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Supply Portfolio of Bioethanol in the Republic of Korea

Jeong Hwan Bae*

Despite the co-benefits of bioethanol, such as energy security, environmental improvement, CO_2 emission reduction and development of associated industry, bioethanol-blended gasoline without subsidy is more expensive than pure gasoline in Korea. The renewable fuel standard (RFS) can contribute to the development of a bioethanol market. However, without controlling the portions of domestic bioethanol, it is highly plausible that a new bioethanol market will be filled with imported bioethanol. If the entire supply of bioethanol is imported, Korea can no longer expect those co-benefits. This study aims at simulating the desirable ratios of domestic versus imported bioethanol as well as domestic versus imported feedstock for producing bioethanol in Korea by combining the marginal social benefit (MSB) with the marginal social cost (MSC) for bioethanol supply. MSB is derived from a choice experiment and the MSC is derived from the differences in the bioethanol production costs and the petroleum price. The simulation results show that considerable portions of bioethanol should be produced domestically under the condition that MSB is equivalent to MSC in bioethanol production. Thus, the upcoming RFS policy should allow for some quota on behalf of domestic bioethanol with domestic feedstock or more credit should be given to the petroleum companies that use domestic bioethanol with domestic feedstock.

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I. Introduction

The renewable fuel standard (RFS) was enacted in the Republic of Korea in June of 2013 and will be implemented at the beginning of 2015. The United States, Brazil and several European countries have already implemented the RFS in order

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* Department of Economics, College of Business Administration, Chonnam National University, Yongbongro 77, Bukgu, Gwangju, Republic of Korea, E-mail: jhbae@jnu.ac.kr, Tel.: +82-62-530-1542. I sincerely appreciate two anonymous referees for the precious comments and suggestions. All potential errors belong to the author's responsibility.

to substitute fossil fuels with biofuels, such as bioethanol, biodiesel or biogas. Concerning the utilization of biofuels, there have been on-going debates with regard to issues such as agflation due to excessive fuel demand on feedstock (World Bank, 2008; Cha and Bae, 2011), the destruction of tropical forests and inefficiency of government subsidy on agriculture for biofuel feedstock (Hill et al., 2006). Recently more advanced biofuel technology has been developed to avoid the overconsumption of food resources for bioethanol manufacturing. Cellulosic bioethanol based on crops, trees, grasses or wood wastes is known as one of the most sustainable ways of producing biofuels (Heiman and Solomon, 2007).

However, Korea has limited biomass resources for raising the production of domestic biofuels, such that Korean researchers have investigated alternative resources to replace the conventional biomass resources. The alternative cellulosic resources include aquatic biomass, such as macroalgae and foreign plantation wastes (Kim et al., 2010). More recently, in pursuit of a more efficient separation process in manufacturing bioethanol, membrane technologies have been investigated in three ways: microalgae harvesting, sugar concentration and detoxification, and bioethanol recovery (Wei et al., 2014).

Apart from the current debates on externality issues that occurred in the production of biofuels, petroleum companies insist that bioethanol can be entirely imported from foreign countries, such as Brazil, the United States or Southern Asian countries, on efficiency grounds. Meanwhile, alcoholic beverage companies argue that some portion of bioethanol should be produced domestically by using domestic feedstock in view of energy security, mitigation of CO_2 emission, improvement of air quality, and development of bioethanol industry and agricultural sector.

If economic efficiency is the predominant criterion in the supply of bioethanol in Korea, bioethanol will not be produced domestically at all because the price of imported bioethanol is substantially competitive relative to the production cost of domestically produced bioethanol. If this is the case, energy independence, industrial and agricultural development effects as well as environmental improvement will not be obtained from the RFS policy. Therefore, in order to accomplish multiple goals of the RFS policy, the government should intervene in the initial bioethanol market in order to encourage the domestic production of bioethanol using domestic feedstock. In numerous countries that have implemented the RFS, such as the United States and EU countries, biofuels have been produced domestically even if the prices of domestic biofuels were not competitive relative to import prices. A substantial amount of subsidy as well as oil tax exemption has been paid to the suppliers of feedstock for biofuels, biofuel producers and consumers of biofuels (Ferris and Joshi, 2004; de Gorter and Just, 2007; Vedenov and Wetzstein, 2008).

In this context, the extent of government intervention on the initial bioethanol market will depend on not only the expected marginal social gains from domestic bioethanol, in terms of energy security, abatement of CO_2 emission, environmental improvement, and industrial development effects, but also on the marginal costs which arise from the increase in the price of petroleum when bioethanol is blended. As long as the marginal social benefit is higher than the marginal cost of bioethanol-blended petroleum, the government can justify its actions to control a relative portion of domestic bioethanol to that of imported bioethanol.

Vedenov and Wetzstein (2008) derived an optimal U.S. bioethanol subsidy as $0.22/gallon (54 KRW/liter[1]) by estimating a theoretical model on the social benefits of bioethanol, such as enhanced environmental quality, fuel security and economic development. According to Solomon and Johnson (2009), the marginal willingness to pay (MWTP) for biomass bioethanol was estimated as 40 cents per gallon (98.2 KRW/liter). They used a fair share survey and a multi-part, split sample contingent valuation method for valuing biomass bioethanol. Petrolia et al. (2010) estimated the social values of E10[2] and E85 by applying the contingent valuation method with satisfaction questions; they discovered that the MWTP for E10 was between 6 to 12 cents per gallon (15 to 30 KRW per liter), whereas the MWTP for E85 was between 12 to 15 cents per gallon (30 to 37 KRW per liter).

As a first step of this study, I measure MWTP for the production of bioethanol with different pathways. MWTP for domestic bioethanol with domestic feedstock can be interpreted as the marginal social benefit (MSB) from industrial and agricultural development, energy security, mitigation of CO_2 emission and environmental effects (Petrolia et al., 2010). The choice experiment approach was employed in order to derive Korean petroleum consumers' MWTP on the marginal social gains from bioethanol production (Train, 2009). Three different production pathways (1: domestic production of bioethanol combined with domestic feedstock, 2: domestic bioethanol with imported feedstock, 3: import of bioethanol) and three levels in the blending ratios for bioethanol (3%, 5% and 10% of blending ratios) were considered as the attributes of alternative bioethanol.

At the second step, I estimate the price increase of petroleum blended with bioethanol by 3% (E3). The production costs of various types of bioethanol are estimated by using various panel econometric models (fixed and random effect models, generalized least square and dynamic panel models). The difference between the before tax petroleum price and that of 3% bioethanol-blended petroleum can be regarded as the marginal social cost (MSC) of producing bioethanol. By combining the MSB of domestic bioethanol with the MSC, a desirable portfolio of bioethanol production can be derived at the point where the

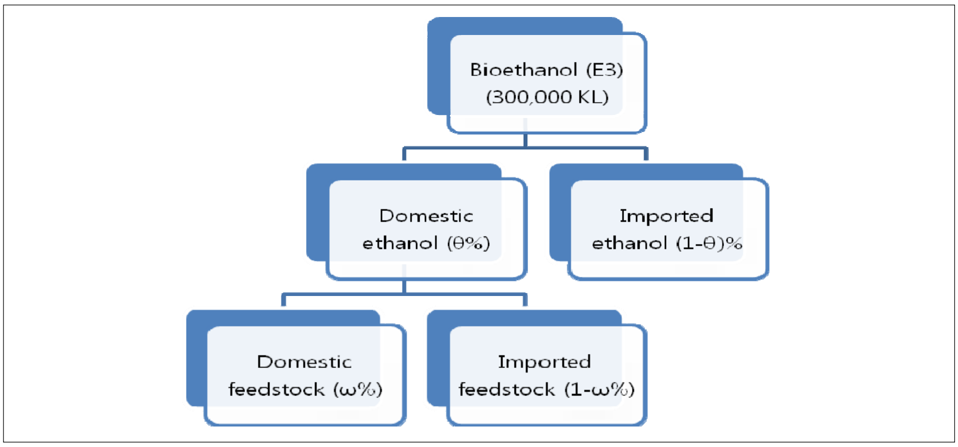
[1] As of 2012, exchange rate of KRW for 1 USD was 1,126 KRW.

[2] E10 implies bioethanol blended gasoline within 10% for general gasoline vehicle, whereas E85 means that the bioethanol blending ratio is within 85% and further, vehicles for E85 should be modified.

marginal benefits of domestic bioethanol are equal to the marginal social costs of bioethanol.

Combining the marginal gain with the marginal cost, the final purpose is to derive socially desirable portfolio of bioethanol supply. An identical equation between the MSB and MSC of bioethanol is established in order to simulate the appropriate weights on the production level of domestic bioethanol with domestic feedstock, domestic bioethanol with imported feedstock, and imported bioethanol. Figure 1 shows the framework for supply portfolio of bioethanol. In the short run, E3 will be provided under the RFS policy. About 300 thousand KL of bioethanol should be provided in order to meet the required volume of the E3. Alcoholic beverage companies can provide θ% of the E3, and approxiamtely (1-θ) % of the E3 should be imported. Meanwhile, some portion (ω) of the domestic feedstock (barley)[3] relative to the imported one (Tapioca) (1-ω) can be used as materials for the production of bioethanol.

[Figure 1] Supply Structure of Bioethanol in the Republic of Korea



The research is expected to contribute to which degree the government should control a new market for bioethanol in the transportation sector. Once the RFS policy is introduced, at least 3% of the petroleum will be replaced by bioethanol and major petroleum companies, as monopsonists can affect the bioethanol market substantially. Thus, it is unavoidable for the government to intervene in this new market due to not only the efficiency ground, but also the co-benefits aspects. If the government only controls the total amount of bioethanol that should be provided by the petroleum companies, then there is no way of raising the domestic bioethanol industry at the present, because petroleum companies are supposed to entirely rely

[3] There are abundant set-asides for raising barley during the winter season as demand for barley in Korea has diminished consistently.

on the imports of bioethanol. The outcome of this research reveals that some portions of bioethanol should be produced domestically by using domestic feedstock under the condition that the MSB is equal to the MSC of bioethanol production. Hence, it is crucial for the government to intervene in the new bioethanol market with respect to securing some portion of domestic bioethanol with domestic feedstock.

The next section provides the estimated MWTPs for different types of domestic bioethanol combined with various feedstock and different blending ratios by applying the choice experiment approach. In section III, the unit production costs of bioethanol are estimated depending on the different combinations of domestic and imported feedstock. By combining the results of section II and section III, section IV simulates what would be desirable weights between domestic versus imported bioethanol as well as domestic feedstock versus imported feedstock within domestic bioethanol. The policy implications are discussed based on various simulations. Finally, section V discusses the major findings and policy suggestions.

II. Co-Benefits of Domestic Bioethanol Production

2.1. Choice Experiment for Valuing the Co-Benefits

One of the most widely used methods for examining the stated preferences in fields such as communication, transportation, environment and medicine, amongst others, is the choice experiment (Batt and Katz, 1997; Hensher, 1994; Hanley et al., 1998; Slothuus et al., 2002). In the choice experiment, potential consumers are asked to choose the most preferred alternative among various choice sets. The alternatives in each set are composed of various attributes with different levels. Further, the choice experiment is theoretically based on the random utility model, which assumes that a consumer's utility is split into observable utility and unobservable utility. The unobservable utility follows a Type I extreme-value or the Gumbel distribution:

$$U_{ni} = V'_{ni}\theta + \varepsilon_{ni}\,,\quad F(\varepsilon_{ni}) = \exp(-\exp(-\varepsilon_{ni})) \tag{1}$$

A potential consumer n chooses an alternative i if his utility U_{ni} from choosing alternative i exceeds U_{nj} from an alternative j. The choice probability can be transformed into a conditional logit model:

$$\Pr ob(Y_n = i) = \frac{\exp(V'_{ni}\theta)}{\sum_{j=1}^{J}\exp(V'_{nj}\theta)}\,,\quad V_{ni} = [X_{ni}, Z_i]\,,\quad \theta = [\alpha', \beta']' \tag{2}$$

The observable utility V_{ni} is affected by individual specific variables (X_{ni}) as well as alternative specific attributes (Z_i). If there is no individual specific effect, the conditional logit model becomes the multinomial logit model (Greene, 2008).

The conditional logit model can be transformed into a panel logit model when the data has a panel structure. In this choice experiment, each respondent is required to answer a series of choice sets with different attribute levels and different scenarios. This panel logit model assumes that the unobserved factors can affect the repeated choices of each respondent, which implies that the respondent's present choices are dependent on his/her past choices (Train, 2009). In the panel logit model, an individual's utility from alternative j in choice situation s consists of both observable and unobservable utility.

$$U_{njs} = V'_{njs} + \varepsilon_{njs} \tag{3}$$

$$\Pr ob(Y_{ns} = j) = \frac{\exp(V'_{njs}\theta)}{\sum_{i=1}^{J} \exp(V'_{nis}\theta)} \tag{4}$$

Individual or situation specific effects can be considered as a fixed or a random effect panel model (Greene, 2008). The fixed effect panel logit model is typically the same as the conditional logit model because the conditional probability approach is applied to fit the fixed effect panel logit model (STATA, 2009). When the unobserved factors of the panel data are correlated over different choice situations, the panel probit model can be alternatively applied to the choice experiment. Error terms of the panel probit model is normally distributed with a mean vector of zero and covariance matrix Ω; the probability density function of the error terms is $\Theta(\varepsilon_{njs})$.

$$P_{njs} = \Pr ob(V_{njs} + \varepsilon_{njs} > V_{nis} + \varepsilon_{nis}) \quad (j \neq i), \quad \Theta(\varepsilon_{njs}) = \frac{\exp(-(1/2)\varepsilon'_{njs}\Omega^{-1}\varepsilon'_{njs})}{(2\pi)^{J/2}|\Omega|^{1/2}} \tag{5}$$

The panel logit fixed, random effect models and panel probit model will be applied in order to estimate the parameters of attributes in bioethanol production.

2.2. Survey Design and Data Description

A face-to-face choice experimental survey was conducted between November and December of 2012 for 500 car owners in Korea, and a stratified sampling method was applied. Prior to conducting the final version of the survey, a pre-test and a review of the focus group were implemented.

The final version of the survey consists of three sections: 1) background questions on car ownership, fuel cost, knowledge on bioethanol and benefits of bioethanol production, 2) description of various types of bioethanol with different economic and environmental effects and choice questions, and 3) socio-demographic questions.

In the first section of the survey, the questions were based on the following: ownership of car, gender, age, importance of fuel price, distance to fuel station, brand name of fuel station, auxiliary services of fuel station in the choice of fuel station, type of car, average driving distance per day, purpose of driving a car, average fuel economy, monthly fuel cost, recognition of bioethanol as fuel, importance of various effects of bioethanol as fuel, and importance of various bioethanol supportive policies.

Section two includes the comparison of benefits and costs among domestic bioethanol with domestic feedstock, domestic bioethanol with imported feedstock and imported bioethanol as well as the attributes and levels of bioethanol-blended petroleum (Table 1). Next, we explained how the different blending ratios of bioethanol had different environmental effects (mitigation of greenhouse gases) (Table 2). In section three, each respondent was asked to choose the most preferred alternative among the three different fuels: two bioethanol-blended gasoline fuels and one gasoline fuel. The respondent had to answer nine choice sets with different combinations of attributes for the alternative fuels (Figure 2). Before the respondents could answer the choice questions, the attributes and levels of alternative bioethanol were described (Table 3).

[Table 1] Comparison of effects among different bioethanol production pathways

Types of bioethanol supply	Domestic feedstock+domestic ethanol	Imported feedstock+domestic ethanol	Import of ethanol
Development of agricultural sector	○	X	X
Development of ethanol industry	○	○	X
Domestic energy production effect	○	△	X
Environmental improvement	○	△	△
Necessity of government subsidy	○	△	X

(○: very positive effect, △: mild effect, X: no effect/neutral.)

[Table 2] Mitigation of greenhouse gases according to different blending ratios of bioethanol

Blending ratio of bioethanol	Substitution of gasoline (Unit: 1,000 liter)	Mitigation of green house gases (Unit: ton)
3% of bioethanol blending	300,000	100,000 ~ 250,000
5% of bioethanol blending	500,000	170,000 ~ 410,000
10% of bioethanol blending	1,000,000	240,000 ~ 580,000

[Table 3] Attributes and levels of alternative bioethanol for choice experiment

Attribute	Level
Price changes of gasoline	1) Increase of 20 KRW per liter in gasoline price 2) Increase of 80 KRW per liter in gasoline price 3) Increase of 120 KRW per liter in gasoline price
Method of providing bioethanol	1) Use of domestic feedstock for domestic bioethanol: Domestic barley is used for producing domestic bioethanol 2) Use of imported feedstock for domestic bioethanol: Tapioca is imported for producing domestic bioethanol 3) Import of bioethanol : Bioethanol is imported
Blending ratios of bioethanol to gasoline	1) 3% of bioethanol blending 2) 5% of bioethanol blending 3) 10% of bioethanol blending ※ There is no significant damage to the performance of a car even if 10% of bioethanol is blended with gasoline

[Figure 2] A sample choice set

Q 10-1) Type 1	Bioethanol A	Bioethanol B	No choice
Gasoline price per liter	Increase of 80 KRW/liter	Increase of 20 KRW/liter	
Method for providing bioethanol	Use of imported feedstock for domestic bioethanol	Import of bioethanol	
Blending ratios of bioethanol to gasoline	3%	3%	
The most preferred alternative	①	②	③

Each set includes the choices among two alternative bioethanol and an opt-out gasoline option. Each alternative bioethanol varies with different attributes: method of supply, blending ratio and increases in the purchase price of bioethanol-blended petroleum per liter. The bioethanol supply methods consist of three different pathways: 1) domestic production of bioethanol with domestic feedstock, 2) domestic production of bioethanol with imported feedstock and 3) purely imported bioethanol. The bioethanol blending ratio is divided into E3, E5 and E10. Price increases in the petroleum blended with bioethanol are split into 20, 80 and 120 KRW increases per liter relative to pure petroleum. Because the attribute on the bioethanol pathways is a qualitative as well as a categorical variable, the effect coding method was used instead of the dummy coding method for the purpose of avoiding perfect collinearity or the dummy variable trap (Beck and Hansen, 2005). In table 4, the third level, as a reference point, perfectly correlates with the first and second levels by encoding it as -1. Hence, the parameter for the third level (imported bioethanol) can be indirectly derived by a minus sum of the estimated parameters for the first level (domestic bioethanol with domestic feedstock) and the second one (domestic bioethanol with imported feedstock). Owing to the effect coding, the alternative specific constant (ASC) term can be interpreted as a quantified utility level for choosing an opt-out option (no choice).

[Table 4] Effect coding for the bioethanol production pathway variable

Bioethanol production pathway	EC1	EC2
Domestic bioethanol with domestic feedstock	1	0
Domestic bioethanol with imported feedstock	0	1
Imported bioethanol	-1	-1

The choice experiment on bioethanol consists of 18 choice sets for each respondent. SPSS (version 19) was used to extract the orthogonal choice sets. Further, unrealistic choice sets were excluded by comparing the levels of attributes within the choice set (Holmes and Adamowicz, 2003). For example, choice sets with low petroleum price increases and high bioethanol blending ratio and domestic feedstock were removed. Also, the choice sets were selected in order to consider the trade-off relationship between the financial and non-financial attributes (Champ et al., 2003). Finally, 8,946 choices were selected for the estimation of parameters.

Our sample was selected from owners of cars for those over the age of 19 who live in the Republic of Korea. In the sampling process, spatial as well as sex, age, education and income distribution were considered as impartially as possible. The number of samples for each region was determined according to the proportion of the total population in the region. Among the 500 samples, approximately 76% of the respondents were male and 72% were aged between their 40s and 50s (Table 5). About 95% of the respondents graduated at least high school, and approximately 60% of the respondents earn between 3,000 and 5,000 thousand KRW monthly. The survey results of 497 respondents were used in the analysis because there were three missing answers in the survey questions.

[Table 5] Basic statistics for respondents in the choice experiment survey

Socio-economic characteristics of sample		Observations (person)	Percentage
Sex	Male	381	76.2
	Female	119	23.8
Age	19-29	31	6.2
	30s	89	17.8
	40s	149	29.8
	50s	210	42.0
	60s and over	21	4.2
Region	Seoul	89	17.8
	Inchon/Gyeonggido	145	29.0
	Chungchungdo	53	10.6
	Gyeongsangdo	145	29.0
	Joenlado	47	9.4
	Gangwon/Jeju	21	4.2
Education	Elementary	1	0.2
	Middle school	24	4.8
	High school	231	46.2
	University	234	46.8
	Graduate school	10	2.0
Income	Less than 3,000 thousand KRW	128	25.6
	3,000-4,000 thousand KRW	156	31.2
	4,000-5,000 thousand KRW	139	27.8
	5,000 thousand KRW	74	14.8
	Unknown	3	0.6
Total		500	100.0

2.3. Parameter Estimation and MWTP for Attributes of Bioethanol

The specific choice model for alternative fuels are as follows.

$$Y_{is} = ASC + \alpha_1 P_{is} + \alpha_2 E_{is} + \alpha_3 R_{is} + \alpha_4 R^2{}_{is} + U_{is} \tag{6}$$

, where Y_{is} is a dummy with 1 if an alternative bioethanol blended petroleum fuel is chosen, and 0, otherwise by respondent i within a choice set s. The ASC captures the people's preference of the opt-out option, which means a preference on pure gasoline. P_{is} is the price of an alternative fuel per liter, E_{is} is a categorical variable that is divided into domestic bioethanol with domestic feedstock, domestic bioethanol with imported feedstock and imported bioethanol. R_{is} is the bioethanol blending ratio and R_{is}^2 is the square term of the blending ration for testing non-linearity of preference structure on the bioethanol demand. U_{is} is a residual term for any unobservable factors that affect the choice of alternative fuels.

As the price of alternative fuel increases, the chance of choosing it will decline; hence, a negative sign is expected on the parameter estimate. People who concern energy security, clean technology, industrial development, and climate change are most likely to select domestic bioethanol with domestic feedstock, followed by domestic bioethanol with imported feedstock. The attribute for imported bioethanol is not included in the choice model because this attribute is a reference point in the categorical variable. A negative sign on the square term and positive sign on the linear term of the blending ratio attribute implies that people have an inverse U-shaped preference on bioethanol. Those people might prefer other options than bioethanol because an excessive amount of bioethanol can cause the destruction of tropical forests or food crisis. There might be others who are concerned about the potential problems regarding their vehicles at some threshold bioethanol blending ratio level.[4]

Three different estimation methods are applied in order to estimate the parameter coefficients of attributes that are associated with alternative bioethanols. Each method has two model specifications: the first equation includes the square term on the blending ratio variable while the second one includes only linear term. Therefore, there are six equations (1)∼(6) in table 6.

Primarily, the parameter estimation on the attributes of bioethanol was performed by using panel logit models for the fixed effect and random effect models. MWTPs for the non-monetary attributes of bioethanol were derived by using the parameter estimates for monetary and non-monetary attributes. Table 6 shows that slight differences exist in the parameter estimates between the fixed and random effect panel logit models. I performed Hausman test to select one bewteen two models but the test failed to satisfy the asymptotic assumption due to the negative chi square statistics (-22.81) (refer to table A1 in the appendix). Hence, the test result is indeterminate regarding the null hypothesis on the independence of regressors and error term. Therefore, a panel logit random effect as well as fixed effect results are all included in table 6. The panel probit model is added in order to compare the robustness of the ASC term, which appears in the panel logit random effect model.

Throughout all model specifications, the price increase of bioethanol-blended gasoline reduces the chance of choosing an alternative fuel. The use of domestic feedstock for producing domestic bioethanol increases the likelihood of choosing an alternative fuel. People have a positive preference on bioethanol that is domestically produced by imported feedstock; however, the preference weights are small relative to domestic bioethanol with domestic feedstock and also, statistically insignificant.

[4] Before I determined the final choice experiment survey design, I asked the responsible survey conductors to implement a preliminary survey and a focus group for small random sample. In the discussion on the revision of the survey design after the pre-tests, I found that some respondents were afraid of vehicle malfunction due to the higher blending of bioethanol with petroleum. Therefore, I decided to include an instruction in the final survey stating that there should be no impact on the safety of vehicles within 10% of bioethanol blending with gasoline.

The coefficients of imported bioethanol were calculated as the minus sum of the estimated coefficients of domestic bioethanol with domestic feedstock and domestic bioethanol with imported feedstock. The coefficients show that people have negative preferences on imported bioethanol.

As more bioethanol was blended into the petroleum, the probability of choosing bioethanol increased; however, the square term of the bioethanol blending ratio was negative for model specifications (1), (3) and (5). This means that people's preference on the bioethanol blending ratio shows the inverse U shaped curve. When I include only the linear term on the bioethanol blending ratio, as shown in models (2), (4), (6), all of the parameter estimates for the bioethanol blending ratio are negative; now, the estimates of domestic bioethanol with imported feedstock are statistically significant. In the sense that a negative sign in the estimates of the bioethanol blending ratio is inappropriate to our expectation, models (1), (3) and (5) are adopted in order to calculate the MWTP for the attributes of bioethanol production.

The ASC terms in the panel logit random effect as well as in the panel probit models in model (3) and (5) have negative signs, but are statistically insignificant, which shows weak evidence that people have negative utility from choosing pure gasoline instead of bioethanol-blended gasoline.

[Table 6] Parameter estimation on bioethanol choice model

Model	Panel logit FE		Panle logit RE		Panel probit	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Price	-0.030***	-0.035***	-0.029***	-0.035***	-0.018***	-0.021***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Domestic ethanol with domestic feedstock	1.552***	1.761***	1.507***	1.743***	0.920***	1.057***
	(0.107)	(0.096)	(0.107)	(0.096)	(0.064)	(0.057)
Domestic ethanol with imported feedstock	0.034	0.145*	0.028	0.148*	0.018	0.086*
	(0.085)	(0.082)	(0.084)	(0.082)	(0.051)	(0.049)
Imported ethanol	-1.586	-1.906	-1.534	-1.891	-0.938	-1.143
Blending ratio	0.622***	-0.036***	0.689***	-0.036***	0.391***	-0.023***
	(0.152)	(0.011)	(0.152)	(0.011)	(0.091)	(0.007)
$\{\text{Blending ratio}\}^2$	-0.048***		-0.053***		-0.030***	
	(0.011)		(0.011)		(0.007)	
ASC	-		-0.595	1.682***	-0.260	1.043***
	-		(0.590)	(0.430)	(0.357)	(0.263)
LL(0)	-5551.56	-5509.18	-5601.85	-6046.36	-5606.21	-6046.36
LL(b)	-5428.30	-5413.95	-5489.16	-5500.62	-5489.83	-5500.28
Pseudo R^2	0.022	0.017	0.020	0.09	0.021	0.09

(† Standard errors are in parenthesis. *, ** and *** indicate that the estimated coefficients are significant at the 10%, 5% and 1% level, respectively.)

MWTPs for domestic bioethanol with domestic feedstock for the three models (1), (3) and (5) are derived by dividing the monetary parameter estimates by the non-monetary parameter estimates in equation (6) and by multiplying the outcome by minus one. In particular, the MWTP for the bioethanol blending ratio is calculated by differentiating the dependent variable in equation (6) with regard to the bioethanol blending ratio variable and price variable, then obtaining the ratio between two partial derivatives, as shown in equation (7).

$$-\frac{\partial Y_{is} / \partial R_{is}}{\partial Y_{is} / \partial P_{is}} = -\frac{(\hat{\alpha}_3 + 2\hat{\alpha}_4 \overline{R})}{\hat{\alpha}_1},$$

$$\text{where } \overline{R} = 6\% \text{ (Mean value of bioethanol blending ratio)} \qquad (7)$$

The MWTP for producing bioethanol by using domestic feedstock is about 51.7∼52.4 KRW/liter, which can be interpreted as social gains from domestic bioethanol with domestic feedstock (first row in table 7). The MWTP for bioethanol blending ratio to gasoline is about 1.41∼1.76 KRW/liter, which includes the social benefits from the reduction of CO_2 emission (second row in table 7). Therefore, the total MWTP for bioethanol production, which is the sum of MWTP for domestic bioethanol with domestic feedstock and MWTP for bioethanol blending ratio, ranges between 53.2∼54.2 KRW/liter, as shown in the third row in table 7.[5] The upper bound of MWTPs is used in the simulation section.[6]

As people's preference on the blending volume of bioethanol is concave, the turning points of the preference curves on the bioethanol blending ratio are calculated as differentiating the estimated models with regard to the bioethanol blending ratio. The turning points vary between 6.43∼6.47%, depending on the different models, where the marginal utility of the bioethanol blending ratio is equal to zero (the last row in table 7).

As far as I know, there is no such studies that examine the non-linear preference on biofuel, even if there are numerous studies on the environmental Kuznets curves between air pollution and economic growth since Grossman and Kruger (1995) (Holtz-Eakin, Selden, 1995; Schmalensee et al., 1998; Unruh, Moomaw, 1998; Galeotti, Lanza, 1999; Halkos, Tsionas, 2001; Galeotti et al., 2006; Aslanidis, Anastasios, 2006; Mizobuchi, Kakamu, 2007; Aslanidis, Susana, 2009; Galeotti et al., 2009). On the other hand, Petrolia et al. (2010) report that E85 is preferred over E10 in the United States. They also find that other options, such as the use of a more

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[5] I admit a possibility of overlap between MWTP for domestic bioethanol with domestic feedstock and MWTP for bioethanol blending ratio even if I tried to separate the benefits of the two attributes in the survey questionnaire.

[6] As there are little differences in the MWTPs for different models, I use upper bound of the MWTPs for simulation and 10% reduction of the upper bound for sensitivity.

efficient hybrid, electric or hydrogen fuelcell vehicle (Bae and Cho, 2010) and public transit, are more preferred over bioethanol due to the potential externality of bioethanol production. This is one possibility of explaining why people have non-linear preferences on bioethanol. The other way of interpreting the reason behind the inverse U-shaped demand for bioethanol is that people are concerned over the possible damages of their vehicles due to the higher blending of bioethanol.

[Table 7] WTP and turning points of the bioethanol blending ratio for different models

Models	Panel logit FE	Panel logit RE	Panel probit
WTP for Domestic ethanol with domestic feedstock (KRW/liter)	52.346	52.423	51.715
WTP for higher bioethanol blending ratio (KRW/liter)	1.412	1.756	1.498
Total WTP	53.758	54.179	53.213
Turning point of ethanol blending ratios	6.433%	6.474%	6.439%

III. Estimation of Production Costs of Bioethanol

The 79 panel data for the financial variables of 9 alcoholic beverage companies between 2002 and 2011 (with the exception of 2008), collected from the Korea Alcohol and liquor Industry Association,[7] are used to estimate the average production cost of alcohol.[8] The average production cost of alcohol was 1,439 KRW/liter, and 73% of the production cost was from feedstock cost (table 8). Alcohol should be transformed to bioethanol throughout the anhydrization process of which the cost per liter is estimated as 118～150 KRW. Thus, the final bioethanol production cost was determined by the sum of alcohol production cost and upper bound of the anhydrization costs.

[7] Annual production of alcohol by each company was collected from the Korea Alcohol and Liquior Industry Association website at http://www.kalia.or.kr/customer_support/k_statis.html, and the cost information was directly collected from the secretary's office of the association.

[8] Two observations are removed from 81 observations for 9 firms with 9 years of time periods due to the lack of labor cost information. For the study period, there are 10 alcoholic beverage companies in Korea, but one company closed in the middle of the period. Thus, the final number of firms used in the analysis is nine.

[Table 8] Basic statistics for fermented alcohol production cost

Variables (KRW/liter)	Number of observation	Average	Standard deviation	Minimum	Maximum
Labor cost	79	97	35	37	222
Fuel cost	79	149	90	31	510
Environmental management cost	79	27	21	0	107
Capital cost	79	64	41	7	170
Marketing cost	79	58	29	11	146
Management cost	79	49	20	16	117
Feedstock cost	79	1,046	597	450	2,849
Production cost	79	1,439	635	796	3,389

(Source: Korea Alcohol and Liquor Industry Association, 2012.)

The primary econometric model for estimating production cost of bioethanol is constructed, as shown in equation (8).

$$\ln(TC/Q)_{it} = \beta_0 + \beta_1 \ln(C_L/Q)_{it} + \beta_2 \ln(C_K/Q)_{it} + \beta_3 \ln(C_M/Q)_{it} + \beta_4 \ln(C_F/Q)_{it} \\ \beta_5 \ln(C_E/Q)_{it} + \beta_6 \ln(C_{MK}/Q)_{it} + \beta_7 \ln(C_{MG}/Q)_{it} + \varepsilon_{it} \quad (8)$$

Hereby, TC, Q, C_L, C_K, C_M, C_F, C_E, C_{MK} and C_{MG} denote the total cost, output, labor cost, capital cost, feedstock cost, fuel cost, environmental cost, marketing cost and management cost for firm i at year t.

The average production cost of alcohol was estimated by using the panel analysis on various input costs (labor, capital, feedstock, fuel and other costs). The fixed and random effect model, generalized least square and dynamic panel analysis were applied to estimate the parameters (Greene, 2000).

For different estimation models, the estimation results were similar as shown in table 9; thus, the robustness of the estimation was satisfied; further, the Hausman test demonstrated that the fixed effect estimates are better than the random effect ones because the chi square statistics is 18.84 within the 1% significance level, implying that the null hypothesis of the independence of regressors and error term can be rejected (refer to table A2 in the appendix). Panel GLS as well as the dynamic panel estimation methods are added to allow for heteroskedasticity as well as to identify if the lagged dependent variable affects the overall estimation. AIC (Akeike information criteria) and BIC (Baysian information criteria) are implemented to select the most appropriate estimator among panel fixed, GLS and dynamic panel models. As a result, the GLS and dynamic panel estimates are selected (refer to table A3 in the appendix).[9] The parameter estimates for feedstock

[9] AIC and BIC for the dynamic panel analysis could not be obtained due to the different number of

cost are 0.728 for the dynamic panel model and 0.742 for the panel GLS model. The average of these two estimates (73.5%) was considered as the elasticity of alcohol production cost on feedstock cost.

[Table 9] Parameter estimates of the unit production cost for different models

Variables	Panel fixed	Panel random	Panel GLS	Dynamic panel
Log (labor cost)	0.100*** (0.021)	0.083*** (0.018)	0.065*** (0.014)	0.091*** (0.024)
Log (fuel cost)	0.051*** (0.018)	0.095*** (0.013)	0.115*** (0.01)	0.043 (0.056)
Log (environmental management cost)	0.006 (0.004)	0.004 (0.004)	0.004 (0.004)	0.023*** (0.008)
Log (capital cost)	0.058*** (0.009)	0.046*** (0.008)	0.040*** (0.006)	0.061** (0.025)
Log (marketing cost)	0.060*** (0.016)	0.048*** (0.013)	0.042*** (0.011)	0.024 (0.045)
Log (management cost)	0.021 (0.014)	0.004 (0.014)	-0.004 (0.013)	0.061 (0.041)
Log (feedstock cost)	0.738*** (0.009)	0.740*** (0.009)	0.742*** (0.009)	0.728*** (0.017)
Log (lagged production cost)	-	-	-	-0.03** (0.013)
Constant	0.715**	0.817***	0.935***	-
Rho	0.706535	0.23245	-	-
Log likelihood	-	-	147.6399	-
F-value	1280.26***	-	-	-
Wald chi2	-	7779.23***	7635.27***	9987.79***

(† Standard errors are in parenthesis. * Statistically significant at 10%, ** statistically significant at 5%, *** statistically significant at 1%.)

Next, the elasticity of alcohol production cost on feedstock cost was used to derive the average alcohol production cost with 100% domestic feedstock (barley). The annual cost of barley in 2011 was about 2,270 KRW/liter of alcohol, which increases the average feedstock cost (1,696 KRW) by 117%; on the other hand, the annual cost of imported tapioca which is used as feedstock for alcohol was about 761 KRW/liter, which decreases the average feedstock cost by 27%. When only domestic barley is used as feedstock for producing alcohol, the average alcohol production cost rises by 86%, which is derived from multiplying 117% by 73.5%. On the other side, if only imported feedstock, tapioca, is used as feedstock for bioethanol production, the average alcohol production cost declines by 20%. The production cost of alcohol

observations and degrees of freedom.

with domestic feedstock (3,154 KRW) can be derived from [1,696*(1+0.86)], whereas the production cost of alcohol with imported feedstock (1,356 KRW) can be derived from [1,696*(1-0.20)]. Combined with the anhydrization cost (150 KRW),[10] the final bioethanol production cost with domestic feedstock is estimated as 3,304 KRW/liter while bioethanol production cost with imported feedstock is estimated to be 1,506 KRW/liter (Table 10).

[Table 10] Derivation of domestic bioethanol production cost

Factor	Bioethanol with domestic feedstock (barley)	Bioethanol with imported feedstock (tapioca)
Production cost of alcohol (2011)	1,696	1,696
Price of feedstock (2011)	2,270	761
Elasticity of alcohol production cost on feedstock cost	73.5%	73.5%
Percentage increase of the average feedstock cost	117%	-27%
Percentage increase of the average alcohol production cost	86%	-20%
Production cost of alcohol with domestic feedstock	3,154	1,356
Anhydrization cost	150	150
Bioethanol production cost	3,304	1,506

IV. Simulation and Policy Implication

4.1. Simulation of Bioethanol Blending Ratio

The socially desirable proportion of domestic bioethanol relative to imported bioethanol and the ratio of domestic feedstock relative to imported feedstock within the domestic bioethanol can be derived in the following way.

$$MSB_{e3} = MWTP_{e3} = [0.97P_{oil} + 0.03P_e] - P_{oil} = MSC_{e3} \tag{9}$$

$$P_e = \theta P_e^d + (1-\theta)P_e^i \tag{10}$$

$$P_e^d = \omega P_f^d + (1-\omega)P_f^i \tag{11}$$

Plugging equations (10) and (11) into equation (9) yields:

[10] I apply the maximum value for the anhydrization cost in order to derive a conservative estimation on the bioethanol production cost.

$$MSC_{e3} = MWTP_{e3} = [0.97P_{oil} + 0.03\{\theta(\omega P_f^d + (1-\omega)P_f^i) + (1-\theta)P_e^i\}] - P_{oil} \quad (12)$$

Hereby MSB_{e3} is the marginal social benefit of providing 3% bioethanol (E3),[11] $MWTP_{e3}$ is the marginal willingness to pay for E3, P_{oil} is the price of petroleum, and MSC_{e3} is the marginal social cost of E3. P_e is the price of bioethanol, θ is the weight on domestic bioethanol production, P_e^d is the price of domestic bioethanol, P_e^i is the imported bioethanol price, ω is the weight on domestic feedstock within domestic bioethanol, P_f^d is the price of domestic bioethanol with domestic feedstock, and P_f^i is the price of domestic bioethanol with imported feedstock.

In equation (9), the marginal benefit from E3 should be equal to the price increase of E3, which is the difference between the petroleum price and 3% bioethanol blended petroleum price. Bioethanol price is defined as the weighted average of domestic and imported bioethanol prices in equation (10). The price of domestic bioethanol is composed of the weighted average prices of domestic bioethanol with domestic feedstock and imported feedstock, as shown in equation (10). Combining equations (10) and (11) into equation (9) yields equation (12). Because there are two unknown parameters, θ and ω, for one equation (12), a simulation approach should be applied in order to derive θ^* and ω^* that satisfy equation (12).

The average $MWTP_{e3}$ is given as 54.2 KRW/liter, which is derived from panel logit random effect model, P_{oil} is given as 945 KRW/liter, which is before the taxed average gasoline price for 2012, P_f^d is given as 3304 KRW/liter, P_f^i is given as 1,506 KRW/liter, and P_{e3}^i is given as 1,100 KRW/liter in 2012, as provided in table 10 (Petronet, 2012).[12]

The baseline simulation on θ and ω was conducted by plugging these data into the equation (12). Figure 3 shows the break-even curve, where MSB is equal to MSC when the MWTP is given as 54.2 KRW. The vertical axis presents the weights of domestic feedstock for domestic bioethanol and the horizontal axis presents the weights of domestic bioethanol. According to the baseline simulation results, the maximum weight of domestic bioethanol is 74% if all of the feedstock are domestic, which implies that 26% of bioethanol should be imported. Also, if 100% of

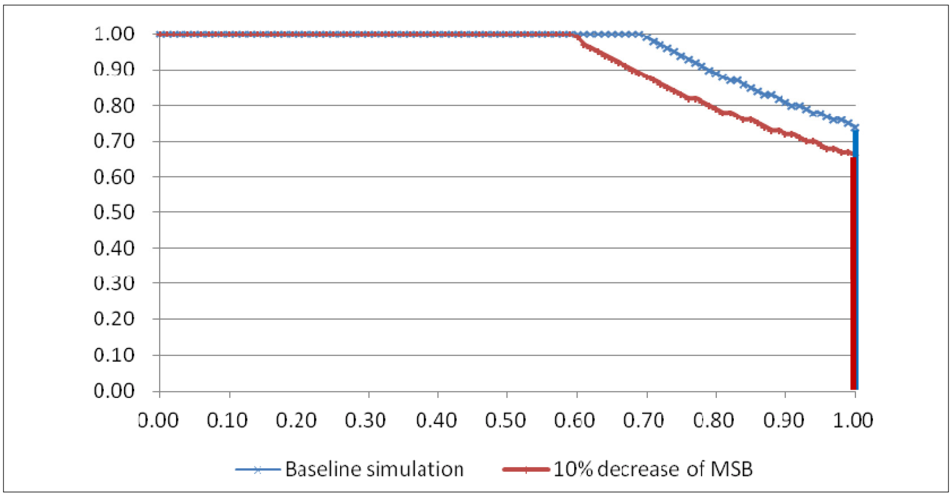
[11] More precisely, the MSB of bioethanol should be the weighted average of MWTP for domestic bioethanol and that for imported bioethanol in the first tier. In the second tier, the MWTP for domestic bioethanol is the weighted average of that for domestic bioethanol with domestic feedstock and that for domestic bioethanol with foreign feedstock. However, this study finds that only the estimates of MWTP for the domestic bioethanol with domestic feedstock is statistically significant; hence, the MWTP for the domestic bioethanol with imported feedstock as well as that for the imported bioethanol are assumed to be zero.

[12] Details of the calculation of bioethanol production cost, when the feedstock is either barley or tapioca, are explained in table 10.

bioethanol are domestically produced, the maximum weight of domestic bioethanol with domestic feedstock is 69%, which implies that 31% of the feedstock should be imported.

The impact of the decrease in MSB by 10% is examined, given that all other parameters are fixed. As the MSB declines by 10%, the maximum attainable weight of domestic bioethanol is reduced to 66%, which is 8% point less than the baseline when the material for domestic bioethanol is entirely supplied by domestic feedstock. Moreover, if 100% of bioethanol is domestically supplied, the maximum attainable weight of domestic feedstock for domestic bioethanol falls to 59%, which is 10% point less than the baseline.

[Figure 3] Ratio of domestic bioethanol and /or domestic feedstock (Baseline)

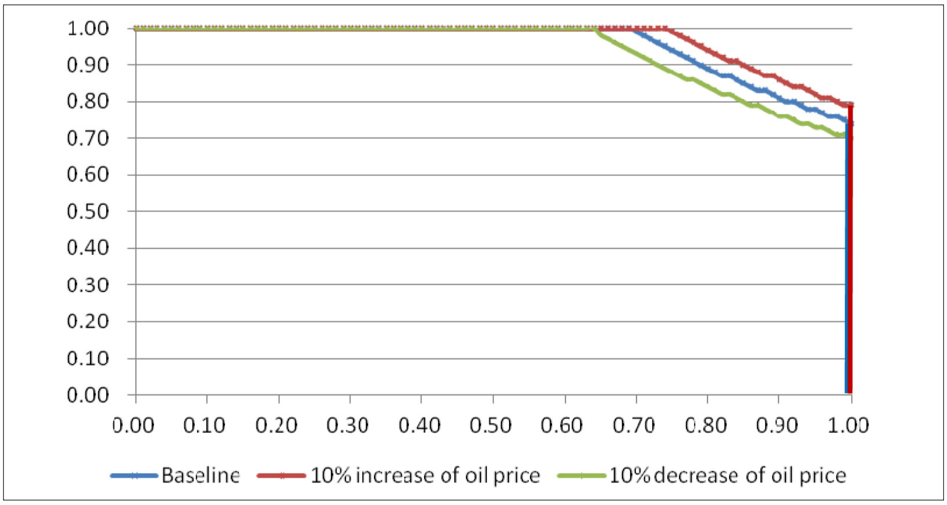


I perform a sensitivity analysis when the before taxed gasoline price changes within 10%, given that all other parameters are fixed. Figure 4 shows the break-even curves when the gasoline price increases by 10% as well as when it decreases by 10% relative to the baseline. The maximum weight of domestic bioethanol rises up to 79%, given that all of the feedstock are domestically supplied, which is 5% point higher than the baseline result. Again, the maximum weight of domestic feedstock increases to 74% if all of bioethanol are domestically provided, which is 5% points higher than the baseline result.

Contrarily, if the gasoline price declines by 10%, then the maximum attainable weight of domestic bioethanol falls up to 70%, given that all of the feedstock are domestically supplied, which is 4% points lower than the baseline result. Meanwhile, the maximum weight of domestic feedstock diminishes to 64% under the condition that all bioethanol is domestically provided, which is 5% points lower than the baseline result.

Ultimately, the simulation and sensitivity analysis shows that the socially desirable bioethanol blending ratio can be affected significantly by the changes in the estimated MSB as well as the price of petroleum.

[Figure 4] Ratio of domestic bioethanol and /or domestic feedstock (Sensitivity to oil price)



4.2. Policy Implication of Bioethanol Production Portfolio

Relying on the simulation results, I calculate and compare the amounts of different policy costs for four types of bioethanol production portfolio: baseline, 10% decrease in the MSB, 10% increase in the petroleum price, and 10% decrease in the petroleum price. Each scenario is divided into two cases: case I assumes that all of the feedstock are domestically provided and case II supposes that all of the bioethanol are domestically supplied. I calculate the policy costs for eight cases in total (cases I∼VIII) as shown in table 11.

The policy costs are regarded as the sum of the MSC of bioethanol production, which implies a difference between the total costs of 100% gasoline and bioethanol-blended gasoline within 3% (300,000 KL) of the total gasoline consumption for the 2012 road transport in Korea.

For case I of the baseline scenario, the maximum weight of domestic bioethanol is 74% if all of the feedstock are domestically supplied, and the weight for imported bioethanol is 26% while the maximum weight of domestic feedstock is 69% if 100% of bioethanol should be domestically produced; further, the weight for imported feedstock is 31% for case II. Hence, the total volume of domestic bioethanol with domestic feedstock is 222,000 KL, the total volume of imported bioethanol is 78,000 KL. The total cost of domestic bioethanol with domestic feedstock is 733,488 million KRW, and the total cost of imported bioethanol is 85,800 million KRW.

Hence, the total cost of bioethanol supply is 819,288 million KRW. Finally, the total social cost is derived as 535,788 million KRW from the difference between the total cost of bioethanol production and the total cost of gasoline supply, which is 283,500 million KRW.

[Table 11] Policy costs of bioethanol production for various simulation results

Simulations	Unit	Baseline (MSB=54.2)		10% decrease of MSB (MSB=48.78)		10% increase of oil price		10% decrease of oil price	
Factors		CaseI	CaseII	CaseIII	CaseIV	CaseV	CaseVI	CaseVII	CaseVIII
Weight on domestic bioethanol with domestic feedstock	%	74%	69%	66%	59%	79%	74%	70%	64%
Weight on imported bioethanol	%	26%	-	34%	-	26%	-	26%	-
Weight on domestic bioethanol with imported feedstock	%	-	31%	-	41%	-	26%	-	36%
Volume of domestic bioethanol with domestic feedstock	KL	222,000	207,000	198,000	177,000	237,000	222,000	210,000	192,000
Volume of imported bioethanol	KL	78,000	-	102,000	-	78,000	-	78,000	-
Volume of domestic bioethanol with imported feedstock	KL	-	93,000	-	123,000	-	78,000	-	108,000
Total cost of domestic bioethanol with domestic feedstock	Million KRW	733,488	683,928	654,192	584,808	783,048	733,488	693,840	634,368
Total cost of imported feedstock	Million KRW	85,800	-	112,200	-	85,800	-	85,800	-
Total cost of domestic bioethanol with imported feedstock	Million KRW	-	140,032	-	185,204	-	117,447	-	162,618
Total cost of bioethanol	Million KRW	819,288	683,928	766,392	584,808	868,848	733,488	779,640	634,368
Total cost of petroleum	Million KRW	283,500	283,500	283,500	283,500	283,500	283,500	283,500	283,500
Total policy costs	Million KRW	535,788	400,428	482,892	301,308	585,348	449,988	496,140	350,868
Subsidy on domestic bioethanol with domestic feedstock	Million KRW	12,032	11,219	10,732	9,593	12,845	12,032	11,382	10,406

Following the same procedure, the total social cost for case II in the baseline simulation is derived as 400,428 million KRW. For case III in the 10% decrease of the MSB simulation, the total policy cost is estimated as 482,892 million KRW, whereas the policy cost of case IV of the 10% decrease of the MSB is 301,308 million KRW. When we confront 10% increases in the petroleum price, the policy costs for cases V and VI are individually 585,348 and 449,988 million KRW, whereas if the petroleum price falls by 10%, the policy costs for cases VII and VIII diminish to 496,140 and 350,868 million KRW.

The estimation of policy costs for various bioethanol production pathways ranges between 301,308 and 585,348 million KRW, depending on the changes in the MSB and petroleum prices. Unfortunately, this study cannot confirm that people's willingness to pay for bioethanol production can offset the entire policy costs because only the MWTP for domestically produced bioethanol, which uses domestic feedstock, is found as the statistically significant estimator. In this context, further research will be required in order to derive the MWTP for the domestic bioethanol with imported feedstock and imported bioethanol.

However, as the Korean government implements the RFS policy, the government is authorized to subsidize at least the domestic bioethanol with domestic feedstock as a first stage before transferring to the obligation stage of renewable fuel consumption onto the petroleum companies. Proportions of the domestic bioethanol with the domestic feedstock are 59∼79%, relying on different simulations as shown in table 11. Hence, the maximum feasible amounts of financial subsidy range between 9,593∼12,845 million KRW. Up till now, the most general means of subsidy is known as fuel tax exemption on the consumption of renewable fuels. Alternatively, if the Korean government considers to introduce the RFS policy directly without a preliminary stage, higher credits or compulsory quota might be applied to the production of domestic bioethanol with domestic feedstock.

V. Conclusions

The choice experiment on the supply pathways of bioethanol in the Republic of Korea revealed that Korean gasoline drivers prefer purely domestic bioethanol to imperfect domestic as well as imported bioethanol as an appropriate supply method of bioethanol. The MWTP for domestic bioethanol with domestic feedstock within E10 was about 51.7∼52.4 KRW/liter, which is associated with energy security, environmental improvement, CO_2 reduction and rural and industrial development. In addition, the MWTP for bioethanol blending ratio to gasoline is estimated as 1.41∼1.76 KRW/liter, which is related to the benefit from the mitigation of greenhouse gases. Therefore, the total MWTPs for domestic bioethanol with domestic feedstock within E10 production ranges between 53.2∼54.2 KRW/liter.

The estimated MWTPs in this study are higher than the MWTP (15∼30 KRW/liter) for E10 estimated in Petrolia et al. (2010). Then, where does this difference come from? There might be two possible interpretations: First, the average retail petroleum price (2012) in Korea is approximately 2.89 times of the price (2007) in the United States.[13] Second, our choice experiment emphasizes the use of purely domestic bioethanol, whereas the study of Petrolia et al. (2010) focuses on the environmental gains of E10 and E85. However, according to the study of Vedenov and Wetzstein (2008), which was based on an analytic model, a socially desirable subsidy on bioethanol was estimated as $0.22/gallon (54 KRW/liter), which is very close to the estimate of our study. In this regard, the estimated co-benefits of bioethanol produced in Korea do not differ fundamentally from those in the United States.

The outcome from the choice experiment also conveys that the Korean people have an inverse U-shaped (concave) preference on the bioethanol blending ratio to gasoline. This finding implies that the demand for bioethanol will increase at first, but will begin to diminish at the turning point. The turning point of the bioethanol blending ratio was estimated as 6.43∼6.47%. This outcome implies that people might prefer other options to excessive use of biofuels, such as electric or hybrid vehicles, use of more efficient small vehicles or public transit due to the negative externality of bioethanol production. Alternatively, as more bioethanol is blended with gasoline in vehicles, some drivers might be concerned about the potential impairment to their vehicles if too much bioethanol is blended with gasoline.

The production cost function for bioethanol was estimated by employing the panel fixed, random effect, GLS and dynamic models. According to the Hausman test, AIC and BIC procedures, the average of the parameter estimates for the feedstock cost of the panel GLS and dynamic models, which is 73.5%, was used as the elasticity of bioethanol production costs on various feedstock costs, such as domestic barley and imported tapioca. Combined with other production costs, the final bioethanol production cost with domestic feedstock was calculated as 3,304 KRW/liter, bioethanol production cost with imported feedstock was accounted as 1,506 KRW/liter, and imported bioethanol price was assumed as 1,100 KRW. Ultimately, the marginal social cost was defined as the difference between bioethanol costs and the average annual gasoline price in 2012.

By employing the estimated MSB and MSC of bioethanol production in Korea, I performed a baseline simulation as well as alternative simulations. The baseline simulation shows that the ratio between domestic bioethanol with domestic feedstock and imported bioethanol for E3, when domestic bioethanol should use only domestic feedstock, turned out to be approximately 74%:26% when the total MWTP is given as 54.2 KRW. Also, the ratio between domestic bioethanol with domestic feedstock and domestic bioethanol with imported feedstock was calculated as 69%: 31%, under the condition that 100% of domestic bioethanol is used for E3.

[13] The average retail petroleum price in Korea 2012 was 1986 KRW/liter, and the retail price in the U.S. in 2007 was $2.8/gallon.

I also performed a sensitivity analysis on the baseline simulation by changing the MSB as well as petroleum prices. Accordingly, I found that a decrease in the MSB (or MWTP) resulted in the fall of weights of domestic bioethanol with domestic feedstock. Morever, a 10% increase in the petroleum price led to the rise in the portion of domestic bioethanol with domestic feedstock, whereas a 10% decrease in the petroleum price reduced domestic bioethanol with domestic feedstock. Therefore, changes in petroleum prices or the MWTP for bioethanol production substantially affect the supply portfolio of bioethanol. Although this study did not take the sensitivity analysis of changes in different feedstock costs or imported bioethanol prices, these factors will definitely affect the simulation results as well. In this sense, the simulation results shown in this study should be interpreted as some plausible illustrations of deriving the socially desirable bioethanol supply pathway for Korea.

According to the results, importing all bioethanol in order to implement the conditions for the RFS regulation will not be desirable in terms of multiple criteria, such as economic efficiency, environmental aspects and energy security aspects. Further, the outcome advocates to raise uses of domestic feedstock for providing E3, even if domestic feedstock is much more expensive than the imported one. Korean consumers on E3 are ready to endure the increases of petroleum price in order to attain the co-benefits derived from domestic bioethanol with domestic feedstock. In practice, when the Korean government implements the RFS, the minimum quota system may be considered to produce bioethanol domestically or otherwise, higher credits should be given to the petroleum companies that use domestic bioethanol rather than imported bioethanol. Before the RFS system is introduced, the government might subsidize the price of domestic bioethanol with domestic feedstock within the social gains.

In the long term, the RFS system would have to consider a more variety of alternative options due to the inverse U-shaped preference on the use of bioethanol, as portrayed in this study. People might have concerns over the potential damages to their vehicles with higher bioethanol blending ratios or prefer other alternative solutions, such as more uses of electric or hybrid vehicles and public transit. Moreover, a wide spread of conventional bioethanol technology might not only have negative impacts on tropical forests, but also conflict with the food market.

Further research should be followed by this study in terms of the marginal gains as well as marginal costs of producing bioethanol. Although the marginal gains should be the weighted average of domestic bioethanol with domestic feedstock, domestic bioethanol with imported feedstock, and imported bioethanol, I obtained a statistically significant estimate on only the MWTP for domestic bioethanol with domestic feedstock; hence, the MWTPs for domestic bioethanol with imported feedstock and imported bioethanol were assumed to be zero, which can then lead to an overestimation or underestimation of the marginal benefit from producing bioethanol. Therefore, additional research will be required on how to derive a significant estimate on the MWTP for the domestic bioethanol with the imported feedstock as well as for the imported bioethanol.

On the marginal cost side, additional study will enhance the robustness of this study by examining the impact on the marginal costs due to changes of feedstock resources, such as barley and tapioca used in this study, by the conventional biomass or next generation feedstock resources, such as macro algae. Furthermore, if membrane technology, which is a more energy-saving separation process than the conventional one used in this study, is considered, then the average production cost of biothanol will be affected substantially. Ultimately, changes in the feedstock as well as in the conversion process will affect the optimal trajectory of bioethanol supply pathway throughout the changes in the marginal production cost of bioethanol.

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<Appendix>

[Table A1] Hausman test results for panel logit fixed and random effects on the choice experiment

Variables	coefficients of FE(b)	coefficients of RE(B)	Difference(b-B)	sqrt(diag(V_b-V_B))
price	-0.030	-0.029	-0.001	.
ecf1	1.552	1.507	0.045	.
ecf2	0.034	0.028	0.007	0.008
mixture	0.622	0.689	-0.067	0.009
mixture2	-0.048	-0.053	0.005	0.001

[Table A2] Hausman test results for panel logit fixed and random effects on the production cost equation

Variables	coefficients of FE(b)	coefficients of RE(B)	Difference (b-B)	sqrt (diag(V_b-V_B))
ln(labor cost)	0.099642	0.082543	0.017099	0.01127
ln(fuel cost)	0.051407	0.094833	-0.04343	0.011531
ln(environmental cost)	0.006184	0.003554	0.002629	.
ln(capital cost)	0.058185	0.045887	0.012298	0.00508
ln(marketing cost)	0.05979	0.047718	0.012072	0.008419
ln(management cost)	0.020827	0.003863	0.016964	.
ln(feedstock cost)	0.738005	0.740064	-0.00206	.

[Table A3] Comparison of fixed effect and GLS models by AIC and BIC procedures

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
Fixed effect	79	-28.2026	167.8992	8	-319.798	-300.843
GLS	79	-28.2026	147.6399	8	-279.28	-260.324