



Analyzing Factors of Hybrid Electric Vehicle Adoption Using Total Cost of Ownership

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Abstract

Around 20% of total greenhouse gas emissions occur in transportation, 85% of which takes place in road traffics. Environmentally friendly vehicles are a transport type which has less environment impacts compared to existing internal combustion engine vehicles. Among them hybrid electric vehicles (HEVs) have increased steadily in South Korea. This paper analyzes the sales of YF SONATA HEV and K5 HEV, which account for 85% of the domestic HEV market, compared to gasoline engine versions of the same models from Total Cost of Ownership (TCO) viewpoint. The relationship between the vehicle's TCO and HEV sales share were analyzed as well as the consumer's perception about the value associated with purchasing HEVs. This research conducts a quantitative study on the necessary government incentives on HEV sales for the expansion of HEV market in Korea. This work could contribute to the design of government policy to promote environmentally friendly vehicles. Additionally, this work can serve to analyze the effect of such incentive policies on environmental conservation and reduction of social expenses.

Keywords: Hybrid vehicle adoption; Total cost of ownership; Environmental policy.



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1. Introduction

The importance of Environmentally Friendly Vehicles (EFVs) is emerging due to the world-wide concern for the depletion of petroleum and global climate change. The global emissions of greenhouse gases have been on a steady rise. Currently, roughly a quarter of carbon dioxide (CO₂) emissions were accounted by transport industry alone. Three quarters of such transport related emissions were from road vehicles (Metz *et al.*, 2007). Although vehicle manufacturers have been actively pursuing research and development (R&D) programs to improve fuel efficiency and reduce engine emissions, transport-related emissions remain as the fastest growing source of emissions, which are predicted to increase by 80% from 2007 to 2030 (Woodcock, 2009).

It is also widely established that road vehicles will remain a key means of transportation for decades more to come. Reducing the environmental impact of road vehicles is therefore an important issue; the technology and source of energy used to provide this mobility service should be sustainable in the long run. Ideally, the entire well-to-wheel energy chain should be supplied by renewable sources and should not emit emissions harmful to the environment. As of today, however, over 95% of energy utilized for transport is derived from fossil fuel (Palmer *et al.*, 2018).

A complete transition to EFVs, which produce zero or much lower emissions compared to a similar traditional vehicle is sought in the long run in both advanced nations and emerging economies. With an extensive strategic push towards R&D of EFVs, South Korea has also seen moderate success in diffusion of EFVs. The most commercially successful EFVs in South Korea are Hybrid Electric Vehicles (HEVs). The first HEV in the market was LPG engine-based AVANTE LPi HEV which was introduced in July 2009. By 2013, five types of gasoline engine-based HEVs including YF SONATA HEV and K5 HEV were sold. The HEV sales have been continuously increasing, as HEVs appeal to the customer with its high fuel efficiency. The number of HEV sold in July 2009 was only 1038. With the release of various models and due to their high fuel efficiency, the sales increased up to 350% in two years to sell 3543 HEVs by December 2012. Nonetheless, in spite of the key advantages in fuel efficiency and low carbon dioxide emission, the sales of HEVs in the year 2019 only still accounted for 2.9% of the entire automobile sales due to their high prices and low horsepower. The Korean government has announced 'Green-car development roadmap' for the diffusion of the EFVs. According to the local tax law, tax exemption and other supporting systems on eco-friendly vehicle are given to the drivers. In accordance with the law of eco-friendly vehicle development and promoting adoption, individual consumption tax, acquisition tax, and purchase price of metropolitan transit bond could be exempted at a certain price. Other incentives to buy EFVs such as the exemption of Seoul Nam-san tunnel's congestion fee, reduction of public parking lot fee, provision of hybrid-only parking lot, and exclusion in self car free day could be enlarged as well. What is important in the driver (consumer)'s mind is the total cost of ownership (TCO) for a vehicle; therefore, all these benefits should exceed the total cost of purchasing the car, operating/maintaining it and even its disposal/resale.

In this paper, we analyze the automobile market penetration of HEVs in South Korea with the following questions: (1) Does the difference of total costs of ownership between gasoline vehicles and HEVs in the same automobile model affects HEV sales share? (2) If so, how sensitively does the HEV sales share respond to the difference of total costs of ownership between gasoline vehicles and HEVs? From these questions, we could analyze how vehicle prices, government subsidies, manufacture's incentives, gas prices, and used car prices affect the HEV sales share. The SONATA and K5 which occupy 85% of Korea's HEV automobile were selected as the analysis target. We analyze them with the monthly sales rate data from 2011 (when HEV model started to sale) to 2013. It still has a significance in measuring the total cost of ownership in the position of the consumer by analyzing the EFV market with the actual amount of sales data in the past because the EFV market share is still small and not easily expanded. Thus an analysis of the past period with active sales and government policies could provide important insight.

First, a brief literature review in consumers' new technology adoption and government policy is provided in Section 2. Data and research methodology that were used for the analysis of the Korean HEV market are described in Section 3, and results and a discussion are provided in Section 4.

2. Literature Review

There are varieties of studies to be conducted to contemplate about eco-friendly vehicle's market diffusion and come up with its activation strategy. It is important to understand the overall trends of the eco-friendly vehicle market. The following are the previous studies on the diffusion of eco-friendly vehicles, government incentive policy and consumer's perception from the TCO perspectives.

2.1. Economic and Government Policy Mechanisms for HEV Adoption

Eppstein *et al.* (2011), developed an agent-based consumer vehicle selection model and investigated the potential about plug-in HEV's market penetration. In existing simulations, the model suggested policies affecting plug-in HEV market penetration. However, it did not consider the total costs of owning a vehicle but only a limited number of parameters from fuel price, purchase price, rebate of plug-in HEV, battery capacity, and intention to select plug-in HEV technology.

Dijk and Yarime (2010), analyzed the effect of tax rebates offered by Canadian Provinces on the sales of HEVs. They found out that tax rebates had a large and positive effect on the HEV market share. Ambarish *et al.* (2010), examined the determinants of HEV demand by focusing on gas prices and income tax incentives. As a result, it was shown that gas price and federal income tax incentives had effects largely on HEV sales share. Arie and Shanjun (2011), investigated about consumption tax reduction and income tax deduction as well as non-tax incentives. The study showed that the non-tax benefit types were as important as the tax benefit amounts. Moreover, it was analyzed that gas price and HOV lane access had correlation with HEV sales and quantity. Also, they estimated that a 100 dollar saving in annual fuel costs would be associated with a 13% increase in HEV sales. Kelly and Erich (2011) focused on the impact of government incentive policies designed to promote the adoption of HEVs. It mentioned that several factors such as government incentives, vehicle miles traveled, and gas prices had a direct impact on total cost of ownership on a HEV. And they found that gas prices were the most visible signal for the vehicle purchaser to think about cost savings and fuel efficiency, which can directly relate to HEV sales.

David (2009), also explains the role of technological and economic mechanisms as well as social normative mechanisms for electric engine development. This socio-technical perspective would be useful for the adoption analysis of many of today's new technologies but is beyond the scope of this research focused on the total cost of ownership analysis.

2.2. Consumer Perceptions

Lee and Cho (2009), looked at the estimated demand of diesel cars in government regulation and consumers' preference in Korea. They concluded that the consumer would prefer diesel cars despite of higher purchase prices because of operating cost savings. Shin *et al.* (2012), considered electric car's consumer preference and using patterns by conducting Korea's 250 household consumer surveys. It estimated vehicle's future market share in accordance with consumer preference, and analyzed the effect of tax benefits stimulating electric car use. Mau *et al.* (2008), estimated Canadian's preference of new car technologies based on surveys about hybrid cars and hydrogen fuel cell vehicles. Both of these research results supported the relationship of purchase price (constructing consumers' preference about green transportation technology) and diverse properties of vehicles. Roche *et al.* (2010), provides various conceptual frameworks and methodologies. Skerlos and Winebrake (2010), a study using diverse social demographic variables, discussed how the plug-in HEV support policy was applied differently by the consumer's income or purchase area. Also, Hirdue *et al.* (2011) analyzed the preference in electric car selection, based on US survey data. In the survey, the 3029 respondents had selected to choose better one in gasoline or electric engine equipped in their preferred car model. This study was conducted in the biggest size among existing studies; this calculated the "willingness to pay" by differentiating electric car's price and properties (mileage, charging time, fuel cost reduction, pollution reduction, and efficiency). Few of these studies considered the total costs associated with owning the vehicle and how TCO consideration could affect consumer responses.

2.3. Total Cost of Ownership

In this research, the total cost of ownership analysis is applied to internal combustion engine vehicles and hybrid electric vehicles in order to calculate the total costs incurred during their life cycle. In other words, the current HEV purchase price is very high but the operating cost is significantly lower compared to gasoline vehicles. The TCO analysis is intended to compare the value over the life cycle by considering purchase costs, financial incentives, operating/maintenance costs and used car prices. [Mark and Timothy \(2001\)](#), used a life cycle analysis to estimate the life cycle cost of the electric vehicle and compared it to that of the internal combustion vehicle. Their study indicated that the electric vehicle battery prices occupied a very large part of the full price, so in order to justify the introduction of the electric car, the battery cost should be reduced to around \$200/kWh. [Lester and Lave \(2002\)](#) analyzed the life cycle cost of the Toyota COROLLA and PRIUS with a consideration of more detailed environmental costs. According to their study, it appeared that PRIUS would be more dominant than the Corolla in the price competition as gasoline prices go up because of the apparent savings in the fuel cost. To answer the research question of this paper, a TCO analysis is well suited as one can understand when purchasing a HEV makes the most economic, at which point the market share of environmentally friendly vehicles can be increased significantly.

3. Data and Methodology

In this paper, we analyze the HEV market penetration based on the HEV sales share in South Korea. We examine monthly sales of gasoline and hybrid vehicles for the four models (Kia K5 gasoline/HEV and Hyundai SONATA gasoline/HEV) introduced around 2010. Their data have been collected from 2011 to 2018 through KAMA (Korea Automobile Manufacturers Association), TS (Korea Transportation Safety Authority) Opinet and BOK (The Bank of Korea) data base.

[Table 1](#) provides the description of the variables. Each data type is classified by the corresponding TCO stage in the lifecycle. The features and origins such as vehicle sales volume, gas price, manufacture incentive, government subsidy, consumer sentiment index and used car price are examined for performing TCO analyses.

Table-1. Description of the TCO variables

Stage	Factors	Unit	Source
HEV Sales ratio	HEV Sales volume	%	KAMA
Purchase	MSRP (price tag)	won	Automobile manufacturer
	VAT (tax)	won	Framework Act on National Taxes
	CSI	index	The Bank of Korea
Registration	Acquisition tax	won	Ministry of Public Administration and Security
	Public bond	won	Ministry of Land, Transport and Maritime Affairs
	Government HEV subsidy	won	Ministry of Trade, Industry and Energy
	Government temporary tax cut	won	Government article
Possession & Use	Manufacturer Incentive	won	Automobile manufacturer
	Gas price	won	Korea National Oil corporation,
	Annual vehicle travel distance	km	Korea Transportation Safety Authority
	Insurance cost	won	Anycar-direct
	Annual Vehicle tax	won	Local tax
	Education tax	won	Ministry of Strategy and Finance
	Maintenance cost	won	Automobile manufacturer
Disposal	Depreciation Used car prices	won	SK EnCars

We collected the monthly sales data for K5 and SONATA from KAMA. Three types of models: gasoline, HEV and LPG were sold for SONATA and K5. In the case of LPG-based model, we excluded it from analysis, since it was being sold as vehicles only for business use or the disabled. The average monthly sales volume of SONATA and K5 was 7,885 in 2011— which occupied 65% of the midsize vehicle market. Gas price was collected by using the ‘Trend analysis of Korea oil price’ from Opinet. Domestic gasoline price was showing a steady upward tendency reaching 1,956 won per liter in 2013, a 22% increase in three years. Each manufacturing firm had special purchase benefits to buyers in order to enhance their vehicle sales. The purchase benefits of HEV for SONATA and K5 were higher than gasoline models. The government enforced a short term reduction in the individual consumption tax, and a tax incentive to stimulate environmentally friendly vehicle sales. To promote HEV sales, they provided a tax reduction benefits for HEV buyers under the “Law of eco-friendly vehicle development and facilitating propagation”. The government tax incentives and tax change status are shown in [Table 2](#).

Table-2. Tax incentives on environmentally friendly vehicles and government tax change

Classification	Tax Exemption	Tax discount rates	Time
Tax incentives on EFV	Individual Consumption Tax	1 million won	`09.7.1~ 15.12.31
	Education Tax	300 thousand won	`09.7.1~ 15.12.31
	Acquisition Tax	1.4 million won	`11.1.1~ 14.12.31
	Urban Rail bonds	2 million won	`09.7.1~ 14.12.31
	Regional Development Bonds	1.5 million won	`09.10.01~`14.12.31
Government tax change status	Individual consumption tax	▪ Before: 10% of factory price ▪ After: 8% of factory price	`12.3.15~
	Individual consumption tax	▪ Below 2000cc: from 5% of factory price to 3.5% ▪ Over 2000cc: from 8% of factory price to 6.5%	`12.9.11~ 12.12.31
	Automobile tax	▪ 20 won reduction per cc for vehicles over 2000cc: from 220 won/cc to 200 won/cc	`12.3.15~

In this research, we set the Consumer Sentiment Index (CSI) as a dummy variable for the awareness of the state of the economy and marked 1 when CSI was 100 or higher, and 0 when it was lower than 100. The used car price was assessed with the data of SK EnCar's average prices for the used cars on sales. We estimated the monthly used car prices in the four car models, the gasoline engine and the HEV for SONATA and K5 each. Regarding the depreciation rates measured with the used car prices, the depreciation of HEVs was higher than the gasoline vehicles, and the K5 was higher than the SONATA. The annual depreciation of the HEV models was determined from 11 to 12% and that of the gasoline models was from 8 to 9%. The annual average vehicle travel distance was assessed with the data from Korea Transportation Safety Authority's estimation of vehicle kilometers. In this paper, we calculated the TCO of the vehicles with the following conditions: 1500CC~1900CC engine-sized K5 and SONATA models, and 13,614km/year as the annual average travel distance.

3.1. Total Cost of Ownership Analysis

Total Cost of Ownership is used to estimate the cost borne by vehicle owners over the life cycle (from purchase to scrapping). TCO includes not only the cost of purchase, but also the costs of maintenance or operation. For automobiles, it is calculated by considering government subsidies, insurance fees, taxes, fuel prices, repair costs, and the cost of vehicle depreciation in the certain period of possessing the car from the purchase. Based on the assumption that the buyer possesses the vehicle for five years, this paper calculated the TCO on the consumer's part by considering current value (Mitropoulos *et al.*, 2017).

Unlike other studies, we considered Net Present Value (NPV) when calculating TCO. NPV is the present worth of costs occurring in future years using a real discount rate to incorporate the time value of money. The NPV was calculated with the following equation:

$$NPV = \frac{A_0}{(1+r)^n}, A_0 = \text{Amount of recurring cost}, r = \text{Real Discount Rate}, n = \text{Time}$$

$$NPV_{TCO} = P - F + NPV_O - NPV_D \tag{1}$$

The TCO from the standpoint of the vehicle buyers is shown in Equation (1). TCO has been divided into four significant stages in the sequence of cost and time. The "P" represents the cost used in the purchase and registration stage; the "F" the financial incentives; the "NPV_O" the operation and maintenance cost; the "NPV_D" the used car price.

$$P = \text{Ex Factory price} + \text{Excise Tax} + \text{Education Tax} + \text{VAT} + \text{Acquisition Tax} + \text{Public bond} \tag{2}$$

Equation (2) shows the first stage of the TCO—the cost for vehicle purchase and registration. The cost for the vehicle purchase consists of an ex-factory price, an excise tax, and an education tax. Supposing x to be the retail price, the ex-factory price turns out to be '0.86x', the excise tax to be '0.04x', the education tax to be '0.01x', and the Value Added Tax (VAT) to be '0.09x'. Registration fees are determined by the supply price. With the retail price as x, the acquisition tax becomes '0.0637x', and the public bond becomes '0.1092x'.

$$F = \text{Temporary tax cut} + \text{HEV government subsidy} + \text{Manufacture incentive} \tag{3}$$

The benefit of vehicle purchasing as the TCO's second stage in Equation (3) is comprised by government support policies—HEV subsidy, temporary tax, and manufacture incentive. HEV subsidy stands for the cost of a tax reduction policy in buying eco-friendly vehicles under the law of developing cars and stimulating supply. Government temporary tax cut represents the way for reducing the price of individual consumption tax to promote the domestic sales of cars. Other manufacturing firms also offer monthly purchase benefits of a certain amount to promote their vehicle sales.

$$NPV_O = NPV_{\text{Fuel cost}} + NPV_{\text{Maintenance cost}} + NPV_{\text{Insurance cost}} + NPV_{\text{tax}} \tag{4}$$

$$NPV_{\text{Fuel cost}} = \sum_{t=0}^n \frac{(\text{Annual vehicle travel distance}) \times (\text{Gas price})}{\text{Fuel efficiency} \times (1+i)^t}$$

$$NPV_{\text{Maintenance cost}} = \sum_{t=0}^n \frac{\text{Annual Repair cost} + \text{Replacement component cost}}{(1+i)^t}$$

$$NPV_{Insurance\ cost} = \sum_{t=0}^n \frac{Annual\ Insurance\ cost}{(1+i)^t}$$

$$NPV_{Tax} = \sum_{t=0}^n \frac{Automobil\ tax + Automobile\ Education\ tax}{(1+i)^t}$$

Equation (4) stands for the TCO's third stage of vehicle operation and maintenance, which contains fuel, insurance, repair and parts, the annual vehicle tax and the education tax. The fuel cost in driving cars could be calculated by multiplying the fuel price by annual average mileage, adjusted by fuel efficiency. The maintenance cost includes repair and replacing components and is calculated by the recommended manual of the manufacturers for each vehicle model. The insurance fees are calculated on the basis of the annual insurance fee data of Samsung Anycar-Direct, which is Korea's major insurance company. Annual vehicle tax is imposed once a year. In the case of the SONATA and K5, the cars whose engine size is larger than than 1600cc pay 200 won tax per cc, This tax is reduced by 5% per year (up to max. 50%) starting from the third year after initial registration of new cars. The education tax is calculated to be 30% of annual vehicle tax. The HEV and gasoline models for K5 and SONATA's pay the same amount of automobile tax because they are in the same vehicle size category.

$$NPV_D = NPV_{Depreciation\ cost} = \frac{Used\ car\ price}{(1+0.05)^5} \tag{5}$$

The last stage, used car price, is shown in Equation (5).

In this paper, the following assumptions are made to analyze TCO: (a) 5% of discount rate, (b) 5 years of vehicle possession, and (c) Individual variabilities such as toll use and parking fees are not considered in the calculation.

The relationship between the vehicle's TCO and HEV sales share were analyzed by using linear regression. It could be estimated whether TCO affects the HEV sales share through this analysis. We calculated it by setting the dependent variable y as the HEV sales share, and the independent variable x as the difference in the TCO's of HEV and gasoline vehicles.

After verifying the research question, "Does the TCO difference between the gasoline vehicle and the HEV affect the HEV sales share?" we then examine the subsequent question, "How much does a reduction in HEV's TCO contribute to an increased HEV sales share?" The sales share of the HEV is also important to reducing greenhouse gases and fuel consumption in traffic. The HEV sales share, a dependent variable, is shown in Equation (6) since the vehicle sales volume has been often used as the dependent variable in previous studies. Unlike the previous research, by setting the TCO difference between the HEV and gasoline vehicle as an independent variable (i.e. driving factor), we propose a model that could perform the quantitative analysis in this research in order to offer insights into transitioning the automobile industry toward higher shares of HEVs.

$$HEV\ Sales\ Share = \frac{HEV\ sales\ volume}{(ICEV+HEV)sales\ volume} \tag{6}$$

The expected effects by analyzing the HEV market penetration through sales percentage was as followed: (a) It could minimize the effectiveness of the vehicle design, the sales corporation, the vehicle performance, and the safety in the selection of ICEV vs. HEV. (b) It could minimize the impacts of exogenous variables such as economic recession, strike and the number of days of sales by using the HEV sales share.

$$Y_{i,t} = \alpha + \beta \times (HEV\ TCO_{i,t} - ICEV\ TCO_{i,t}) + \epsilon_{i,t} \tag{7}$$

I = Vehicle model indicator

t = monthly time indicator

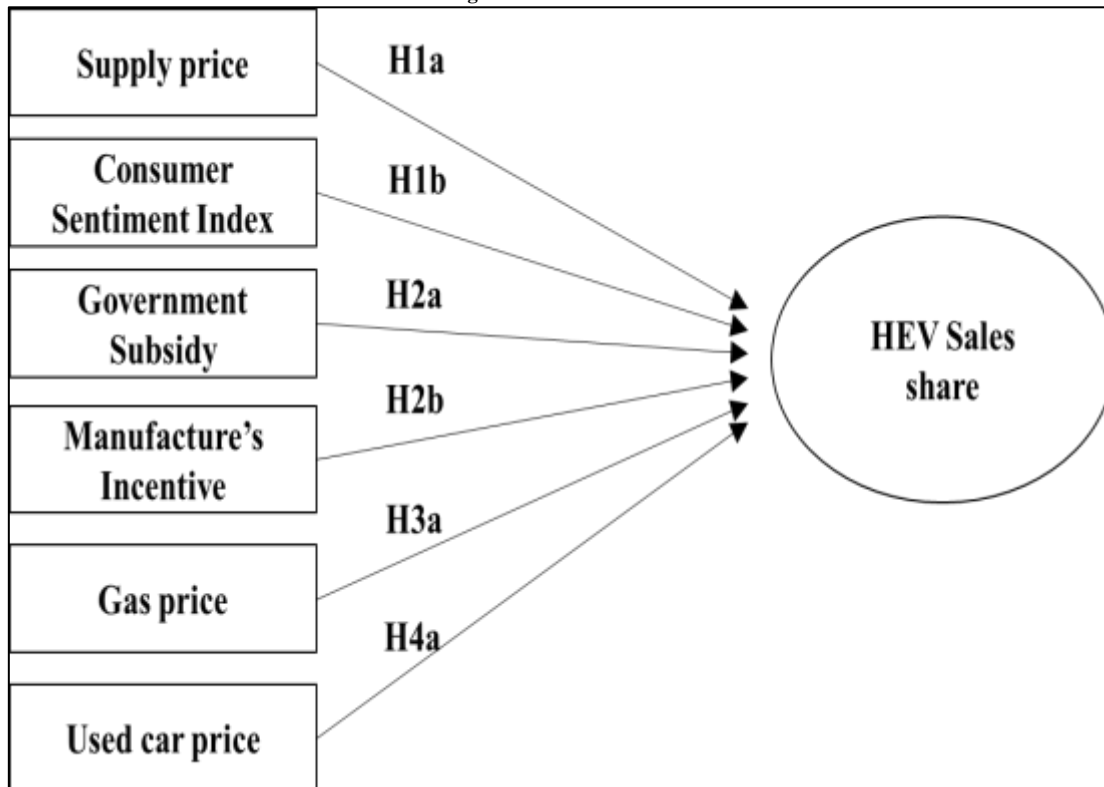
Y = Monthly HEV sales share ICEV = Internal Combustion Engine Vehicle

The HEV's market penetration is shown above in Equation (7). "i" is the vehicle model indicator, "t" the monthly time indicator, and Y the HEV sales share. "i" can be represented by 1, 2, 3, 4 where 1 is for SONATA ICEV, 2 for SONATA HEV, 3 for K5 ICEV and 4 for K5 HEV. "t" is increased monthly from period 1, the starting point of data analysis. "t" can be calculated up to 22nd month until the completion point of the analysis, in the case of K5 model, up to 24th month, in the case of SONATA.

3.2. Hierarchical Multiple Regression Analysis

Hierarchical multiple regression is conducted in stages set theoretically during the regression analysis. Two regression models can be compared among the regression model with predicted variables in the repeatedly simulated regression analysis and the regression model less predicted variables. If the former model has all the predicted variables in the latter model, it could be said that they are in the hierarchical relationship. The hierarchical relationship equation is compared to see how the new predicted variable accounts for standard variables by regulating predicted variables in the lesser model— a hierarchical regression analysis process. In other words, this analysis determines the contribution of additional variables by F-test. Therefore, in order to answer how the each stage of the vehicle's TCO affects the HEV sales share and to understand its relative effectiveness, we use hierarchical regression analysis in this section.

Figure-1. Research model



The hypotheses tested in this paper are as follows: (Figure 1)

H1a: The supply price difference between HEV and ICEV will affect the HEV sales share.

H1b: Consumer Sentiment Index will affect the HEV sales share.

H2a: The government subsidy difference between HEV and ICEV will affect the HEV sales share.

H2b: The manufacturer's incentive difference between HEV and ICEV will affect the HEV sales share.

H3a: Gas price will affect the HEV sales share.

H4a: The used car price difference between HEV and ICEV will affect the HEV sales share.

No difference between HEV and ICEV is assumed for the factors such as insurance cost, maintenance cost and tax, which are excluded in the hierarchical multiple regression model. Also, the Consumer Sentiment Index is considered as a dummy variable in Model 1.

With this research model, we attempt to verify the most effective cost elements in the TCO for the HEV sales share including the order of those elements and how consumers' perception about the NPV differs between the various cost elements in the initial, middle and final TCO stages. This could help make a strategy to increase the HEV sales share for the government and enterprises

4. Results

From the modeling of TCO with its net present value, we calculated five-year TCO's for each of K5 and SONATA's gasoline and HEV models. The initial vehicle purchase cost for HEV was 700~800 million won more expensive than the gasoline vehicle. However, this price gap was reduced by the government subsidies, the incentives of manufacturing firms, and the advantages in fuel efficiency. Consequently, we observed that the TCO of both the gasoline vehicles and HEVs became close at around 3250 million won if both cars were retained for the same five years. Table 3 shows the TCO's for each vehicle during this period.

Table-3. Summary of descriptive statistics for Vehicle TCO (in million Won)

	N	Min. value	Max. value	Mean	Std. Dev
K5	22	2944.10	3175.88	3050.69	67.32
K5 HEV	22	3029.49	3461.61	3290.37	122.58
SONATA	24	3082.64	3436.95	3232.22	103.27
SONATA HEV	24	3058.10	3412.67	3252.04	124.75

Equation (8) is the linear regression equation which sets the HEV sales share as the dependent variable y and the TCO difference between HEV and the gasoline vehicle as the independent variable x. Table 4 indicates the summary statistics of the regression analysis. The adjusted R-square shows a relatively high value of 0.65. From this, we suppose that TCO does affect the HEV sales share inverse proportionally.

$$y = -0.0544x + 37.158 \tag{8}$$

The result of the relationship between the HEV sales share and TCO is depicted in Figure 2. The horizontal axis indicates the TCO difference between HEV and the gasoline vehicle (independent variable), and the vertical axis

indicates the HEV sales share (dependent variable). Each data point represents the TCO of a certain vehicle model and its HEV sales share during a specific month of the five-year period.

Figure-2. HEV Sales vs. TCO Analysis (ICEV: Internal Combustion Engine Vehicle)

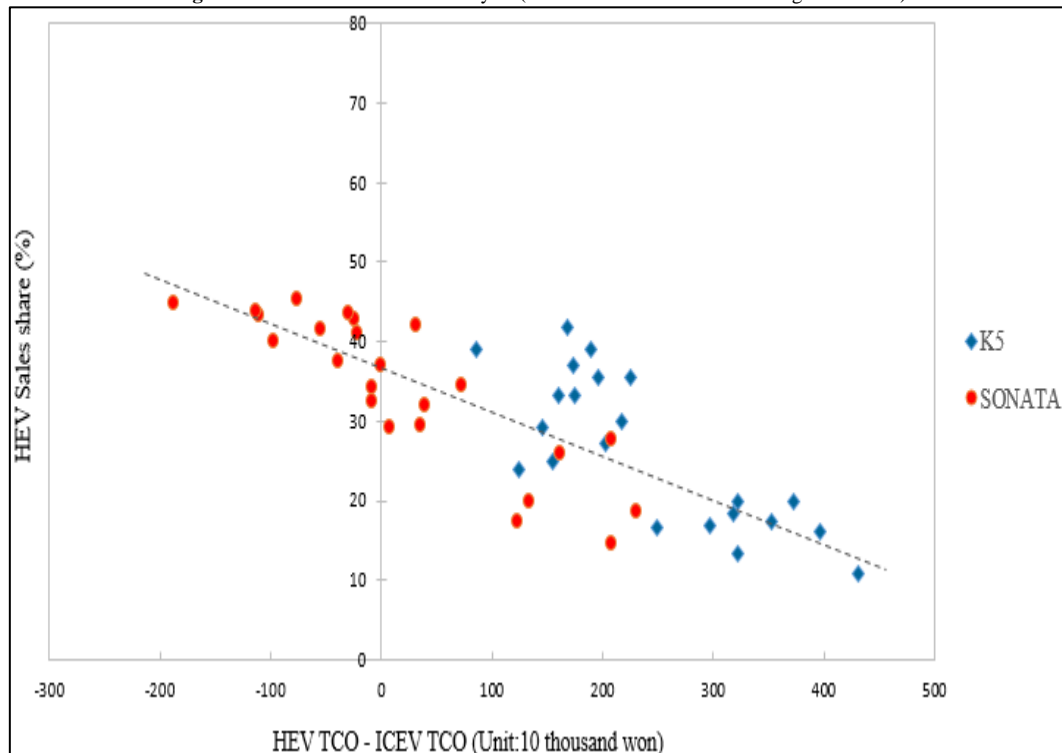


Table-4. Regression Statistics

Multiple R	R-square	Adjusted R-square	Standard Error	Observations
0.807	0.651	0.643	6.089	46

If the TCO difference between HEV and the gasoline vehicle appears on the left side (-) of the horizontal axis, the TCO of HEV is lower than that of the gasoline vehicle if it is retained for five years. In short, buying a hybrid car is more cost effective than buying a gasoline engine model from the total cost of ownership perspective. However, when the TCO of HEV is greater than that of the gasoline vehicle as indicated by the TCO difference appearing on the right side (+), the costs of buying and maintaining are still much larger so they offset the benefits of buying a gasoline vehicle in the short run. Note that the HEV sales share decreases as the gap between the higher TCO of HEV and that of the gasoline vehicle increases to the right.

Based on the linear regression result, it is expected that the TCO difference between the HEV and the gasoline vehicle should be reduced by about 1.8 million won via financial incentives or price cuts in order to increase 10% of the HEV sales share. In addition, increased HEV sales are expected with respect to enhanced fuel efficiency leading to less fuel costs. That is, the HEV sales share could increase as much as 10% if the existing HEV's fuel efficiency improved by the 4.5km/l.

At the zero point where there is no TCO difference between the HEV and the gasoline vehicle, the total ownership cost would be the same between the two vehicle types for five years of possession. Nonetheless, the fact that the HEV sales share is 35%, not 50% at that point could be due to (a) individual, non-cost-related preference for vehicle types, (b) the consumer's negative perception about the larger initial purchase cost for HEVs, (c) function-related concerns such as max. output and max. torque of the HEV is lower than that of the gasoline vehicle and (d) switching costs including the perceived difficulty associated with operating and maintaining HEVs.

These findings seem to indicate that monetary incentives alone cannot promote the HEV sales in the long run and that enhancing the HEV's fuel efficiency and reliability as well as reducing manufacturing costs is necessary through continuous R&D investments while environmentally friendly vehicles are still in the early stage of development and market introduction.

We conducted hierarchical multiple regression to analyze the consumer's perception about the NPV which was used for each TCO calculation and the relative ranking of factors that can affect TCO's for the HEV sales share shown in Table 5. This regression consisted of four stages: purchase, financial incentive, operation and depreciation as in the TCO analysis. In Model 1, the value of Consumer Sentiment Index (CSI) and the difference between the sales prices of the HEV and the gasoline vehicle were used as the independent variable. In addition to vehicle price, CSI index, which reflects the consumer's overall awareness for the economy, was considered as a dummy variable. In Model 2, the TCO's second stage includes government subsidies and manufacture's incentives in addition to Model 1. In Model 3, gas price is added in the third stage of TCO. Lastly, used car price is added to the last stage of TCO as shown in Model 4. Car taxes, insurance fees, and repair costs that would have no difference between the HEV and the gasoline vehicle are excluded in this analysis.

Table-5. Hierarchical multiple regression model for HEV market penetration

Model	Sub model
M1	$\beta_0 + \beta_1 \times V. price + \beta_2 \times CSI$
M2	$\beta_0 + \beta_1 \times V. price + \beta_2 \times CSI + \beta_3 \times Subsidy + \beta_4 \times Incentive$
M3	$\beta_0 + \beta_1 \times V. price + \beta_2 \times CSI + \beta_3 \times Subsidy + \beta_4 \times Incentive + \beta_5 \times Gas price$
M4	$\beta_0 + \beta_1 \times V. price + \beta_2 \times CSI + \beta_3 \times Subsidy + \beta_4 \times Incentive + \beta_5 \times Gas price + \beta_6 \times Used. price$

Table 6 shows the results of the hierarchical multiple regression analysis on the variables that impact the HEV sales share. In Model 1, the difference between the sales prices of the two vehicle types explains 69% of variance on the HEV sales share. This implies that the HEV sales share increases with respect to HEV sales price decrease. Model 2 explains 8.6% more of variance than Model 1 on the HEV sales share. This further shows that the provision of government subsidies and corporate incentives have positive effects on enlarging the HEV sales share. Model 3 explains 6.7% more of variance than Model 2 to suggest that fuel price hikes have negative effects on HEV sales. Lastly, Model 4 explains 85.8% of variance on the HEV sales share to indicate that HEV sales would decrease if the HEV's used car prices decreased.

The relative influence among the variables that could improve the HEV sales share can be determined by the absolute value of β (beta) for each variable in Model 4. The p-values of the five variables were considered statistically significant as they are all below 0.1. This analysis result indicates that the vehicle price is most influential to the HEV sales share. The second is the manufacture's incentives. The government subsidies ranks third, the fuel price fourth, and the used car price fifth. This suggests that the HEV buyers consider the difference of the initial cost (e.g. purchase price) between the HEV and the gasoline vehicle. Furthermore, we analyze that the factors such as gas price and used car price, the costs of which are taken into account at a later operation stage of ownership have relatively a low effect on HEV selection.

5. Conclusions and Future Work

Today, environmentally friendly vehicles such as HEV, electric vehicle (EV) and fuel cell electric vehicle (FCEV) have been proposed as alternatives to the conventional internal combustion engines. To expedite the diffusion of low to zero carbon emission vehicles that help to address the challenges posed by global climate change, local air pollution and subsequent human health effects as well as depletion of natural resources, this research presented total cost of ownership analyses on the HEV market penetration in Korea.

The results showed that car purchases were influenced by the TCO difference between the HEV and the ICEV. The HEV sales share increased as the TCO of the HEV decreased. The vehicle price, manufacture's incentive and used car price were determined to have the greatest effects on the HEV sales share. Given more than 90,000 units of SONATA and K5 are sold annually, if the HEV sales share increases by 10% induced by subsidies and higher fuel efficiency benefits, over 1,800 tons of CO2 emissions could be eliminated.

A limitation of this research is that only Korea's HEV market has been examined. Moreover, the analysis was confined to the two HEV models: the SONATA and the K5. For this reason, the dependent variable was calculated by reflecting their HEV sales share. An extended TCO-based research is desirable to include more vehicle models across different regions.

Table-6. Hierarchical multiple regression analysis results

Independent Variable	Model 1			Model 2			Model 3			Model 4			Tolerance
	SE	β	t (Sig.)	SE	β	t (Sig.)	SE	β	t (Sig.)	SE	β	t (Sig.)	
(Constant)	13.119	-	11.505(.000)	217.440	-	-.819(.418)	194.502	-	-2.230(.031)	189.553	-	-1.977(.055)	
Vehicle price	.018	-.856	-	.022	-.591	-	.019	-.623	-	.025	-	-3.522(.001***)	.229
CSI	1.840	-.081	9.398(.000***)	1.923	.102	5.387(.000***)	1.704	.203	6.675(.000***)	1.655	.444	2.745(.009***)	.541
			-.889(.379)			1.072(.290)			2.406(.021**)		.223		
Government Subsidy				.016	-.281	-2.188(.034*)	.014	-.094	-.799(.429)	.017	-	1.870(.069*)	.184
Corporate Incentive				.757	-.149	-1.305(.199)	.724	-.357	-	.719	.263	2.813(.008***)	.312
									3.279(.002***)		-.304		
Fuel price							.017	-.296	-	.017	-	-3.635(.001***)	.713
									4.127(.000***)		.260		
Used car price										.009	.176	2.032(.049**)	.483
Statistics	R ² =.690, Adjusted R ² =.675, F=47.812, p=.000			R ² =.776, Adjusted R ² =.754, F=35.544, p=.000			R ² =.843, Adjusted R ² =.823, F=42.959, p=.000			R ² =.858, Adjusted R ² =.836, F=39.286, p=.000, Durbin-Watson=1.900			

Note: With the tolerance limit higher than 0.1, multicollinearity has been checked. Durbin-Watson of 1.9 is near the reference value 2, and not close to 0 and 4 – there is no correlation between the residuals. Therefore, the regression model is acceptable. The variables whose p-value is below 0.01 is marked ***, below 0.05 ** and below 0.1 *.

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