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Analysis on the feedback effect for the diffusion of innovative technologies focusing on the green car

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ABSTRACT

Previous studies of technical competitive relationship have mostly focused on the analysis of one-directional impact of the technical attribute on market share. However, there is a cyclical feedback effect between the technical attributes and market share, and that means the small difference of competitiveness at the early phase of technology diffusion can greatly affect the final market share. As such, this study presents the system dynamics model which can forecast sales of innovative technology considering the feedback effect of market share on technical attributes. For that, the causal loop diagram among the various variables was defined using the econometric model applied and proven in various studies of the Bass diffusion model, discrete choice model, etc. to reinforce the theoretical background of the causal relationship among the variables of the forecasting model. Furthermore, infrastructure building scenarios and feedback effect scenarios were applied to the developed forecasting model to present the implication for successful adoption of green car technology from the infrastructure development view point.

1. Introduction

Korea established green growth as its new national development paradigm to help to solve the problems of global warming, the energy crisis, etc. and to create a new growth engine and it has been investing in various efforts to accomplish this new goal (Presidential Commission on Green Growth [1]). As a part of these efforts, the government voluntarily announced on November 17, 2009 its target to reduce green house gas emissions by 30% compared with BAU (Business As Usual) by 2020. This 30% reduction target is the most aggressive target of the three originally proposed reduction scenarios and can be accomplished only when actively adopting the various green house gas reduction measures. Particularly, it will require the deployment of green cars such as electric vehicles (EV) and hydrogen fuel cell vehicles (HFCV), in addition to energy consumption saving through a strong demand management policy (Presidential Commission on Green Growth [2]). Therefore, the development and distribution of green car technology that can drastically reduce green house emissions in the transportation sector will be the key to accomplishing the green house gas reduction target.

However, EVs and HFCVs are still in the early phase of technology development and require many technical breakthroughs for them to be commercialized, thus uncertainty of their technology development continues to be high. Furthermore, they use a motor and battery or hydrogen fuel cell as their key power source and are completely different technology in feedstock from the conventional vehicles using internal combustion engines. Therefore, the technology cannot be widely deployed without the construction of a new recharging infrastructure first. As such, the hybrid electric vehicle (HEV), which uses a motor and battery in parallel with the internal combustion engine can thus be distributed without the requirement of a new recharging infrastructure, is gaining attention as the short-term alternative for the deployment of green cars. Eventually, the speed of market entry of green

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cars and the market share of the alternative technologies will be determined by the outcome of green car technology development and the degree of recharging infrastructure development.

This study attempts to envisage the future of transportation by developing the model which can forecast sales of green car alternative technology according to a dynamic change of factors such as fuel efficiency, feedstock cost, vehicle price and degree of infrastructure development that affects the vehicle consumer utility. There is a feedback effect particularly between the vehicle price/degree of infrastructure development and market share (Meyer [3]). This feedback effect shows that the market share increases when the price of a vehicle technology decreases or infrastructure development is promoted, and that increase of the market share accelerates the reduction of vehicle price and infrastructure development. Such feedback effects can cause a small competitive edge within a technology in the early distribution phase to result in a major difference of market share during the technology maturity phase. Therefore, analyzing the impact of the feedback effect on sales of new technology is an important part of forecasting sales of not only green cars but also other innovative technologies.

To consider how the feedback effect, mostly from green car technology, impacts sales of innovative technologies and competitive relationships among the technologies, Chapter 2 reviews the existing related studies while Chapter 3 studies the three key methodologies for market forecasting model development. Chapter 4 presents the developed sales forecasting model developed using the methodologies presented above and Chapter 5 studies the baseline data and parameters to apply the forecasting model to green cars. Chapter 6 deducts the sales forecasting results for the green car technologies based on the various scenarios and Chapter 7 summarizes the significance of this study and future study directions.

2. Literature review

The total market size of green car technology has mostly been quoted directly from the government's deployment target or technical prediction of manufacturers, or by using a qualitative method such as establishing the distribution scenario (The National Academies [4], EIA [5] and IEA [6]). However, there are few quantitative forecasting studies for future green car market size using the diffusion model based on the past time series data (Park [7]). The reason is because there are no sufficient data to estimate the future because innovative technology is not yet established in the market. Park's study used the hybrid vehicle sales volume data in the Japanese market, which is the pioneer in hybrid vehicle deployment, to forecast sales of green cars in Korea. But, it has the limitation of not being able to consider the competitive relationship of various alternative green car technologies.

While there is a shortage of studies forecasting the total green car market size, there have been many studies analyzing the impact of technical attribute changes on the market share of the technology (Golob [8], Ewing [9], Mau [10] and Axsen[11]). This is because most studies of technical competitive relation used the discrete choice model, which has the strength of easy availability of data for estimating the model parameters as it uses a consumer survey result. However, most studies of competitive relations had their own limitations on forecasting the deployment volume of each technology, as they only estimated the selective probability of the technology without consideration to the total market size.

Therefore, there is a need to integrate the diffusion model and discrete choice model to develop one that predicts the total market size while considering the competition among the technologies. Although Jun and Kim developed prediction models integrating the diffusion model and discrete choice model, they were limited in that they did not consider repurchase (Jun [12] and Kim [13]). Most diffusion models forecast the market distribution by considering only the initial purchase, but repurchase with consideration to the life of the technology needs to be considered also in order to recognize the transition among competing technologies through the integration of the discrete choice model. Jun presented an integrated model that includes both the diffusion model and discrete choice model with consideration to repurchase, but it was not a complete integrated model as the methodology merely applied the various models sequentially (Jun [14] and Jun [15]). Furthermore, it was based on the discrete choice model based only on the one-directional impact of technical attribute on probability of product purchase and was not able to analyze the feedback effect of the accumulated product purchase volume on the technical attribute.

The existing economic models are limited in analyzing the feedback effect between the technical attributes and product purchase probability. Therefore, the feedback effect studies have been using the system dynamics or agent based modeling (ABM) based on the complexity economic theory. Dogan and Patrick used the system dynamics technique to forecast sales of HFCV while Malte predicted the same with ABM (Keles [16], Schwoon [17], Schwoon [18] and Patrick [3]). Although the studies analyzing the feedback effect develop and utilize very detailed simulation models to consider the composite effects of the various factors affecting the market distribution of HFCV, its weakness is that it has a weak theoretical background of the causal relationship among the variables. Therefore, this study intends to supplement the weakness of the existing simulation model by deploying the system dynamics based on the simulation model integrating the diffusion model and discrete choice model with consideration to repurchase. Sales forecasting considering the diffusion model, repurchase, customer choice model, and feedback effect simultaneously is the method that was first proposed in this study.

3. Research methodologies

3.1. Diffusion model

This study forecasts the total green car market size using the Bass diffusion model. The Bass diffusion model, proposed by Bass in 1969, is the most widely used diffusion model. It defines the probability of a consumer adopting a new product at time T in terms of the innovator group's adoption probability and imitator group's adoption probability, called the innovation factor p and