International
Input
Output
Meeting on
Managing the
Environment

Input - Output & Environment

SEVILLE (SPAIN)
July 9 - 11, 2008
http://www.upo.es/econ/IIOMME08

Environmental Impacts of Alternative Consumption Patterns with Their Related Income and Price Changes

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Abstract

A new analytical model for evaluating the environmental loads induced by consumption will be introduced. The model is developed by integrating existing ones: the waste input-output (WIO) model and one of the economics models describing consumer's behaviour. The WIO model [1], [2] is one of the hybrid LCA tools, by which the environmental loads due to consumption can be evaluated for each product in the manner similar to the conventional input-output model. In addition, these environmental loads are related to the upstream of the 3 stages of consumption (purchase, use, and disposal). In the consumer model, meanwhile, given prices, income, and time, consumers are assumed to choose their operation levels of consumption "technologies" which maximize their utility. A notable feature of our consumers' model is similar to the household production model proposed by prominent economists, Lancaster, Muth, and Becker, in 1960's. A consumption "technology" is expressed as a set of products and time necessary to achieve some purpose, such as eating, spending leisure time and transportation. By connecting these models, we can evaluate environmental loads induced by products required for each consumption "technology." In addition, price changes of consumed products and income changes are incorporated into our model. Thus this model explains a part of the so-called "economy-wide rebound effects," as well as both time and income rebound effects. Several scenario analyses will be presented, where environmental impacts of alternative consumption “technologies” are compared.

Keywords: sustainable consumption, household production, waste, time use, rebound effect.

1. Introduction

It is broadly recognized that the rebound effects must be properly considered in the comparison between consumption patterns. Although the term “rebound effect” has broad meanings, the basic ideas are summaries as follows. When consumers change their consumption patterns for a more environmentally friendly one, income and time that are required also change. These changes possibly cause increases in environmental loads in the end because of additional consumption by saved income and time. These effects are included in the direct rebound effect which is routinely included in the assessment of consumption (Hertwich [3]). In the sustainable consumption literature, the income rebound effects have been analyzed in many researches (Takase, Kondo and Washizu [4] among others); on the other hand, the time rebound effects have been rarely examined at least in empirical studies. The notable exception is Jalas [5], [6] in which the time rebound effects are considered, while the income rebound effects are not discussed. To consider the rebound effects with respect to both income and time, we introduce a new model.

As is pointed out by Hertwich [3], there are other indirect rebound effects. For example, change of the amount of consumption of each product also affects the relation between supply and demand of these products, and then, price changes of the products will occur in general. These price changes possibly affect the households’ consumption patterns even if their income and time remains unchanged. As a result, the economy-wide rebound effects due to price changes might happen in the whole economy. The question which consumption pattern is more environmentally sound might be undetermined beforehand.

By integrating a consumer model and the cost and price counterpart of the hybrid LCA tool termed the waste input-output model (Nakamura and Kondo [1], [2]), we will propose an analytical model of environmental loads induced by households, which deals with the income rebound effects, the time rebound effects, and a part of the economy-wide rebound effects.

2. The Rebound Effects

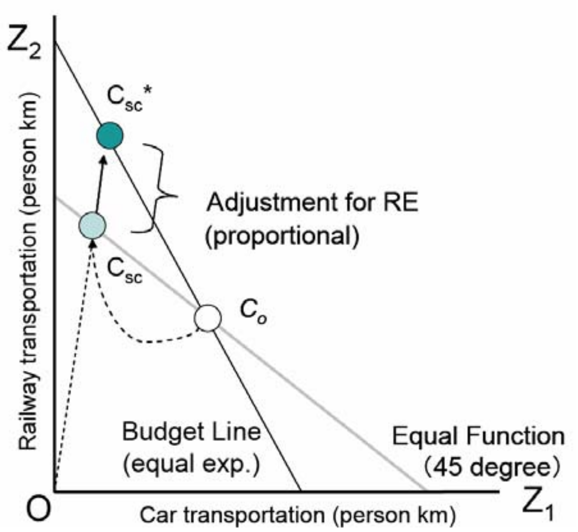

Fig. 1 The income rebound effect and the consumption

Before we introduce our model, let us briefly review the issues of the rebound effects graphically. Fig. 1 illustrates how the rebound in terms of income happens. Suppose Z_1 and Z_2 are alternative technologies. In other word, the same activity can be attained by these technologies. The horizontal axis in Fig. 1 measures the level of Z_1 while the vertical axis measures the level of Z_2. Suppose further that the 45 degree line describes the combination of Z_1 and Z_2 in which they bring consumer the equal function. For instance, Z_1 is transportation by passenger car, while Z_2 is transportation by train. In this case, the function is such as 10 person-km transportation. The budget line depicts the combination of Z_1 and Z_2, all the point on which the total expenditure on them is the same. The combination of these technologies is at the point C_o initially, for instance. If consumers believe that Z_2 induces less environmental loads than Z_1, then, they incline to shift their consumption pattern from Z_1 to Z_2. The point C_{sc} is the new combination, where the subscript sc stands for (alleged) sustainable consumption. Because the point C_{sc} is inside the budget line, the saved expenditure can be spent on other activities that might cause more environmental loads. Thus, the comparison between environmental loads evaluated at C_o and C_{sc} is not enough to conclude that one induce less environmental loads than the other. This belief was the basic motivation of our previous research (Takase, Kondo and Washizu [4]) where we compared the environmental loads evaluated at Co and C_{sc}^*. The remaining budget is allocated proportionally to all products in the new consumption pattern C_{sc}^*, that is the total amount of money spent is the same on the points C_o and C_{sc}^*. The straight arrow in Fig. 1 represents the proportional adjustment of the income rebound effects.

The same kind of adjustment can be possible for the time rebound effect in principle (Jalas [5]). However, if we include time-use aspects of the consumption patterns in addition to the monetary aspect, the issues of the rebound effect become more complicated. In some scenarios, the question which technology is more environmentally friendly might be undetermined beforehand because it is practically impossible to adjust total expenditure and total time at the same time. For example, car transportation cost more than train transportation in general, while the train travel needs more time than the car travel. Therefore, either of money and time will remain without being used up by this kind of adjustment. For this reason, we will employ a new model to evaluate the environmental impacts of several consumption patterns in the following sections.

In addition to the income and time rebound effect which are categorized into the direct rebound effects, our model will consider a part of the indirect rebound effects caused by price changes of consumed products through the waste input-output model.

3. The Model

The model of this paper has two components; (1) the economics model describing consumer behaviour, and (2) the waste input-output (WIO) model.

3.1 Consumer Model

For including the time-use aspect of consumption into our analysis, we introduce the consumer model a notable feature of which is similar to the idea proposed by K. J. Lancaster, R. F. Muth, and G. S. Becker in 1960s. In our model, consumers are supposed to carry out their activities through several consumption "technologies." A consumption "technology" is expressed as a set of products and time necessary to achieve some purpose. Fig 2 illustrates the relation between activities and consumption "technologies." For example, consumers "produce" their activity of passenger

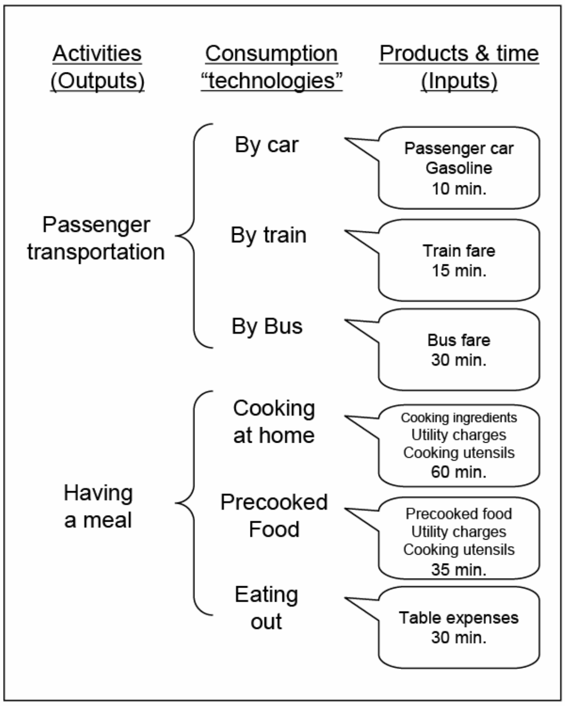

Fig. 2 The consumer model (activities, consumption "technologies" and inputs)

transportation by several consumption "technologies," such as by car, by train or by bus. Likewise, the activity of having a meal can be done by various consumption "technologies," such as by cooking and eating at home, by eating precooked food at home or by eating at restaurants. Because products and time required for each consumption "technology" differ, a consumption "technology" is expressed as a combination of inputs (products and time).

For example, car transportation employs a passenger car, a certain amount of gasoline and 10 minutes as inputs, while transportation by train requires the train fare and 15 minutes, and travelling the same route by bus needs bus fare and 30 minutes. Similarly, cooking at home can be attained by cooking ingredients, utility charges, cooking utensils and 60 minutes, for instance, while eating at restaurants needs table expenses and 30 minutes. In our model, consumers are assumed to choose their optimal allocation of time as well as budget to each consumption "technology" to maximize their utility (the economics terminology for "satisfaction"). Our consumer model describes how products and time are consumed for each activity through consumption "technologies."

Suppose there are m consumption "technologies." The operation level of each consumption "technology" is expressed as a scalar z_j (j=1,...,m); and the vector z (m-by-1) is the operation level of the all consumption "technologies." The i-th products and time needed for all consumption "technology" is expressed by

$$x_i = b_{i1}z_1 + b_{i2}z_2 + \cdots + b_{im}z_m \quad (i=1,2,...,n), \qquad (1)$$

$$t = b_{T1}z_1 + b_{T2}z_2 + \cdots + b_{Tm}z_m \,, \qquad (2)$$

where the scalar b_{ij} is the i-th products and b_{Tj} is the time required for one unit of the j-th consumption "technology." The parameters b's are constant coefficients of consumption "technologies" that are similar to the input coefficients of the production technologies. The products and time required for all consumption is given by

$$\begin{bmatrix} x \\ t \end{bmatrix} = Bz \qquad (3)$$

where B is the (n+1)-by-m matrix of b_{ij}'s and b_{Tj}'s. The coefficients in the matrix B are estimated based on the governmental surveys on household expenditure and time-use in Japan. In addition, some technical information on transportation is used in estimating the initial values of the variables.

Consumers are assumed to maximize their utility subject to the time constraint in addition to the budget constraint. Therefore this consumer model describes how time and budget are allocated among consumption "technologies." Mathematically, the consumers model is expressed by the optimization problem as follows,

$$\begin{aligned} &\text{Maximize } \; u=u(z_1,z_2,\ldots,z_m) \\ &\text{subject to } \; \begin{bmatrix} x \\ t \end{bmatrix} = Bz,\, p'x = M, t = T, z \geq 0_m \end{aligned} \qquad (4)$$

where u is the utility function defined over consumption "technologies," M is total budget, and T is the given total time (24 hours for one day). The first restriction describes the correspondence between consumption "technologies," products and time. The second and the third restrictions are the budget constraint and the time constraint, respectively.

Scenarios on consumption are given by the additional restriction functions. If we set the ratio of the i-th and the j-th consumption "technologies" to be 1:r, for example, the restriction $rz_i= z_j$ is added at the utility maximization. The solutions of the optimization problems will give us the "optimal" operation levels of consumption "technologies." Both budget and time are used up at the solutions. Moreover, the solutions satisfy the all scenarios, simultaneously. In other words, the solutions, z_1^*, z_2^*, ..., z_m^*, satisfy

$$\begin{bmatrix} x^* \\ T \end{bmatrix} = Bz^*, p'x^* = M, rz_i^* = z_j^*. \qquad (5)$$

Therefore, the adjustments of the rebound effects described in the previous section will not required in this model.

As the utility function, we employ linear expenditure system, which is one of the most fundamental functions in economics model,

$$u = \alpha_1 \ln(z_1 - \gamma_1) + \alpha_2 \ln(z_2 - \gamma_2) + \cdots + \alpha_m \ln(z_m - \gamma_m) \quad .(6)$$

The parameter γ_i can be interpreted as a minimum requirement of the *i*-th consumption “technology” in the linear expenditure system.

With this consumer model, given prices, income, and time, the consumers choose the operation levels of consumption “technologies” which maximize their utility. In addition, environmental loads related to the upstream of the three stages of consumption (purchase, use, disposal) are evaluated by the waste input-output model as in the LCA.

3.2 The WIO model

The WIO model developed by Nakamura and Kondo [1] is an extension of the conventional input-output (IO) model. The WIO model is one of the hybrid LCA tool specially designed for considering waste disposal and management. By the WIO model, we can easily evaluate direct and indirect (induced) environmental impacts of consumers’ behaviour in the similar manner to the conventional IO model. In addition to the desirable features of the IO model, the WIO model takes into account the interdependence between the flow of products and waste. Consequently, we can also evaluate the environmental emissions induced by the treatments of waste discharged by consumers as well as waste from goods- and service-producing sectors. The WIO model deals with environmental impacts directly and indirectly induced by three stages of consumer behaviour (such as purchase, use and disposal) for each product (Takase, Kondo and Washizu [4]). The WIO model describes the correspondence of consumed products to environmental loads through the life cycle of the products.

The WIO price model is the cost and price counterpart of the WIO quantity model. In the WIO price model, price of a given product includes the following:

(a) the cost for the intermediate input of products,

(b) the cost for the waste treatment,

(c) the cost for the input of waste materials,

(d) the revenue from the sale of waste materials, and

(e) the cost for the input of primary factors.

The price depends upon the results of the WIO quantity model. Unlike the price counterpart of the conventional IO model, the WIO price model is not dual to the quantity model because of the presence of waste as joint products and the recycling of waste materials whose price can be negative. See Nakamura and Kondo [2] for the full description and the detailed discussions about the WIO price model.

In addition, to incorporate the income changes, we regard the consumer as if it were an industrial sector (or an intermediate sector) in our model. The household sector inputs products, and its output is labour or work time. In the conventional IO analysis, this is known as the endogenization of household (Miyazawa [7]). So the income changes affect the consumers' demand of products.

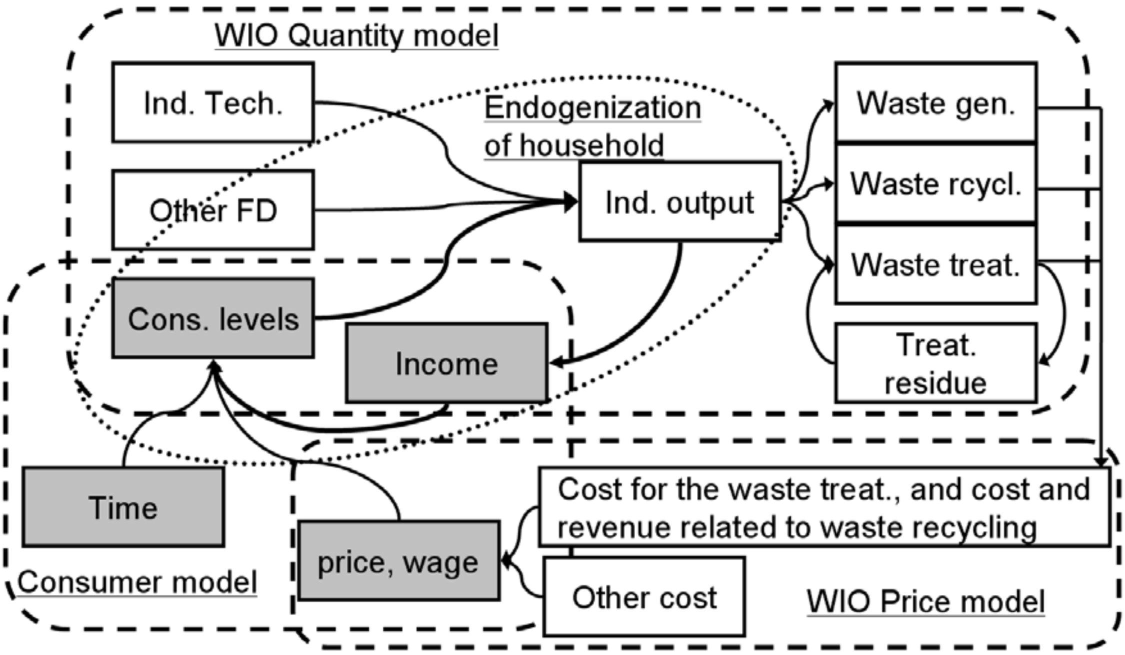

Fig. 3 Feedback to consumption through price & income change

Fig. 3 illustrates the interdependence between the consumer model, the WIO quantity model, the WIO price model, and endogenization of household. By the consumer model introduced in the previous section, income and time rebound effects are considered in our integrated model. In addition, the economy-wide rebound effects that relate to the price changes are also taken into account through the interdependence between the consumer model and the WIO model.

4. Concluding Remark

This paper has provided a new framework to evaluate consumption patterns in terms of environmental impacts. It has been also shown that the income and time rebound effects are incorporated into our model. The model also considers the economy-wide rebound effect by the joint use of the WIO quantity model, the WIO price model and the endogenization of household. Several scenario analyses will be presented, where environmental impacts of alternative consumption "technologies" are compared.

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