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Optimal Supply of New Energy Vehicles With Subsidizing Under Demand Uncertainty

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Abstract

For increasing the production of new energy vehicles, government's subsidy policy was implemented in the early stage of its development. This paper considers consumer subsidies and manufacturer subsidies, and modeling to compare the manufacturer's optimal production and profit of two subsidy mechanisms under certainty and uncertainty demand. Research shows manufacturer's supply and profit are the same under two subsidies with certain demands; we also show that the production supply is not always decreased with the increase of demands' uncertain, and compare to manufacturer subsidies, consumer subsidies is more benefit the production of new energy vehicles for government.

Key words: New energy vehicle; Consumer subsidies; Manufacturer subsidies; Demand uncertainty

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INTRODUCTION

Recently, energy shortage and environmental pollution problems are becoming more serious, and have captured the attention of the public and government. For the sustainable development of society, to ease the energy crisis and improve air pollution, the government began to promote updating of automobile industry. For example, new energy vehicles have received significant interest in the last decade. However, in the early development of new energy vehicles, the factors such as restriction of core technologies, high cost of new energy vehicles, low acceptance of consumers and so on, restrict its development. Therefore, the government offers subsidies to promote the development of new energy vehicles. During The 12th Five-Year Plan, our government issued "energy saving and new energy automotive industry development plan (2012-2020)", offering subsidies to expand the market demand.

Currently, numerous papers focus on subsidy. Lobel and Perakis (2013) had research on the problem of optimizing subsidy policies for solar panels and present an empirical work of the German solar market. Alizamir et al. (2013) study the feed-in-tariff design problem, comparing strategies for welfare maximization and adoptions targets. Ovchinnikov and Raz (2013) study the public goods price problem with considering government subsidy. The authors compare different government intervention mechanisms and study under what conditions the system are coordinated with considering welfare. Zhou (2010) compare, for the case of certainty demand, different subsidy mechanisms.

Considering the subsidy policies for new energy vehicles, there is a significant amount of empirical work in the literature. For example, Gallagher and Muehlegger (2011) show that for hybrid cars, sales tax-free are more effective than income tax income tax credits. Sierzchula et al. (2014) present an empirical study of different countries, show that electric cars adoption rates are strongly correlated with financial incentives and charging infrastructure. Cheng (2010) shows that governments offer tax concessions and subsidy to promote the new energy vehicles industry after comparing the automotive industry policy of domestic and foreign. Sun et al. (2011) explore the ways to improve the effectiveness of subsidies by analyzing the existing subsidies policy for electric vehicles for domestic and foreign. Yang (2012) present an empirical study of the impact of government subsidy and tax exemptions, infrastructure investment and electric vehicles R&D on consumers' willingness to buy. Wang et al. (2013) the asymmetry of information will increase the motivation of enterprises strategic acquisition of subsidies, and bring a negative impact on the development of new energy vehicles.

Also in literature, one can find a vast amount of papers that focus on modeling research. Xiao (2014) compare, for the case of deterministic demand, different government subsidies mechanisms and study the impact of government subsidies on the demand and supply chain of new energy vehicles. For the new energy vehicles supply chain, Zhang and Wang (2015) analyze the impact of government subsidies on consumers and use Shapley value method to solve the problem of profit distribution of supply chain members. Zhang, Sheng and Meng (2015) use multi-agent method to study the problem of how the sales efforts of new energy vehicles can be encouraged with the government subsidy.

2012, our government announced the "energy saving and new energy automotive industry development plan", note than the production of new energy vehicles will reach 2 million by 2020. Based on this, in our model the government is assumed to have an objective to maximize the quantities of new energy vehicles in the market. Our goals are (a) to study if the impact of demand on the manufacturer subsidy mechanism and consumer subsidy mechanism and (b) to compare the outcomes of both mechanisms.

1. PROBLEM DESCRIPTION

For the problem of subsidizing the new energy vehicles, government makes the decision of subsidizing the manufacturer's cost or the consumer. Offering subsidies directly to the manufacturer can be implemented by partially sharing the cost of production or in form of loans or free capital to the supplier. Offering rebates to the end consumers can expand the demands and improve consumer acceptance of new energy vehicles. We assume a single time period model with a unique supplier and consider a full information setting (see Figure 1). The government decides subsidy object and the supplier follows by setting the price *p* and production quantities *Q* to maximize his/her profit.

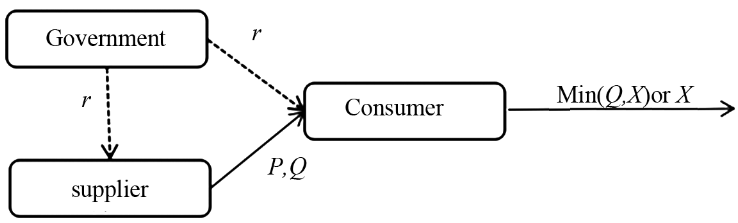

Figure 1
Model

The variables and assumptions involved in this paper as follows:

p : the price of new energy vehicles
Q : the quantity of new energy vehicles
X : the demand of new energy vehicles
c : the cost of new energy vehicles
s : the subsidy of new energy vehicle
b : price-sensitive factor

Assuming $c<p<2c$ for the high cost of new energy vehicles.

2. CERTAINTY DEMAND MODEL

This part considers linear and nonlinear demand respectively, compare the optimal price, outcome and profit of new energy vehicles of subsidy mechanism and consumer subsidy mechanism.

2.1 Linear Demand, Assuming the Demand of New Energy Vehicles Is *X=a-b*p*

(a) Subsidizing the consumer

The government provides a rebates s to consumers, given the subsidy level *s*, the supplier faces the following profit maximization problem.

$$\pi_c = \max_{p,q}(p_c - c)*[a - b*(P_c - s)] .$$

(b) Subsidizing the manufacturer

Instead of offering rebates to the end consumers, the government provides a subsidy *s*, directly to the manufacturer. Given a subsidy level *s* announced by the government, the supplier faces the following profit maximization problem.

$$\pi_m = \max_{p,q}[p_m - (c - s)]*(a - b*P_m) .$$

THEOREM 1. Assume a linear demand, the comparisons for the manufacturer and consumer subsidy mechanism are given by:

$$p_c - s = p_m = \frac{a + (c - s)b}{2b},$$

$$Q_c = Q_m = \frac{a - (c - s)b}{2},$$

$$\pi_c = \pi_m = \frac{[a - (c - s)b]^2}{4b} .$$

Remark 1. For linear deterministic demand, the quantity and profit of supplier are the same of both subsidy mechanisms.

2.2 Nonlinear Demand, Assuming the Demand of New Energy Vehicles Is $X=a*p^{-b}$, $b>1$

(a) Subsidizing the consumer

The government provides a rebates s to consumers, given the subsidy level s, the supplier faces the following profit maximization problem.

$$\pi_c = \max_{p,q} (p_c - c)*a*(P_c - s)^{-b} .$$

(b) Subsidizing the manufacturer

Instead of offering rebates to the end consumers, the government provides a subsidy s, directly to the manufacturer. Given a subsidy level s announced by the government, the supplier faces the following profit maximization problem.

$$\pi_m = \max_{p,q} [p_m - (c-s)]*a*P_m^{-b} .$$

THEOREM 2. Assume a nonlinear demand, the comparisons for the manufacturer and consumer subsidy mechanism are given by:

$$Q_c = Q_m = a[\frac{(c-s)b}{b-1}]^{-b},$$

$$\pi_c = \pi_m = \frac{a}{b}[\frac{(c-s)b}{b-1}]^{1-b} .$$

Remark 2. For nonlinear deterministic demand, the quantity and profit of supplier are the same of both subsidy mechanisms.

3. UNCERTAINTY DEMAND MODEL

We denote that the total demand X of new energy vehicles follows a stochastic distribution with density function (pdf), $f(x)$, and cumulative distribution function (cdf) $F(x)$. And the manufacturer is price taker.

3.1 Subsidizing the Consumer

Assuming the subsidy s only influences the mean value of the demand. Then the pdf of the demand with subsidy is $f_s(x)=f(x-s)$ and the cdf is $F_s(x)=F(x-s)$.

Therefore, the profits of the manufacturer as follows:

$$\pi_c = \max_{p,q} p_c * \min(Q, X(s)) - cQ .$$

3.2 Subsidizing the Manufacturer

In this case, the government provides a subsidy s directly to the manufacturer, so the manufacturer's cost is $c-s$, therefore the profits of the manufacturer as follows:

$$\pi_m = \max_{p,q} p * \min(Q, X) - (c-s)Q .$$

3.3 Analysis

This paper uses the uniform distribution on $[u-\sigma, u+\sigma]$ ($u>\sigma$)to describe the new energy vehicles demand without subsidy. Then we have

$$f(x)=1/(2\sigma),\ F(x)=(x-u+\sigma)/(2\sigma) .$$

Therefore, the optimal expressions as follows:

$$Q_c = s+u+K ,\ Q_m = u+K+\frac{2\sigma s}{p} .$$

$$\pi_c = (p-c)(s+F^{-1}(\frac{p-c}{p})) - p\int_0^{s+F^{-1}(\frac{p-c}{p})} F(x-s)\mathrm{d}x$$
$$= (p-c)(s+u+K) - p(\frac{K^2-(s+u)^2+2\sigma K}{4\sigma} + \frac{s+u}{2}).$$

$$\pi_m = (p-(c-s))F^{-1}(\frac{p-(c-s)}{p})) - p\int_0^{F^{-1}(\frac{p-(c-s)}{p})} F(x)\mathrm{d}x$$
$$= (p-c+s)(u+K+\frac{2\sigma s}{p}) - \frac{p}{4\sigma}[(u+K+\frac{2\sigma s}{p})^2 + 2(\sigma-u)(u+K+\frac{2\sigma s}{p})] .$$

Where K is defined as: $K = \sigma - \frac{2\sigma c}{p}$.

Corollary 1.

a) $\frac{\mathrm{d}Q_c}{\mathrm{d}\sigma} = 1 - \frac{2c}{p} < 0$, $\frac{\mathrm{d}\pi_c}{\mathrm{d}\sigma} < 0$,

b) $\frac{\mathrm{d}Q_m}{\mathrm{d}\sigma} = 1 - \frac{2(c-s)}{p}$, $\frac{\mathrm{d}\pi_m}{\mathrm{d}\sigma} = \frac{p}{4}(1-\frac{u^2}{\sigma^2}) + (c-s)(\frac{c-s}{p} - 1) < 0$,

c) $Q_c - Q_m = s - \frac{2\sigma s}{p} = (1-\frac{2\sigma}{p})s$, $\frac{\mathrm{d}(Q_c - Q_m)}{\mathrm{d}\sigma} = -\frac{2s}{p} < 0.$

Corollary 1 shows that for stochastic demand, profit of supplier is always decrease with the increase of uncertainty. But if s is big enough, the quantity of new energy vehicles will be increase with the increase of uncertainty, this shows that when profit margins are smaller, the government should to increase the subsidy amount and share a larger part of risk to boost quantity.

3.4 Computational Results

In this section, we present some numerical examples to illustrate the results found in the previous sections and to provide further insights. We consider that

p=42000, c=36000,

u=40000, σ=5000-30000,

s=10000 or s=16000.

Considering the impact of different values of on quantity and profit of both mechanisms. The plots are reported in Figure 2.

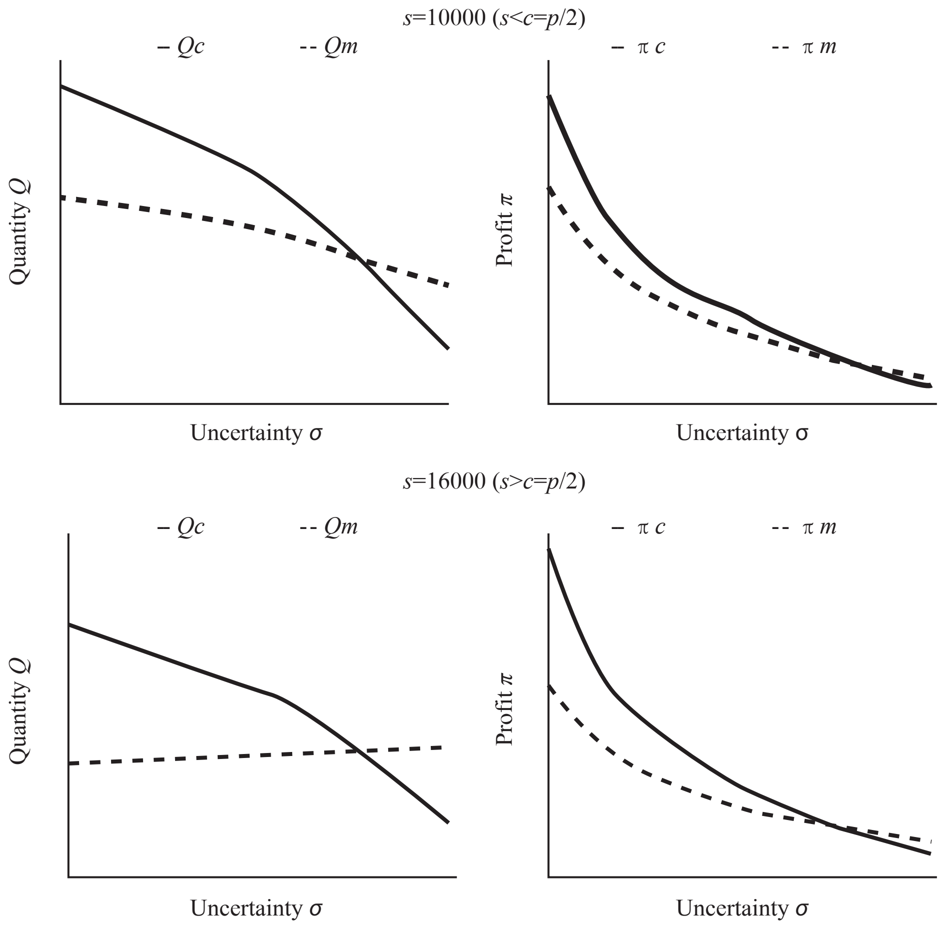

Figure 2
Optimal Quantity and Profit

As can be seen from Figure 2, when s=10000(s<c-p/2), the optimal production and profits of both mechanisms are reduced with the increase of uncertainty. When s=16000 (s>c-$p/2$), for manufacturer subsidies, the optimal production is increased with the increase of uncertainty. Also it can be seen that, in most cases ($2\sigma<p$), comparing the manufacture subsidy, the government offer subsidy to the consumers, the quantities and the profits of the supplier are greater. If $2\sigma>p$, the demand uncertainty is large, the Government should share a large pare of the risk and offer subsidies to manufacture, to compensate for uncertain demand.

CONCLUSION

With the lack of energy, the development of new energy automotive industry can ease the pressure of energy crisis. The government offers subsidies in the early stage of new energy automotive industry. We propose a model to analyze the interaction between the government and the supplier when comparing different government subsidy mechanisms.

Focusing on the deterministic demand model, we find that the price consumers paid and the quantity manufacturer sold of both mechanisms are the same. For higher cost of new energy vehicles, the government will need to increase the subsidy amount. We also evaluate the uncertainty impact on supplier, it is found that the outcomes of new energy vehicles decreases with the increase of uncertainty, but consumer subsidy is more useful than manufacturer subsidy to increase the quantities of new energy vehicles. But when the uncertainty is big enough, the government should offer subsidy to supplier and pay a large share for the risk.

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