Agent based model for estimating hybrid electric vehicle market: The case of Korea

Jinho Choi  
School of Business  
Sejong University  
Seoul, Korea  
jhchoi@sejong.edu

Namgyu Im  
Dept. of Computer Engineering  
Sejong University  
Seoul, Korea  
coutinueing@gmail.com

Jaechan Park  
School of Business  
Sejong University  
Seoul, Korea  
filia79@gmail.com

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Abstract
The increasing automobile vehicles and congestions in the world cause critical pollutions such as air and noise. Hence, we need comprehensive measures to reduce carbon dioxide (CO₂) emission in transportation area. Many researchers have studied the impact of adopting eco-friendly vehicles such as electric vehicle (EV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and fuel cell vehicle (FCV) to reduce CO₂ emissions; furthermore, these green cars have better fuel economy than internal combustion engine (ICE) vehicles. Many countries are implementing various policies to this end, and Korea is also conducting or planning several policies.

In the paper, we studied the impact of vehicle prices, subsidies/penalties, and tax incentives that affect the hybrid car market penetration in Korea. We adopted an agent-based model (ABM) to analyze dynamic interaction between market participants. To derive the analytical results close to the realistic situation of Korea, we used diverse real statistical data of income statement, driving needs, etc. Our simulation consists of four cases: base case, vehicle price change, subsidy/penalty change, and tax incentive change. All the factors we investigated in this paper affect consumer-purchase.

1. INTRODUCTION
The increasing number of automobile vehicles and congestions in the world cause serious air pollution and noise pollution, and we need pressing and broad measures to reduce carbon dioxide (CO₂) emission from the transport sector, which captured significant percentage of the total CO₂ emission in most of the world [EVAAP 2012; Zhang and Cooke 2009]. Moreover, the needs of an extended fuel economy car grow bigger and faster although purchasing less emission vehicles have become more popular [Romm and Frank 2006]. When oil prices started recently rising, better fuel economy became a highly desirable feature [Romm and Frank 2006].

Most of researches and institutes concern about aiming to induce consumers to use or to purchase more fuel efficient vehicles [Hickman 2009]. Many researchers [Beresteau and Li 2011; Chandra et al. 2010; Diamond 2009; Gallagher and Muehlelegger 2011; Heutel and Muehlelegger 2010] endeavor to figure out what factors might affect or encourage consumers to buy HEVs.

However, these studies have many limitations. First, the results of each research in different countries are not comparable together because of their own independent situations and policies. Second, they did not fully reflect dynamic interactions among participants on HEV markets. Finally, they used past data and therefore cannot fully reflect the present, future market conditions. Due to these limitations, it is not appropriate to apply the existing research results to the Korean market.

Therefore, in this paper, we analyze the major determinants of HEV penetration in the Korean vehicle market, paying particular attention to vehicle price changes and government supports such as subsidy/penalty, and tax incentives along with fuel prices. We adopt agent-based model to estimate critical factors that have influence on the current dynamic vehicle market. One of the main features of Agent Based Modeling (ABM) is repeated interaction among participating agents in market [Bonabeau 2002]. ABM could offer a natural description and help us identify the situation out more dynamically due to its flexibility. Furthermore, we employ real data of Korea to reflect the status accurately.

The paper is organized as follows. The next section, we propose an agent-based model of Korean HEV market model and discuss the research methods. The third section presents the results of simulations. The fourth section, we conclude the paper with comments on contributions and weaknesses. We discuss important implications of our findings for the future of the hybrid vehicle market in Korea, offer suggestions for policy, and make suggestions for
future research.

2. MODELING

As mentioned previously, one of our aims is to evaluate the impact of vehicle price, subsidy/penalty, and tax incentive on HEV purchase, using ABM approach for the first time.

To estimate the marketplace more correctly and more closely to the real world, we use consumers’ attributes from reliable institutes such as the Bureau of Statistics, MLTM, KNOC, and Environmental Transportation Division in Korea. Moreover, we adopt an ABM to analyze the automobile market, especially hybrid vehicles’ market penetration rate in 2032, 20 years later.

Our model analyzes a level of diffusion of HEVs with regard to various factors of each agent. Agents in the automobile marketplace consist of consumers, manufacturers, fuel suppliers, and government. These agents interact with each other as shown in Figure 1. Consumers consider purchasing a new car from a choice list of available cars: calculating vehicle miles traveled (VMT), monthly fuel price, and life of vehicle. Manufacturers control the vehicle prices. Government allows subsidies and imposes a penalty pursuant to the policies that separate vehicles into subsidy and penalty cars according to the amount of CO\textsubscript{2} emission. Furthermore, government offers tax incentives for the HEV buyers to vitalize eco-friendly cars. Fuel suppliers determine gasoline, diesel, and LPG prices.

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2.1. Consumers

We assume that there are 10,000 agents of consumers in the model, and each agent has its own attributes composed of income statement, monthly budget, purpose of drive, and vehicle preferences. Monthly budget is composed of two elements. First is the cost paid as the car payment every month (B1).

Second is the cost paid as car fuel price every month (B2). For accurate results, we adopt the real data of each attribute except vehicle preference in 25 different boroughs in Seoul from the Bureau of Statistics of Korea. The vehicle preferences are collected by analyzing a market share of current vehicle models in automotive industry of Korea that show how many people purchase a certain car. Consumers can be divided into three groups with respect to their own perceptions as stated in Sullivan et al. (2009), which are committed, neutral, and inclined. Consumers calculate their

![Figure 1 Agent Based Model of Korean HEV](image-url)
budget status every month, especially monthly payments and fuel prices, and compare budget with a new car they are deciding to purchase. When reaching the time of buying a new car, consumers go through the purchase decision process as follows. First, consumers select vehicles that can be purchased according to their budget. If there are no cars available for purchase within their budget, they give up their efforts to buy a car. Second, consumers select a car completely matching with their brand and size preference among the cars available for purchase. Third, if there are no cars fully matching with their preference, they select one matching with any of brand or size, or economical one in terms of fuel economy. Finally, they purchase the car they selected.

2.2. Manufacturers

Manufacturers are agents that control vehicle prices including HEVs. Types of vehicles consist of 11 ICE’s and 5 HEV’s. Brand has been collected by its market shares in Korea. Total market share of three companies in the list captured almost the entire market, over 90%. Models in the list are also gathered by its sales ranking from each automobile manufacturer, and these models have over 70~80% market share in each brand [KARI 2012]. Specifically, each model has over 80~90% market shares in the same size category. As enacted by Korean law, size can be divided into four segments comprised of City, Small, Medium and Large [MLTM 2011]. Oil type, vehicle price, fuel economy and CO₂ emission are determined by corresponding models [KARI 2012].

2.3. Fuel suppliers

Fuel suppliers control the fuel market by increasing or decreasing fuel prices. We use the fuel price data of the past 10 years. The average fuel prices in Korea are $6.5 per gallon for gasoline, $6.0 per gallon for diesel, and $3.5 per gallon for LPG [KNOC 2011]. We adjust the fuel prices from 70% up to 160% at intervals of 30% to estimate the impact of fuel prices. Each change is increased or decreased with target price over 20 years. For example, if gasoline cost goes down by 70%, the fuel price is reduced from $6.5 in 2012 to $4.5 equivalent to 70% in 2032.

2.4. The Korea government has offered tax incentives since Jan. 2012 to consumers to encourage them to purchase new hybrid cars. The amount of tax incentives, approximately $2,600 per purchase, is given at once. Furthermore, the government plans to provide subsidies or penalties with consumers in terms of CO₂ emission when they purchase a new HEV as well as from 2013 [MOE 2012]. The subsidy and penalty depending on the amount of CO₂ emission, it will be applied next year in Korea. Neutral, 131~140g/km of CO₂ emission, does not have any of subsidies/penalties. Otherwise, consumers have either subsidies or penalties in accordance with the amount of CO₂ emission of his/her own vehicle [MOE 2012].

3. SIMULATION RESULTS

As mentioned in previous sections, we analyze determinants of consumer purchasing behavior on HEV purchase through interaction among agents. We analyze HEV market penetration changes with regard to vehicle prices, subsidies/penalties, and tax incentives. These factors are analyzed simultaneously with the change of fuel price that changes at interval of 30% from 70% up to 160%. Thus, we can observe the influences of fuel prices on each scenario type for the same period.

Scenario 1, base case, shows the current situation of Korea with government policy that confers tax incentives of $2,600 on each HEV purchase and imposes subsidy/penalty on every vehicle in accordance with the amount of CO₂ emission, all other factors being fixed. In scenario 2, all vehicle prices change from 90% to 150% with other factors being remained current. In scenario 3, subsidy/penalty changes from 0% to 200% at 10% interval. Lastly, tax incentives vary between 0% and 200% in scenario 4.

Some assumptions are necessary for our simulation. First, the population of consumers is fixed, and each consumer has only one vehicle within budget. Second, individual income increases at 5.80%, which is the average wage increasing rate over the past 10 years in Korea [MOEL 2011]. Third, agent population follows Korean income distribution. Lastly, our simulation will start at 0% of HEV market penetration. Though, the sales of HEV have started in 2007, the market share of HEVs in Korea is still only 0.21% as of Dec. 2011, thus we assume that there is no HEVs in the automotive market at the beginning because excluding the existing HEV market penetration rate can simplify the simulation for better understanding.

3.1. Scenario 1: Base case

In the base case, we focus on the current situation without any assumptions. Base case maintains current fuel prices and policies. Fuel types consist of gasoline, diesel and LPG, which prices follow $6.5 per gallon for gasoline, $6.0 per gallon for diesel and $3.5 per gallon for LPG [KNOC 2011]. In each subcase, compared with the current price, fuel price changes to 70%, 100%, 130%, and 160% by 2032.

Vehicle prices and other attributes are compliant with Table 1 in section 3. Tax incentives are $2,600 for buying a new HEV [MOE 2012], and subsidy/penalty follows Table 2 in section 3. By comparing with the analysis results of several scenarios to be presented in the next sections, the independent effect on each factor can be compared and verified.
In Figure 2, HEV penetration rate draws a gentle growth line and reaches 6.40% average of four different fuel changes after 20 years from now. Though fuel price continuously increases and 20 years have passed since the introduction of HEV, penetration does not reach 7%. This can be attributed to the following two causes.

First, the price difference between these vehicles is approximately $5,200. The tax incentive and subsidy/penalty used in this scenario cannot reduce the vehicle price differences between HEV and ICE within equivalent specification, which means one of hybrid models has same specification with ICE except engine type. Even though the tax incentive and subsidy/penalty are applied, hybrid is still $1,300 more expensive than ICE.

Second, it is because fuel price did not serve as an important factor in purchasing HEV. In Korea, fuel prices are formed in a relatively higher range than other countries because fuel tax accounts for approximately 50% in the fuel price of Korea, approximately 7-8 times higher based on the same market conditions and purchase quantity compared to the U.S. [KNOC 2012]. Due to the relatively high fuel tax, gasoline prices of Korea are two times more expensive than those of the U.S [EIA 2012; KNOC 2012].

For these reasons, absolute gasoline prices are high, and therefore the sensitivity to price changes is relatively lower than that of other countries. In conclusion, when consumers purchase a car, though HEV vehicles show generally high fuel economy, their preference for HEV is not high.

3.2. Scenario 2: Vehicle price change

In this section, we focus on vehicle price change pursuant to fuel price change in all scenarios, and we identify the impact of vehicle price changes in 2032. Manufacturers change the vehicle prices from 90% up to 150%. This will show us the effectiveness of vehicle price adjusted.
As illustrated in Figure 3, we can confirm the penetration rate of HEVs is higher when the overall vehicle prices are relatively low. In case of the whole vehicle prices going down, lower income consumers would have the same effect of increasing the budget for the proportion of payment of vehicle in a month. This explains why there are more choices to consumers. Consequently, they can reflect their preference when they purchase a vehicle. But consumers still want to buy vehicles that have higher fuel economy because the permitted rate of fuel budget is not changed for simulation. Accordingly, as the vehicle prices decrease, the penetration rate of HEVs rises. Instead, when the vehicle prices go up, lower income consumers would purchase low-priced vehicles or give up buying the vehicle. Hence, the HEV market share becomes low. According to Figure 3, we can find that the lower the vehicle price is, the higher the market share. In case of 90% of current vehicle price, it reaches 8.05%. If the overall vehicle prices decrease, consumers with low income feel the same effect like affordable B1 (monthly car installment payment) increases due to a decrease in vehicle prices. Accordingly, when purchasing a car, they have a lot of options and their car preferences can be fully reflected. However, since there is no change in the ratio of B2, consumers are still trying to purchase a car with good fuel economy. Therefore, as the vehicle prices go down, the market share of HEV with high fuel economy goes up. On the contrary, if the vehicle prices go up, the HEV market share gets lowered because consumers must give up buying one or instead buy a low-priced car. Like the result of base case, we can find that fuel price changes do not affect penetration rate in the situation of adjusting the vehicle prices.

### 3.3. Scenario 3: Subsidy/Penalty

In this section, we simulate the case where government imposes policies regarding subsidy/penalty when consumers purchase HEVs. Subsidy/penalty is given by the levels of CO₂ emission of vehicles [MOE 2012]. We estimate HEV penetration ratio changes by subsidies/penalties under the condition that fuel prices vary between 70% and 160% at 30% interval. Government controls the range of subsidy/penalty within 0%~200%. Vehicle prices and tax incentives remain the same levels as the current situation of Korea.
According to Figure 4, the regulation of subsidy/penalty has no significant influence on the market share of HEVs because subsidy cannot fill in the price gap between HEVs and ICEs, average $5,200, and some HEVs even receive penalty depending on the level of CO$_2$ emission. Even if subsidy/penalty is doubled from the current level, penetration rate reaches just 7.39%, an increased average of 0.99% by considering fuel changes. There are only 1.26% differences between 0% changing ratio and 200% changing ratio when fuel prices are fixed. Therefore, even though subsidy/penalty on CO$_2$ emission maintains the current level or increases or decreases at the same rate, consumers feel little benefits from HEVs. Like the previous scenario, there is no connection between subsidy/penalty and fuel price change.

3.4. Scenario 4: Tax incentives

Currently, $2600 of tax incentives are given on HEV purchase in Korea. In this scenario, we identify the impact of tax incentives in accordance with fuel price change. The range of taxes will be 0% up to 200%. Vehicle prices and subsidy/penalty maintain at current level.

ICEs and HEVs that have equivalent specifications show the vehicle price gap of $5,200 on average. Hence, if the tax level, which only affects HEVs, is raised, the penetration rate of HEVs becomes higher naturally. On the other hand, if the tax level drops, the market share of HEVs also goes down. If the doubled tax incentive is given in comparison to the existing tax incentive, it is expected that the largest HEV penetration rate reach 11.51%. Namely, the line of the penetration rate rises in proportion to a raise in tax incentive level as shown in Figure 5.
ICE and HEV with the same class specifications show the average price difference of about $5,200. Therefore, as tax incentive applied to only HEV gets higher, the HEV market share becomes higher naturally. On the other hand, if tax incentive currently applied is reduced, HEV has low market share. As shown in Figure 5, if the level of tax incentive currently applied is doubled, HEV penetration is expected to reach 11.51% in 2032. The research findings concluding that tax incentive affects HEV sales have been proven through the research findings of Beresteanu and Li (2011), Chandra et al. (2010), and Sallee (2008). In contrast, as shown in the Figure 5, no matter how fuel price changes, it does not affect changes in penetration.

4. CONCLUSION AND DISCUSSION

Our simulation consists of four cases: base case, vehicle price change, subsidy/penalty change, and tax incentive change. All the factors we investigated in this paper affect consumer-purchase. The first scenario simulates the policies currently implemented in Korea. The result shows an average of 6.4% of HEV market share in 20 years. The second scenario simulates HEV market when all vehicle prices vary to 90% ~ 150% while other factors are remained. In this case, HEV purchase increases as the average vehicle price gets lower. Especially, as the vehicle price decreases 10%, we can observe the HEV penetration rate increasing up to 8.05%. This is interpreted like that because as the overall vehicle price goes down, the entry barrier to HEV vehicle purchase gets lower. The third scenario simulates HEV market when subsidy/penalty is changed to 0% ~ 200%. The analytical result showed that it increased by only 0.99% than the average of four different fuel prices in base case. The reason is because even subsidy increased to 200% does not fully cover the average price difference ($5,200) between HEV and ICE, and even some models of HEV receive penalty. Finally, the influence of tax incentive on HEV penetration rate turned out to be very high. The result of analyzing the case from 0% to 200% by comparing the current payment level showed that as tax incentive decreases, HEV penetration rate has been reduced drastically. On the contrary, as tax incentive increases, HEV penetration rate also continued to increase and reached maximum 11.51%.

Unlike other research findings, subsidy in Korea turned out to affect less in our research. The reason is as follows. At present, Korean policy [MOE 2012] determines the applicable vehicles of subsidy/penalty depending on CO2 emissions, so consumers receive benefits also when they possess ICE with less CO2 emissions and that’s why consumers do not fully recognize the necessity of HEV. Therefore, we think if subsidy is purely applied to only HEVs, penetration will appear to be higher than the results of this study. Looking at vehicle price changes, if the price goes down more than 10%, the HEV market can be expanded even faster, but we think that in reality, it will be difficult for manufacturers to lower the vehicle price more than 10%. If manufacturers provide additional price cuts for HEVs, it will show the result to be higher than 8.05%, the maximum value of the scenario.

Finally, to evaluate the justification of this study, verification based on the present actual data is required. First, verification can be done based on actual HEV market data. In case of Korea, less than 5 years have passed since HEV was introduced so sufficient validation data cannot be used but compared to our actual simulation, in which almost similar spreading trend was shown. At present, 4 years have passed since HEV was introduced, and the HEV market share of Korea is 0.21%. The result of base case representing the current market situation and policy of Korea shows 0.22% of HEV market share in 2016, 4 years later, which presents nearly corresponding results with the real HEV market share.

The limitations of our study are as follows. First, in our study, the network effect was not reflected. Some studies including Eppsteins (2011) and Zhang et al. (2011) reflected the network effect as the factor affecting the market share. However, our study that was conducted based on statistical data did not consider the network effect because the network effect could not be obtained with existing statistical data. Second, the data collected for our modeling are not the data obtained from one institution so we expect that there would be lack of consistency and some distortion among diverse institutions. Therefore, to ensure consistent data, a systematic survey targeting Korean drivers is required.

In the further research, we will secure more accurate and detailed data not used in this study such as preference for HEV and additional demographic data on ICE user status or HEV user, influence of the media, degree of influence from people around (word of mouth effect, social effect, etc.) through survey and conduct ABM research based on them. Also, it is necessary to examine the integrated effect among several influence factors such as vehicle price, subsidy/penalty, and tax incentive.

References
Chandra, A., S. Gulati, and M. Kandlikar. 2010. "Green


MOE. 2012. The subsidy/penalty plan in terms of CO2 emission level. edited by Environmental Transportation Division: Environmental Transportation Division.


**Biography**

**Jinho Choi** is an associate professor of School of Business at Sejong University. He received his master and PhD degree from Korea Advanced Institute of Science and Technology (KAIST). Prior to joining Sejong University, he worked for Entrue Consulting Partners, LG CNS as a business/IT consultant and worked for International Center for Electronic Commerce (ICEC) and Human Computers as a researcher. His research works has appeared in several international journals including OMEGA, Information & Management, JCIS, JASSS, Scientometrics, and ESWA. His research interests are green car, sustainability, knowledge evolution and knowledge management, and graph mining.