Energy Policy 39 (2011) 3307–3315

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Development of a market penetration forecasting model for Hydrogen Fuel Cell Vehicles considering infrastructure and cost reduction effects

Sang Yong Park [a,*], Jong Wook Kim [a], Duk Hee Lee [b]

[a] Energy Policy Research Department, Korea Institute of Energy Research, 71-2, Jang-dong, Yuseong-gu, Daejeon 305-343, Republic of Korea
[b] Department of Management Science, Korea Advanced Institute of Science and Technology, 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea

ARTICLE INFO

Article history:
Received 27 May 2010
Accepted 7 March 2011
Available online 6 April 2011

Keywords:
Hydrogen Fuel Cell Vehicle
Market penetration forecasting
Generalized Bass diffusion model

ABSTRACT

In order to cope with climate change, the development and deployment of Hydrogen Fuel Cell Vehicles (HFCVs) is becoming more important. In this study, we developed a forecasting model for HFCVs based on the generalized Bass diffusion model and a simulation model using system dynamics. Through the developed model, we could forecast that the saturation of HFCVs in Korea can be moved up 12 years compared with the US. A sensitivity analysis on external variables such as price reduction rates of HFCVs and number of hydrogen refueling stations is also conducted. The results of this study can give insights on the effects of external variables on the market penetration of HFCVs, and the developed model can also be applied to other studies in analyzing the diffusion effects of HFCVs.

1. Introduction

The global warming problem due to climate change has been threatening the sustainable development of all humankind (IPCC, 2007). In order to cope with climate change, many new technologies that can reduce greenhouse gas (GHG) emissions have been developed and deployed (IEA, 2008). The Hydrogen Fuel Cell Vehicle (HFCV) is especially considered as the most promising technology to reduce GHGs emissions in the transportation sector (Barreto et al., 2003; Clark and Rifkin, 2006; Dunn, 2002; Winebrake, 2002). Therefore, the demand for studies to forecast the market penetration of HFCVs has increased to establish successful commercialization strategies for HFCVs (McDowall and Eames, 2006).

The most widely used model to forecast the demand for new products is the Bass diffusion model because it can describe the S-shape penetration curve of new products with meaningful parameters such as the innovation factor and imitation factor (Bass, 1969; Mahajan et al., 1990; Nigel and Towhidul, 2006). However, the Bass diffusion model cannot consider external variables that can affect the market penetration of new products such as marketing effort and cost reduction, so the generalized Bass diffusion model was proposed (Bass et al., 1994). The greatest difficulty when applying the diffusion model to a real problem is that there is not available data to estimate model parameters because the target of forecasting is a new product that has not yet been introduced to the market. For this reason, most of the studies related to the market penetration forecasting of HFCVs have used a discrete choice model based on survey results, and the generalized Bass diffusion model using historical time series data has not yet been applied to HFCVs (Green, 2001; Paulus, 2008). Gustavo developed a forecasting model for HFCVs using a logistic diffusion model, but the developed model could not analyze the effects of external variables such as infrastructure and cost reduction (Gustavo, 2007).

Therefore, the main purpose of this paper is to develop a new forecasting model for the market penetration of HFCVs, based on a generalized Bass diffusion model using alternative products such as the Hybrid Electric Vehicles (HEVs). In addition, we develop a simulation model for the market penetration of HFCVs, using a system dynamics approach, which can analyze system behavior based on the positive and negative feedback effects among system components.

Through this study, we can provide insight as to the effects of external variables such as infrastructure and cost reduction on the market penetration of HFCVs, and we can develop a simulation model that can enhance the versatility and practicality of the forecasting model. The results of this study can promote research related to the market penetration forecasting for HFCVs using the generalized Bass diffusion model, and the developed simulation model can be applied to other studies in analyzing the effect of HFCVs diffusion.

2. Method

2.1. Generalized Bass diffusion model

In this study, the penetration of HFCVs was forecasted by a generalized Bass diffusion model. The generalized Bass diffusion

* Corresponding author. Tel.: +82 42 860 3037; fax: +82 42 860 3135.
E-mail address: gspeed@kier.re.kr (S.Y. Park).

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.03.021

model is a developed version of the Bass diffusion model, which is one of the most widespread diffusion models. The Bass diffusion model can describe the S-shape diffusion curve of a new product using the innovation factor and the imitation factor, based on the assumption that the probability of adoption of a new product or technology at time T is the summation of the probability of adoption by an innovator group and the probability of adoption by an imitator group (Bass, 1969). The innovation factor and the imitation factor refer to the probability of adoption by an innovator group and by an imitator group, respectively. While the probability of adoption by an imitator group, represented by q, is dependent on the number of previous adopters, the probability of adoption by an innovator group, represented by p, is independent of the number of previous adopters. Hence, if $f(T)$ is the density function of adoption a new product or technology at time T, and $F(T)$ is the cumulative function, the hazard function which describes the probability that an adoption will occur at time t given that it has not yet occurred can be expressed by the following mathematical form:

$$f(T)/[1-F(T)]=[p+qF(T)] \quad (1)$$

However, the Bass diffusion model cannot consider external variables that can affect diffusion such as marketing and cost-reduction effects, and it also cannot consider that the innovation factor and the imitation factor are varied by time due to the influence of external variables. For this reason, a generalized Bass diffusion model was developed in order to overcome such limitations of the Bass diffusion model. In the generalized Bass diffusion model, the mapping function $x(T)$, which describes the current effect of the decision variables on the conditional probability of adoption at time T, was added to the hazard function of the Bass diffusion model (Bass et al., 1994):

$$f(T)/[1-F(T)]=[p+qF(T)]x(T) \quad (2)$$

The generalized Bass model has some strong points compared with other diffusion models which also consider the effects of external variables. First, if decision variables are constant for all T, the generalized Bass diffusion model reduces to the Bass diffusion model. Therefore a certain level of consistency with the Bass diffusion model can be achieved. Second, it is possible to express p, q, and m as separate functions of the decision variable. Hence the meaning of the innovation factor and imitation factor can be maintained. Third, the generalized Bass diffusion model has a closed form and this helps to more easily understand the behavior of the model in the time domain. If a cumulative mapping function is defined as $X(T)$, the closed form of the generalized Bass diffusion model can be derived as

$$f(T)=x(T)\left[\frac{(p+q)^2}{p}\right]e^{-(X(T)-X(0)(p+q)}\Big/\left(\left(\frac{q}{p}\right)e^{-(X(T)-X(0))(p+q)}+1\right)^2 \quad (3)$$

Bass proved that the generalized Bass diffusion model has higher forecasting power than the Bass diffusion model when external variables are not correlated with the time variable. If external variables are strongly correlated with the time variable, the addition of external variables into a forecasting model cannot improve the forecasting power (Bass et al., 1994).

However, a study forecasting the penetration of HFCVs using a generalized Bass diffusion model has not been conducted so far because the sales data, which is necessary to estimate the coefficients of a generalized Bass diffusion model, is not available. Hence, forecasting based on the Bass diffusion model cannot help but use an alternative product that has enough past diffusion data and similar diffusion characteristics with the targeted product. This study assumes that the penetration characteristics of HFCVs are the same as the penetration characteristics of the HEV. The HEV is activated by an internal combustion engine and an electric motor. Therefore, various new technologies such as a large scale battery have to be applied in order to develop the HEV. This is the reason why customers have doubts about the reliability of the HEV and accept the HEV as an innovative product (Bose et al., 1996). Because HFCVs also require new technologies such as fuel cells, customers will accept it as an innovative product and will show similar purchase patterns as with the HEV. Hence, we can utilize the innovation factor of the HEV as the basis of the innovation factor for HFCVs in order to conduct a sensitivity analysis (Gustavo, 2007).

This study also considers the number of hydrogen fueling stations and the price of HFCVs as external variables because previous studies related to the penetration of HFCVs also considered the infrastructure and cost reduction of HFCVs as important factors that can affect the diffusion of HFCVs (Keles et al., 2008; Meyer and Winebrake, 2009). Hence, a mapping function for this study can be defined as follows:

$$x(T)=1+\beta_1\frac{P(T)-P(T-1)}{P(T-1)}+\beta_2\frac{G(T)-G(T-1)}{G(T-1)} \quad (4)$$

where

$$P(t)=\frac{\text{Price of HFCV}}{\text{Price of Conventional Vehicle}} \quad (5)$$

$$G(t)=\text{number of hydrogen fueling stations} \quad (6)$$

Therefore, we need to estimate five parameters in order to forecast the penetration of HFCVs using a generalized Bass diffusion model: (1) an innovation factor (p), (2) an imitation factor (q), (3) the price of HFCVs (β_1), (4) the number of hydrogen fueling stations (β_2), and (5) the potential market size (m).

First, we estimated coefficients of an innovation factor, an imitation factor, and the price of HFCV using the sales volume of HEVs in Japan from 1997 to 2006, the price of the Prius from 1997 to 2006, and the price of the Corolla from 1997 to 2006. In this study, the sales volume of the Prius is used to estimate coefficients because the Prius is the best selling HEVs. The price level of the HEVs is estimated by dividing the cost of the Prius by the cost of the Corolla which has a great sales volume and has a similar size as the Prius. Tables 1 and 2 show the time series data set on the cumulative sales volume of the Prius in Japan and the prices of the Prius and the Corolla, respectively.

The estimated value for the imitation factor has to be adjusted because the innovation factor reflects the characteristics of the product and/or technology itself, but the imitation factor reflects not only the product or technology characteristics but also customer characteristics (Bass, 1969). Hence, the estimated value of the imitation factor from the sales volume of Japan has to be adjusted to be able to reflect Korea's purchasing behavior.

Table 1
The cumulative sales volumes of HEVs in Japan.
Source: JAMA (2009).

1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
10,000	22,500	37,400	50,400	74,600	91,200	132,500	196,800	256,600	346,900