OPTIMAL INVESTMENT STRATEGIES FOR HYDROGEN MOBILITY INFRASTRUCTURE CONSIDERING INDIRECT NETWORK EFFECTS AND COMPETITION

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Overview

The global community is in the process of implementing policies that phase out the use of internal combustion engine vehicles (ICEVs). The expansion of charging station infrastructure is critical for the growth of the eco-friendly vehicle market. However, charging station businesses have yet to attain profitability, resulting in limited private investment. In Korea, private investment in charging stations for battery electric vehicles (BEVs) and fuel cell electric vehicles (FCEVs) is currently at 26% and 22% respectively. As the adoption of eco-friendly vehicles continues to rise, governments are facing difficulties in allocating additional funds for charging station investment due to budget constraints. On the other hand, eco-friendly vehicle manufacturers can secure the profitability of charging station businesses while taking into account indirect network effects.

This study proposes optimal charging station investment strategies for manufacturers of eco-friendly vehicles, taking into account the indirect network effects between eco-friendly vehicles and charging stations. The expansion of charging station infrastructure is essential for the growth of the eco-friendly vehicle market, but charging station businesses have yet to achieve profitability, resulting in limited private investment. By considering the indirect network effects, manufacturers of eco-friendly vehicles can secure the profitability of charging station businesses. Specifically, we analyze the optimal charging station investment strategy in the current vehicle market and the equilibrium in the competitive environment between eco-friendly vehicles post-phase-out of internal combustion engines. Our findings indicate that Nash equilibria exist in the form of a winner-takes-all scenario. An empirical analysis of the Korean market is conducted, revealing that fuel cell electric vehicles are not yet viable when compared to battery electric vehicles.

Methods

The vehicle demand function for quantifying indirect network effects is formulated using discrete choice theory. The binary logit model is used to reflect consumer utility for charging stations. The profit function for eco-friendly vehicle manufacturers includes net income from selling these vehicles, as well as revenue from charging station operation and the cost of charging station investment. The optimal number of charging stations is determined by maximizing this profit function in the current market, where ICEVs dominate. In the future, when ICEVs phase out, it is assumed that there are only two manufacturers producing different eco-friendly vehicles, and that their only strategy is to maximize profit through charging station investment. Given these assumptions, Nash equilibria are derived using the Cournot game approach. To conduct empirical analysis in the Korean vehicle market, Korean market data are collected. For example, the logit parameters, which are the utility coefficients about vehicle attributes like the number of charging stations in the market and vehicle prices, are collected from a reference conducting choice game for Korean consumers. Finally, sensitivity analysis is conducted for major factors such as vehicle price, annual driving range, and indirect network effects.

Results

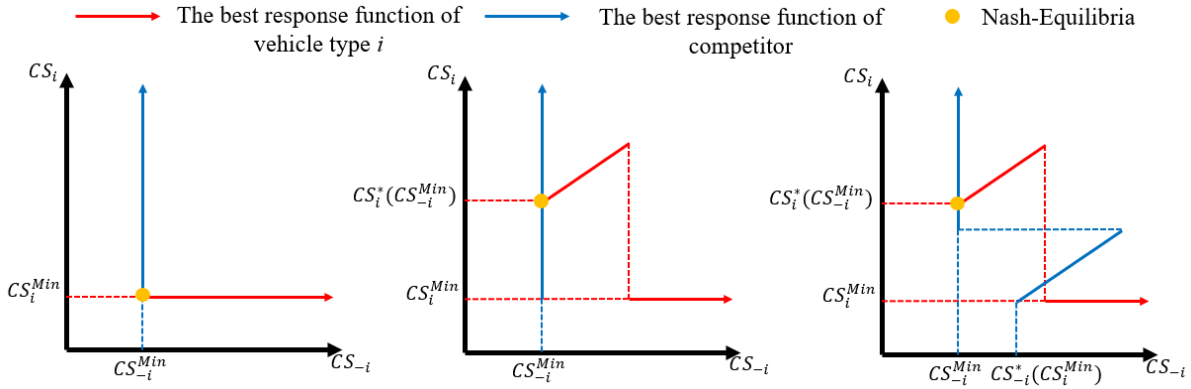

Fig. 1: The best response functions and Nash-Equilibria in competition between eco-friendly vehicles

In the current vehicle market, the optimal charging station investment strategies are found to exist only at the minimum investment or unique local maximum point. This characteristic is also observed in the case of a future competitive eco-friendly vehicle market. Figure 1 illustrates the possible combinations of best response functions and Nash equilibria. "CS" stands for the number of charging stations for each player. The analysis shows that if a Nash equilibrium exists, it is unique and take the form of a winner-takes-all scenario. The results of the empirical analysis in the Korean vehicle market indicate that BEVs will dominate the market compared to FCEVs in Korea. Sensitivity analysis reveals that the most important factor for BEVs is the size of the total vehicle market, as it will be the dominant market. However, for FCEVs, the most important factor is government subsidies, but this is only in the case of the small-SUV market. The results could be different in other cases. For example, BEVs are not suitable for heavy-trailer use due to the weight of the battery and long driving distances. Therefore, it is important to adopt a positioning strategy that takes into account the pros and cons of each vehicle type in the future eco-friendly market

Conclusions

This study proposes an optimal charging station investment strategy for manufacturers of eco-friendly vehicles, taking into account the indirect network effects between eco-friendly vehicles and charging stations. It is determined that optimal investment strategies are located at minimum investment or unique local maximum points. As such, it is crucial to ensure the profitability of charging stations in order to shift the optimal investment point towards the local maximum. In the future market, where internal combustion engine vehicles are phased out, it is found that, if a Nash equilibrium exist, it will be unique and result in a winner-takes-all scenario. Consequently, it is recommended that eco-friendly vehicle manufacturers consider dividing the market based on factors such as region, vehicle size, and driver characteristics, and position their products accordingly, taking into account the respective pros and cons of each vehicle type.

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