 http://dx.doi.org/10.17287/kmr.2018.47.1.177

Performance Advantage for Electric Vehicles under Competition*

Dawoon Jung(First Author)
Korea University Business School
(*bogsil@korea.ac.kr*)
Byung Cho Kim(Corresponding Author)
Korea University Business School
(*bkim@korea.ac.kr*)
Myungsub Park(Co-Author)
Korea University Business School
(*mspark@korea.ac.kr*)

Although most electric vehicles (EVs) can cover the majority of daily driving needs, customers are anxious that they will run out of electricity on the road before arriving at the destination. Thus, the availability and accessibility of charging stations become critical for increasing sales in EV market. As well as charging convenience, customers are attracted by high-performance, meaning that all relevant features (acceleration, maximum speed, braking, riding comfort, durability, safety, charging time, etc.) need to be balanced. However, in many cases, achieving the optimal balance requires additional expense so that it may cause pressure on price despite its expected benefits. Thus, we investigate how the EV manufacturers can cope with the trade-off between lowering price and improving performance under competition. Then, we compare the equilibrium performance levels and prices of EVs when performance improvement costs of competing firms differ. We also examine the equilibrium decision from the social perspective and provide the implications of how the socially favorable decision is different from that for manufacturers.

Key words: electric vehicle (EV), R&D capability, performance improvement

Ⅰ. Introduction

After the Volkswagen's emissions scandal, electric vehicles (EVs) are now considered as the most promising sustainable transport and receiving significant attention from customers. According to Rapier (2017), increase in global EV sales has continued to grow for the last several years. The sales of EV reached 777,497 units worldwide in 2016, more than twice of the sales volume in 2014. As well as declining demand for the clean diesel cars in the wake of the scandal, customers' growing interest in EVs has spurred massive investments in EV development.

Manufacturers have been focusing on the choice of different technologies for EV development.

최초투고일: 2017. 10. 18   게재확정일: 2018. 1. 14
* This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (NRF-2014S1A5A8019068).
* This study was supported by the Institute for Business Research & Education (IBRE) and Korea University Business School Research Grant.

However, recent signs from the industry are now showing that the EV market is more skewed towards the Full-EVs (FEVs) which use electric power stored in battery packs as the sole source of propulsion. While BMW, Volvo, and Hyundai-Kia are still holding both cards of FEV and plug-in hybrid system, Rolls-Royce announced that it would not put efforts for any other bridge technologies and go straight to the FEVs (Szymkowski, 2017). Tesla, Lucid Motors or Faraday Future, the rising stars of the EV industry, are planning to expand their production capacity only for the FEVs. Even Toyota, which has long been focusing on hydrogen fuel cell development, claims that it already achieved a breakthrough in battery research and will launch its first FEV by 2020.

Since most smartphone users have experienced a discharged battery, one of the main concerns for potential EV drivers is range anxiety; the battery may go dead before arriving at the next charging station. While the short driving range was a major problem in the early stage of development, the range is no longer an issue due to the recent advances in battery technology. Recently, most EVs can cover the majority of driving needs, regarding the fact that the average daily mileage of people in Korea is less than 25 miles (under 40 miles in the US). Thus, building an available and accessible charging network becomes a vital part of EV manufacturers' mission to boost the sales.

Meanwhile, suppose you are buying a new car. Would you simply consider how long the car can go without refueling? Probably not. You would think about the car performance in all features like acceleration, maximum speed, braking, riding comfort, durability, safety, etc. Likewise, customers who are interested in buying a new car with a focus on the environmental sustainability would also take all of the relevant features into account as well as the driving range on a single charge.

Naturally, improving the comprehensive EV performance requires additional expense, so it may lead to an increase in price which causes pressure on demand. At the same time, charging stations may become less profitable given the reduced installed-base. Because of these related customers and charging stations, EV market exhibits strong network externality (Basu, Mazumdar, and Raj, 2003; Li, Tong, Xing, and Zhou, 2017; Liebowitz and Margolis, 1994). Thus, the objective of this paper is to present the impact of vehicle performance on EV market competition in the presence of network externality. Grounded on Armstrong (2006), we present a model of competing EVs to provide foundations for understanding how the decision on car performance influences the manufacturer's profitability as well as the role of R&D capability. Our work also involves analysis which considers a welfare-maximizing equilibrium from a social planner's perspective.

The rest of this paper is organized as follows. The next section presents the literature review. Section 3 describes the basic model structure, followed by the competition under capability asymmetry in R&D. In section 4, a social welfare analysis is included to find out the best decision for the entire society. Finally, we discuss the potential contributions of our paper and provide venues for future research.

Ⅱ. Literature Review

Most studies on the markets with network externality investigate the impact of potential network size on customer utility in the presence of network externality.

Network externality can be defined as interdependence between the demand for a primary product or service and the supply of complementary ones: the value of a product increases with the availability of complementary products (Basu, Mazumdar, and Raj 2003; Katz and Shapiro 1985; Liebowitz and Margolis 1994). Due to the interdependence, the customers tend to wait for complementary products or services to mature and vice versa. Therefore, the key research streams are concerned with this coordination problem for the markets with network externality (Armstrong, 2006, Caillaud and Jullien, 2003; Rochet and Tirole, 2003). Since the network externality is the most important attribute in this context, academics make strategic suggestions for growth while paying little attention to earning the competitive advantage from the performance perspective.

While it is clear that the product with better performance significantly influences firm success in conventional product market (Sethi, 2000; Tellis and Johnson, 2007), product performance has been heralded as a subject for further study in case that the market exhibits network externality. Thus, there has been a vigorous academic debate on the merits of product performance. Anderson, Parker, and Tan (2014) argue that heavily investing in the product performance does not always leads to a competitive edge, especially in content-driven markets. Zhu and Iansiti (2012) examine the relative importance of primary product performance, network externality, and consumer expectations as drivers of firm success. They explained that even in a market with significant network externality, no single strategy will work because different industries exhibit different dynamics and firms should offer product performance at least comparable to that of their competitors. Prasad, Venkatesh, and Mahajan (2010) empirically show that the impact of network externality can vary across product attributes. Tellis, Yin, and Niraj (2009) find that the product performance becomes even more critical in high-tech product markets while both the network externality and the product enhancement affect the market share. While our work is an extension of this research stream, we consider the EV market competition which involves a high level of R&D as well as the network externality.

Modeling-wise, our work is closely related to Armstrong (2006) in that we were inspired by the way he captured the competition in the presence of network externality. Contrary to Armstrong (2006) which assumes exclusivity on both sides, Hagiu and Lee (2011) consider non-exclusive content providers given the exclusive customers. Similarly, to capture the market reality, our model assumes that the charging stations are not exclusive to a specific EV while the customers are not allowed to buy more than one EV. However, we further attempt to capture the economic implications of investment in primary product performance while the focus of Hagiu and Lee (2011) is on the control over content pricing without regarding how good the performance of primary product or service is. As an extension of this research stream, we employ a stylized game-theoretic model that captures the economic implications of investment in EV performance.

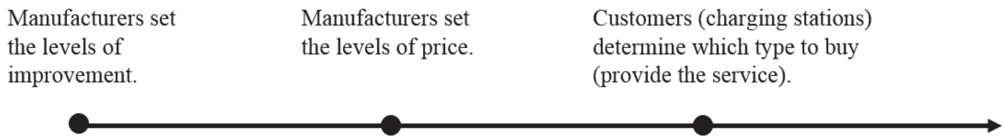
Ⅲ. Model

3.1 Benchmark

In this benchmark, we establish a simple duopoly competition that considers performance impact as an extension of Armstrong (2006). We assume that there are two EV manufacturers at the endpoints of a line with length one. The Manufacturers are indexed by $i=1,2$ that offers an EV with the same level of baseline value v to customers. There are customers(C) and charging stations(S), assumed to be uniformly distributed in $[0,1]$. We assume that the customers are allowed to buy only one EV and the numbers of customers who buy an EV offered by the manufacturer i is denoted by n_{Ci}. Contrary to the customers, charging stations can choose whether to provide exclusive service or not. Then, n_{Si} represents the number of charging stations that provide the services only for the buyers of EV offered by the manufacturer i.

The decision flow of the model is as follows. The manufacturers simultaneously determine the level of their EV performance, $\theta_i \in [0,\infty)$. Next, they set the price, $p_i \in [0,\infty)$. Finally, customers (charging stations) choose which one to buy (provide their service) after observing the performance and price levels. 〈Figure 1〉 describes the decision timeline of all agents in the market.

Then, a customer's utility of buying an EV offered by a manufacturer i depends on price p_i and the number of charging stations that provide service for her. Since our model is an application of Hotelling's specification as in Armstrong (2006), if parameter t denotes the



〈Figure 1〉 Decision Timeline

customers' transportation cost per unit length, a customer at location $x \in [0,1]$ enjoys utility as below:

$$u_{C1} = \alpha(1-n_{S2}) + v(1+\theta_1) - p_1 - tx; \qquad (1)$$
$$u_{C2} = \alpha(1-n_{S1}) + v(1+\theta_2) - p_2 - t(1-x).$$

Note that parameter α measures the scope of benefit a customer enjoys from the charging stations and θ_i denotes the endogenously determined level of performance by the manufacturer i. On the charging stations' side, we let σ represent the profit that a charging station can earn from a customer. If we normalize fixed cost of installing supply equipment for the offerings from the manufacturer i to zero, an exclusive charging station can generate profit of $u_{Si} = \sigma n_{Ci}$ while a non-exclusive one's profit becomes $u_{Si} = \sigma$. Thus, we can realize that all charging stations will choose to be a non-exclusive provider, since $n_{Ci} \le 1$.

As a result, the location of the customer who is indifferent of buying an EV offered by either manufacturer is given by:

$$x^{\dagger} = \frac{t - p_1 + p_2 + v(\theta_1 - \theta_2)}{2t}. \qquad (2)$$

This implies that the number of customers that choose the manufacturer i's EV is as:

$$n_{C1} = \frac{t - p_1 + p_2 + v(\theta_1 - \theta_2)}{2t};$$
$$n_{C2} = \frac{t + p_1 - p_2 + v(\theta_2 - \theta_1)}{2t}. \qquad (3)$$

Then, we can define the manufacturer i's profit as below:

$$\pi_i = p_i n_{Ci} - c_D \theta_i^2, \qquad (4)$$

where the both manufacturers incur the same cost of c_D per a unit performance improvement. This assumption reflects that both manufacturers identically efficient in R&D activities. As outlined above, the two manufacturers simultaneously determine the levels of performance, and then price. Subsequent to the decisions, customers choose to which manufacturer's EV to buy. Charging stations, at the same time, make their decision on the service provision. (This framework of assumptions will be used in analyzing the following sections) Solving the manufacturers' profit maximization problem gives the followings:

$$\theta_i^* = \frac{v}{6c_D};\ p_i^* = t;\ \pi_i^* = \frac{t}{2} - \frac{v^2}{36c_D}. \qquad (5)$$

Note that we need a condition $v^2-18tc_D<0$ to ensure the concavity of manufacturer i's profit. By inserting the equilibrium levels of performance and price in equation (3), the number of customers who choose to buy manufacture i's EV becomes as: $n_{Ci}^*=\frac{1}{2}$. Given the results, we can state our first proposition as below:

Proposition 1. *In equilibrium, both manufacturers have incentives to invest in performance improvement. Two competing manufacturers evenly split the EV market and earn the same profit by setting the same levels of equilibrium performance and price; i.e.,* $n_{Ci}^*=\frac{1}{2}$, $\theta_i^*=\frac{v}{6c_D}$, and $p_i^*=t$.

According to Proposition1, both manufacturers are willing to put an effort in enhancing the performance, even if they are evenly efficient in R&D activities. Then, naturally, we question whether the competition will be different when the manufacturers are not equivalent regarding R&D efficiency.

3.2 Asymmetric efficiency in performance improvement

In this section, we extend the benchmark by considering an asymmetric competition. Suppose that two manufacturers possess different knowledge and resources and thus are not equivalently efficient in R&D activities. That is, the less efficient manufacturer should endure heavier cost burden in achieving the same level of performance. If we assume that the manufacturer 1 has a lead in R&D capability, it will be more efficient in improving the performance than the competitor, the manufacturer 2. To capture this manufacturer 1's cost advantage over the manufacturer 2, we let $\delta\in(1,\infty)$. Then, we write the manufacturers' profit as follows:

$$\pi_1=p_1n_{C1}-c_D\theta_1^2;\ \pi_2=p_2n_{C2}-\delta c_D\theta_2^2. \tag{6}$$

By solving the manufacturers' profit maximization problem, we have the equilibrium levels of performance and price as:

$$\theta_1^*=\frac{v(9\delta tc_D-v^2)}{3c_D\{18\delta tc_D-v^2(1+\delta)\}};$$
$$\theta_2^*=\frac{v(9tc_D-v^2)}{3c_D\{18\delta tc_D-v^2(1+\delta)\}}, \tag{7}$$

and

$$p_1^*=\frac{2t(9\delta tc_D-v^2)}{18\delta tc_D-v^2(1+\delta)};\ p_2^*=\frac{2\delta t(9tc_D-v^2)}{18\delta tc_D-v^2(1+\delta)}. \tag{8}$$

Then, each manufacturer generates the profit as:

$$\pi_1^*=\frac{(18tc_D-v^2)(v^2-9\delta tc_D)^2}{9c_D\{v^2(1+\delta)-18\delta tc_D\}^2};$$

$$\pi_2^* = \frac{\delta\left(18tc_D - v^2\right)\left(v^2 - 9tc_D\right)^2}{9c_D\left\{v^2(1+\delta) - 18\delta tc_D\right\}^2}. \tag{9}$$

Next, to examine the impact of asymmetric capability in R&D, taking the derivative of equilibrium levels of performance and price gives the followings:

$$\frac{\partial\theta_1^*}{\partial\delta} = \frac{v^3\left(9tc_D - v^2\right)}{\left\{v^2(1+\delta) - 18\delta tc_D\right\}^2};$$
$$\frac{\partial\theta_2^*}{\partial\delta} = \frac{-v\left(18tc_D - v^2\right)\left(9tc_D - v^2\right)}{\left\{v^2(1+\delta) - 18\delta tc_D\right\}^2}. \tag{10}$$

and

$$\frac{\partial p_1^*}{\partial\delta} = \frac{2tv^2\left(9tc_D - v^2\right)}{\left\{v^2(1+\delta) - 18\delta tc_D\right\}^2};$$
$$\frac{\partial p_2^*}{\partial\delta} = \frac{-2tv^2\left(9tc_D - v^2\right)}{\left\{v^2(1+\delta) - 18\delta tc_D\right\}^2}. \tag{11}$$

We summarize the investigation in our next proposition.

Proposition 2. *In equilibrium, a more efficient manufacturer provides a higher level of performance than its rival. The equilibrium levels of performance and price become as:*

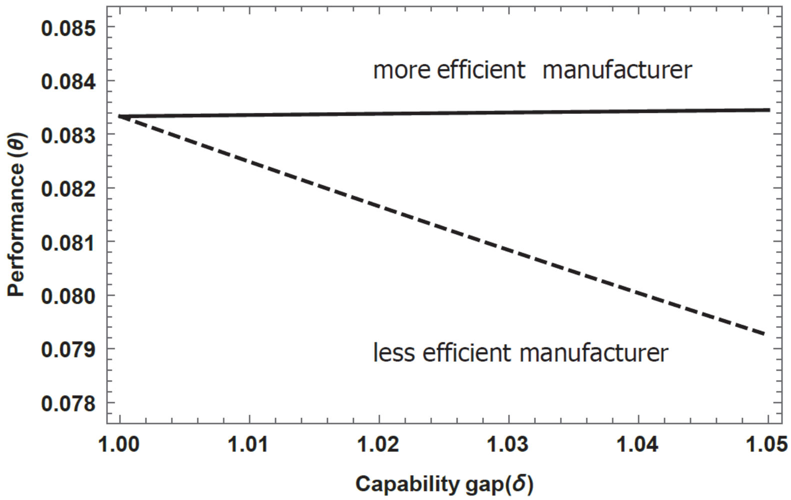
$$\left(\theta_1^* = \frac{v\left(9\delta tc_D - v^2\right)}{3c_D\left\{18\delta tc_D - v^2(1+\delta)\right\}};\right.$$
$$\left.\theta_2^* = \frac{v\left(9tc_D - v^2\right)}{3c_D\left\{18\delta tc_D - v^2(1+\delta)\right\}}\right) \text{ and}$$
$$\left(p_1^* = \frac{2t\left(9\delta tc_D - v^2\right)}{18\delta tc_D - v^2(1+\delta)}; p_2^* = \frac{2\delta t\left(9tc_D - v^2\right)}{18\delta tc_D - v^2(1+\delta)}\right).$$

The more (less) efficient manufacturer will provide the higher (lower) level of performance and price as the difference in R&D capability becomes large.

Proposition 2 means that the performance levels are differentiated due to the manufacturers' asymmetric R&D capabilities. The more efficient manufacturer, which has a competitive lead in the performance improvement, offers an EV with higher performance at a higher price. As the capability difference grows, the more efficient manufacturer utilizes its cost advantage by offering an EV with a higher level of performance while its competitor has no choice but to offer a lower EV performance at a lower price. Figure 2 illustrates the equilibrium performance change concerning the R&D capability difference.

Some customers may pay a premium price for the EV with highly differentiated performance. On the other hand, there may exist some other customers who prefers EV with relatively low performance in that it offers a lower price. If a mass of the former type of customers is disappointingly small, the capability difference may not sufficiently contribute to the profitability of manufacturer that offers the premium EV. Thus, we next examine the manufacturers' market share in equilibrium to find out whether the capability difference boosts the more efficient manufacturer's profit.

By using the same logic that we derive n_{Ci}^*



$v=0.1; t=0.1; c_D=0.2; \alpha=0.1; \sigma=0.1$

〈Figure 2〉 Performance Comparison

given in the Proposition 1, we can realize the manufacturer i's market share as follows:

$$n_{C1}^{*}=\frac{9\delta t c_D - v^2}{18\delta t c_D - v^2(1+\delta)};$$
$$n_{C2}^{*}=\frac{\delta(9 t c_D - v^2)}{18\delta t c_D - v^2(1+\delta)}. \quad (12)$$

A further analysis leads us to have the following proposition.

Proposition 3. *In equilibrium, the more efficient manufacturer has a greater market share than its competitor. As the R&D capability difference increases, the market share of more (less) efficient manufacturer increase (decrease). However, the market will never be dominated by the premium EV.*

Proposition 3 indicates that the greater number of customers will buy the EV with better performance despite its higher price. Furthermore, the market share of this premium EV will grow if it is more clearly differentiated as the R&D capability difference becomes large. However, the market will never be dominated by the premium EV, since lower price appeals more to some customers.

In sum, under duopolistic competition, the R&D capability difference results in polarized outcomes regarding both the performance improvement and market share. Once a manufacturer is left behind in the R&D activities, it faces an unavoidable uphill battle. The less efficient manufacturer experiences both lower performance and smaller market share as the capability difference increases due to its heavier cost burden. In contrast, the more efficient manufacturer can provide higher performance at an increased price by capitalizing on this cost gap. Consequently, we can readily see that the asymmetry in R&D capability eventually contributes to (deteriorates) the profitability of the more (less) efficient manufacturer in that most of the customers are more attracted to the EV with highly differentiated performance.

Given the discussion above, a further question emerges: What if there exists a social planner who considers how much value the market creates for the entire society? This perspective will be analyzed in the following section.

Ⅳ. Social Welfare

In this section, we explore the implications of improving the EV performance from the social perspective, that is, the social planner determines the levels of performance and price for the entire society.

In considering social perspective, we evaluate the social welfare; the sum of all users' surpluses and the manufacturers' profits in the market. Thus, we define the social welfare as follows:

$$SW = \int_0^{x^\dagger} u_{C1}dx + \int_{x^\dagger}^1 u_{C2}dx + \sigma + \pi_1 + \pi_2. \quad (13)$$

Working with equation (13) and holding that the manufacturer 1 is more efficient in R&D activities, the welfare-maximizing levels of performance are given by:

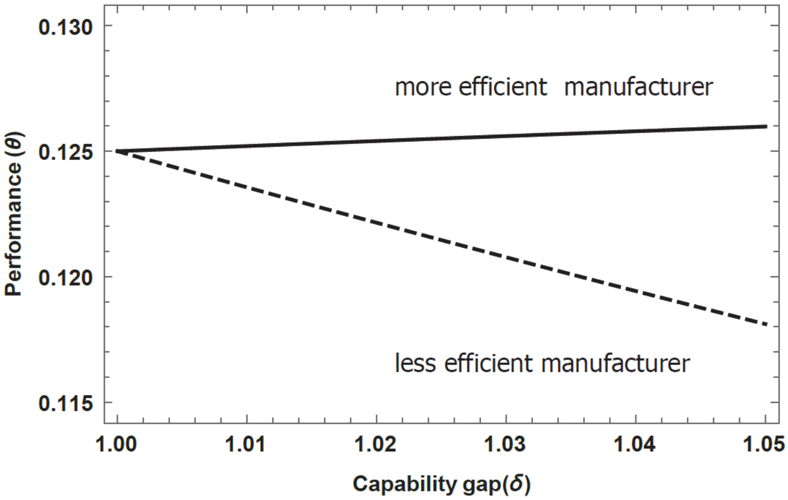
$$\theta_1^* = \frac{v\left(2\delta t c_D - v^2\right)}{2c_D\left\{4\delta t c_D - v^2(1+\delta)\right\}};$$
$$\theta_2^* = \frac{v\left(2 t c_D - v^2\right)}{2c_D\left\{4\delta t c_D - v^2(1+\delta)\right\}}, \quad (14)$$

while the equilibrium prices are described as $p_1^* - p_2^* = 0$. Comparing social planner's decision on the performance to the those of manufacturers results in the following proposition.

Proposition 4. *In equilibrium, performance levels determined for the best social outcome will be higher than those set for the manufacturers' profit maximization.*

Socially desirable levels of performance are different from those determined to maximize the manufacturers' profit. That is, regarding the entire society, the manufacturers will be forced to provide better performance that they would not have set for the private purpose. Next, by focusing on the welfare-maximizing equilibrium, we have the proposition as below.

Proposition 5. *A wealth-maximizing social planner will require the more efficient manufacturer to provide a higher level of performance than its counterpart, at the same price.*



$v=0.1; t=0.1; c_D=0.2; \alpha=0.1; \sigma=0.1$

〈Figure 3〉 Performance Comparison

From Proposition 5, we can see that the EVs are also differentiated though the improvement process like the private case which solely considers manufacturers' profit. The impact of capability difference on the equilibrium performance levels are the same as well; the level of performance that the more (less) efficient manufacturer provides increases (decreases) as the R&D cost gap grows. Figure 3 presents how the equilibrium performance levels change concerning the R&D capability difference.

However, in equilibrium, the social planner sets the same price for both EVs even though the respective level of performance that each manufacturer is required to provide is not equivalent. Then, despite the better alternative, would somebody buy an EV with lower performance at the same price? Or, would the market eventually be dominated by the premium EV? To answer the questions, we next examine the market share in equilibrium.

Given the social planner's decision on the performance and price, the number of customers who choose the manufacturer i's offering becomes as follows:

$$n_{C1}^{*}=\frac{2\delta t c_D-v^2}{4\delta t c_D-v^2(1+\delta)};\ n_{C2}^{*}=\frac{\delta\left(2tc_D-v^2\right)}{4\delta t c_D-v^2(1+\delta)}. \quad (15)$$

We also can compute the equilibrium level of social welfare as below:

$$SW^{*}=\frac{4c_D\delta t\{4(v+\alpha+\sigma)-t\}-2v^2(1+\delta)\{2(v+\alpha+\sigma)-t\}-v^4}{4c_D\left\{4\delta t c_D-v^2(1+\delta)\right\}}. \quad (16)$$

A further analysis gives our last proposition.

Proposition 6. *In equilibrium, dominance never occurs. The equilibrium level of social welfare decreases as the R&D capability difference becomes large.*

According to Proposition 6, there always exist some customers who prefer an EV which provides relatively low performance, even though it is possible to enjoy the better performance at the same price. This can be understood due to the customers' preference towards certain manufacturer or brand. When a customer decides to purchase an EV, she may prefer one manufacturer or brand to another. For example, a customer who has a lot of faith in conventional car manufacturers (such as BMW or Nissan), but not in rising stars (such as Tesla or Faraday Future), is more likely to consider to buy i3 or Leaf than Model 3 or FF 91. Furthermore, the proposition 5 shows that the welfare of the entire society will be weakened if the R&D capabilities of competing manufacturers vary greatly. Thus, we can infer that the social-planner should pay a lot of attention to keep the market more competitive regarding R&D capabilities. To do that, it is crucial to establish R&D-friendly infrastructure and policies which allow a manufacturer to keep up easily with the intensified R&D competition. No one should be left behind too far in R&D for achieving higher social value.

Ⅴ. Conclusion

To the best of our knowledge, very few research papers in this area have examined the impact of product performance and manufacturers' R&D capabilities even in the case that the markets are technology-driven fields. Thus, our goal in this paper is to provide the generalized implication that product superiority in performance can be an effective weapon in many ways. We believe that our work answers the question of why an EV manufacturer should be concerned about performance. We suggest that neither startup manufacturer that wants to enter the EV market nor the manufacturer that already has a lead in the market can ignore the lessons on product performance in the presence of strong network externality.

In this paper, we presented a model of EV market competition in regards to performance improvement. We show that the performance can be seen as a firm's core competency even under the network externality. In line with the conventional wisdom on product performance, enhanced performance extends the firm's strategic options and provides a good way to establish a foundation for the future. Our results show that the greater R&D capability

〈Table 1〉 Findings and Contributions

Criterion	Contributions of the study	Findings
Academic	• Added a performance dimension to competing EV manufacturers that are not equivalent in internal R&D competency.	• In making a decision on EV performance, the manufacturers differentiate their offerings; the policy of R&D leader is opposite of that of R&D follower (under conditions of asymmetric R&D positions).
Practical	• Determined optimums from the private perspectives as well as social perspective. • Showed the impact of asymmetric R&D capabilities. • Found the role of social planner for optimizing social value.	• Findings give business executives insights into their R&D decision making • Findings inform social-planners about how to manage the EV market competition.

gap deteriorates the profitability of the low-end manufacturer. The manufacturer has no choice but to cut its price to overcome the relative weakness in R&D capability. Consequently, our work indicates that the effort for performance superiority makes a manufacturer more competitive and provides stable profit in the long run. We also find that both manufacturers will offer more enhanced EVs where a social planner plays an active role in the market. In both of private and social cases, the results imply that polarization will naturally arise so that the customers can enjoy a variety of EVs given the competing manufacturers' different R&D capabilities. We summarize contributions and findings in Table 1.

Our work has several limitations that require consideration since we construct a tractable model by making some simplifying assumptions. First, we assume that once a manufacturer invests in improving the performance, it is immediately and perfectly enhanced, which is to say that no delay or failure happens during the improvement process. Second, in our model, we did not consider the market expansion effect because we assumed a uniform distribution of customers and charging stations for simplicity. As most of our results hold on robustness to this distributional assumption which is widely accepted in the literature, we leave the extension of the model with a more general assumption for future studies.

References

Anderson, E. G., Parker, G., and Tan, B(2014), "Platform Performance Investment in the Presence of Network Externality," *Information*

Systems Research, 25(1), 52-172.

Armstrong, M(2006), "Competition in Two-sided Markets," *Rand Journal of Economics,* 37 (3), 668-691.

Basu, A., Mazumdar, T., and Raj, S. P(2003), "Indirect Network Externality Effects on Product Attributes," *Marketing Science*, 22 (2), 209-221.

Caillaud, B. and Jullien, B(2003), "Chicken & Egg: Competition among Intermediation Service Providers," *Rand Journal of Economics,* 34 (2), 309-328.

Hagiu, A., and Lee, R. S(2011), "Exclusivity and Control," *Journal of Economics and Management Strategy*, 20(3), 679-708.

Liebowitz, S., and Margolis, S(1994), "Network Externality: An Uncommon Tragedy," *The Journal of Economic Perspectives,* 8(2), 133-150.

Li, S., Tong, L., Xing, J., & Zhou, Y(2017), "The Market for Electric Vehicles: Indirect Network Effects and Policy Design," *Journal of the Association of Environmental and Resource Economists*, 4(1), 89-133.

Prasad, A., Venkatesh, R., and Mahajan, V(2010), "Optimal Bundling of Technological Products with Network Externality," *Management Science*, 56(12), 2224-2236.

Rapier, R(2017) "U.S. Electric Vehicle Sales Soared In 2016," *Forbes*. February 5. Available at: https://www.forbes.com/sites/rrapier/2017/02/05/u-s-electric-vehicle-sales-soared-in-2016/#48551491217f (accessed August 20, 2017).

Rochet, J. C., and Tirole, J(2003), "Platform Competition in Two sided Markets," *Journal of the European Economic Association*, 11(4), 990-1029.

Sethi, R(2000), "New Product Quality and Product Development Teams," *Journal of Marketing*, 64(2), 1-14.

Szymkowski, S(2017) "Rolls-Royce is Skipping Hybrids and Going Straight to Electric Cars," *Business Insider,* July 9, Available at: http://www.businessinsider.com/rolls-royce-to-skip-hybrids-and-go-straight-to-electric-cars-2017-7 (accessed August 20, 2017).

Tellis, G. J., and Johnson, J(2007), "The Value of Quality," *Marketing Science*, 26(6), 758-773.

______, G. J., Yin, E., and Niraj, R(2009), "Does Quality Win? Network Effects Versus Quality in High-tech Markets," *Journal of Marketing Research*, 46(2), 135-149.

Zhu, F., and Iansiti, M(2012), "Entry into Platform-based Markets," *Strategic Management Journal,* 33(1), 88-106.

〈Appendix〉

Proof of Proposition 2

Equilibrium exists only when $9\delta c_D - v^2 > 0$, since the levels of performance and price should be continuous. Under the condition above, $18\delta c_D - v^2(1+\delta) > 0$. Thus, all of θ_i^* and p_i^* given in the equation (7) and (8) are strictly positive and the difference between the equilibrium levels of performance become the following:

$$\theta_1^* - \theta_2^* = \frac{3tv(\delta-1)}{18\delta t c_D - v^2(1+\delta)} > 0. \tag{A1}$$

We get the results below when we take the derivative of equilibrium level of performance with respect to δ:

$$\frac{\partial\theta_1^*}{\partial\delta} = \frac{v^3\left(9tc_D - v^2\right)}{3c_D\left\{v^2(1+\delta) - 18\delta t c_D\right\}^2} > 0;\ \frac{\partial\theta_2^*}{\partial\delta} = \frac{-\left(18tc_D - v^5\right)\left(9tvc_D - v^3\right)}{3c_D\left\{v^2(1+\delta) - 18\delta t c_D\right\}^2} < 0. \blacksquare \tag{A2}$$

Proof of Proposition 3

We have the results below by taking the limits of n_{Ci}^* as $\delta \to \infty$:

$$\lim_{\delta\to\infty} n_{C1}^* = \frac{9tc_D}{18tc_D - v^2};\ \lim_{\delta\to\infty} n_{C2}^* = \frac{9tc_D - v^2}{18tc_D - v^2}. \tag{A3}$$

Then, taking the derivative of n_{Ci}^* with respect to δ results in the followings:

$$\frac{\partial n_{C1}^*}{\partial\delta} = \frac{v^2\left(9tc_D - v^2\right)}{\left\{v^2(1+\delta) - 18\delta t c_D\right\}^2};\ \frac{\partial n_{C2}^*}{\partial\delta} = \frac{-v^2\left(9tc_D - v^2\right)}{\left\{v^2(1+\delta) - 18\delta t c_D\right\}^2}. \tag{A4}$$

respectively. Furthermore, from the proposition 1, we know that $n_{Ci}^* = \frac{1}{2}$ when the manufacturers have the same level of capability in R&D, i.e., $\delta = 1$. In sum, we can realize as: $0 < n_{C2}^* < n_{C1}^* < 1$. $\blacksquare$

Proof of Proposition 4

For the more efficient manufacturer, the limits of the welfare-maximizing performance level become as:

$$\lim_{\delta \to 1}\theta^*_{1W} = \frac{v}{4c_D};\ \lim_{\delta \to \infty}\theta^*_{1W} = \frac{tv}{4tc_D - v^2}, \tag{A5}$$

while $\dfrac{\partial\theta^*_{1W}}{\partial\delta} = \dfrac{v^3\left(2tc_D - v^2\right)}{2c_D\left\{v^2(1+\delta) - 4\delta tc_D\right\}^2} > 0$.

On the other hand, taking the limit of the profit-maximizing performance gives the following:

$$\lim_{\delta \to \infty}\theta^*_{1P} = \frac{3tv}{18tc_D - v^2}, \tag{A6}$$

where we already know that $\lim_{\delta \to 1}\theta^*_{1P} = \dfrac{v}{6c_D}$ and it is an increasing function of δ. Note that the welfare(profit)-maximizing case is denoted by *W(P)*.

Since, $\lim_{\delta \to 1}\theta^*_{1W} > \lim_{\delta \to 1}\theta^*_{1P}$ and $\lim_{\delta \to \infty}\theta^*_{1W} - \lim_{\delta \to \infty}\theta^*_{1P} = \dfrac{2tc_D\left(3tc_D + v^2\right)}{\left(4tc_D - v^2\right)\left(18tc_D - v^2\right)}$, we can conclude that $\theta^*_{1W} > \theta^*_{1P}$.

For the less efficient manufacturer, it is possible to know $\theta^*_{2W} > \theta^*_{2P}$ with the similar logic. Note that the equilibrium performance level decreases as δ becomes large, for the both of private and social cases.■

Proof of Proposition 5

Equilibrium exists only when $2\delta c_D - v^2 > 0$, since the levels of performance and price should be continuous. Then, $4\delta c_D - v^2(1+\delta) > 0$, so that the equilibrium levels of performance given in the equation (14) become positive.

$$\theta^*_1 - \theta^*_2 = \frac{tv(\delta - 1)}{4\delta tc_D - v^2(1+\delta)} > 0. \blacksquare \tag{A7}$$

Proof of Proposition 6

By taking the limits of n_{Ci}^{*} as $\delta \rightarrow \infty$, following results are derived:

$$\lim_{\delta \rightarrow \infty} n_{C1}{*} = \frac{2tc_D}{4tc_D - v^2};\ \lim_{\delta \rightarrow \infty} n_{C2}{*} = \frac{2tc_D - v^2}{4tc_D - v^2}. \tag{A8}$$

Then, taking the derivative of n_{Ci}^{*} with respect to δ gives the following results:

$$\frac{\partial n_{C1}^{*}}{\partial \delta} = \frac{v^2\left(2tc_D - v^2\right)}{\left\{v^2(1+\delta) - 4\delta tc_D\right\}^2};\ \frac{\partial n_{C2}^{*}}{\partial \delta} = \frac{-v^2\left(2tc_D - v^2\right)}{\left\{v^2(1+\delta) - 4\delta tc_D\right\}^2}, \tag{A9}$$

respectively. Regarding that $n_{Ci}^{*} = \frac{1}{2}$ where $\delta = 1$, we can conclude that $0 < n_{C2}^{*} < n_{C1}^{*} < 1$.

Next, with respect to δ, the derivative of equilibrium level of social welfare presented in equation (16) is given by: $\frac{\partial SW^{*}}{\partial \delta} = \frac{-\left(v^3 - 2tvc_D\right)^2}{4c_D\left\{v^2(1+\delta) - 4\delta tc_D\right\}^2}$. ■

경쟁 상황에서의 전기자동차 성능 향상에 관한 연구

정다운* · 김병조** · 박명섭***

요 약

최근 출시된 대부분의 전기자동차는 일상적 사용에 지장을 초래하지 않는 수준의 주행거리를 제공하고 있지만, 많은 소비자들은 여전히 배터리 방전과 관련된 불안감을 가지고 있다. 따라서 전기자동차 시장이 성장하는 데 있어 편리하고 접근성 높은 충전소 확충은 매우 중요한 문제이다. 한편, 충전 편의성과 함께 전기자동차 판매에 큰 영향을 미치는 요인으로 차량 자체의 성능을 들 수 있다. 자동차 성능은 가속성, 최대속도, 제동력, 승차감, 내구성, 안전성 등 다양한 특성 간 균형에 의해 결정되는데, 이들 특성을 조율하여 최적화하는 것은 전기자동차 시스템을 개발하는 것과는 별도의 경험과 비용이 요구되는 일이기 때문에 전기자동차의 가격 상승 요인으로 작용할 수 있다. 본 연구에서는 전기자동차 성능과 가격 간 교환 관계 속에서 경쟁 상황에 놓인 전기자동차 생산기업들의 의사결정 문제를 다루었다. 먼저, 차량의 성능향상 관련 역량이 서로 다른 두 전기자동차의 균형가격 및 성능 수준을 기업의 수익성 차원에서 도출하였고, 이를 사회적 복리를 고려한 의사결정과 비교하였다.

주제어: 전기자동차, R&D 역량, 성능향상

* 고려대학교 경영학과(bogsil@korea.ac.kr), 주저자
** 고려대학교 경영대학 부교수(bkim@korea.ac.kr), 교신저자
*** 고려대학교 경영대학 교수(mspark@korea.ac.kr), 공저자

- 저자 정다운은 이화여자대학교에서 화학을 전공으로 이학사를 취득하였으며, 고려대학교 경영학과에서 석·박사 통합 과정 졸업예정이다. 현재 강의를 하면서 논문 게재를 위한 연구에 힘쓰고 있다. 주요 연구 관심분야는 플랫폼전략, 기술경영, 신제품 개발, IoT 등이다.

- 저자 김병조는 서강대학교에서 수학 전공으로 이학사를 취득하였으며, University of Chicago 에서 통계학 석사, Carnegie Mellon University에서 경영학 석·박사 학위를 취득하였다. 미국 Virginia Tech 경영대학 조교수를 역임하였으며 현재 고려대학교 경영대학에서 부교수로 재직중이다. MIS Quarterly, Production and Operations Management, Decision Sciences 등 저널에 논문을 게재하였으며 주요 연구 관심분야는 기술경영, 기술혁신, 정보기술 등이다.

- 저자 박명섭은 고려대학교에서 무역학 전공으로 경영학사를 취득하였으며, 버지니아 주립대학교에서 경제학 석사, 텍사스 A&M 대학교에서 경영학 박사 학위를 취득하였다. 켄자스 주립대학교 경영대학 조교수를 역임하였고, 현재 고려대학교 경영대학에서 교수로 재직하고 있다. 한국생산관리학회 및 한국구매조달학회의 회장으로 활동한 바 있으며 주요 연구 관심분야는 구매공급관리, 물류정보시스템, 제품개발 및 운영관리 등이다.