Study on the Optimal Subsidy Policy for the Development of Methanol Vehicle in China

Chengjinag LI[a], Wen Long YUE[b] and Xin ZOU[c]

[a,b,c] *School of Natural and Built Environments, the University of South Australia, South Australia, SA5095, Australia*
[a] *Email: chengjiang.li@mymail.unisa.edu.au*
[b] *Email: wen.yue@unisa.edu.au*
[c] *Email: zouxy011@mymail.unisa.edu.au*

Abstract: Methanol as a fuel for vehicle is economy and environmental friendly, compared with gasoline. The development of methanol vehicle conforms to China's goal of achieving sustainable development as it would accelerate energy restructure by reducing the dependence on fossil fuels. However, the promotion of methanol vehicle in China is slow. While the governments in China have offered subsidy to electric vehicles, there is lack of financial incentive for other alternative fuels. Without an integrated subsidy system, manufacturers would be hardly involved. This paper introduces methanol as a fuel for vehicle and proposes an optimal subsidy model based on microeconomic theories. As subsidy policy may also be influenced by other criteria, the development of a logit model which includes the designed subsidy model would be a future research direction.

Keywords: Methanol, Methanol Vehicle, Subsidy Policy, Subsidy Model, Logit Model

1. INTRODUCTION

The development of alternative fuels for vehicles (AFVs) which include electric power, natural gas, ethanol and methanol for replacing conventional fuels plays a vital role in different levels: from national level, oil crisis has warned countries which highly depend on crude oil import the importance of alternative fuels for enhancing national security (Pontau *et al.*, 2015); from environment perspective, the promotion of AFVs which generates less pollutant and improves energy efficiency, would reduce the impact on environment (CULCEN, 2012); from socioeconomic perspective, with governmental subsidy offered, manufacturers can accelerate the development of AFVs, which would bring socioeconomic benefits including: stimulating the transition of energy structure; increasing the efficiency of energy consumption; improving technologies in relevant industries; increasing social stability (Bockris, 2007).

Nowadays, China consumes the most conventional fuels and faces issues which resulted from excessive fossil fuel consumption, such as: imbalanced energy structure, deteriorated air quality and high dependence on oil import (Peng, 2006). As the impacts of vehicular emission have driven policy discussions from conventional fuels to AFVs (Yang *et al.*, 2014), a series of transport policies have been implemented by multi-level authorities. On one hand, it aims to restrict the use of conventional vehicles; on the other hand, it promotes the development of AFVs. The implementation of policies which restricting conventional vehicles offers a great opportunity for the development of AFVs. Table1 takes Beijing as an example to summary the existing policies which include the restriction of conventional vehicles and the promotion of AFVs (Deng, 2010; Yin, 2012; Wang *et al.*, 2013; Yang *et al.*, 2014).

Table 1. Policies on restricting conventional vehicles and promoting clean-energy vehicles

Year	Policy	Objective	Division
2008	Odd-even License Plate Policy	To improve air quality	Restrictive
2009	End-number License Plate Policy	To reduce congestions and emissions	Restrictive
2011	Small Passenger Car Purchase Policy	To slow the increase of vehicles	Restrictive
2014	Action Plan for Promoting Electric Vehicles (Clean Air Action Plan)	To promote electric vehicles	Innovative
2016	Clean-energy Vehicles Subsidy Policy	To financially support the promotion of electric vehicles	Innovative

Apart from restrictive policies, innovative policies predominately focus on the promotion of AFVs. However, several reasons including exorbitant price of AFVs, immature core technologies and the lack of market demand have slowed the form of AFVs industrial scale. Therefore, financial subsidy becomes vital for the acceleration of AFVs industry.

In China, AFVs have new energy vehicles (NEVs) which are blade electric vehicle (BEV), hybrid electric vehicle (HEV) and fuel cell electric vehicle (FCEV), hydrogen internal combustion engine vehicle (HICEV), ethanol vehicle, methanol vehicle, etc. Among all AFVs, China currently focuses on the development of electric vehicles, especially BEV, by constructing infrastructures and providing financial subsidies (He, 2016). Both the central and local governments in China have provided manufacturers and consumers subsidy. Table 2 summarizes Beijing 2016 New-energy Vehicles Subsidy Policy (Nie, 2016).

Table 2 Summary of Beijing 2016 New-energy Vehicles Subsidy Policy

Type	Battery Range (km)	National Subsidy (¥)	Regional Subsidy (¥)
Blade Electric Vehicles	$100 \leq R < 150$	25,000	25,000
	$150 \leq R < 250$	45,000	45,000
Plug-in Hybrid Electric Vehicle	$R \geq 250$	55,000	55,000
	$R \geq 50$	30,000	0

Despite the Chinese governments have offered a huge amount of subsidy, the market share of electric vehicle is still low. On one hand, it would take a long period for manufacturers to update core technologies, extending the battery life for example. On the other hand, it requires more infrastructures such as charging stations which need to be widely installed to shorten the queuing time during peak hours (Tu, 2014).

Apart from electric vehicles, other types of AFVs such as methanol vehicle which assists to achieve environmental and economic benefits should also be promoted. According to Mr. He Guangyuan (2016), the former minister of Machine Building Industry of China, with the same amount of financial subsidy, the development of the methanol vehicle industry would bring more benefits than the electric vehicle industry in China.

2. METHANOL AND METHANOL VEHICLE

2.1 Methanol

To meet mankind's ever-increasing energy needs, different alternative energy resources have been explored and developed. Methanol (CH_3OH) as one of alternative energy resources, has been broadly used: it can be blended with gasoline as an oxygenated additive to fuel vehicle with internal combustion engines (ICEs); it may generate electricity in fuel cells; it would also react directly with air in the direct methanol fuel cell (DMFC). Moreover, methanol serves as an original material for chemical products such as pharmaceuticals (Olah, 2003).

Methanol can be made from a wide variety of resources such as coal, natural gas and biomass; it could also be synthesized from carbon dioxide and hydrogen (Olah, 2003; Peng, 2006). The wide use of methanol has gradually liberated mankind from fossil fuels (Olah, 2005).

2.2 The Advantage of Methanol as a Fuel for Vehicle

Methanol can fuel ICEs either in combination with gasoline or in neat. Table 3 shows how methanol could be blended with conventional gasoline in different proportions (Dolan, 2008).

Table 3. The division of methanol fuel

Division	Description
High proportion methanol fuel	M70 to M85 (high methanol content standard)
Low proportion methanol fuel	M15 (15% methanol includes additive/co-solvent)
Convertible methanol fuel	M100 (neat methanol fuel, with no gasoline blended)

The chemical composition indicates that methanol is composed of only one carbon atom, compared with conventional gasoline which is a complex mixture of many different hydrocarbons and additives with four to twelve carbon atoms (Figure 1). The reaction of methanol in air indicates that methanol molecule burns in oxygen would generating carbon dioxide and water (Olah, 2003):

$$CH_3OH + 3O_2 \rightarrow 2O_2 + 4H_2O.$$

While gasoline burns in air, hydrocarbons are converted into carbon dioxide and water:

$$2C_8H_{18} + 25O_2 \rightarrow 16O_2 + 18H_2O$$

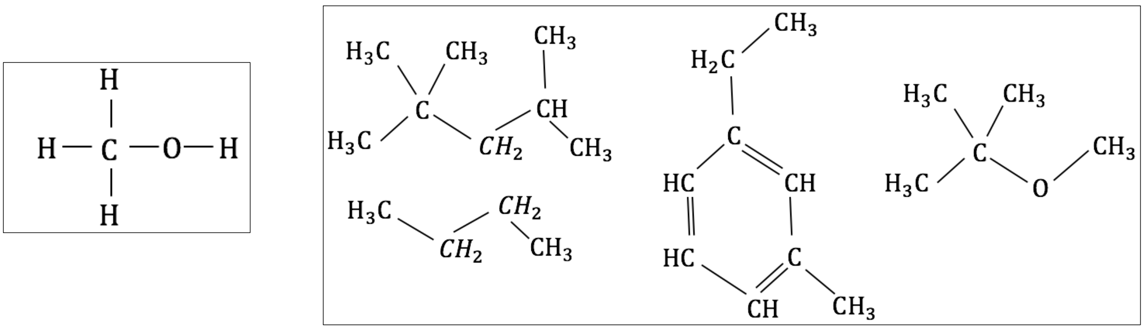

Figure 1. The comparison of chemical composition of methanol (left) and gasoline (right)

Accordingly, the combustion of methanol needs less oxygen and produces less carbon dioxide, compared with conventional gasoline. In short, methanol burns cleaner than conventional gasoline, which minimizes air pollution. Also, methanol has many advantages compared with other fuels. Table 4 summaries the comparison among methanol and other major fuels for vehicles (Peng, 2006).

Table 4. The comparison among methanol (M100) and other fuels for vehicles

Subject / Fuels	Oxygen content (%)	Air-fuel ratio	RON	Flammable limits (%)	Emission			Price (¥/ton)	Building a station (¥)
					CO	HC+ NOx	Benzene		
Methanol	50	6.4	112	6.7	0.56	0.135	0	2180	100,000
Ethanol	35	9	103	4.3	0.56	0.135	0	6010	100,000
LPG	0	15.7	112	2.1	0.89	0.27	0.5	3800	1,110,000
Diesel	0	14.5	N/A	0.6	0.24	0.765	1.5	5500	500,000
Gasoline	0	14.8	100	1.4	1.47	0.405	4.7	5900	500,000

Note: a. Emission unit: g/km;
b. Price: Based on the fuel price in China in 2016;
c. RON: Research octane number.

Table 4 indicates that the neat methanol fuel has the best performance on most features. With diminishing conventional energy reserves, the development of methanol as fuel would play a vital role in the age of diversifying energy structure (He, 2016).

3. THE DEVELOPMENT OF METHANOL VEHICLE IN CHINA

Since late 1980s, China has already started the research on methanol vehicle (Xin, 2016). To optimize energy structure as well as to reduce environmental pollution, the Chinese government aims to form a multi-energy consumption structure which includes the development of methanol vehicle. According to Zhang (2016), China is now leading the world in using methanol as fuel and 7% of the total methanol productions have been used for transportation. About 0.5 million vehicles including buses, trucks have been converted into ‘high proportion’ methanol vehicles in China. The Ministry of Industry and Information Technology of China (MIIT) has launched several programs of testing methanol vehicles in provinces with rich coal resource which can be used to produce methanol (Liu, 2012; MIIT, 2017). These pilot programs aim to ‘digest’ the overcapacity of coal, to increase the regional economy and to reduce vehicular emissions. With these programs developed, the commercialization process of methanol vehicle would be accelerated (MIIT, 2017).

3.1 The Pilot Program of Testing Methanol Vehicle in Shanxi Province

According to Jinzhong Economy and Information Committee (JZEIC, 2016a), a pilot program has been launched in Jinzhong, Shanxi province since 2014. Over 100,000 methanol vehicles have been operated in Jinzhong. 150 methanol taxis (M100) were tested to evaluate based on criteria including economy, emission and overall performance (Wang, 2016). The results of the evaluation indicate that methanol vehicle has the following features (JZEIC, 2016b):

1) Economy. The procedure for economic evaluation is:

$$\text{Economy} = \left[\left(\frac{\text{Petrol price}}{100\text{km}} - \frac{\text{Methanol price}}{100\text{km}}\right) \div \frac{\text{Petrol price}}{100\text{km}}\right] \times 100\%$$

Table 5 shows that the price of using methanol is averagely around 42.2% of using petrol.

Table 5. Economy of methanol vehicle

Price \ Time	2013.09	2014.03	2014.09	2015.03	2015.09	2016.03
Petrol (¥/L)	7.65	7.63	7.25	6.15	5.68	5.4
Petrol price per 100km (¥)	71.1	71.0	67.4	57.2	52.8	50.2
Methanol 100% (¥/L)	2.5	2.5	2.5	2.25	1.78	1.65
Methanol price per 100km (¥)	40.3	40.3	40.3	36.4	29.3	27.2
Economy	43.3%	43.2%	40.2%	36.4%	44.5%	45.8%

2) Environmentally sustainable. Table 5 illustrates that the tested methanol vehicles' emissions reached China V standard; the emissions of HC and NO_x meet Euro IV standard (0.08 g/km) and the emission of CO meet Euro VI standard (1g/km).

Table 6. Emissions from tested methanol vehicle

Plate \ Subject	Year	Mileage (km)	HC (g/kwh)	CO (g/kwh)	NO_x (g/kwh)	Methanol (mg/km)
(Jin) KT1312	2015	123203	0.08	0.66	0.08	1.039
(Jin) KT1316	2015	119928	0.08	0.97	0.08	1.390
(Jin) KT1324	2016	225493	0.074	0.605	0.044	1.679
(Jin) KT1325	2016	185454	0.082	0.788	0.052	1.220
(Jin) KT1336	2016	198179	0.065	0.463	0.031	1.055
(Jin) KT1414	2016	176363	0.083	0.840	0.040	1.496
(Jin) KT1421	2016	203613	0.082	0.638	0.044	1.943

Note: Jin is the abbreviation of Shanxi province.

3) Serviceability. The results of overall performance indicate that tested methanol vehicles are serviceability. Also, the data from low temperature starting test indicate that tested methanol vehicles have the ability of cold start.

4) Reliability. Among 1963 times faults during the pilot program, 13 times faults were due to methanol fuels: 9 times for pumps; 4 times for liquid level sensors. As a result, there is no big difference between methanol vehicle and gasoline vehicle in terms of the fault rate.

3.2 Advantages and barriers for methanol vehicle in China

Many researchers and experts in China (Peng, 2006; He, 2016; Xin, 2016) emphasized the development of methanol vehicle conforms to the goal of achieving sustainable development in China:

- The production of methanol for coal poly-generation would push the transformation of coal industry and it would promote the utilization of coal resource in an efficient way;
- China has rich coal resource for producing methanol;
- As China has limited oil and gas, but rich coal resource, the energy structure is imbalanced. The development of methanol vehicle would improve the energy structure of China as well as to balance the energy consumption by reducing the dependence on fossil fuels;
- Technology of methanol vehicle in China is mature;
- The low price of methanol in China would attract more consumers;
- The development of methanol as fuel for vehicle would contribute to solve environmental problems by reducing approximately 80% PM2.5 emissions. Vehicular emissions including CO and NO would be reduced 25% and 10%, respectively (JZEIC, 2016b).

However, there are still barriers for the promotion of methanol vehicle. On one hand, the Chinese governments need to accelerate the construction of infrastructures such as filling stations; on the other hand, an effective subsidy policy is required for the emerging methanol vehicle market, specifically for the engagement of manufacturers (Peng, 2008; Wang, 2016; Chen, 2016). Therefore, this study aims to develop an optimal subsidy model for the promotion of methanol vehicle in China. The following sections provide a detailed explanation.

4. THE OPTIMAL SUBSIDY MODEL FOR METHANOL VEHICLE

Aiming to provide decision makers from governments an optimal subsidy policy, a subsidy model for the promotion of methanol vehicle in China has been designed, based on microeconomic theories. As methanol vehicle is an emerging market in China, the subsidy policy which focuses on the engagement of manufacturer should be the priority. Then, the subsidy for consumers would be offered after the engagement of enough manufacturers (Ma *et al*., 2009; Zhu, 2011). This section develops a model which describes the relationships among consumers, manufacturers and governments in terms of the subsidy for methanol vehicle, followed by a case study which is used to test the rationale of the designed model.

When conducting research on subsidy policy, microeconomic theories such as demand and supply, willingness to pay, margin cost and margin revenue, social welfare are appropriate for the development of relevant models for different sub-topics (Clarke & Islam, 2004; Han & Zhang, 2012; Zu & Zhang, 2012). Clarke & Islam (2004), Han & Zhang (2012) and Zu & Zhang (2012) have explained and summarized basic microeconomic theories, in their books. Some research regarding subsidy policy have been done based on microeconomic theories (Zhu, 2011; Hao *et al.*, 2014; Song, 2015; Troidl *et al.*, 2016).

Specifically, Zhu (2011) analyzed existing subsidy policies based on microeconomic theories which include supply and demand in the AFVs market in China. The results indicate that the subsidy policies need to be improved. This study provides the importance of considering demand and supply in the market of AFVs before offering subsidy. Also, Hao *et al.* (2014) designed several models based on economic theories for the evaluation of the rationale and impacts of China's electric vehicles (EVs) subsidy scheme. A comprehensive summary of subsidy policies for EVs has been offered; criteria including fuel cost and vehicle price have been discussed. Song (2015) developed several models for the analysis of subsidy scheme for AFVs. While the explanations based on microeconomic theories were sufficient, some models would be hardly applied in practice due to the lack of critiera which have profoundly impacts on the real market. Troidl *et al.* (2016) studied on consumer valuation of fuel consumption in the Australian market based on marginal willingness to pay for fuel consumption by utilizing data on vehicle sales. The designed model of cost-saving has emphasized that consumer's willingness to pay would profoundly impact the AFVs market.

4.1 The Impacts of Offering Subsidy to Methanol Vehicle Manufacturers

When comparing two types of vehicle, it is necessary to consider them at the same level in terms of price and overall performance. Accordingly, Geely Automobile which has models for both conventional fuel and methanol has been selected as a case study.

According to Geely Automobile (2017), the price of Dihao (a brand of Geely) for a conventional fuel model is about ¥45,000 and for a methanol fuel model is around ¥50,000. Accordingly, the price of a methanol vehicle P_m is higher than the price of a conventional vehicle P_c: $P_m > P_c > 0$.

Based on the given prices for two models, the cost of Dihao for a conventional fuel model would be around ¥25,000 and for a methanol fuel model would be around ¥30,000. Therefore, the cost of a methanol vehicle C_m is higher than the cost of a conventional vehicle C_c: $C_m > C_c > 0$ (As the cost of a vehicle is confidential, the figures of costs are based on prediction. These figures will be used in Section 4.2).

Moreover, the governments would offer subsidy when the revenue of a methanol vehicle more than that of a conventional vehicle. Thus, selling a methanol vehicle R_m should make more revenue than selling a conventional vehicle R_m: $R_m > R_c > 0$.

The consumer's willingness to pay would be θ_n which locates between [0, 1]. If consumer surplus (CS) for one vehicle is CS_n ($CS_n \geq 0$), then:

$$CS_n = \theta R_n - P_n \ \ (n = 0, 1) \tag{1}$$

If θ_c represents a consumer's willingness whether to pay for a conventional vehicle, then:

$$\theta_c R_c - P_c = 0, \ \theta_c = \frac{P_c}{R_c} \tag{2}$$

If θ_m represents a consumer's willingness to pay for either a methanol vehicle or conventional vehicle, then:

$$\theta_m R_m - P_m = \theta_m R_c - P_c, \ \theta_m = \frac{(P_m - P_c)}{(R_m - R_c)} \tag{3}$$

If U represents the total number of potential consumers for both types of vehicles, the demand of conventional vehicles D_c and the demand of methanol vehicles D_m would be:

$$D_c = (\theta_m - \theta_c)U = \left(\frac{P_m - P_c}{R_m - R_c} - \frac{P_c}{R_c}\right)U \tag{4}$$

$$D_m = (1 - \theta_m)U = \left(1 - \frac{P_m - P_c}{R_m - R_c}\right)U \tag{5}$$

Accordingly, the relationship among CS_c, CS_m, D_c, D_m θ_m and θ_n could be shown as (Figure 2):

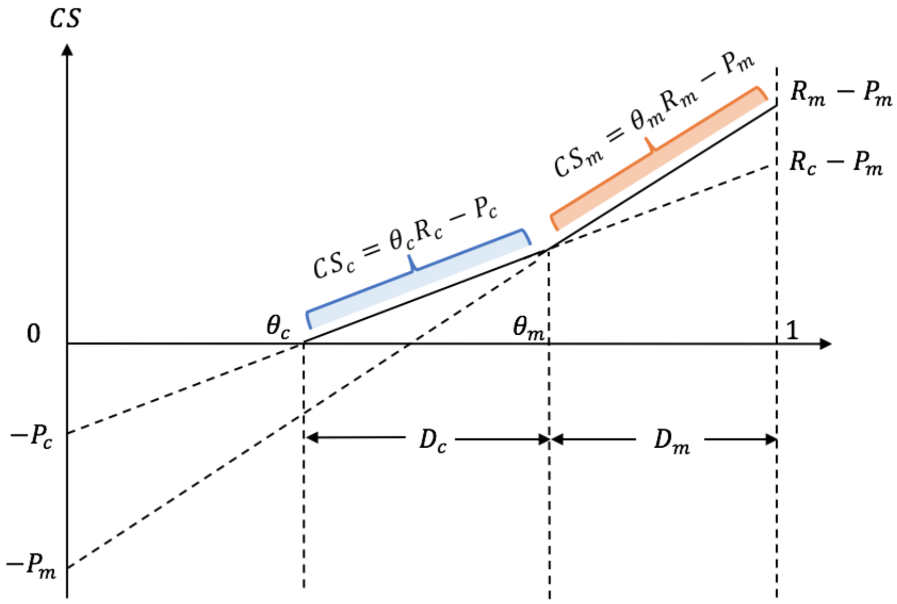

Figure 2. The relationship among consumer surplus, demand and willingness to pay

Now, introducing the governmental subsidy for the manufacturer of methanol vehicle S $(S \geq 0)$ into the equations, the profit of conventional vehicles I_c and the profit of methanol vehicles I_m would be:

$$I_c = (P_c - C_c)D_c = (P_c - C_c)\left(\frac{P_m-P_c}{R_m-R_c} - \frac{P_c}{P_c}\right)U \tag{6}$$

$$I_m = (P_m - C_m + S)D_m = (P_m - C_m + S)\left(1 - \frac{P_m-P_c}{R_m-R_c}\right)U \tag{7}$$

To maximize the profits of manufacturers for both conventional vehicle and methanol vehicle: $\frac{\partial I_c}{\partial P_c} = 0$, $\frac{\partial I_m}{\partial P_m} = 0$. Then, the optimal selling prices for a conventional vehicle P_c' and a methanol vehicle P_m' would be:

$$P_c' = \frac{R_mR_c+C_mR_c-SR_c+2C_cR_m-{R_c}^2}{4R_m-R_c} \tag{8}$$

$$P_m' = \frac{R_m(2R_m-2R_c+2C_m-2S+C_c)}{4R_{m,}-R_c} \tag{9}$$

Accordingly, the optimal demands for conventional vehicles D_c' and methanol vehicles D_m' would be:

$$D_c' = \frac{R_m(R_mR_c+C_mR_c-SR_c+C_cR_c-2C_cR_m-{R_c}^2)}{R_c(4R_m-R_c)(R_m-R_c)}U \tag{10}$$

$$D_m' = \frac{(2R_m^2+C_mR_c-SR_c+C_cR_m-2R_mR_c-2C_mR_m+2SR_m)}{(4R_m-R_c)(R_m-R_c)}U \tag{11}$$

The maximum profits for conventional vehicles I_c' and methanol vehicles I_m' would be:

$$I_c' = \frac{R_m(R_mR_c+C_mR_c-SR_c+C_mR_c-2C_cR_m-R_c^2)^2}{R_c(4R_m-R_c)^2(R_m-R_c)}U \tag{12}$$

$$I_m' = \frac{(2R_m^2+C_mR_c-SR_m+C_cR_m-2R_mR_c-2C_mR_m+2SR_m)^2}{(4R_m-R_c)^2(R_m-R_c)}U \tag{13}$$

If taking partial derivative of subsidy S, then:

$$\frac{\partial P_c'}{\partial S} < 0,\ \frac{\partial P_m'}{\partial S} < 0, \frac{\partial D_c'}{\partial S} < 0, \frac{\partial D_m'}{\partial S} > 0, \frac{\partial I_c'}{\partial S} < 0, \frac{\partial I_m'}{\partial S} > 0 \tag{14}$$

4.2 The Development of An Optimal Subsidy Model for Methanol Vehicle

According to the principles of consumer surplus and manufacturer surplus, the consumer surplus (CS_m) and the manufacturer surplus (MS_m) for methanol vehicle would be:

$$CS_m = \left[\int_{\theta_m}^{1}(\theta_mR_m - P_m)d\theta_m\right]U \tag{15}$$

$$MS_m = I_m' \tag{16}$$

If the marginal cost of a methanol vehicle is F and the marginal revenue of a methanol vehicle is G: $F > 0, G > 0$. Then, the social welfare from the promotion of methanol vehicle with subsidy W_m would be:

$$W_m = CS_m + MS_m - FD_m' + GD_m' - SD_m' \tag{17}$$

To maximize W_m, $\frac{dW_m}{dS} = 0$. Then, the optimal subsidy for methanol vehicle manufacturers S' would be:

$$S' = \frac{(2R_m-R_c)\left[(2R_m^2+C_mR_c+C_cR_m-2R_mR_c-2C_mR_m)-(G-F)(4R_m-R_c)\right]}{R_m^2} \tag{18}$$

Data gained from Geely Automobile are used to validate the designed subsidy model (described in Section 4.1). According to the data from the case study of Dihao for both conventional and methanol fuel: the cost of a conventional vehicle C_c= ¥20,000; the cost of a methanol vehicle C_m= ¥30,000; the approximate revenue of a conventional vehicle R_c= ¥50,000; the relevant revenue of methanol vehicle R_m= ¥60,000.

Based on the designed subsidy model, the relationship among the marginal revenue of methanol vehicle G, the marginal cost of methanol vehicle F and the optimal subsidy S' would be:

$$S' = \begin{cases} 0.583 - 3.694(G-F) & when\ 0 < G \leq 0.158 + F \\ 0 & when\ G > 0.158 + F \end{cases} \tag{19}$$

As $G > 0, F > 0, S' \geq 0$, the result of this case study shows: when the marginal revenue of a methanol vehicle $G > 0.158 + F$, the governments wouldn't need to offer subsidy; when the marginal revenue of a methanol vehicle $0 < \mathrm{G} \leq 0.158 + \mathrm{F}$, the governments would offer subsidy to manufacturers for the development of methanol vehicle. In short, whether the governments should provide subsidy depends on if the marginal revenue of a methanol vehicle is more than 0.158, after removing the marginal cost.

4.3 Result Analysis

According to the above analysis and the model development, when the governments offer manufacturers subsidy for the promotion of methanol vehicle:

- The prices of both conventional and methanol vehicle would decrease;
- The demand of conventional vehicles would slightly decrease and the demand of methanol vehicles would increase;
- The revenue of manufacturing methanol vehicles would increase;
- The sales of methanol vehicle would increase;
- The engaged manufacturers would gain more profits;
- Social welfare would be increased, with the promotion of methanol vehicle.

However, in the real automobile market in China, the constantly increase of the conventional vehicle number shows that at the current stage, most consumers haven't considered buying methanol vehicles (He, 2016). Moreover, while the designed subsidy model provides decision-makers with a theoretical basis of offering methanol vehicle manufacturers subsidy, many criteria from governmental, socioeconomic, political and environmental levels such as energy security, market acceptance, and fuel price also need to be considered. Therefore, the future study would focus on the establishment of an integrated subsidy system which can be widely implemented for the promotion of AFVs.

5. THE DEVELOPMENT OF A LOGIT MODEL AS FUTURE STUDY

According to Retherford and Choe (2011), logit analysis, developed by David Cox in 1958, can be used when response variables are dichotomous (i.e., binary or 0-1). The binary logistic model is used to estimate the probability of a binary response based on one or more variables. In other words, the implementation of a logit model allows decision-makers to evaluate that how the presence of a risk factor would increase the probability of a given outcome by a specific percentage. In this study, a designed logit model would help to predict the market acceptance of methanol vehicle. Based on the probability of the market acceptance, decision makers from governmental levels would decide how to offer manufacturers subsidy, with the previous subsidy model combined. In this way, the subsidy scheme in practice would be more accurate and rational, with multi-criteria considered.

The logit analysis which can interpret both qualitative and quantitative has been used in many areas including marketing (Retherford & Choe, 2011). Ma *et al.* (2009) introduced a logit model for the prediction of future AFVs market in China. While the results indicate that governmental regulations have strong impacts on AFVs, the current market shares of AFVs are far lower than the prediction results from the designed model, mainly due to some variables such as subsidy and energy restructure haven't been considered in the establishment of utility functions. Therefore, although the study combined multi-criteria decision analysis, the development of its logit model could be improved with more criteria input.

Moreover, Hess *et al.* (2012) developed a cross-nested logit model to capture correlation patterns in forecasting the demand for AFVs. From a modelling perspective, this study focused on the representation of complex correlation structure that developed in the context of multi-dimensional choice process. Hackbarth and Madlener (2013) also analyzed the potential demand for AFVs with applying a mixed logit model. The research not only listed many variables, but also implemented the concept of willingness to pay. However, data from these two studies were only collected from consumers. Stakeholders including manufacturers and governments also need to be involved as their decisions would be important in guiding the market of AFVs. Diamond (2009) analyzed the impact of government incentives for HEVs with an example of US states. While the study shows that subsidy has few impacts on the development of AFVs, the logit model with multiple variables has been well designed which offers a good direction for the development of an integrated logit model for methanol vehicle.

Therefore, the implement of an integrated logit model for the promotion of methanol vehicle based on multi-criteria can be developed as a future research direction, with the designed optimal subsidy model in this study combined.

For example, to predict the market of methanol vehicle is to predict the potential probabilities (P_m) of methanol vehicle may be selected by consumers in the future market. Then:

$$P_m = \frac{e^{U_m}}{1 + e^{U_m}} = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n}}{1 + e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n}}$$

where $0 < \mathrm{P_m} < 1$; $\mathrm{U_m}$ is the utility function which combines all variables and coefficients; β_0 is a constant, β_n is a coefficient of a variable $\mathrm{x_n}$.

For example, when considering several variables ($n = 9$) which affect consumers' willingness to pay for methanol vehicle, the estimated P_m would be:

$$P_m = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3++\beta_4 x_4+\beta_5 x_5+\beta_6 x_6+\beta_7 x_7+\beta_8 x_8+\beta_9 x_9}}{1 + e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\beta_3 x_3++\beta_4 x_4+\beta_5 x_5+\beta_6 x_6+\beta_7 x_7+\beta_8 x_8+\beta_9 x_9}}$$

where $\mathrm{x_1}$ the overall performance of methanol; x_2 the price of methanol fuel; x_3 the price of methanol vehicle; x_4 the subsidy for methanol vehicle; x_5 the cost of fundamental facilities for a methanol vehicle station; x_6 the testable vehicular emissions from methanol vehicle; x_7 the market acceptance of methanol vehicle; x_8 the ratio of methanol impacts on the energy restructure; x_9 the storage and supply of methanol. The future study would mainly focus on the adjustment of these variables and to define each coefficient. The methodology would be mainly based on market survey and expert interview.

Moreover, the designed logit model could be developed as a multinomial logit model in the application when there are more than one alternatives (AFVs). In this case, the probability of each AFV P_i would be described as:

$$P_i = \frac{e^{U_i}}{\sum_{i=1}^{n} e^{U_i}} = \frac{e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n}}{\sum_{i=1}^{n} e^{\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_n x_n}}$$

where $i = 1, 2 \ldots, n$; U_i is the utility function which combines all variables and their coefficients; β_0 is a constant, β_n is a coefficient of a variable $\mathrm{x_n}$.

To sum up, the development of a logit model with multi-criteria variables which provides decision makers, when considering subsidy scheme, an overall picture of all criteria that impact the market of AFVs would be a future research direction.

6. CONCLUSION AND RECOMMONDATION

In conclusion, methanol as fuel for vehicle with its advanced overall performance, is economy and environmental friendly, compared with conventional fuels. The promotion of methanol vehicle which conforms to the strategy of achieving sustainable development in China would achieve environmental and economic benefits. As the current methanol vehicle market is immature, both the central and local governments in China need to not only improve fundamental infrastructures, but also develop an integrated subsidy mechanism to involve more manufacturers and consumers. The designed optimal subsidy model which focuses on the subsidy for manufacturers has offered decision makers an idea of how to improve the subsidy scheme for the acceleration of methanol vehicle development in China.

Apart from economic factors, many other criteria would also impact the development of methanol vehicle. Therefore, the establishment of a logit model which aims to form an integrated subsidy scheme with multi-criteria involved would be a future research direction.

REFERENCES

Bockris, J. (2007) Will lack of energy lead to the demise of high-technology countries in this century? *Journal of Hydrogen Energy,* vol. 32, pp. 153–158.

Chen, J. (2016) The report of the pilot program of methanol vehicle in Guiyang city. *Conference for China Alcohol Ether Fuel & Vehicle Developmen*t, 2016, Fujian, China.

China Urban Low-carbon Economy Network (CULCEN). (2012) The current situation of clean energy and the issues existing in the development of clean energy. Viewed 03 April 2017 <http://www.cusdn.org.cn/news_detail.php?id=21636>. (in Chinese)

Clarke, M & Islam, MN. (2004) *Economic growth and social welfare operationalizing normative social choice theory*, 1st edn, Chapter 5, Elsevier, Boston.

Deng, H. (2010) Market structure and pricing strategy of China's automobile industry. *Journal of Industry and Economics*, vol. 58 (4), pp. 818–845.

Diamond, D. (2009) The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Journal of energy policy*, vol. 37, pp. 972-983.

Dolan, G. (2008) China takes gold in methanol fuel. *Journal of energy security,* Asian, 06 Oct 2008.

Geely Auto. (2017) Price list of existing vehicle model on website. Viewed 25 May 2017, http://www.geely.com/welcome/index.html. (in Chinese)

Hackbarth, A & Madlener, R. (2013) Consumer preferences for alternative fuel vehicles: A discrete choice analysis. *Transportation Research Part D*, vol. 25, pp. 5-17.

Han, Y & Zhang, Y. (2012) *Microeconomics (series of economics),* Chapter 2, 10 & 11. Economic Science Press, ISBN: 9787514110142. Beijing, China. (in Chinese)

Hao, H, Ou, X, Du, J, Wang, H & Ouyang, M. (2014) China's electric vehicle subsidy scheme: Rationale and impacts. *Energy Policy*, vol. 73, pp. 722-722.

He, G.Y. (2016) The development of methanol-fueled vehicle meets the need of Chinese economy and energy restructure. *China Automobile,* 2016-2. (in Chinese)

Hess, S, Fowler, M, Adler, T. (2012) A joint model for vehicle type and fuel type choice: evidence from a cross-nested logit study. *Transportation*, vol. 39, pp. 593-625.

Jinzhong Economy and Information Committee (JEIC). (2016a) Summary of tested methanol cars in Jinzhong. *China's Ministry of Industry and Information Technology (MIIT).* (in Chinese)

Jinzhong Economy and Information Committee (JEIC). (2016b) Results of tested methanol vehicles. *China's Ministry of Industry and Information Technology (MIIT)*. (in Chinese)

Liu J. (2012) China Ministry Launches Methanol Car Tests. *Global Refining & Fuels Report*, vol. 16, no. 6, pp. 22-23.

Ma, J, Wang, N, Kong, D. (2009) Market forecasting modeling study for new energy vehicle based on AHP and Logit regression. *Journal of Tongji University*, vol. 08.

Ministry of Industry and Information Technology of China (MIIT). (2017) Summary of the development of methanol vehicle in pilot programs. Viewed 15 April 2017, <http://www.miit.gov.cn/n1146285/n1146352/n3054355/content.html>. In Chinse

Nie H. (2016) Beijing has published subsidy policy for electric vehicle in 2016. Viewed 01 Nov 2016, <http://www.d1ev.com/42994.html>. (in Chinese)

Olah, G. (2003) *The Methanol Economy*. Chemical & Engineering News. 81 (38): 5. doi:10.1021/cen-v081n051.p005.

Olah, G. (2005) *Beyond Oil and Gas: The Methanol Economy*. Angewandte Chemie International Edition. 44 (18): 2636–2639.doi:10.1002/anie.200462121. PMID 15800867.

Peng, Z (2006) The development of methanol-fueled vehicle in the new stage. *China Clean Energy Conference Experts' Communication*. (in Chinese)

Peng, Z. (2008) New orientation and new progress of fuel methanol industry in China, and new thinking on the industry. *Tthe 17th International Symposium on Alcohol Fuels*. Taiyuan, China. (in Chinese)

Pontau, P, Hou, Y, Cai, H, Zhen, Y, Jia, X, Chiu, AS (2015) Assessing land-use impacts by clean vehicle systems. *Resources, Conservation & Recycling*, vol. 95, pp. 112-119.

Retherford, RD & Choe, MK. (2011) *Logit Regression*, Statistical Models for Causal Analysis, Chapter 5, pp.119-150.

Song, H. (2015) Study on subsidy policy of China's new energy vehicles. *Master degree thesis for Beijing Institute of Technology.* (in Chinese)

Troidl, A, Templeton, SR, Espey, M & Fleck, R. (2016) Consumer valuation of fuel economy in the Australian automobile market. *ProQuest Dissertations and Theses.*

Tu, L. (2014) Why it is difficult to promote electric cars in Beijing? *Beijing Daily,* 2014-08-05. Beijing, China. (in Chinese)

Wang, L, Xu, J, Zheng, X & Qin, P. (2013) Will a Driving Restriction Policy Reduce Car Trips? A Case Study of Beijing. *Environment for Development*, 2013-09. (In Chinese)

Wang, L. (2016) The report of the pilot program of methanol vehicle in Jinzhong city. *China Alcohol Ether Fuel & Vehicle Development Conference*, 2016, Fujian, China. (In Chinese)

Xin, Y. (2016) How to accelerate the development of methanol vehicle in Shanxi province? *Shanxi Automobile,* 2016-06. (in Chinese)

Yang, J, Liu, Y, Qin, P & Liu, A. (2014) A review of Beijing's vehicle registration: short-term effects on vehicle growth and fuel consumption. *Energy policy*, vol. 75, pp. 157-166.

Yin, W. (2012) Effects of vehicle restriction will be reduced. *Beijing News* 2012-05-11, viewed 25 May 2016, <http://auto.people.com.cn/GB/1049/9369015.html>. (in Chinese)

Zhang, H. (2016) The strategies of the development of clean energy, Methanex. *Conference papers for China Alcohol Ether Fuel & Vehicle Development*, 2016, Fujian, China.

Zhu, K. (2011) The analysis of subsidy policy on new energy vehicle in China. *Journal of Sino-Global Energy,* vol. 10, pp 44-48. (in Chinese)

Zu, X & Zhang, M. (2012) *Microeconomics* (*selective textbook for institutions of higher learning*), 1st edn, Chapter 1, 2, 4 & 10. Southwest University of Finance and Economics Press, ISBN: 9787550404847. Chengdu, China. (in Chinese)