Additional Cost for Achieving the Minimum Energy Consumption in Kumamoto Region

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1. INTRODUCTION

With increased standard of living, the world is shifting toward faster modes, which also are more energy intensive[1]. The rapid progress of civilization induces high standard of living, but meanwhile brings energy related problems. Nowadays, governments worldwide set up goal to reduce energy consumption. But it may not be welcomed by residents as the possibility of decreasing their utility levels. As individual desire strongly influences the feasibility and success of policy, it is very important to consider it when makes policy. How to estimate and achieve the minimum energy consumption on present utility level will no doubt be more suggestive in city planning. This paper first proposes a method to estimate the minimum individual energy consumption on the present utility from a microeconomic viewpoint. Then it discusses some essential conditions for achieving the minimum energy consumption, such as additional cost in this paper. We show the whole method and analysis by a case study in Kumamoto metropolitan region.

2. METHODOLOGY

(1) Minimum energy consumption

As impulse of all civil activities in the city are assumed to satisfy the demands of residents. In microeconomics, the need of people is represented by the demand of goods and service, which can be explained by personal consumption behaviors. Income is an important economic factor, which not only constraints the demand but also influences consumption behaviors. At the theoretical level, we can examine the individual energy consumption from demands of goods. People are assumed to make decisions based on their preferences over different goods, the cost of these goods, and the budget constraints (income) to maximize the utility. The energy consumption can be estimated based on the demand of goods on maximum utility.

Considering the influence of transport sector on energy consumption, we classified all goods into two types: mobility goods and composite goods. Mobility goods include car trips and mass transit trips. Composite goods are all other goods except for mobility goods. We would like to explore the minimum individual energy consumption on the maximum utility u_i^* (Eq. (1)). E is sum of individual energy consumption E_i of each zone i. e_1, e_2, e_3 are the energy consumptions unit of composite goods, car trip and mass transit trip, which is indicated by the value of energy needed for per goods. Considering the relationship between energy consumption and traffic congestion, we introduce the average trip time of the car trip and mass transit trip t_{2Ci}, t_{2Mi} into the estimation function, which are dynamic functions of trips.

$$\min_{\{x_{1i},x_{2Ci},x_{2Mi}\}} \quad E=\sum_i E_i=\sum_i \left(e_1x_{1i}+e_2t_{2Ci}(x_{2Ci},x_{2Mi})x_{2Ci}+e_3t_{2Mi}(x_{2Ci},x_{2Mi})x_{2Mi}\right) \qquad s.t.\quad u_i(x_{1i},x_{2Ci},x_{2Mi})=u_i^*,\forall i \tag{1}$$

We assume that people would like to maximize both utility and mobility. The consumption behaviors are expressed by the demand of goods on the maximum utility, which is calculated by solving two maximization problems[2]. Posed as Eq. (2), the maximum mobility is determined by car trips and mass transit trips subject to transportation budget. The maximum utility is determined by consumption of composite goods and maximum mobility under the income constraint, posed as Eq. (3). p_{1i}, p_{2i}, p_{2Ci}, p_{2Mi} are the price of composite goods, mobility goods, car trips and mass transit trips in zone i, respectively. I_i is the individual income and I_{2i} is the individual transportation budget, each in zone i.

$$\max_{x_{1i},x_{2i}}: u_i=\left\{\alpha_1x_{1i}^{(\sigma_1-1)/\sigma_1}+\alpha_2x_{2i}^{(\sigma_1-1)/\sigma_1}\right\}^{\sigma_1/(\sigma_1-1)} \qquad s.t.\quad p_{1i}x_{1i}+p_{2i}x_{2i}\le I_i \tag{2}$$

$$\max_{x_{2Ci},x_{2Mi}}: x_{2i}=\left\{\alpha_{2C}x_{2Ci}^{(\sigma_2-1)/\sigma_2}+\alpha_{2M}x_{2Mi}^{(\sigma_2-1)/\sigma_2}\right\}^{\sigma_2/(\sigma_2-1)} \qquad s.t.\quad p_{2Ci}x_{2Ci}+p_{2Mi}x_{2Mi}\le I_{2i} \tag{3}$$

(2) Additional cost

If utility is continuous and no commodities are free of charge, then there is always a unique maximizer, then it is called the Marshallian demand function. Given a consumer's utility function, prices, and a utility target, what could the consumer buy to meet this utility target while minimizing expenditure? This is answered by the Hicksian demand function. The Hicksian demand of each goods at the maximum utility is the same as the Marshallian demand at the minimum expenditure. The unique solution shows minimum expenditure and maximum utility.

Figure 1 illustrates the unique solution of the maximum utility u_i^* for the income I_i. The demand of composite goods and mobility goods are shown as x_{1i}^*, x_{2i}^* , that are solutions at point A. If the price is not changed, x_{1i}^*, x_{2i}^* are the solutions not only of the maximum utility for limited income I_i, but also of the minimum expenditure that needed to achieve this utility level. It means that more money is needed to achieve the utility level on all other points on this indifference utility curve except point A. However, the solutions of minimizing energy consumption moves to point B with the changed prices (**Figure 2**). Here, the demand of goods are x_{1i}^{**}, x_{2i}^{**}, which are different from the maximum utility solutions x_{1i}^*, x_{2i}^*. The utility level at point A and B is same as they are on the same indifference utility curve. But it needs more money to realize the utility at point B. The expenditure at point B is shown as needed income I_i^*. The value of I_i^* is larger than the I_i. Additional cost is needed.

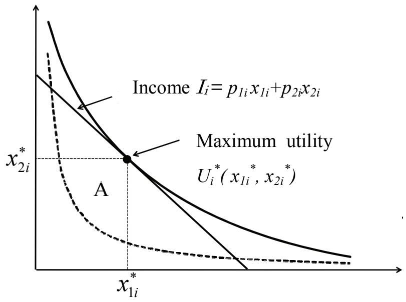


Figure 1 Max. utility and min. expenditure problem

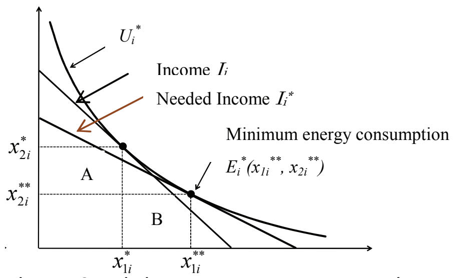


Figure 2 Minimum energy consumption problem

The Additional cost $\triangle I_i$ is used to analyze the difference between income I_i and needed income I_i^* for the minimum energy consumption. The needed additional cost for each person in zone i is calculated by following Eq. (4). p_{2i}^{**} and p_{2i}^* are the price of mobility goods in minimum energy case and maximum utility case, respectively.

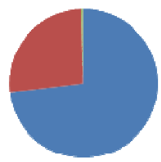
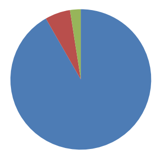
$$\nabla I_i = I_i^* - I_i = (x_{1i}^{**} + p_{2i}^{**}x_{2i}^{**}) - (x_{1i}^* + p_{2i}^* x_{2i}^*) \quad (4)$$

3. APPLICATION

We chose Kumamoto metropolitan regions for our case study. The Kumamoto metropolitan area is located in Kumamoto Prefecture on the island of Kyushu, southern Japan. Two cities (Kumamoto and Uto), fourteen towns, and one village are included. The region is divided into 177 traffic zones. The whole region covers roughly 1077 km^2 of land and has a population of 1,460,000 (Municipality Kumamoto Prefecture, 2000 Census).

We estimated the actual and minimum individual energy consumption and analyzed the needed additional cost per person to achieve the minimum energy consumption in each zone. Presented in **Table 1**, more than ten percent of energy consumption can be reduced from estimated actual to the estimated minimum by decreasing the energy consumption for car trips but increasing the composite goods consumption and mass transit trips. To reach to goal of minimum energy consumption, averaged 401 yen is needed per person in Kumamoto metropolitan region. If we would like to reduce the energy consumption of 5388 kcal to achieve the minimum energy consumption per person per day, averaged 401 yen of subsidy is needed.

Table 1 Estimation results of in the Kumamoto region

	Estimated actual	Estimated minimum
Energy share	Car trips 26.48%; Mass transit trips 0.41%  Composite goods 73.12%	Car trips 5.79%; Mass transit trips 2.47%  Composite goods 91.74%
Total energy consumption (kcal/person·day)	3.72×10^4	3.19×10^4 (-14.2%)
Additional cost (yen/person)	401	

Note: ( ) indicates the reduced percent from estimated actual to estimated minimum

4. CONCLUSION

The paper discussed how to estimate and achieve the minimum energy consumption on present utility level from the viewpoint of microeconomics. The most creative point of this study is showing a method for estimating minimum individual energy consumption without decreasing the personal utility level. It proved that consumption pattern with decreased car trips but increased mass transit trips and composite consumption contributes to less energy consumption. Moreover, averaged 401 yen of subsidy is needed to reduce 5388 kcal for one person in one day in the Kumamoto metropolitan region.

REFERENCE

1) Salvatore, D.: Globalization, growth and poverty. Journal of Policy Modeling 26 (4), 543–551, 2004.

2) Yanhong Yin, Shoshi Mizokami: Evaluating compactness of cities by energy consumption efficiency, Journal of the Eastern Asia Society for Transportation Studies, 9, 713-723, 2011.