumer does not buy any automobile if $\eta_1 < w_1$, $\eta_2 < w_2$, and $\hat{\eta} < \kappa(n) + \hat{w} - s$. In addition, we define $\tau_1 \equiv \eta_1 - w_1$, $\tau_2 \equiv \eta_2 - w_2$, and $\hat{\tau} \equiv \hat{\eta} - \kappa(n) + s - \hat{w}$, and summarize our findings in Theorem 1.

D.5 Impact of the Subsidy s on Negotiated Retail Prices p_i^* $(i = 1, 2)$ and $\hat{p}^*$

Using our above analytic results, we investigate the impact of s on the negotiated retail prices of three automobiles (i.e., p_i^*, $i = 1, 2$, and $\hat{p}^*$). We start with our analysis for the negotiated retail price p_1^*, which is given as in Table 1. Noting that τ_1 and τ_2 are both independent of s, we provide our analysis as follows.

1. When $\tau_1 \geq 0$, $\tau_2 \leq 0$, and $\hat{\tau} = \hat{\eta} - \kappa(n) + s - \hat{w} \leq 0$, we find that $p_1^* = p_{15}^*$, which is independent of s. Therefore, if the value of s is increased such that $\hat{\tau} \leq 0$, then the negotiated retail price p_1^* is not changed.

   When s is increased to a value such that $\hat{\tau} > 0$, we find that, if $0 \leq \tau_1 \leq \hat{\beta}\hat{\tau}$, then p_1^* is not changed; otherwise, if $\tau_1 \geq \hat{\beta}\hat{\tau}$, then p_1^* is changed from p_{15}^* to p_{14}^*, which is smaller than p_{15}^*, as indicated by Table 1.
2. When $\tau_1 \geq \hat{\beta}\tau_2$, $\tau_2 \geq 0$, and $\hat{\tau} \leq 0$, we find that $p_1^* = p_{13}^*$, which is independent of s. If the value of s is increased such that $0 \leq \hat{\tau} \leq \tau_2$, then the negotiated retail price p_1^* is changed from p_{13}^* to p_{11}^*. Since $p_{11}^* = p_{13}^*$, the negotiated retail price p_1^* is not changed when $0 \leq \hat{\tau} \leq \tau_2$.

   If the value of s is increased such that $\hat{\tau} \geq \tau_2$, then the negotiated retail price p_1^* is changed from p_{11}^* to p_{12}^*. Noting that $p_{11}^* \geq p_{12}^*$ (because $\hat{\tau} \geq \tau_2$), we conclude that the negotiated retail price p_1^* is reduced as the value of s is increased such that $\hat{\tau} \geq \tau_2$.

We learn from the above that the negotiated retail price for the FA_1 is decreasing in the subsidy s. Similarly, we can show that the negotiated retail price for the FA_2 (p_2^*) and the negotiated retail price for the EA ($\hat{p}^*$) are decreasing and increasing in the subsidy s, respectively. In addition, it is easy to show that the retail price for each automobile is increasing in the wholesale price for the automobile. This theorem is thus proved.

Appendix E Distribution of the Charging Stations in the United States

The U.S. Department of Energy (2012a) reported that, as of May 17, 2012, the average number of charging stations in each state in the U.S. is around 100. The U.S. Department of Energy also provided the distribution of charging stations in the U.S., as shown in Figure A.

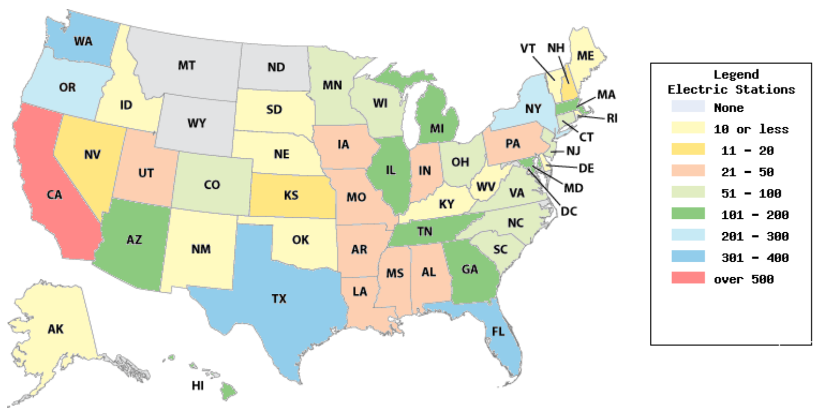

Figure A: The distribution of charging stations in the United States.

Appendix F Numerical Results for Sensitivity Analyses in Section 2.2

Using the parameter values in Example 1 as the base values, we present our numerical results regarding the impact of the government's subsidy s, the number of service and charging stations for the EA (i.e., n), and the mean value of consumers' relative bargaining power β (i.e., μ_β) on (i) wholesale prices in Nash equilibrium, (ii) the demands for the FA_i ($i = 1, 2$) and the EA, and (iii) the system-wide profits of two supply chains. Note that the results for s, n, and μ_β are provided in Tables E, F, and G, respectively.

s ($\times 10^3$)	**Wholesale Prices in Nash Equilibrium**		
	w_1^N	w_2^N	$\hat{w}^N$
5.5	27117.41 (↓ 0.856%)	28222.37 (↓ 0.317%)	31734.63 (↑ 2.462%)
6.0	27011.51 (↓ 1.244%)	28123.37 (↓ 0.667%)	31981.21 (↑ 3.258%)
6.5	26841.12 (↓ 1.867%)	27923.20 (↓ 1.374%)	32296.14 (↑ 4.275%)
7.0	26633.48 (↓ 2.626%)	27451.29 (↓ 3.040%)	32612.43 (↑ 5.296%)
7.5	26431.65 (↓ 3.364%)	27209.66 (↓ 3.894%)	32901.33 (↑ 6.228%)
8.0	26259.12 (↓ 3.994%)	26999.33 (↓ 4.637%)	33214.04 (↑ 7.238%)
8.5	26210.44 (↓ 4.172%)	26883.73 (↓ 5.045%)	33435.90 (↑ 7.954%)
9.0	26158.95 (↓ 4.361%)	26815.04 (↓ 5.288%)	33713.04 (↑ 8.849%)
9.5	26111.77 (↓ 4.533%)	26749.32 (↓ 5.520%)	33899.03 (↑ 9.450%)
10.0	26062.60 (↓ 4.713%)	26714.93 (↓ 5.641%)	34121.33 (↑ 10.167%)
s ($\times 10^3$)	**Demands**		
	FA	**EA**	**Total**
5.5	8597 (↓ 4.854%)	419 (↑ 20.728%)	9015 (↓ 3.909%)
6.0	8573 (↓ 5.121%)	429 (↑ 23.789%)	9002 (↓ 4.053%)
6.5	8545 (↓ 5.430%)	441 (↑ 27.145%)	8986 (↓ 4.226%)
7.0	8505 (↓ 5.876%)	454 (↑ 30.836%)	8959 (↓ 4.519%)
7.5	8480 (↓ 6.144%)	465 (↑ 34.057%)	8945 (↓ 4.658%)
8.0	8484 (↓ 6.098%)	473 (↑ 36.438%)	8958 (↓ 4.526%)
8.5	8489 (↓ 6.049%)	482 (↑ 39.063%)	8971 (↓ 4.381%)
9.0	8496 (↓ 5.973%)	489 (↑ 40.896%)	8984 (↓ 4.240%)
9.5	8501 (↓ 5.911%)	495 (↑ 42.659%)	8996 (↓ 4.116%)
10.0	8509 (↓ 5.832%)	499 (↑ 43.804%)	9008 (↓ 3.997%)
s ($\times 10^3$)	**Profits ($\times 10^7$) in Two Supply Chains (SC)**		
	The FA SC	**The EA-FA SC**	**Total Profit**
5.5	1.571 (↓ 20.375%)	4.983 (↑ 9.589%)	6.554 (↑ 0.521%)
6.0	1.466 (↓ 25.697%)	5.216 (↑ 14.713%)	6.682 (↑ 2.485%)
6.5	1.392 (↓ 29.437%)	5.452 (↑ 19.903%)	6.844 (↑ 4.972%)
7.0	1.328 (↓ 32.691%)	5.600 (↑ 23.158%)	6.928 (↑ 6.258%)
7.5	1.289 (↓ 34.668%)	5.759 (↑ 26.657%)	7.048 (↑ 8.100%)
8.0	1.253 (↓ 36.493%)	5.835 (↑ 28.326%)	7.088 (↑ 8.712%)
8.5	1.230 (↓ 37.658%)	5.862 (↑ 28.920%)	7.092 (↑ 8.773%)
9.0	1.213 (↓ 38.520%)	5.882 (↑ 29.360%)	7.095 (↑ 8.819%)
9.5	1.200 (↓ 39.179%)	5.903 (↑ 29.822%)	7.103 (↑ 8.942%)
10.0	1.191 (↓ 39.635%)	5.914 (↑ 30.064%)	7.105 (↑ 8.972%)

Table E: The sensitivity analysis for the impact of the subsidy s on the wholesale prices in Nash equilibrium, the demands for two FAs and the EA, and the profits of two supply chains. Note that the mark "↑" or "↓" represents the percentage increase or decrease compared with the case of no subsidy ($s = 0$).

n	**Wholesale Prices in Nash Equilibrium**		
	w_1^N	w_2^N	$\hat{w}^N$
30	26637.06 (↓ 2.613%)	27528.57 (↓ 2.768%)	32461.34 (↑ 4.808%)
40	26636.13 (↓ 2.616%)	27514.80 (↓ 2.816%)	32467.61 (↑ 4.828%)
50	26635.48 (↓ 2.618%)	27501.62 (↓ 2.863%)	32475.71 (↑ 4.854%)
60	26634.98 (↓ 2.620%)	27488.63 (↓ 2.909%)	32484.24 (↑ 4.882%)
70	26634.58 (↓ 2.622%)	27476.22 (↓ 2.952%)	32583.18 (↑ 5.201%)
80	26634.19 (↓ 2.623%)	27464.97 (↓ 2.992%)	32592.31 (↑ 5.231%)
90	26633.82 (↓ 2.625%)	27456.58 (↓ 3.022%)	32602.30 (↑ 5.263%)
100	26633.48 (↓ 2.626%)	27451.29 (↓ 3.040%)	32612.43 (↑ 5.296%)
110	26633.16 (↓ 2.627%)	27447.17 (↓ 3.055%)	32623.55 (↑ 5.332%)
120	26632.87 (↓ 2.628%)	27443.20 (↓ 3.069%)	32636.88 (↑ 5.375%)
n	**Demands**		
	FA	**EA**	**Total**
30	8478 (↓ 6.168%)	438 (↑ 26.438%)	8916 (↓ 4.963%)
40	8481 (↓ 6.132%)	441 (↑ 27.070%)	8922 (↓ 4.905%)
50	8486 (↓ 6.083%)	443 (↑ 27.867%)	8929 (↓ 4.828%)
60	8493 (↓ 6.005%)	447 (↑ 29.014%)	8940 (↓ 4.711%)
70	8497 (↓ 5.962%)	449 (↑ 29.574%)	8946 (↓ 4.648%)
80	8502 (↓ 5.909%)	451 (↑ 30.161%)	8953 (↓ 4.575%)
90	8503 (↓ 5.888%)	453 (↑ 30.543%)	8956 (↓ 4.542%)
100	8505 (↓ 5.876%)	454 (↑ 30.836%)	8959 (↓ 4.519%)
110	8508 (↓ 5.839%)	456 (↑ 31.446%)	8964 (↓ 4.460%)
120	8509 (↓ 5.823%)	458 (↑ 31.966%)	8967 (↓ 4.427%)
n	**Profits ($\times 10^7$) in Two Supply Chains (SC)**		
	The FA SC	**The EA-FA SC**	**Total Profit**
30	1.441 (↓ 26.964%)	5.090 (↑ 11.942%)	6.531 (↑ 0.169%)
40	1.421 (↓ 27.978%)	5.148 (↑ 13.218%)	6.569 (↑ 0.752%)
50	1.402 (↓ 28.941%)	5.216 (↑ 14.713%)	6.618 (↑ 1.503%)
60	1.385 (↓ 29.802%)	5.302 (↑ 16.604%)	6.687 (↑ 2.561%)
70	1.371 (↓ 30.512%)	5.386 (↑ 18.452%)	6.757 (↑ 3.635%)
80	1.356 (↓ 31.272%)	5.495 (↑ 20.849%)	6.851 (↑ 5.077%)
90	1.342 (↓ 31.972%)	5.560 (↑ 22.278%)	6.902 (↑ 5.862%)
100	1.328 (↓ 32.691%)	5.600 (↑ 23.158%)	6.928 (↑ 6.258%)
110	1.305 (↓ 33.837%)	5.662 (↑ 24.522%)	6.967 (↑ 6.862%)
120	1.298 (↓ 34.212%)	5.706 (↑ 25.489%)	7.004 (↑ 7.423%)

Table F: The sensitivity analysis for the impact of the number of service and charging stations (i.e., n) on the wholesale prices in Nash equilibrium, the demands for two FAs and the EA, and the profits of two supply chains. Note that the mark "↑" or "↓" represents the percentage increase or decrease in the result for the case when $s = \$7,000$ compared with the case of no subsidy ($s = 0$).

μ_β	**Wholesale Prices in Nash Equilibrium**		
	w_1^N	w_2^N	$\hat{w}^N$
0.30	26956.14 (↓ 1.446%)	27863.97 (↓ 1.583%)	35682.30 (↑ 15.207%)
0.35	26789.03 (↓ 2.057%)	27662.59 (↓ 2.294%)	34327.69 (↑ 10.834%)
0.40	26633.48 (↓ 2.626%)	27451.29 (↓ 3.040%)	32612.43 (↑ 5.296%)
0.45	26479.04 (↓ 3.190%)	27250.30 (↓ 3.750%)	32192.43 (↑ 3.940%)
0.50	26355.72 (↓ 3.641%)	27051.46 (↓ 4.453%)	31789.26 (↑ 2.638%)
0.55	26241.58 (↓ 4.059%)	26866.69 (↓ 5.105%)	31401.27 (↑ 1.385%)
0.60	26140.25 (↓ 4.429%)	26688.92 (↓ 5.733%)	31023.29 (↑ 0.165%)
0.65	26039.26 (↓ 4.798%)	26524.69 (↓ 6.313%)	30622.08 (↓ 1.131%)
0.70	25946.69 (↓ 5.137%)	26383.58 (↓ 6.812%)	30270.50 (↓ 2.266%)
0.75	25870.70 (↓ 5.415%)	26261.72 (↓ 7.242%)	29969.39 (↓ 3.238%)
μ_β	**Demands**		
	FA	**EA**	**Total**
0.30	8399 (↓ 7.048%)	379 (↑ 9.389%)	8778 (↓ 6.440%)
0.35	8450 (↓ 6.476%)	419 (↑ 20.853%)	8869 (↓ 5.466%)
0.40	8505 (↓ 5.876%)	454 (↑ 30.836%)	8959 (↓ 4.519%)
0.45	8536 (↓ 5.523%)	486 (↑ 40.136%)	9022 (↓ 3.835%)
0.50	8566 (↓ 5.191%)	499 (↑ 43.884%)	9065 (↓ 3.377%)
0.55	8535 (↓ 5.536%)	567 (↑ 63.554%)	9102 (↓ 2.982%)
0.60	8513 (↓ 5.782%)	615 (↑ 77.424%)	9128 (↓ 2.706%)
0.65	8482 (↓ 6.125%)	681 (↑ 96.253%)	9163 (↓ 2.341%)
0.70	8435 (↓ 6.645%)	783 (↑ 125.806%)	9218 (↓ 1.749%)
0.75	8417 (↓ 6.844%)	976 (↑ 181.572%)	9393 (↑ 0.120%)
μ_β	**Profits ($\times 10^7$) in Two Supply Chains (SC)**		
	The FA SC	**The EA-FA SC**	**Total Profit**
0.30	1.360 (↓ 31.069%)	5.717 (↑ 25.731%)	7.077 (↑ 8.543%)
0.35	1.351 (↓ 31.531%)	5.606 (↑ 23.288%)	6.957 (↑ 6.699%)
0.40	1.328 (↓ 32.691%)	5.600 (↑ 23.158%)	6.928 (↑ 6.258%)
0.45	1.315 (↓ 33.355%)	5.415 (↑ 19.090%)	6.730 (↑ 3.219%)
0.50	1.296 (↓ 34.308%)	5.245 (↑ 15.351%)	6.541 (↑ 0.324%)
0.55	1.283 (↓ 34.982%)	5.094 (↑ 12.030%)	6.377 (↓ 2.196%)
0.60	1.269 (↓ 35.702%)	4.965 (↑ 9.193%)	6.234 (↓ 4.393%)
0.65	1.254 (↓ 36.427%)	4.855 (↑ 6.765%)	6.109 (↓ 6.305%)
0.70	1.239 (↓ 37.217%)	4.756 (↑ 4.592%)	5.995 (↓ 8.060%)
0.75	1.197 (↓ 39.321%)	4.681 (↑ 2.943%)	5.878 (↓ 9.847%)

Table G: The sensitivity analysis for the impact of the mean value of consumers' relative bargaining power (i.e., μ_β) on the wholesale prices in Nash equilibrium, the demands for two FAs and the EA, and the profits of two supply chains. Note that the mark "↑" or "↓" represents the percentage increase or decrease in the result for the case when $s = \$7,000$ compared with the case of no subsidy ($s = 0$).

Appendix G Numerical Results Regarding Sensitivity Analyses for the Decentralized Setting in Section 3.2.1

Using the parameter values in Example 1 as the base values, we present our numerical results regarding the impact of the government's subsidy s, the number of service and charging stations for the EA (i.e., n), and the mean value of consumers' relative bargaining power β (i.e., μ_β) on consumers' net surplus, environmental hazard, and social welfare in the decentralized setting. Note that the results for s, n, and μ_β are provided in Tables H, I, and J, respectively. We also provide Table K to show the allocation of supply chain profits between the FA and the EA markets.

s ($\times 10^3$)	Consumers' Net Surplus ($\times 10^7$)		
	Total Surplus of FA Consumers $[\sum_{i=1}^{2} \Pi_{Ci}(s)]$	**Total Surplus of EA Consumers** $[\hat{\Pi}_C(s)]$	**Total Surplus of All Consumers**
5.5	0.626 [↓ 0.099 (13.655%)]	1.045 [↑ 0.481 (85.284%)]	1.671 [↑ 0.382 (29.635%)]
6.0	0.627 [↓ 0.098 (13.517%)]	1.071 [↑ 0.507 (89.894%)]	1.698 [↑ 0.409 (31.730%)]
6.5	0.628 [↓ 0.097 (13.379%)]	1.091 [↑ 0.527 (93.440%)]	1.719 [↑ 0.430 (33.359%)]
7.0	0.629 [↓ 0.096 (13.241%)]	1.120 [↑ 0.556 (98.582%)]	1.749 [↑ 0.460 (35.687%)]
7.5	0.631 [↓ 0.094 (12.966%)]	1.141 [↑ 0.577 (102.305%)]	1.772 [↑ 0.483 (37.471%)]
8.0	0.633 [↓ 0.092 (12.690%)]	1.162 [↑ 0.598 (106.028%)]	1.795 [↑ 0.506 (39.255%)]
8.5	0.636 [↓ 0.089 (12.276%)]	1.187 [↑ 0.623 (110.461%)]	1.823 [↑ 0.534 (41.427%)]
9.0	0.640 [↓ 0.085 (11.724%)]	1.201 [↑ 0.637 (112.943%)]	1.841 [↑ 0.552 (42.824%)]
9.5	0.643 [↓ 0.082 (11.310%)]	1.211 [↑ 0.647 (114.716%)]	1.854 [↑ 0.565 (43.832%)]
10.0	0.647 [↓ 0.078 (10.759%)]	1.225 [↑ 0.661 (117.199%)]	1.872 [↑ 0.583 (45.229%)]
s ($\times 10^3$)	Environmental Hazard ($\times 10^7$)		
	The Impact of the FAs	**The Impact of the EA**	**Total**
5.5	1.719 [↓ 0.088 (4.854%)]	0.0502 [↑ 0.0086 (20.703%)]	1.770 [↓ 0.079 (4.279%)]
6.0	1.715 [↓ 0.093 (5.121%)]	0.0515 [↑ 0.0099 (23.701%)]	1.766 [↓ 0.083 (4.473%)]
6.5	1.709 [↓ 0.098 (5.430%)]	0.0529 [↑ 0.0113 (27.162%)]	1.762 [↓ 0.087 (4.696%)]
7.0	1.701 [↓ 0.106 (5.878%)]	0.0545 [↑ 0.0129 (30.880%)]	1.756 [↓ 0.093 (5.051%)]
7.5	1.696 [↓ 0.111 (6.144%)]	0.0558 [↑ 0.0142 (34.057%)]	1.752 [↓ 0.097 (5.239%)]
8.0	1.697 [↓ 0.110 (6.098%)]	0.0568 [↑ 0.0152 (36.438%)]	1.754 [↓ 0.095 (5.141%)]
8.5	1.698 [↓ 0.109 (6.049%)]	0.0579 [↑ 0.0163 (39.063%)]	1.756 [↓ 0.093 (5.033%)]
9.0	1.699 [↓ 0.108 (5.973%)]	0.0586 [↑ 0.0170 (40.896%)]	1.758 [↓ 0.091 (4.917%)]
9.5	1.700 [↓ 0.107 (5.911%)]	0.0594 [↑ 0.0178 (42.659%)]	1.760 [↓ 0.089 (4.818%)]
10.0	1.702 [↓ 0.105 (5.829%)]	0.0599 [↑ 0.0183 (43.862%)]	1.762 [↓ 0.087 (4.710%)]
s ($\times 10^3$)	Social Welfare ($\times 10^7$)		
	FA-Related Social Welfare	**EA-Related Social Welfare**	**Total Welfare**
5.5	4.294 [↓ 0.297 (6.463%)]	1.532 [↑ 0.562 (57.893%)]	5.825 [↑ 0.265 (4.764%)]
6.0	4.291 [↓ 0.299 (6.511%)]	1.665 [↑ 0.695 (71.665%)]	5.957 [↑ 0.396 (7.127%)]
6.5	4.285 [↓ 0.305 (6.651%)]	1.830 [↑ 0.860 (88.625%)]	6.115 [↑ 0.554 (9.970%)]
7.0	4.282 [↓ 0.308 (6.714%)]	1.922 [↑ 0.952 (98.128%)]	6.204 [↑ 0.644 (11.576%)]
7.5	4.277 [↓ 0.313 (6.827%)]	2.043 [↑ 1.073 (110.583%)]	6.320 [↑ 0.759 (13.655%)]
8.0	**4.253 [↓ 0.337 (7.346%)]**	**2.098 [↑ 1.128 (116.260%)]**	**6.351 [↑ 0.791 (14.217%)]**
8.5	4.222 [↓ 0.368 (8.019%)]	2.127 [↑ 1.157 (119.302%)]	6.349 [↑ 0.789 (14.192%)]
9.0	4.189 [↓ 0.401 (8.746%)]	2.150 [↑ 1.180 (121.612%)]	6.338 [↑ 0.778 (13.995%)]
9.5	4.151 [↓ 0.440 (9.576%)]	2.177 [↑ 1.207 (124.398%)]	6.327 [↑ 0.767 (13.795%)]
10.0	4.118 [↓ 0.472 (10.284%)]	2.198 [↑ 1.228 (126.624%)]	6.316 [↑ 0.756 (13.599%)]

Table H: The sensitivity analysis for the impact of the subsidy s on consumers' net surplus, environmental hazard, and social welfare in the decentralized setting. Note that the mark "↑" or "↓" represents the increase (percentage increase) or decrease (percentage decrease) compared with the case of no subsidy ($s = 0$).

n	**Consumers' Net Surplus ($\times 10^7$)**		
	Total Surplus of FA Consumers [$\sum_{i=1}^{2} \Pi_{Ci}(s)$]	**Total Surplus of EA Consumers [$\hat{\Pi}_C(s)$]**	**Total Surplus of All Consumers**
30	0.6756 [↓ 0.0494 (6.814%)]	1.0531 [↑ 0.4891 (86.720%)]	1.7287 [↑ 0.4397 (34.112%)]
40	0.6653 [↓ 0.0597 (8.234%)]	1.0652 [↑ 0.5012 (88.865%)]	1.7305 [↑ 0.4415 (34.251%)]
50	0.6576 [↓ 0.0674 (9.297%)]	1.0741 [↑ 0.5101 (90.443%)]	1.7317 [↑ 0.4427 (34.344%)]
60	0.6522 [↓ 0.0728 (10.041%)]	1.0832 [↑ 0.5192 (92.057%)]	1.7354 [↑ 0.4464 (34.631%)]
70	0.6483 [↓ 0.0767 (10.579%)]	1.0995 [↑ 0.5315 (94.238%)]	1.7438 [↑ 0.4548 (35.283%)]
80	0.6452 [↓ 0.0798 (11.007%)]	1.1005 [↑ 0.5365 (95.124%)]	1.7457 [↑ 0.4567 (35.431%)]
90	0.6414 [↓ 0.0836 (11.531%)]	1.1060 [↑ 0.5420 (96.099%)]	1.7474 [↑ 0.4584 (35.562%)]
100	0.6290 [↓ 0.0960 (13.241%)]	1.1200 [↑ 0.5560 (98.582%)]	1.7490 [↑ 0.4600 (35.687%)]
110	0.6249 [↓ 0.1001 (13.807%)]	1.1247 [↑ 0.5607 (99.415%)]	1.7496 [↑ 0.4606 (35.733%)]
120	0.6211 [↓ 0.1039 (14.331%)]	1.1292 [↑ 0.5652 (100.213%)]	1.7503 [↑ 0.4613 (35.787%)]

n	**Environmental Hazard ($\times 10^7$)**		
	The Impact of the FAs	**The Impact of the EA**	**Total**
30	1.6956 [↓ 0.1115 (6.168%)]	0.0526 [↑ 0.0110 (26.438%)]	1.7482 [↓ 0.1005 (5.434%)]
40	1.6963 [↓ 0.1108 (6.132%)]	0.0529 [↑ 0.0113 (27.070%)]	1.7492 [↓ 0.0995 (5.384%)]
50	1.6972 [↓ 0.1099 (6.083%)]	0.0532 [↑ 0.0116 (27.867%)]	1.7504 [↓ 0.0983 (5.319%)]
60	1.6986 [↓ 0.1085 (6.005%)]	0.0537 [↑ 0.0121 (29.014%)]	1.7522 [↓ 0.0964 (5.217%)]
70	1.6993 [↓ 0.1077 (5.962%)]	0.0539 [↑ 0.0123 (29.574%)]	1.7533 [↓ 0.0954 (5.162%)]
80	1.7003 [↓ 0.1068 (5.909%)]	0.0542 [↑ 0.0126 (30.161%)]	1.7545 [↓ 0.0942 (5.097%)]
90	1.7007 [↓ 0.1064 (5.888%)]	0.0543 [↑ 0.0127 (30.543%)]	1.7550 [↓ 0.0937 (5.068%)]
100	1.7010 [↓ 0.1061 (5.878%)]	0.0545 [↑ 0.0129 (30.880%)]	1.7555 [↓ 0.0932 (5.051%)]
110	1.7016 [↓ 0.1055 (5.839%)]	0.0547 [↑ 0.0131 (31.446%)]	1.7563 [↓ 0.0924 (4.999%)]
120	1.7018 [↓ 0.1052 (5.823%)]	0.0549 [↑ 0.0133 (31.966%)]	1.7568 [↓ 0.0919 (4.973%)]

n	**Social Welfare ($\times 10^7$)**		
	FA-Related Social Welfare	**EA-Related Social Welfare**	**Total Welfare**
30	4.305 [↓ 0.286 (6.225%)]	1.780 [↑ 0.810 (83.502%)]	6.085 [↑ 0.524 (9.428%)]
40	4.296 [↓ 0.294 (6.409%)]	1.786 [↑ 0.816 (84.100%)]	6.082 [↑ 0.522 (9.380%)]
50	4.290 [↓ 0.300 (6.539%)]	1.799 [↑ 0.829 (85.444%)]	6.089 [↑ 0.529 (9.507%)]
60	4.287 [↓ 0.303 (6.603%)]	1.830 [↑ 0.860 (88.633%)]	6.117 [↑ 0.557 (10.011%)]
70	4.286 [↓ 0.305 (6.637%)]	1.867 [↑ 0.897 (92.510%)]	6.153 [↑ 0.593 (10.659%)]
80	4.284 [↓ 0.306 (6.665%)]	1.921 [↑ 0.951 (98.132%)]	6.205 [↑ 0.645 (11.617%)]
90	**4.283 [↓ 0.307 (6.705%)]**	**1.935 [↑ 0.965 (99.505%)]**	**6.218 [↑ 0.658 (11.823%)]**
100	4.282 [↓ 0.308 (6.714%)]	1.922 [↑ 0.952 (98.128%)]	6.204 [↑ 0.644 (11.576%)]
110	4.280 [↓ 0.310 (6.753%)]	1.921 [↑ 0.951 (98.075%)]	6.202 [↑ 0.641 (11.534%)]
120	4.278 [↓ 0.312 (6.796%)]	1.919 [↑ 0.949 (97.820%)]	6.197 [↑ 0.637 (11.454%)]

Table I: The sensitivity analysis for the impact of the number of service and charging stations (i.e., n) on consumers' net surplus, environmental hazard, and social welfare in the decentralized setting. Note that the mark "↑" or "↓" represents the increase (percentage increase) or decrease (percentage decrease) in the result for the case when $s = \$7000$ compared with the case of no subsidy ($s = 0$).

μ_β	**Consumers' Net Surplus** ($\times 10^7$)		
	Total Surplus of FA Consumers [$\sum_{i=1}^{2} \Pi_{Ci}(s)$]	**Total Surplus of EA Consumers** [$\hat{\Pi}_C(s)$]	**Total Surplus of All Consumers**
0.30	0.514 [↓ 0.211 (29.103%)]	0.572 [↑ 0.008 (1.418%)]	1.086 [↓ 0.203 (15.749%)]
0.35	0.605 [↓ 0.120 (16.552%)]	0.821 [↑ 0.257 (45.567%)]	1.426 [↑ 0.137 (10.628%)]
0.40	0.629 [↓ 0.096 (13.241%)]	1.120 [↑ 0.556 (98.582%)]	1.749 [↑ 0.460 (35.687%)]
0.45	0.729 [↑ 0.004 (0.552%)]	1.257 [↑ 0.693 (122.908%)]	1.986 [↑ 0.697 (54.088%)]
0.50	0.829 [↑ 0.104 (14.345%)]	1.389 [↑ 0.825 (146.277%)]	2.218 [↑ 0.929 (72.071%)]
0.55	0.920 [↑ 0.195 (26.897%)]	1.513 [↑ 0.949 (168.333%)]	2.433 [↑ 1.144 (88.782%)]
0.60	1.007 [↑ 0.282 (38.897%)]	1.633 [↑ 1.069 (189.539%)]	2.640 [↑ 1.351 (104.810%)]
0.65	1.088 [↑ 0.363 (50.069%)]	1.702 [↑ 1.138 (201.773%)]	2.790 [↑ 1.501 (116.447%)]
0.70	1.155 [↑ 0.430 (59.310%)]	1.804 [↑ 1.240 (219.858%)]	2.959 [↑ 1.670 (129.558%)]
0.75	1.223 [↑ 0.498 (68.690%)]	1.981 [↑ 1.417 (251.241%)]	3.204 [↑ 1.915 (148.565%)]
μ_β	**Environmental Hazard** ($\times 10^7$)		
	The Impact of the FAs	**The Impact of the EA**	**Total**
0.30	1.680 [↓ 0.127 (7.048%)]	0.046 [↑ 0.004 (9.389%)]	1.725 [↓ 0.123 (6.678%)]
0.35	1.690 [↓ 0.117 (6.476%)]	0.050 [↑ 0.009 (20.853%)]	1.740 [↓ 0.108 (5.861%)]
0.40	1.701 [↓ 0.106 (5.878%)]	0.055 [↑ 0.013 (30.880%)]	1.756 [↓ 0.093 (5.051%)]
0.45	1.707 [↓ 0.100 (5.523%)]	0.058 [↑ 0.017 (40.136%)]	1.766 [↓ 0.083 (4.495%)]
0.50	1.713 [↓ 0.094 (5.191%)]	0.060 [↑ 0.018 (43.884%)]	1.773 [↓ 0.076 (4.086%)]
0.55	1.707 [↓ 0.100 (5.536%)]	0.068 [↑ 0.026 (63.554%)]	1.775 [↓ 0.074 (3.981%)]
0.60	1.703 [↓ 0.104 (5.782%)]	0.074 [↑ 0.032 (77.424%)]	1.777 [↓ 0.072 (3.909%)]
0.65	1.696 [↓ 0.111 (6.125%)]	0.082 [↑ 0.040 (96.253%)]	1.778 [↓ 0.071 (3.820%)]
0.70	1.687 [↓ 0.120 (6.645%)]	0.094 [↑ 0.052 (125.806%)]	1.781 [↓ 0.068 (3.663%)]
0.75	1.683 [↓ 0.124 (6.844%)]	0.117 [↑ 0.076 (181.572%)]	1.800 [↓ 0.048 (2.603%)]
μ_β	**Social Welfare** ($\times 10^7$)		
	FA-Related Social Welfare	**EA-Related Social Welfare**	**Total Welfare**
0.30	4.301 [↓ 0.289 (6.297%)]	1.471 [↑ 0.501 (51.644%)]	5.772 [↑ 0.212 (3.811%)]
0.35	4.284 [↓ 0.307 (6.679%)]	1.665 [↑ 0.695 (71.686%)]	5.949 [↑ 0.389 (6.992%)]
0.40	4.282 [↓ 0.308 (6.714%)]	1.922 [↑ 0.952 (98.128%)]	6.204 [↑ 0.644 (11.576%)]
0.45	4.179 [↓ 0.412 (8.969%)]	2.032 [↑ 1.062 (109.456%)]	6.210 [↑ 0.650 (11.690%)]
0.50	4.092 [↓ 0.499 (10.860%)]	2.145 [↑ 1.175 (121.120%)]	6.237 [↑ 0.676 (12.164%)]
0.55	4.031 [↓ 0.560 (12.190%)]	2.207 [↑ 1.237 (127.559%)]	6.238 [↑ 0.678 (12.189%)]
0.60	**3.990 [↓ 0.600 (13.078%)]**	**2.276 [↑ 1.306 (134.689%)]**	**6.266 [↑ 0.706 (12.700%)]**
0.65	3.961 [↓ 0.630 (13.721%)]	2.284 [↑ 1.314 (135.458%)]	6.244 [↑ 0.684 (12.303%)]
0.70	3.935 [↓ 0.656 (14.287%)]	2.290 [↑ 1.320 (136.072%)]	6.224 [↑ 0.664 (11.943%)]
0.75	3.891 [↓ 0.700 (15.243%)]	2.307 [↑ 1.337 (137.867%)]	6.198 [↑ 0.638 (11.466%)]

Table J: The sensitivity analysis for the impact of the mean value of consumers' relative bargaining power (i.e., μ_β) on consumers' net surplus, environmental hazard, and social welfare in the decentralized setting. Note that the mark "↑" or "↓" represents the increase (percentage increase) or decrease (percentage decrease) in the result for the case when $s = \$7000$ compared with the case of no subsidy ($s = 0$).

s ($\times 10^3$)	**Supply Chain Profit** ($\times 10^7$)		
	Profit in the FA Market	**Profit in the EA Market**	**Total Profit**
5.5	5.387 [↓ 0.285 (5.031%)]	1.167 [↑ 0.319 (37.683%)]	6.554 [↑ 0.034 (0.521%)]
6.0	5.379 [↓ 0.293 (5.172%)]	1.303 [↑ 0.455 (53.728%)]	6.682 [↑ 0.161 (2.485%)]
6.5	5.366 [↓ 0.306 (5.402%)]	1.478 [↑ 0.631 (74.398%)]	6.844 [↑ 0.324 (4.972%)]
7.0	5.354 [↓ 0.318 (5.613%)]	1.574 [↑ 0.726 (85.701%)]	6.928 [↑ 0.408 (6.258%)]
7.5	5.342 [↓ 0.330 (5.825%)]	1.706 [↑ 0.859 (101.286%)]	7.048 [↑ 0.528 (8.100%)]
8.0	5.317 [↓ 0.355 (6.265%)]	1.771 [↑ 0.923 (108.943%)]	7.088 [↑ 0.568 (8.712%)]
8.5	5.284 [↓ 0.388 (6.847%)]	1.808 [↑ 0.960 (113.308%)]	7.092 [↑ 0.572 (8.773%)]
9.0	5.248 [↓ 0.424 (7.482%)]	1.847 [↑ 0.999 (117.909%)]	7.095 [↑ 0.575 (8.819%)]
9.5	5.208 [↓ 0.464 (8.187%)]	1.895 [↑ 1.047 (123.572%)]	7.103 [↑ 0.583 (8.942%)]
10.0	5.173 [↓ 0.499 (8.804%)]	1.932 [↑ 1.084 (127.938%)]	7.105 [↑ 0.585 (8.972%)]
	Supply Chain Profit ($\times 10^7$)		
n	**Profit in the FA Market**	**Profit in the EA Market**	**Total Profit**
30	5.325 [↓ 0.348 (6.131%)]	1.206 [↑ 0.359 (42.331%)]	6.531 [↑ 0.011 (0.169%)]
40	5.327 [↓ 0.345 (6.087%)]	1.242 [↑ 0.394 (46.520%)]	6.569 [↑ 0.049 (0.752%)]
50	5.330 [↓ 0.343 (6.042%)]	1.288 [↑ 0.441 (51.994%)]	6.618 [↑ 0.098 (1.503%)]
60	5.334 [↓ 0.339 (5.973%)]	1.353 [↑ 0.506 (59.674%)]	6.687 [↑ 0.167 (2.561%)]
70	5.337 [↓ 0.336 (5.918%)]	1.420 [↑ 0.573 (67.567%)]	6.757 [↑ 0.237 (3.635%)]
80	5.340 [↓ 0.333 (5.869%)]	1.512 [↑ 0.664 (78.327%)]	6.851 [↑ 0.331 (5.077%)]
90	5.342 [↓ 0.331 (5.828%)]	1.560 [↑ 0.713 (84.096%)]	6.902 [↑ 0.382 (5.862%)]
100	5.354 [↓ 0.318 (5.613%)]	1.574 [↑ 0.726 (85.701%)]	6.928 [↑ 0.408 (6.258%)]
110	5.357 [↓ 0.315 (5.560%)]	1.610 [↑ 0.763 (89.995%)]	6.967 [↑ 0.447 (6.862%)]
120	5.359 [↓ 0.313 (5.523%)]	1.645 [↑ 0.797 (94.066%)]	7.004 [↑ 0.484 (7.423%)]
	Supply Chain Profit ($\times 10^7$)		
μ_β	**Profit in the FA Market**	**Profit in the EA Market**	**Total Profit**
0.30	5.467 [↓ 0.205 (3.621%)]	1.610 [↑ 0.762 (89.948%)]	7.077 [↑ 0.557 (8.543%)]
0.35	5.369 [↓ 0.304 (5.352%)]	1.588 [↑ 0.740 (87.353%)]	6.957 [↑ 0.437 (6.699%)]
0.40	5.354 [↓ 0.318 (5.613%)]	1.574 [↑ 0.726 (85.701%)]	6.928 [↑ 0.408 (6.258%)]
0.45	5.157 [↓ 0.516 (9.088%)]	1.573 [↑ 0.725 (85.583%)]	6.730 [↑ 0.210 (3.219%)]
0.50	4.976 [↓ 0.696 (12.275%)]	1.565 [↑ 0.717 (84.639%)]	6.541 [↑ 0.021 (0.324%)]
0.55	4.818 [↓ 0.855 (15.066%)]	1.559 [↑ 0.711 (83.931%)]	6.377 [↓ 0.143 (2.196%)]
0.60	4.686 [↓ 0.987 (17.397%)]	1.548 [↑ 0.700 (82.633%)]	6.234 [↓ 0.286 (4.393%)]
0.65	4.569 [↓ 1.104 (19.454%)]	1.540 [↑ 0.692 (81.689%)]	6.109 [↓ 0.411 (6.305%)]
0.70	4.467 [↓ 1.206 (21.259%)]	1.528 [↑ 0.680 (80.274%)]	5.995 [↓ 0.526 (8.060%)]
0.75	4.351 [↓ 1.321 (23.295%)]	1.527 [↑ 0.679 (80.156%)]	5.878 [↓ 0.642 (9.847%)]

Table K: The allocation of supply chain profit in the FA and the EA markets. Note that the mark "↑" or "↓" represents the increase (percentage increase) or decrease (percentage decrease) compared with the case of no subsidy ($s = 0$).