R&D Investment Strategies for New Energy Vehicles Firm Based on Consumers’ Preference and Government Subsidy

Y Wang1, W D Meng1, Y Y Li2, B Huang1* and C Y Wang1

1 School of Business and Economics, Chongqing University, Chongqing, China
2 School of Economics and Management, Chongqing Normal University, Chongqing, China
E-mail: huangbo@cqu.edu.cn

Abstract. Under the assumption that the emergence and expansion of the new energy vehicles market is due to consumer groups entering market sequentially, and the size and characteristics of each consumer group are different, this paper proposes the R&D investment model of a new energy vehicles firm based on product subsidy. The firm’s optimal R&D investment and pricing strategies are given through theoretic analysis. It is found that when the initial value of the firm’s marginal profits is positive, the optimal R&D investment strategy is to make its marginal profits equal zero if its R&D funds is sufficient enough, otherwise, the optimal R&D investment strategy is its whole R&D funds. And when the initial value of the firm’s marginal profits is non-positive, its optimal R&D investment strategy is zero. It is also found that there is a crowding-in effect of product subsidy on the firm’s R&D investment under two conditions: only if the unit product subsidy is large enough when the firm doesn’t conduct R&D without subsidy, and if only the firm has surplus R&D funds when the firm has conducted R&D without subsidy.

1. Introduction
Crude oil dependence and environmental pollution are inevitable disadvantages of traditional automobiles, so new energy vehicles (NEVs) have become the development direction of the automotive industry due to energy conservation and environmental protection [1-2]. The recent developments of NEVs have captured the interest of the public and private sectors, though as the main bearers of NEVs technology R&D, firms usually are unwilling to increase their R&D investment because of low profits or lack of R&D funds [3-4]. Governments hope to foster further research and scale economies of NEVs firms, and product subsidy policy is often introduced by governments to solve these problems [5-6]. However, the product subsidy policy doesn’t reach the expected targets of governments, such as a product subsidy program for NEVs firms in China. Therefore, how to encourage NEVs firms to increase R&D investment through product subsidy is a realistic issue for the NEVs development.

Many scholars have studied the R&D investment strategies of NEVs firms with government subsidy, while very few of them pay attention to the R&D investment strategies with the method of product subsidy. Cao et al. found that government subsidy helps NEVs firms overcome technology barriers and conduct original breakthroughs [7]. Ma et al. found that government subsidy can encourage battery firms increasing R&D investment based on a supply chain integration decision-making model [8]. Both Li et al. and Xiong et al. found that government subsidy has an incentive effect on NEVs firms’ R&D investment, but this effect is inverse “U-shaped” with subsidy intensity [9-10]. Jiang et al. found that if the sample of NEVs firms is divided into two categories, the government subsidy has a...
positive impact on the assembly firms, while it has no such effect on supporting firms [11]. With the emergence of various methods of subsidy policies for NEVs developments, some scholars begin to study the effect of a certain method of government subsidy, or compare effects of two different methods of government subsidy. Albrecht found that although R&D investment subsidy has a significant incentive on environmental technology R&D, such as NEVs technology R&D, it may create a barrier for new entrants with no access receiving subsidy [12]. Liu and Zhao found that the product subsidy stimulates NEVs technological progress in the early stage of NEVs developments, while the R&D investment subsidy for basic and common technologies has an incentive effect in the mature stage [13]. Jin et al. found that the incentive effect of product subsidy policy on technology breakthroughs will be weakened by its effect on NEVs popularization, as the former is different to measure while the latter is highly measurable [14].

However, all these literatures above don’t involve the significant characteristics that different NEVs consumer groups with own characteristics and preferences enter market sequentially. In reality, some scholars have studied the grouping phenomenon of NEVs consumers, while more scholars have explored the characteristics of NEVs consumers [15]. Xiong et al. divided NEVs consumers into two groups, leading group and following group [16]. Moore found that there are a total of five consumer groups in NEVs market, that is, the innovators, the early adopters, the early majority, their later majority and the laggards, and the current consumers group is the early adopters [17]. Huang and Qian found that NEVs consumers are more sensitive to purchasing price, subsidy and coverage of charging stations in third-tier cities of China, while consumers pay attention to monetary attributes, charging service and driving range in lower-tier cities [18]. Javid and Nejat found that consumers’ household income, maximum level of education, charging stations density and gas price affect NEVs consumers’ purchase intention in California [19]. Krupa et al. found that financial and battery-related concerns remain major obstacles to widespread NEVs market penetration [20]. Cecere et al. found that the first most important factor affecting purchase intention is NEVs price reduction, the second is improvement in the driving range, and the third is the possibility of recharging at home in European countries [21].

However, all the literatures above do not consider the impact of product subsidy on NEVs firms R&D investment strategies.

This paper has the following main contributions. Considering that different NEVs consumer groups with own characteristics and preferences enter NEVs market sequentially, this paper develops the NEVs firm’s R&D investment model based on characteristics of current consumer group and product subsidy from governments. Through the theoretic analysis and solving, the firm’s optimal R&D investment and pricing strategies are given. Besides, the effect of product subsidy on NEVs firm’s R&D investment is obtained. The conclusions of this paper can give suggestions to NEVs firms and governments to make relative decisions.

The rest sections are organized as follows. In section 2, we develop the model. In section 3, the optimal pricing and R&D investment strategies are obtained. The product subsidy effect on the firm’s R&D investment is discussed in section 4. Finally, the conclusions of this paper are given.

2. The model

2.1. Problem description

An NEVs firm plans to develop a new type of NEV. First of all, the firm makes its R&D investment decision. The decision should base on the characteristics of the current NEVs consumers group, including of their demands on the technologies and performances of NEVs, and the top NEVs price can be received. The firm found that it is the early adopters group in current NEVs market, and its significant characteristics are requiring improved technologies to bring new and practical functions to match their needs, such as better endurance technology bringing further extended cruising range, while the improved charging technology bringing shorter charging time, etc. In other words, only by continuously providing higher technologies can bring a corresponding expansion of the market size for this group. Besides, the marginal utility of technology growth is diminishing, that is, the same degree of technological progress can cause the less growth rate of NEVs market size. The firm also found that there is an upper limit of NEVs price that the current consumers can receive, because that no essential
functions difference exists between NEVs and traditional automobiles, and the traditional automobile price has become an important reference for NEVs price. After the NEVs firm acquires the characteristics and demands of the current NEVs consumers group, it makes the R&D investment decision according to the characteristics and demands of the current group, as well as its current technology level, its capability of R&D, the amount of its R&D funds. In reality, in the current stage of NEVs developments, the low profits and lack of R&D funds are two main factors hindering the firms to invest more in R&D. So the government decides to implement a product subsidy policy to the firm. That is, it gives the firm a fixed amount of subsidy funds when an NEV is sold. In following sections, we solve the NEVs firm’s optimal pricing and R&D investment strategies. Besides, we also obtain the effect of product subsidy on the firm’s R&D investment.

2.2. The model
The NEVs firm develops a new type of NEVs based on the existing technological level $T_0$, and its technological level function with the firm’s R&D investment as $T = T(i)$, which satisfies $T(0) = T_0$, $T_i = dT/di > 0$ and $T_{ii} = d^2T/di^2 < 0$. Namely, the firm’s whole available R&D funds is limited, which is $\overline{i}$. After the firm finishes the NEVs technology R&D, it produces new NEVs in the unit production cost of $c$, which is a positive constant. As the significant characteristics of current consumers are that they required improved technology to bring practical functions matching their needs, the market size or demands function with NEVs technological level as $a = a(T)$, which satisfies $a(T_0) = a_0$, $a_i = da/dT > 0$, $a_{ii} = d^2a/dT^2 < 0$, where $a_0$ is fixed constant. Namely, the upper limit of acceptable price of the current consumers is $p_0$. Therefore, the demands or sales volume function as

$$q(i,p) = p_0^{-1}a(i)(p_0-p). \quad (1)$$

In order to encourage the firm to commit more R&D funds, the government provides product subsidy to it. That is, the government gives the firm a fixed amount $s$ when an NEV is sold. Then, the firm’s profits as

$$\pi(i,p) = (p-c+s)q(i,p) - i. \quad (2)$$

where the item of $p-c+s$ on the right side is the unit product revenue. Further, let $\pi_o$ be the firm’s profits that it does not conduct R&D.

3. Optimal pricing and R&D investment strategies
Firstly, we obtain the optimal pricing strategy of the NEVs firm. Let the firm’s optimal pricing be $p^*$, and we get proposition 1 as follow.

**Proposition 1.** Regardless of the NEVs firm’s R&D investment, it always prices at a fixed constant, or $p^* = (p_0 + c-s)/2$.

**Proof of Proposition 1.** Take the first and second order partial derivative of the firm’s profits to the price as $\pi_p = \partial \pi / \partial p = p_0^{-1}a(p_0 + c-s - 2p)$ and $\pi_{pp} = \partial^2 \pi / \partial p^2 = -2p_0^{-1}a < 0$. Then, let $\pi_p = 0$, and we get the optimal pricing of NEV as

$$p^* = (p_0 + c-s)/2. \quad (3)$$

Q.E.D.

It is obvious that the increasing of the firm’s R&D investment improves the technological level of NEVs. Although higher technological level brings more consumers of the early adopters group, it doesn’t increase the highest price that the current consumers can receive. Therefore, the firm’s optimal pricing won’t change if the unit product subsidy does not change. Moreover, the firm’s marginal profits equals NEVs price minus its marginal R&D investment and its unit production cost, since the production cost is also constant, the changes of the marginal profits are actually determined by the
marginal R&D investment.

**Lemma 1.** The firm’s marginal profits always decreases with its R&D investment.

**Proof of Lemma 1.** From \( T_a > 0, T_T < 0, T_i < 0 \) and \( T_a > 0 \), we can get \( a_i = a_T T_i > 0 \) and \( a_{ii} = a_T T_{ii} > 0 \). Further, from \( \lim_{i \to \infty} T_i = 0 \), we can get \( \lim_{i \to \infty} a_i = 0 \). As \( a_i > 0 \), \( a_{ii} < 0 \) and \( \lim_{i \to \infty} a_{ii} = 0 \), there is \( \lim_{i \to \infty} a = \bar{a} \). Substitute \( p^* \) into equation (2), we can get the firm’s profits and sales as \( \pi(q) = (p^* - c + s)q - i(q) \) and \( q(i) = p_0^{-1} \left( p_0 - p^* \right) \alpha(i) \). According to the derivative rule of inverse function, we can get \( i_q = q_i^{-1} = p_0 \left( p_0 - p^* \right)^{-1} a_i = 1 > 0 \) and \( i_{ii} = -p_0 \left( p_0 - p^* \right)^{-1} a_{ii} > 0 \).

Further, \( \pi_q = d\pi/dq = p^* - c + s - i_q \) and \( \pi_{qi} = -i_{qi} < 0 \).

**Q.E.D.**

The utility of R&D investment for improving NEVs technologies becomes less and less with the increasing of R&D investment. Though both the firm’s optimal pricing and the unit production cost are fixed constant. Therefore, with increasing of the firm’s R&D investment, the marginal R&D investment increases incrementally. Meanwhile, the firm’s marginal profits decreases diminishingly.

Then, we obtain the NEVs firm’s optimal R&D investment strategies. Let \( i \) be the firm’s optimal R&D investment, and we get proposition 2 as follow.

**Proposition 2.** The NEVs firm’s optimal R&D investment strategies as follows:

(a) When the initial value of the firm’s marginal R&D investment is lower than the unit product revenue, if the firm’s R&D funds is sufficient, its optimal R&D investment strategy is to make its marginal R&D investment equal the unit product revenue, otherwise, its whole available R&D funds;

(b) When the initial value of the firm’s marginal R&D investment is no lower than the unit product revenue, its optimal R&D investment strategy is zero.

**Proof of Proposition 2.** When the initial value of marginal R&D investment is no lower than the unit product revenue, or \( i_q \bigg|_{i \to 0} \geq p^* - c + s \), we can get that the firm’s marginal profits is always non-positive, or \( \pi_q \leq 0 \). That is, the unit product profits always decreases with the firm’s R&D investment, and the highest profits is that without R&D, or \( \pi_0 \). In the other words, the firm’s optimal R&D investment strategy is \( i^* = 0 \).

When the initial value of marginal R&D investment is lower than the unit product revenue, or \( i_q \bigg|_{i \to 0} < p^* - c + s \), there is a point of \( i_k \), where \( i_k = p^* - c + s \) and the firm gets the top profits. Before \( i_k \), there is \( i_q < p^* - c + s \). And the unit product profits increases with the firm’s R&D investment. After \( i_k \), there is \( i_q > p^* - c + s \). And the unit product profits decreases with the firm’s R&D investment. From \( \pi_0 > 0 \), we know that the firm’s highest profits is positive, or \( \pi_q \bigg|_{i \to 0} > 0 \). Therefore, the firm’s optimal R&D investment strategy is \( i^* = i_k \) if it has enough R&D funds, otherwise, \( i^* = \bar{i} \).

In sum, the firm’s optimal R&D investment strategies as

\[
\begin{align*}
\begin{cases}
0 & i_q \bigg|_{i \to 0} \geq p^* - c + s \\
0 & i_q \bigg|_{i \to 0} < p^* - c + s \text{ and } \bar{i} > i_k
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\begin{cases}
\bar{i} & i_q \bigg|_{i \to 0} < p^* - c + s \text{ and } \bar{i} \leq i_k
\end{cases}
\end{align*}
\]

**Q.E.D.**

When the initial value of the firm’s marginal R&D investment is no lower than the unit product revenue, the firm doesn’t conduct R&D investment as its profits is decreasing with R&D investment. Although product subsidy increases the firm’s unit product revenue, the marginal R&D investment is still too high to make the firm benefit.

When the initial value of marginal R&D investment is lower than the unit product revenue, the firm’s profits increases first and then decreases with the increasing of its R&D investment, and there is a
maximum profits. If the firm’s whole available R&D funds is more than the amount of R&D investment that makes it achieve the maximum profits, its optimal R&D investment strategy is this amount, otherwise, the firm’s optimal R&D investment strategy is to commit its whole R&D funds to obtain as much profits as possible.

4. The effect of product subsidy

Let \( i^N, p^N, i^N_i \) be the corresponding \( i^*, p^*, i \) without product subsidy respectively. For lemma 1, it is also correct if the government doesn’t provide product subsidy to the NEVs firm. Then, referring to section 3, we can get the NEVs firm’s optimal R&D investment strategies without product subsidy as

\[
i^N = \begin{cases} 
0 & i_q \mid i = 0 \geq p^N - c \\
i^N_i & i_q \mid i = 0 < p^N - c \text{ and } \bar{T} > i^N_i \\
\bar{t} & i_q \mid i = 0 < p^N - c \text{ and } \bar{T} \leq i^N_i
\end{cases}
\] (5)

Further, by comparing equation (4) and equation (5), we can find the changes of the firm’s optimal R&D investment strategies with and without product subsidy. Let \( \Delta' \) be the difference between the firm’s optimal R&D investment with and without product subsidy, and we get proposition 3 as follow.

**Proposition 3.** There is a crowding-in effect of product subsidy under two conditions:
(a) When the firm does not conduct R&D without product subsidy, the unit product subsidy should be large enough;
(b) When the firm conducts R&D even without product subsidy, it still has surplus R&D funds with product subsidy.

| R&D investment without product subsidy | R&D investment with product subsidy | The crowding-in effect |
|--------------------------------------|-----------------------------------|------------------------|
| \( i_q \mid i = 0 \geq p^N - c \)     | \( i_q \mid i = 0 \geq p^* - c + s \) | \( \Delta' = 0 \)       |
| \( i_q \mid i = 0 \geq p^N - c \)     | \( i_q \mid i = 0 < p^* - c + s \text{ and } \bar{T} > i^N_i \) | \( \Delta' = i_i \) |
| \( i_q \mid i = 0 \geq p^N - c \)     | \( i_q \mid i = 0 < p^* - c + s \text{ and } \bar{T} \leq i^N_i \) | \( \Delta' = \bar{t} \) |
| \( i_q \mid i = 0 < p^N - c \text{ and } \bar{T} \geq i^N_i \) | \( i_q \mid i = 0 < p^* - c + s \text{ and } i^N_i < i^N < \bar{T} \) | \( \Delta' = i_i - i^N_i \) |
| \( i_q \mid i = 0 < p^N - c \text{ and } \bar{T} < i^N_i \) | \( i_q \mid i = 0 < p^* - c + s \text{ and } i^N \leq \bar{T} < i^N \) | \( \Delta' = \bar{T} - i^N_i \) |
| \( i_q \mid i = 0 < p^N - c \text{ and } \bar{T} < i^N_i \) | \( i_q \mid i = 0 < p^* - c + s \text{ and } i^N < \bar{T} < i^N \) | \( \Delta' = 0 \) |

**Proof of Proposition 3.** Firstly, we prove that if the NEVs firm conducts R&D without product subsidy, its optimal R&D investment is always lower than that with product subsidy, or \( i^N_i < i_i \).

From equation (4), we know that there is \( i_q \mid i = 0 < p^N - c \) if the firm conducts R&D without product subsidy. Namely, from equation (3), we know \( p^N = (p_0 + c)/2 \) and \( p^N - p^* = s/2 \). Further, we can get \( i_q = p_0 (p_0 - p^N)^{-1} a_i^{-1} \). Therefore, the only possible condition with product subsidy is \( i_q \mid i = 0 < p^* - c + s \). That is, \( i_q \mid i = 0 < p^N - c < p^* - c + s \).
When there is $i = i^N_i$ without product subsidy, $i_q = p^{**} - c$ and $a_i = p_0 \left( p_0 - p^{**}\right)^{-1} \left( p^{**} - c\right)^{-1}$.

Similarly, when there is $i = i_i$ with subsidy, $i_q = p^* - c + s$ and $a_i = p_0 \left( p_0 - p^*\right) \left( p^* - c + s\right)^{-1}$. As $p_0 \left( p_0 - p^*\right) \left( p^* - c + s\right)^{-1} < p_0 \left( p_0 - p^{**}\right) \left( p^{**} - c\right)^{-1}$, from $a_i < 0$, we can get $i^N_i < i_i$.

Then, compare equation (4) and equation (5), we get the crowding-in effect of product subsidy on the firm’s R&D investment. Please see table 1.

Q.E.D.

Proposition 3 shows that the crowding-in effect of product subsidy on the NEVs firm’s R&D investment is determined by two factors, one is whether the firm’s marginal R&D investment is lower than the unit product revenue with product subsidy, the other is whether the firm has sufficient enough available R&D funds. When the firm’s marginal R&D investment is higher than the unit product revenue with product subsidy, the only case is that the firm doesn’t conduct R&D. When the firm’s marginal R&D investment is lower than the unit product revenue with product subsidy, product subsidy has a crowding-in effect if only the firm hasn’t run out its R&D funds. If the firm has exhausted its whole R&D funds, there is no crowding-in effect as financial constraints.

5. Conclusions

Considering that different NEVs consumer groups with own characteristics and preferences enter NEVs market sequentially, we propose a R&D investment model of a new energy vehicles firm with product subsidy. Based on the model, we solve the firm’s optimal R&D investment and pricing strategies. Besides, the effect of product subsidy on firm’s R&D investment is obtained.

We show that when the initial value of the firm’s marginal R&D investment is lower than the unit product revenue, if the firm’s R&D funds is sufficient, its optimal R&D investment strategy is to make its marginal R&D investment equal the unit product revenue, otherwise, its whole available R&D funds. When the initial value of the firm’s marginal R&D investment is no lower than the unit product revenue, its optimal R&D investment strategy is zero. We also show that there is a crowding-in effect of product subsidy under two conditions. One is that only if the unit product subsidy is large enough when the firm doesn’t conduct R&D without subsidy, and the other is that if only the firm has surplus R&D funds when the firm has conducted R&D without subsidy.

6. References

[1] Li W, Long R, Chen H 2016 Energ. Policy 99 33
[2] Xu L, Su J 2016 Energ. Policy 96 328
[3] X P Z, Jian X, Rao R, Liang Y N 2014 Sustain. 6 8056
[4] Weber M K, Rohracher H 2012 RES. Policy 26 1037
[5] Gallagher K S 2013 Daedalus 142 59
[6] Zhang X, Bai X 2017 RENEW. SUST. ENERG. REV. 70 24
[7] Cao X, Xing Z Y, Zhang L P 2018 Manag. Rev. 30 82
[8] Ma L, Zhong W, Mei Z 2018 Syst. Eng. Theor. Pract. 38 1759
[9] Li Z, Qi X 2017 J. Liaoning Univ. 45 31
[10] Xiong Y, Fan S, Liu X 2018 Sci. Sci. Manag. S. T. 39 72
[11] Jiang C L, Zhang Y, Bu M L, Liu W S 2018 Sustain. 10 1692
[12] Albrecht J A E 1999 SSRN Electron. J. 17
[13] Liu L, Zhao Z 2016 Sci. Res. Manag. 37 58
[14] Jin T, Zheng L H, Jin Y 2017 Sci. Technol. Manag. Res. 21 261
[15] Xiao Y, Xue H, Tao G 2016 Technol. Econ. 35 50
[16] Xiong Y, He S 2017 Sci. Sci. Manag. S. T. 38 61
[17] MOORE G A 2014 Crossing the Chasm (New York: Harper Business Press)
[18] Huang Y, Qian L 2018 TRANSPORT. RES. D-TR. E. 63 482
[19] Javid R J, Nejat A A 2017 Transport Policy 54 30
[20] Krupa J S, Rizzo D M, Eppstein M J 2014 TRANSPORT. RES. A-POL. 64 14
[21] Cecere G, Corrocher N, Guerzoni M 2018 *Energ. Policy* 118 19

**Acknowledgements**

This research is supported by the National Natural Science Foundation of China (No. 71573025), National Social Science Foundation of China (No. 17XGL008), and the Fundamental Research Funds for the Central Universities (No. 2018CDXYJG0040).