Quantifying the Effectiveness of Transportation Policy Measures for Reducing Energy Demand under Energy Emergency

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Abstract: The transportation sector is especially vulnerable to energy emergencies due to its extremely high reliance on petroleum and equally limited fuel substitution possibilities. This study quantitatively analyzes the effectiveness of transportation policy measures for reducing energy demand in the transportation sector using stated preference modeling and the multiple discrete choice modeling methodologies. Impacts of transport policies usually differ across countries or cities depending on socio-economic and infrastructure conditions. Focusing on Korea's environment, the following key results were discovered. Parking cost-related policies can be more effective than fuel cost-related policies. Enhancing the travel speed of public transit can be very effective in increasing the patronage of public transit. Carpool subsidies can also be effective tools for changing people's perception toward carpooling and increasing the level of participation. More elaborate carpool arrangements with acquaintances can also be effective.

Keywords: energy emergency, multiple discrete choice model, carpool, travel speed

1. INTRODUCTION

The transportation sector is especially vulnerable to energy emergencies due to its extremely high reliance on petroleum and equally limited fuel substitution possibilities. The purpose of this study is to quantitatively analyze the effectiveness of transportation policy measures for reducing energy demands in the transportation sector using a stated preference model and the multinomial discrete choice modeling methodology.

Various policy measures can be considered in response to energy emergencies. Rationing of fuel is a drastic measure under extreme conditions. Public transit-related policies could increase public transit patronage. Economic incentives such as subsidizing transit fares or reducing transit fares could also be employed. Other economic incentives intended to modify travelers' behavior are traditional measures for reducing fuel consumption in the transportation sector. In this analysis, fuel rationing and taxation, parking cost-related policies, public transit user subsidies and carpool-related policies are analyzed. In particular, the concept of carpooling is scarcely used as one of the transport policy measures to reduce transport energy demand in Korea since most Korean commuters are unlikely to share their own vehicles with strangers on their commute.

People's perceptions of the policy measures are surveyed and stated-preference (SP) analysis is applied. In general, revealed-preference analysis can be used for specifying models based on data with respect to real choice activities, e.g. to analyze the data related to the

people who currently own vehicles. Hensher (1994) demonstrated that analyzing stated preference data is useful to supplement the revealed preference models, and explained how to accommodate “dynamics (i.e. serial correlation and state dependence) in SP modelling” (p. 107).

Stated-preference analysis is usually employed by applying the survey results to the virtual situation, e.g. to analyze the traffic demand based on the price levels for a newly constructed light rail set in the near future. Leitham, et al. (2000) investigation showed industrial location preference can be remarkably diversified in terms of importance of road, links using a stated preference experiment, and explained the accommodating public transportation can be an important factor in some cases.

Furthermore, Ahern and Tapley (2008) investigated the inclination of passengers on municipal bus and rail, and examined the preferences on the two modes using both stated-preference and revealed preference surveys in Ireland. With respect to a practical assessment of stated preference methods, Ortúzar and Garrido (1994) tried to examine three kinds of stated preferences data collection methods (rankings, ratings, and choices). Concerning parking demand analysis, Hensher and King (2001) examined the objective of parking pricing by point of time and duration of day using the stated preference survey to car drivers and passengers of public transport at several parking lots, transit interchanges, and shopping centers in the Sydney central business district (CBD). The authors found that the factor of parking price in CBD is dominantly significant compared to supply by time of day.

With respect to the weakness of the stated preference method, Fujii and Gärling (2003) indicated that stated preference surveys can produce predictable results in the foreseeable future, which can be fortuitous depending on the circumstances of the survey. The authors illustrated the reason that attitudinal motives occasionally diverge from realistic observance using panel data collected from 903 commuters in Kyoto, Japan. By estimating demand elasticity with respect to policy variables, one can obtain information on the effectiveness of policy measures that can be used by policymakers.

2. SURVEYS AND METHODOLOGIES

2.1 Purpose of the Survey

In this study we conducted two types of surveys targeting 67 transportation experts for two weeks in October 2008. First, the authors conducted a preliminary response survey for residents with regard to energy emergencies that could have occurred in the near future as the authors wanted to estimate the change in drivers’ behavioral responses due to an increase of fuel prices. In conducting the survey, two scenarios were examined: increases in fuel price of 25 percent and 50 percent over the average price in August 2007, after which the price began to increase. Second, several SP surveys were conducted to examine drivers’ preferences with respect to alternative transportation modes under several hypothetical conditions of energy emergency policy measures. The defined conditions include several situations in which hypothetical transportation related prices and subsidies are implemented when a short-term and extreme energy emergency (e.g. fuel rationing) occurs.

2.2 SP Survey and Methodologies

In this survey SP modeling is performed to quantitatively analyze how drivers are willing to change their mode of transportation from automobiles to a more energy efficient and

environmentally sustainable mode such as carpool or transit. Multiple discrete choice modeling is employed to obtain quantitative estimates of policy measures' effectiveness.

The authors specified a model in which the utility of using cars, carpool, or public transportation is displayed by the utility function of each transportation mode. The utility functions with explanatory variables are written below along with the hypothetical policy measures described by the appropriate levels of the variables below.

$$U_{AU} = \alpha_{AU} + \beta_1 FAV + \beta_2 FP + \beta_3 PC$$
$$U_{TR} = \alpha_{TR} + \beta_4 TRS + \beta_5 TRT$$
$$U_{CP} = \beta_6 CPP + \beta_7 CPS \quad (1)$$

Where,

U_{AU} : Utility of Automobile
U_{TR} : Utility of Transit
U_{CP} : Utility of Carpool
α_{AU} : Alternative-Specific Constant of Automobile
α_{TR} : Alternative-Specific Constant of Transit

FAV : Easiness of Purchasing Fuels
2 *Levels* 0: No Rationing System
1: Rationing System

FP : Fuel Price
3 *Levels* 0: Current Price
1: Current Price + 700 won/*l* (Currently 1 USD = 1,175 Korean Won.)
2: Current Price + 1,400 won/*l*

PC : Parking Cost
3 *Levels* 0: Current Price
1: Current Price + 60,000 won/month
2: Current Price + 120,000 won/month

TRS : Transit Subsidy
3 *Levels* 0: No Subsidy
1: Support 50% of Transit Fare
2: Support 100% of Transit Fare

TRT : Transit Time
3 *Levels* 0: No Change
1: Decrease 25% of Transit Time
2: Decrease 50% of Transit Time

CPP : Carpool Partner
2 *Levels* 0: Stranger
1: Colleague

CPS : Carpool Subsidy
3 *Levels* 0: No Change
1: Free Parking + 20,000 won/month (subsidy)
2: Free Parking + 80,000 won/month (subsidy)

In cases such as this where the variables are too numerous and the levels of variables too widely varied in order to be able to identify trade-offs of modal choices, it is practically impossible to create a full factorial design which includes all the possible sets of SP

questionnaires. Therefore, a fractional factorial plan, which analyzes only the main, most important effects and guarantees the orthogonality of variables, is applied in this SP design.

3. SURVEY AND SP RESULTS

3.1 Base Analysis

Gender, age group, occupation, number of vehicles, and the purpose of vehicle usage of each respondent are explained in tables 1 through 6. About 73 percent of respondents were male and around 63 percent of respondents were 30 to 39 years old. The average number of vehicles per household was 1.45 with 45 percent of respondents owning two vehicles, and about 85 percent of respondents use their vehicles for commuting. The average monthly income of respondents was around US $3,600 with 68 percent earning more than $3,200 per month.

Table 1. Gender of the Respondents

Gender	%
Male	73.2
Female	26.8
Total	100

Table 2. Age Group of the Respondents

Ages	%
20 ~ 29	21.4
30 ~ 39	62.5
40 ~ 49	14.3
50 ~ 65	1.8
Total	100

Table 3. Occupation of the Respondents

Occupation	%
Employees	94.6
Self-employed	0.0
Unemployed	3.6
Other	1.8

Table 4. Number of Vehicles of the Respondents

Number of Vehicles	%
One	55.4
Two	44.6
Three or More	0.0
Total	100

Table 5. Purpose of Vehicle Usage of the Respondents

Purpose of Vehicle Usage	%
Commute	85.7
Home, Shopping	1.8
Leisure	10.7
Business	1.8
Other	0.0
Total	100

Table 6. Average Monthly Income of the Respondents

Average Monthly Income (USD)	%
Less than $800	0.0
$800~1,600	8.9
$1,601~2,400	14.3
$2,401~3,200	8.9
$3,201~4,000	30.4
$4,001~$4,800	14.3
More than $4,800	23.2

- Note: Dual-income, income from interest, and income from leasing are included.

3.2 Analysis of Trips

With respect to trips of the respondents, several trip-related items are surveyed: major mode of transportation for commuting, proportions of transportation modes for going to work, commuting times and costs, reasons for preferring their personal vehicles, and so on. For the major mode of transportation for commuting, about 68 percent of respondents prefer using their own private vehicles, about 29 percent opt for public transit, and only about 3 percent choose carpools.

Regarding commuting time, it takes about 33 minutes by automobile and about 65 minutes by public transit on average, so that commuting by public transit takes about twice as long. The average commuting cost shows that it costs on average about 175,000 won per month using a car and 76,000 won per month using public transit. It implies that 2.3 times the commuting cost is required if people use a personal vehicle over public transit.

Table 7. Proportions of Commuting Modes of Transportation

(Unit: %)

Working Days per Week	Personal Vehicle	Public Transit	Carpool
One Day	4.2	6.9	1.4
Two Days	5.6	5.6	0.0
Three Days	6.9	4.2	0.0
Four Days	5.6	4.2	0.0
Five Days	45.8	8.3	1.4
Total	68.1	29.2	2.8

- Note: The accuracy of carpool proportions can be lower since the survey conducted was on a small-scale.

Table 8. Commuting Time and Cost

Mode	Average Commuting Time	Average Commuting

	(Minutes)	Cost (USD[2])
Personal Vehicle (only[1])	33.3	159.3
Public Transit (only)	65.2	69.1
Carpool (only)	32.5	67.7

- Notes: 1. "Only" is applied to average commuting cost.
2. The costs are converted from Korean Won to USD based on "1 USD = 1,100 Korean Won".

With respect to reasons for preferring personally owned vehicles based on the respondents who use only their private car, about 38 percent of respondents answered that they use private passenger cars to save commuting time compared to using public transit, about 18 percent answered that they need a car for work or business uses, about 17 percent prefer cars for comfort reasons, and 12 percent answered that they dislike the discomfort of public transit.

Table 9. Reasons of Preferring Private Vehicles

Reasons	%
Short Commute Time	37.8
Business Applications	17.8
Discomfort of Public Transit Use and Transfers	12.2
Comfort of Cars	16.7
Late to Work	14.4
Other	1.1

In regard to reasons of preferring public transit based on the respondents who only use public transit, about 36 percent cite reducing traveling costs compared to privately owned vehicles, about 15 percent answered their employer set automobile usage restrictions, and about 13 percent prefer transit for personal activities after work.

In carpooling, although only a small number of respondents replied, which could result in reduced accuracy and increased bias, the reasons for preferring carpools comprise of saving travel cost and energy. Reasons for avoiding carpools consist of problems with keeping carpool appointments, utilization of personal time, and carpooling with strangers, among others.

Table 10. Reasons for Preferring Public Transit

Reasons	%
Shortage of Parking Spaces at Work	6.4
High Parking Cost at Work	6.4
Restrictions of Using Automobiles at Work	14.9
Reducing Traveling Cost of Automobiles	36.2
Precise Travel Time	8.5
Reducing Travel Time	0.0
Frequent Gatherings after Work	12.8
Other	14.9

Table 11. Reasons for Avoiding Carpooling

Reasons	%
Carpooling with Strangers	20.0
Problem with Keeping Carpool Schedule	40.0
Utilization of Personal Time	24.0
Burden of Co-obligation towards Fuel Costs	12.0
Increase of Traveling Distance and Time	0.0
Other	4.0

3.3 Response Survey of Transportation Policy

More than 60 percent of respondents believed that the current oil price is high. Regarding the future levels of oil prices, similar proportions of respondents estimated that the oil price will increase or decrease in the future.

With respect to the major implementable policies for transportation, about 41 percent of respondents chose improving the convenience of public transit services and about 30 percent chose supporting public transit users (respondents were allowed to choose up to two policies). Further, concerning the possibility of benchmarking policies from foreign countries, about 63 percent of respondents agreed with the public transit subsidy policy currently employed in Japan which usually provides employees with monthly subway tickets between work and residence.

3.4 Attitude Survey of Oil Price Changes

In August 2007 the domestic gasoline price went up to US $1.60 per liter when the international crude oil price exceeded $140 per barrel. The authors investigated the changes of respondents' travel behavior with gasoline prices at $1.60, $2.00, and $2.40 per liter. On the one hand, the results indicated that about 37.5 percent of respondents answered that there was some change of travel behavior and 32 percent of the respondents said that unnecessary and long distance trips were reduced with the gasoline price at $1.60 per liter.

On the other hand, 77 percent and 88 percent of respondents replied that their travel behavior would change if the gasoline price was at $2.00 or $2.40, respectively. The number of public transit uses per week also increased from 2.5 percent at $1.60 to 4.0 and 4.4 percent at $2.00 and $2.40, respectively. Further, 6 to 15 percent of the respondents would choose to sell their automobiles with fuel prices at $2.00 or $2.40 per liter and 21 to 26 percent of the respondents would consider exchanging their vehicles for higher fuel efficiency vehicles. Meanwhile, the estimated proportion of participation in carpooling increased from 2.1 percent at $1.60 per liter to 19 percent at $2.40 per liter.

3.5 SP Analysis Results

The main purpose of the SP analysis is to quantitatively estimate the effectiveness of policy measures related to travel demand management (e.g. changes of fuel price, parking price, and subsidies for transit users and carpool users), so that energy consumption reduction policies can be efficiently promoted based on the SP results.

3.6 Estimation of Coefficients of the Utility Function

The coefficients of the utility function were estimated based on the results of a multiple

discrete choice analysis from the SP survey as shown in Table 12. The dummy variables α_{AU} (related to private automobile use) and α_{TR} (related to public transit use) represent intrinsic value associated with the modes (the value of α_{AU} is greater than that of α_{TR} indicating higher intrinsic value for private automobiles). It implies that the preferences for private automobiles and public transit are higher than that of carpools, or internal superiority of private automobiles and public transit is expressed. It can also be interpreted that carpools are not yet popular in Korea due to the low intrinsic value attached to carpooling. As described in the results, all coefficients of the independent variables including dummy variables are statistically significant at the 95% level. Furthermore, all signs of the coefficients correspond with the predictions derived from the economic theories.

Table 12. Coefficient Estimates of the Utility Function by Mode

Coefficients	Estimates	t-Value	P[|Z|>z]
α_{AU} (D1)	3.48957364	10.031	.0000
α_{TR} (D2)	3.08336867	9.528	.0000
β_1 (FAV)	-.64900908	-2.619	.0088
β_2 (FP)	-.314677D-05	-4.386	.0000
β_3 (PC)	-.844792D-05	-5.477	.0000
β_4 (TRS)	-.967872D-05	-3.475	.0005
β_5 (TRT)	-.00907594	-2.674	.0075
β_6 (CPP)	.96356976	3.451	.0006
β_7 (CPS)	.122099D-04	3.116	.0018

With respect to the coefficients related to private automobile use, the abstract value of β_3 (parking cost) is greater than that of β_2 (fuel price), which implies that the effectiveness of increasing parking costs can be greater than that of raising fuel prices. The abstract estimate of public transit subsidy, β_4, is greater than those of β_2 and β_3, which indicates that a public transit subsidy policy can also be quantitatively effective. Considering the sign and magnitude of β_6, potential carpool users can be positively changed into being favorable to carpooling if the carpool partners are people who already know each other. Furthermore, since the estimate of β_6 (carpool subsidy) is also estimated as a relatively big value, it implies that the carpool policy can be revitalized if the carpool partners know each other and a certain amount of subsidy is provided for carpool users.

In order to analyze the policy measures' effectiveness more clearly, the authors estimated the elasticities with respect to various policy measures considered in the SP analysis. Using the estimated coefficients of the models, elasticities with respect to the policy variables were estimated through a sample enumeration method. The elasticity is defined as:

$$\eta_{jk}(i) = \delta \log Prob(Y_t = i) / \delta \log X_{tm}(k) = X_{jt}(k) / P_i \times \delta_{jj}(k) \quad (2)$$

Sample enumeration is the method in which the demand change for automobile use is calculated before and after a price change, using an individual's choice probability between a car and the alternative modes obtained from estimated models and an individual's data.

The estimated elasticities are shown in tables below. In this model, the cross elasticities

were estimated as identical according to the independence of irrelevant alternative assumption in the multinomial logit models.

In the analysis the elasticity with respect to parking cost is estimated to be higher than that of fuel cost, implying greater effectiveness of parking-related policies. However the magnitude difference is not as substantial as the coefficient difference. This is due to the relatively low level of parking cost compared with fuel cost in Korea.

In order to increase public transit patronage, enhancing the travel speed of public transit can be very effective according to the elasticity analysis. In order to increase carpooling in Korea, it is estimated that carpool subsidies could be effective tools for changing people's perception toward carpooling.

Table 13. Elasticities with Respect to Fuel Cost

Modes	Average Elasticity	Standard Dev.
Choice=CAR	-.5618	.4793
Choice=TR	.2405	.1651
Choice=CP	.2405	.1651

Table 14. Elasticities with Respect to Parking Cost

Modes	Average Elasticity	Standard Dev.
Choice=CAR	-.5733	.6720
Choice=TR	.1628	.1362
Choice=CP	.1628	.1362

Table 15. Elasticities with Respect to Public Transit Subsidy

Modes	Average Elasticity	Standard Dev.
Choice=CAR	-.1432	.1422
Choice=TR	.2144	.3004
Choice=CP	-.1432	.1422

Table 16. Elasticities with Respect to Public Transit Travel Time

Modes	Average Elasticity	Standard Dev.
Choice=CAR	.2134	.1446
Choice=TR	-.2269	.2041
Choice=CP	.2134	.1446

Table 17. Elasticities with Respect to Carpool Subsidy

Modes	Average Elasticity	Standard Dev.
Choice=CAR	-.0723	.1026
Choice=TR	-.0723	.1026
Choice=CP	.3304	.3368

4. SUMMARY AND CONCLUSIONS

This paper surveys people's general perceptions on automobile use and carpooling. It also quantitatively analyzes the effectiveness of various policy measures aimed at reducing

automobile energy demand in energy emergencies using SP methodology. Elasticities were estimated in order to quantify the effectiveness of the policy measures.

It is found that parking cost-related policies can be more effective than fuel cost-related policies. In order to increase public transit patronage, enhancing the travel speed of public transit can be very effective. To increase carpooling in Korea, carpool subsidies can be effective for changing people's perception toward carpooling. Further, more elaborate carpool arrangements with acquaintances can also be effective.

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