１Ｇ０４
Bassモデルを用いた日本国内外における天然ガス自動車普及に関する研究

○祝悦，時松宏治（東京工業大学），松本光崇（産業技術総合研究所）

In this study, Bass Model was utilized to estimate future diffusion of natural gas vehicles (NGVs) with subject to seek how NGVs in Japan and other nations are going to diffuse. Firstly three scenarios were established to analyze NGV's future diffusion in Japan with highest outcome shown as 8.5 million which accounts for 14% of overall vehicles. Secondly under the purpose of feasibility study, Bass Model was utilized on twelve countries where NGVs are popularized. Finally, difference among nations regarding to the diffusion of NGV were discussed based on results from regression analyses, in which various explanation parameters such as GDP, atmosphere pollution emission, supply of energy, etc. were used.

1. INTRODUCTION

1.1 Background

As realization of sustainable society is moving forward, not only the development of environmentally conscious design products, but also the promotion of their diffusion is becoming increasingly important. In this paper, natural gas vehicle (NGV), one kind of clean energy vehicles, was highlighted as subject for purpose to justify the creative scenarios and probability of its diffusion.

Natural gas, the main fuel for NGV, increases of its share on current primary energy supply compared to those in 1980s when compared with that of oil. In the New Policies Scenario from the World Energy Outlook (WEO) – 2013 [1], the growing speed in primary energy demand for natural gas obviously exceeds than that of any other energy sources, and ends up in 2035 with a some 200% higher level than in 1980s.

Meanwhile in pace with the recent technological progress, natural gas from shale has been the fastest growing contributor to total primary energy in the United States, and has led many other countries to pursue shale deposits. The activity definitely leads to pricing influences to global market of natural gas. According to WEO – 2013 [1], prices of natural gas in three representative regions (Japan, Europe and United States), are all likely to fall down at some extend in the near future.

1.2 Features of NGV

Natural gas vehicle (NGV), as one representative product relative to natural gas, possibly has larger economic and environmental advantages over other vehicles. Engerer and Horn (2010) pointed out that NGV generally has good behavior on less CO2 emission, least emission of NOx and absolute zero emission of particulate matter [2]. Regarded as outstanding clean-energy vehicle, NGV has started diffusing widely in the world and currently total of 19.9 million NGVs are estimated to be hold in the world [3]. In Japan, NGV's diffusion started in 1990, and 43,600 NGVs are running on roads current day [3].

Table 1: NGV's features compared to conventional gasoline vehicle

Life Cycle CO2 Emission	*Life Cycle NOx Emission*	*Atmosphere Pollution*	*Running Distance*
60%~80%	**None**	**None**	**50%**
Running Cost (Fuel price/ running distance)	*Vehicle price*	*Infrastructure*	*Production Technology*
50%	**140%~200%**	**Relatively less**	**Mature**

As comparative contents Table 1 shows, NGV obtains great number of advantages like quite mature producing technology and outstanding behavior on low emission of atmosphere pollutants. For instance, the emission of NOx or SOx of NGV is nearly zero. On the other side, there still exist disadvantages like none-enough gas station and relatively poor running distance.

1.3 Objectives

In this study, scenario analyses were carried out to construct future diffusion of NGV till 2050 in Japan and other nations. The following questions were addressed to be answered.

Firstly, to what extent and how possible are the NGVs in Japan going to diffuse from 2020 to 2050? How should future environmental conditions be changed to promote the highest diffusion level?

Secondly, how is the applicability of the diffusion model when it is applied for other countries where NGV is popularized?

Thirdly, how are Environmental or Economical Factors having influence to NGV's diffusion?

2. Methodology

Bass model is an accurate model widely describing the popularizing process of industrial products, and they follow the rules as below [4] [5]:

1) Customers who buy the products can be regarded as sum of "innovator" who made mind themselves to purchase and "imitator" who followed innovators' decision to make purchase.

2) The proportion of number of innovators (during one period) "Vt" in population who have not ever made purchase (during same period) "Yt" is fixed and could be shown as "p".

3) The proportion of number of imitators (during one period) "Wt" in population who have not ever made purchase (during same period) "Yt" could be shown as "pt'" where it fulfills "pt' = r・nt", "nt" is the diffusion rate (during same period) and "r" is constant.

4) Ultimate diffusion number "N" is fixed. It means population who have not ever made purchase "Yt" and cumulative population who have made purchase "nt・N" do always fulfill "Yt + nt・N = N".

Following above relationship, new customers during period t shown as "Xt" and alternative formula could be listed as below:

$$X_t = V_t + W_t \quad (1)$$

$$V_t = p \cdot Y_t = p \cdot (1 - n_t) \cdot N \quad (2)$$

$$W_t = p_t' \cdot Y_t = r \cdot n_t \cdot Y_t = r \cdot n_t \cdot (1 - n_t) \cdot N \quad (3)$$

Hence in case of period t seen as continuous value, additionally boundary condition settled as "nt=0 = 0" is given, the Bass model with cumulative diffusion number till period t shown as "Nt" is managed to be formulated as below [5]:

$$N_t = N \cdot \frac{1 - e^{-(p+t)t}}{1 + \frac{r}{p} \cdot e^{-(p+t)t}} \quad (4)$$

To make the definition of three parameters meaningfully, "N" is the ultimate carrying capacity, "p" is the coefficient of innovation, "r" is the coefficient of imitation, and "Nt" on the left hand side is the diffusion number at time t.

3. Results

3.1 Japan

3.1.1 Scenario Description

・Scenario 1: NGV's diffusion level till March 2014 was assumed to approach market saturation, thus p, r and N are estimated via up-to-now actual diffusion trend.

・Scenario 2: NGV since 2020 was assumed to have similar diffusion ratio to that of diesel vehicle (DV) experienced in past Japan which was chosen as resembling product with reasons that are described later, and hence the diffusion is supposed to take an obvious leap till 2050.

・Scenario 3: NGV's diffusion will somehow have one-tenth of annual increasing number as that in Scenario 2.

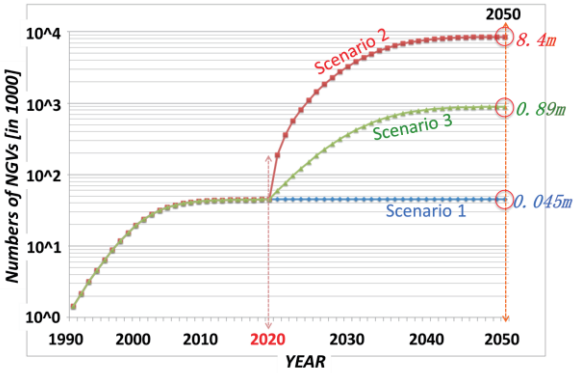

Fig. 1: Results of diffusion level of NGV in Japan under scenarios of 1, 2 and 3

3.1.2 Comparison to report from MOE [6] [9], Japan

In 2009 and 2010, Ministry of the Environment (MOE), Japan twice conducted diffusion simulation mainly based on relationship between population fluctuation and preference on vehicle types in various age groups [6] [9]. Table 3 below shows the measured simulating results from 2010's report from MOE, Japan and NGV diffusion number by 2050 was calculated as 1,289 thousand.

Table 3: Predicted diffusion number by MOE [6], Japan, 2010

Next-generation Vehicle		Diffusion number in 2050 Total as **63,900** (Unit: 1,000)	
Light Vehicle, Track	**EV**	28441	28441
Small-sized & Normal Passenger Vehicle	**EV**	5564	
	HV	11615	
	PHV	11588	31200
	CDV*	0	
	FCV	2421	
Normal Track & Bus	**EV**	289	
	HV	1399	
	NGV	**1289**	4259
	CDV	936	
	FCV	346	

Scenario 1 shows the 2050's NGV diffusion number as 45 thousand, which is extremely lower than that from MOE, Japan, 2010. The scenario does come true only under the condition that no change in future energy market and the policy from Japan government stays the same.

Scenario 3 shows the 2050's NGV diffusion number as 885 thousand, somehow is getting close to the predicted number of NGV (842 thousand) from MOE, Japan, 2009 [9]. It explains that diffusing process of NGV in guiding principle from 2009's Japan government probably has the similar step as that in Scenario 3 which is 90% slower than Scenario 2.

Scenario 2 makes a forecast of diffusion number as 8446 thousand for NGV in 2050, which is about 6.5 times to 1,289 thousand from MOE, Japan, 2010.

3.1.3 Realizing Method of Scenario 2

Although scenario 2 showed an outcome which is about 6.5 times to that from MOE [6], the likelihood that scenario 2 come true in future could be available if the number of NGV substitute for other types of vehicle. EV and PHV (plug-in hybrid vehicle) are most likely to be replaced by NGV among these alternative vehicles besides CDV. Below are several reasons.

Firstly, on April 2014, Ministry of Economy, Trade and Industry (METI) in Japan made a policy to promote the joint fuel station both for NGV and FCV [10]. Therefore following sale of Toyota's FCV "MIRAI" in December, 2014, the first joint Hydrogen and CNG station was successfully built in Nerima District, Tokyo. As the predicted number of Hydrogen in 2050 being 1000 to 5000 from MOE, Japan, 2010 [6], more joint fuel stations like this are optimistically to be constructed, that is obviously helpful for diffusion of NGV.

Secondly, according to MOE, Japan, 2009 [9], EV's price is 200% to 300% times more expensive than same class gasoline vehicle, while NGV's price is only 40% to 100% more expensive than that of gasoline vehicle.

Thirdly similarly based on the information from MOE, Japan, 2009 [9], EV and PHV rely too much on the quality and price of batteries inside themselves. In comparison to them, NGV is relatively relying on natural gas supply system.

As the result of reason above, hypothesis can be done as: NGV completely substitute for CDV (936 thousand) (tab. 2) firstly, the rest part as 6,331 thousand (6,331 = 8,446(scenario 2) - 936 - 1289) could partly replace market of EV and PHV, where the total number of them are calculated as 45,882 thousand (45,882 = 28,441 + 5,564 + 11,588 + 289) (tab. 2). This gives the information that future NGV dominates about 1/7 of EV and PHV market.

3.2 Nations besides Japan

Twelve countries where NGV is considerably diffusing were chosen for research. They are exhibited in order that reduce progressively as Iran, China, Pakistan, Argentina, India, Brazil, Italy, Columbia, Thailand, Ukraine, Bolivia and the U.S.. Since they have introduced NGV to some extent, the values for p, r and N are estimated via up-to-now actual diffusion trend. Furthermore these countries could be divided into two groups according to whether Bass Model can fit them well or not.

3.2.1 Nations that Bass Model could Finely Fit

For nine countries besides China, Pakistan, and the U.S., Bass Model curve could ideally fit the actual diffusion curve, followed by results with current status that were summarized in one table shown as below.

Table 4: Outcomes of three values for nine nations

Countries	**Diffusion Status (2014)**	***N*** **(Ultimate)**	***p***	***r***
Iran	**3,500,000**	**3,900,000**	0.0000412	0.668
Argentina	**2,331,912**	**3,000,000**	0.00287	0.186
India	**1,800,000**	**2,800,000**	0.000495	0.336
Brazil	**1,764,137**	**1,800,000**	0.000283	0.539
Italy	**823,000**	**4,300,000**	0.0000585	0.0671
Columbia	**463,930**	**600,000**	0.0000972	0.350
Thailand	**422,812**	**600,000**	$6.08*10^{-6}$	0.511
Ukraine	**388,000**	**700,000**	$2.83*10^{-12}$	0.343
Bolivia	**273,342**	**600,000**	0.00119	0.295

3.2.2 Nations that Bass Model is Unfitted

Three countries China, the U.S. and Pakistan aren't finely fitted with Bass Model. In case of China, the ultimate diffusion number N was calculated to be infinite. In case of the U.S. and Pakistan, actual diffusion curve could not fit well with Bass Model Curve.

In the case of the U.S.A

In the U.S., NGV had a slight increase around 1990s till 2007, and the NGV penetration was limited for buses, trash trucks and single unit delivery truck fleets [12]. However, the CNG station count decreased between 1996 and 2006, the reason was supposed to be the rising size of the average station [13]. The decrease of the station directly had an impact on diffusion number of NGV at the year of 2008, as the number dropped down to 100 thousand despite it was still 147 thousand in 2007. Following the decline in 2008, number of NGV increased tardily till 2012 with the diffusion shown as 112 thousand [3].

Fortunately, NGV managed to have a boom since 2012 with diffusion number leaped to 250 thousand in the same year [3]. Around the year of 2010, the success of shale gas revolution means the increased availability of natural gas, at the same time gas producers find themselves more and more looking for demand in an oversupplied market [14]. No doubt NGV market was supposed to be the best target for them, as the fact shows that only 3% of 2011's primary energy consumption of natural gas in the U.S. belonged to transportation, NGV market definitely obtain the largest potential. [12]

Moreover, government of the U.S. published plan of "Blue print for a secure energy future" (President Obama, 2011.3) and "NAT GAS ACT of 2011" (the U.S government, 2011.4) to stimulate the diffusion of NGV [14]. Policies like vehicles run in airports being substituted by NGV, maximum as 4,000 dollars being remitted when NGV over mid-size is purchased were constituted [16]. Meanwhile vehicle Companies like Honda, Isuzu, and Ford widened their market in the U.S and promoted NGV sales [14].

Pakistan

Although the NGV was firstly introduced in Pakistan in the early 1990s as 70 years later than its first commercialization of technology in Italy, NGV had been diffusing exponentially till 2010 under the policy of deregulation of its sale in Pakistan. There were two main motivations for NGV's diffusion in Pakistan, 1) Reduction of dependency on imported oil; 2) Availability of local natural gas and existing pipeline infrastructure [17].

As the result of NGV's diffusion, the proportion of natural gas consumption for NGV's fuel had increased from 0.341% (2000) to 7% (2009), such a obvious domination appear to have directly and indirectly crowded out the fertilizer, power and household sectors which used to be relying a lot to natural gas. Therefore, the abnormally excess consumption of natural gas was allocated to transportation, leading to severe power disruptions and shortages of fertilizer, which is a significant input in the main agricultural sector [17].

During such a grim situation, government of Pakistan depressed the diffusion of NGV since 2011 to solve the problem of other sectors' shortage of natural gas. The predicament Pakistan met did certainly give a lesson to those countries who wish to promote NGV as an alternate fuel option. The propitious allocation of natural gas for transportation should be seriously discussed to avoid risk of running out of natural gas [17].

4. Regression analyses to explain diffusion of NGV

4.1 Description

Difference among nations regarding to the diffusion of NGV were purposed to be discussed based on results from regression analyses. The analyses contained various explanation parameters such as GDP per capita, atmosphere pollution emission, supply or consumption of energy, and energy price.

4.2 Nations with one explanation parameter

Iran: $Y = 1521.02X - 38157.62 + \varepsilon$

China: $Y = 263.93X + 17980.67 + \varepsilon$

Pakistan: $Y = 891.15X - 4175.54 + \varepsilon$

Argentina: $Y = 1162.11X - 308032.84 + \varepsilon$

India: $Y = 1870.34X - 97844.82 + \varepsilon$

Italy: $Y = 721.28X - 71793.97 + \varepsilon$

Thailand: $Y = 603.86X - 16987.81 + \varepsilon$

(Y: Yearly diffusion number of NGV; X: Yearly number of Gas Station)

4.3 Nations with two explanation parameters

Brazil: $Y = 952.60X1 - 6404.04X2 + 7236.02 + \varepsilon$

Bolivia: $Y = 975.97X1 - 2439.94X2 - 1805.74 + \varepsilon$

(Y: Yearly diffusion number of NGV; X1: Yearly number of Gas Station; X2: Yearly price of natural gas)

Ukraine: $Y = 1071.89X1 - 63.97X3 + 197139.61 + \varepsilon$

Japan: $Y = 0.0408X1 - 0.0015X3 + 2058.66 + \varepsilon$

(Y: Yearly diffusion number of NGV; X1: Yearly number of Gas Station; X3: Yearly consumption of Gasoline)

4.4 Nations with three explanation parameters

U.S.: $Y = 50.85X1 + 1.75X2 + 0.47X3 - 194709.22 + \varepsilon$

(Y: Yearly diffusion number of NGV

X1: Yearly number of Gas Station

X2: Yearly GDP per capita

X3: Yearly consumption of Gasoline)

5. Conclusion

In conclusion, scenario analyses were carried out to simulate three future diffusion scenarios of NGV based on Japanese experience of introducing NGV. Especially scenario 2 based on experience of DV's diffusion in Japan was particularly highlighted to discuss beneficial conditions for NGV's diffusion. Moreover naturally future diffusion for twelve countries was estimated to show the likelihood of NGV diffusing in large-scale.

Meanwhile throughout the analyses to the illustrative parameters among thirteen nations, diffusion of NGV at several nations was affected by the supply of gasoline or the price of natural gas. The most decided element that positively has correlation with NGV's diffusion is the number of natural gas stations.

Reference

[1] International Energy Agency. World Energy Outlook 2013. p. 45-47; p. 61-65

[2] Hella Engerer, Manfred Horn. Natural gas vehicles: An option for Europe. Energy Policy 38, 2010, p. 1019-1021

[3] The Japan Gas Association. About diffusion of natural gas vehicles, 2014 edition. p. 3; p. 10

[4] M. Matsumoto, S. Kondoh, J. Fujimoto, Y. Umeda, H. Tsuchiya, K. Masui, H-Y. Lee. A Diffusion Model for Clean Energy Vehicles. Journal of Japan Society of Energy and Resources, Vol. 29, No. 3, 2008, p. 49-55

[5] F. M. Bass. A new product growth model for consumer durables, Management Science 1969, 15-1, p. 215-227

[6] Ministry of the Environment, Japan. Strategy for Diffusion of Vehicles Friendly to Environment, 2010.3, p. 23, p. 97, p. 115

[7] Tokyo Gas Corporation. Frequently Asked Questions, Q9, A9
http://eee.tokyo-gas.co.jp/product/ngv/faq.html (access date 30th, Aug, 2015)

[8] ISUZU MOTOTS LIMITED. Diffusion of diesel vehicles in Japan
http://www.isuzu.co.jp/technology/d_databook/status/status_01.html (access date 30th, Aug, 2015)

[9] Ministry of the Environment, Japan. Strategy for Diffusion of Vehicles on Next Generation, 2009.5, p. 76, p. 97, p. 134, p147-148

[10] Ministry of Economy, Trade and Industry, Japan. New policy promotion about the joint fuel station both for NGV and FCV.
http://www.meti.go.jp/press/2014/04/20140421002/20140421002.html (access date 30th, Aug, 2015)

[11] Japan Oil Association. Data for movement of the number on gasoline stations in areas, Japan.
http://www.sekiyu.or.jp/topics/data_a.html (access date 30th, Aug, 2015)

[12] Sector Effects of the Shale Gas Revolution in the US. Alan Krupnick, Zhongmin Wang, and Yushuang Wang,
http://www.rff.org/RFF/Documents/RFF-DP-13-21.pdf (access date 30th, Aug, 2015), p. 3; p. 20

[13] CNG vehicle rise spurs filling station projects.
http://analysis.fc-gi.com/natural-gas-vehicles/cng-vehicle-rise-spurs-filling-station-projects (access date 30th, Aug, 2015)

[14] The contribution of natural gas vehicles to sustainable transport, OECD/IEA2010, p.57

[15] The period of Natural Gas Shift, Masaru Ihara, Yoshifumi Suehiro, B&T Books, Nikkan Industry Expressed, p50-57

[16] Area reports about diffusion of NGV in the U.S., Kimura Makoto.
http://www.jetro.go.jp/ext_images/jfile/report/07001452/us_natural_car.pdf (access date 30th, Aug, 2015)

[17] Running out of Gas? Lessons from the NGV market in Pakistan, Abrar Chaudhury, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=22391524 (access date 30th, Aug, 2015)