A BASIC DEFINITION OF TRANSPORT BENEFITS - ADVOCATING EQUIVALENT VARIATION -

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1. INTRODUCTION AND SUMMARY

When we apply cost benefit analysis to a transport project for evaluation, we need a rigorous and consistent definition for "benefit" and "cost." In many introductory textbooks on transport evaluation, however, it is merely stated only that benefits and costs should be measured by the "willingness to pay (WTP)"; yet there is no definition of WTP, or even if there is, it only refers to the usual consumers' surplus. With notably few exceptions such as Heggie (1972), Bruzelius (1979) and Glaister (1981), then in general, there is no statement on any retationships between WTP and individuals' utility level. Due to this conceptual discontinuity, very little of the current transport evaluation literature has referred to a way of to applying the cost benefit analysis to environmental deterioration and uncertainty. Thus it is manifestly evident that there is still no established concept on the definition of cost and benefit in the field of transport evaluation.

The modern axiomatic theory of cost benefit analysis, such as Currie, Murphy and Schmitz (1971), Mishan (1975), Sugden and Williams (1978) and Gramlich (1981), on the other hand, says that all the losses and gains derived from a transport project should be evaluated by either "compensating variation (CV)" or "equivalent variation (EV)". The former is defined as the amount of money which the affected individual needs to be compensated (or be willing to pay) in order to sustain his before-change utility level following the after-change situation. The latter is defined as the amount of money which he needs to be compensated (or willing to pay) in order to maintain the status quo under the condition of sustaining his after-change utility level.

Thus it can be seen in this field that efforts are being made to refine more strictly the definition of cost and benefit and make more clear the relationship between WTP and utility level.

The question on which CV or EV is more appropriate for measuring the gains and losses is, however, still yet to be answered for the cost benefit analysis of transport projects. This paper approaches this question by examining the welfare implications of both CV and EV and advocates the superiority of EV over CV. This conclusion will be derived from a number of viewpoints described below.

First, since all the impacts of a transport project have incidences to the changes in utility levels of the affected people, it is important to establish a method to measure the individual utility function. On this aspect it can be said that EV is superior to CV because EV can be viewed as an individual utility function itself, for which the same cannot be said for CV per se.

Second, when we confine ourselves to test an economic efficiency of a project, we have to define the concept of economic efficiency. This test is called the compensation test or the potential Pareto test, which says that for any social change, it should be accepted if the gainers could more than compensate losers [Kaldor (1938)]. From this viewpoint of economic efficiency, the positivity of the aggregated EV (denoted ΣEV) which can be derived by simply adding up the EV of affected individuals, is a sufficient condition for passing the compensation test whenever the latter is meaningful, i.e., free of a logical cycle [Morisugi (1983a)]. In this sense ΣEV criterion has consistency between cost benefit analysis and the economic efficiency test, which does not hold for ΣCV criterion.

Third, we may notice that the efficiency test mentioned above has a severe demerit as a social choice test. For it does not take into consideration the equity problem because the compensation in it is not actually carried out but only its possibility is investigated. Even if a project satisfies the compensation test, consequently, the after-change situation does not guarantee the improved income (or welfare) distribution. This undesirable characteristic of efficiency test leads us to consider some of the other types of social welfare functions which can be expressed generally as a weighted sum of affected people's utility change. It is here that EV is useful for this type of social choice test because again EV is a monotonic transformation of (indirect) utility function, which CV does not possess.

Fourth, the question addressed here is whether it is possible in principle to measure EV from the observations of people's daily activities, especially from demand functions for various goods and services including transport, environmental qualities, and uncertainty. It turns out that the answer is yes for EV but no for CV [McKenzie and Pearce (1982)]. Thus EV is superior to CV even from the viewpoint of measurability.

Fifth, having outlined the theoretical conclusions on the superiority of EV over CV, we turn our attention to the practical and empirical measurement methods of EV for various impacts of a transport project which can be classified into the changes in transport price and time, in those of other goods, in (lump sum) income, environmental damage, and uncertainty.

a. Private user benefits: Conventionally this has been measured by the consumers' surplus for ordinal demand function but theoretically this method has shaky foundations. It can be shown from the measurability theory developed in section 6 that EV can be measured by a Taylor's series of individual ordinal transport demand function with respect to any parameters.

b. Price and time change of goods other than transport: The basic method for measuring EV is the same as the case for user benefits.

c. Lump sum income change: This includes all the income change due to the change in production environment such as business trip conditions, production oriented public goods, taxes, subsidies, etc. Such an income change itself should be counted as a portion of EV. There are, therefore, no theoretical problems in measuring this term.

d. Environmental impacts: This item refers mainly to environmental deterioration such as air, water, and noise pollution damage costs for individuals. Although there are very few empirical studies on the difference in values of EV and CV in this field, according to the author's experience, EV is less than CV in absolute terms and the difference between them ranges from 10% to 50%. This indicates that it is very important to measure EV distinguishably from CV not only from the theoretical but also the empirical standpoint [Morisugi (1982)].

e. Uncertainty: Conventionally this has been measured either by the expectation or by the sensitivity analysis, but again theoretically these methods are not correct according to the concept of EV. Although there are also very few empirical studies in this field, according to the author's experience on the uncertainty level of water shortage problem, the multiattribute utility function approach seems to be a prospective method [MRI (1981)].

Summarizing our discussion, the main point of this paper is to advocate the use of equivalent variation EV as the measure for evaluating all the gains and losses derived from any transport project, and to carry out cost benefit analysis based on the concept of EV. All the approximations and empirical studies on cost benefit analysis should be reviewed based on the idea of EV.

2. IMPACTS OF TRANSPORT PROJECT

The goal of impact analysis is to know the change in attainable utility level of every individual in the society. An individual's attainable utility level is defined as his maximum utility level which can be achieved by purchasing various commodities including transport services and his housing location, and/or selling or renting his disporsable labor, and wealth (such as capital and land) under the budget constraint which has the set of prices as parameters, and the time constraint which has the set of required time for consuming one unit of commodity as parameters.

The attainable utility level is, therefore, a function of parameters defined above; prices (including wage and rent), required time and the quality of environment which he can not control directly because it is levied on him by the natural environment. Under the assumption of a world of certainty, this definition of attainable utility can be expressed as $v(p,t,p\bar{x},E)$ by the individual behavior as formulated below;

$$v(p,t,p\bar{x},E) \equiv \max_{x} \; u(x,E) \quad \text{s.t. } px = p\bar{x} \;, \quad tx = T \qquad (1)$$

where x : private consumption and factor supply vector including leisure time with zero price (variable), E : environmental quality vector (parameter), p : price vector of x (parameter), t : required time vector (parameter), $\bar{x}$: his endowment vector (parameter), T : available total time (parameter), u : utility function, and v : attainable utility level (= indirect utility function).

The function v has a technical term of indirect utility function [see, for example Varian (1979)]. Since $v(p,t,p\bar{x},E)$ is a strictly increasing function of $p\bar{x}$ under the usual assumptions, we can solve for px in terms of v,p,t,E to obtain the corresponding expenditure function $p\bar{x} \equiv e(p,t,E,v)$ which may be interpreted as the minimum amount of income necessary to achieve a specific utility level v at price p, time requirement t and environmental quality E.

Our next problem is to determine the level of price vector p for obtaining the attainable utility level v. In order to do so, we need to introduce production activities, and supply and demand equilibrium. The firm, the agent to pursue the production activities is assumed to maximize its profits under its production possibility frontiers. This behavior can be formulated as follows:

$$\pi(p,t,E) = \max_{y}.\ py \quad \text{s.t. } f(y,t,E) = 0 \tag{2}$$

where y :input and output vector (output level if an element is positive and input level if negative), f : production function, and π: attainable profit level.

The demand and supply equilibrium can, therefore, be written as

$$x(p,t,p\bar{x},E) - \bar{x} = y(p,t,E) \tag{3}$$

where $x(p,t,p\bar{x},E)$ is demand and supply function which can be derived from the individual's utility maximization behavior expressed by (1). y is the output and input vector which can be derived from the firm's profit maximization behavior expressed by (2).

These three equations describe the equilibrium state under a given transport condition and an environmental quality. When a transport project is introduced, therefore, some elements of t(time requirement), of p(price), and of E(environmental quality) will be changed so that due to this change in parameters from the viewpoints of consumers and producers, their supply and demand quantities x and y will be induced to change, which have a feed back effect to change some of the equilibrium prices p. These chain of effects results in a change in every individual's attainable level of utility v.

This completes a brief explanation of transport impacts and the next problem is how to evaluate these effects measured by the change in individuals' utility level.

3.TWO COST BENEFIT CRITERIA

Suppose that a transport project induced the price vector p^0 to p^1, a time requirement vector t^0 to t^1 and environmental quality vector E^0 to E^1, respectively. Then an individual's equivalent variation EV and compensating variation CV can be defined as follows [Currie, Murphy and Schmits (1971)]:

EV: the amount of compensation, paid or received, which will leave the individual in his subsequent welfare position in absence of the change in price, time requirement and environmental quality, assuming that except for environmental quality he is free to buy and supply any quantity of the private commodity at the old price and time requirement.

CV: the amount of compensation, paid or received, which will leave the individual in his initial welfare position following the change in price, time requirement and environmental quality, assuming that except for environmental quality he is free to buy and supply any quality of the private commodity at the new price and time requirement.

These two measures can be expressed by both indirect utility and expenditure functions:

$$v(p^0,t^0,p^0\bar{x}+EV,E^0) = v(p^1,t^1,p^1\bar{x},E^1) \tag{4}$$

or $EV = e(p^0,t^0,E^0,v^1) - p^0\overline{x}$ (5)

where $v^1 = v(p^1,t^1,p^1\overline{x},E^1)$

and $v(p^1,t^1,p^1\overline{x}-CV,E^1) = v(p^0,t^0,p^0\overline{x},E^0)$ (6)

or $CV = p^1\overline{x} - e(p^1,t^1,E^1,v^0)$ (7)

where $v^0 = v(p^0,t^0,p^0\overline{x},E^0)$.

Note, first, that given the values of the initial condition expressed by p^0, t^0, E^0, $\overline{x}$ in eq.(5), EV is a function of v^1 alone. And since it can be shown that the expenditure function $e(\cdot)$ is a monotonically increasing function of v^1, EV can be said to be a monotonic transformation of (indirect) utility function v. This is the proof for the first and third conclusions of this paper as mentioned above in section 1.

Notice also that we define EV and CV in such a way that they are positive or negative depending on whether prices of consumption goods fall or rise, prices of supplied factors rise or fall, required time for consuming a unit of good decreases or increases, required time for supplied factors (such as labor) decreases or increases, environmental qualities improve or deteriorate, respectively, so that we may designate these levels of EV and CV as individuals' <u>costs</u> when they are negative, and individuals' <u>benefits</u> when they are positive.

The corresponding <u>social net benefits</u> (denoted respectively by ΣEV and ΣCV) can then be obtained by summing up EV and CV algebraically over the affected individuals. The corresponding cost benefit criteria (CB criteria) can be stated as follows;

(1) <u>the equivalent variation criterion (ΣEV criterion)</u>
if ΣEV > 0, then the change should be accepted.

(2) <u>the compensating variation criterion (ΣCV criterion)</u>
if ΣCV > 0, then the change should be accepted.

In order to demonstrate the relationship between the above cost benefit criteria and the compensation test, it is convenient to introduce the following definitions. If x_i^0 denotes the optimal consumption and factor supply vector for each individual $i \in I$ under a given equilibrium price vector p^0, a given required time vector t^0 and a given environmental vector E^0, and if we write this collection of the individual's optimal choice as $x^0 = (x_i^0 \mid i \in I)$, then the combination (p^0,t^0,E^0,x^0) is said to be an equilibrium state for society I. By a proposed social change for society I, we mean any change which results in the movement from one equilibrium state (p^0,t^0,E^0,x^0) to another, say (p^1,t^1,E^1,x^1). Hence each proposed social change may be formally identified with a pair of equilibrium state $[(p^0,t^0,E^0,x^0), (p^1,t^1,E^1,x^1)]$.

Now given a value of t and E for each individual $i \in I$ with utility function u_i the sets,

$$s_i^0(t^1,E^1) = \{z_i \mid u_i(z_i,E^1) \geq u_i(x_i^0,E^0),\ t^1 z_i = T\},\ i\in I \quad (8)$$

$$s_i^1(t^0,E^0) = \{z_i \mid u_i(z_i,E^0) \geq u_i(x_i^1,E^1),\ t^0 z_i = T\},\ i\in I \quad (9)$$

denote the commodity bundles z_i which are at least as preferred as his equilibrium bundles x_i^0 and x_i^1, under the condition that t and E are fixed reversely at t^1 and E^1, t^0 and E^0, respectively.

In this context, if we consider a given proposed social change $[(p^0,t^0,E^0,x^0), (p^1,t^1,E^1,x^1)]$, then for each individual i we may identify a least expensive commodity bundle c_i under the circumstance of price-time-environmental system p^1,t^1,E^1 which would have i as well off as with the bundle (x_i^0,E_i^0). More formally, we now define a <u>compensating bundle</u> c_i for i to be any bundle $c_i \varepsilon s_i^0(t^1,E^1)$ satisfying

$$p^1 c_i = \min_{z_i} \{ p^1 z_i \mid z_i \varepsilon s_i^0(t^1,E^1)\} \qquad (10)$$

Similarly, any bundle $f_i \varepsilon s_i^1(t^0, E^0)$ satisfying

$$p^0 f_i = \min_{z_i} \{ p^0 z_i \mid z_i \varepsilon s_i^1(t^0,E^0)\} \qquad (11)$$

is a least expensive bundle under the circumstance of price p^0, required time t^0 and environmental quality E^0 which would leave i as well off as he would be with the bundle (x_i^1,E^1). Hence we may designate such f_i as an <u>equivalent bundle</u> for i. Finally, if we define the corresponding aggregate quantities:

$$X^0 = \sum_i x_i^0 , \quad X^1 = \sum_i x_i^1 , \quad C = \sum_i c_i , \quad F = \sum_i f_i , \qquad (12)$$

then the positivity conditions defining the two CB criteria above can be defined formally as follows;

$$\Sigma EV > 0 \leftrightarrow p^0(F - X^0) > 0 \qquad (13)$$

$$\Sigma CV > 0 \leftrightarrow p^1(X^1 - C) > 0 \qquad (14)$$

where prices are in row vector form and commodities are in column vector form.

4. TWO COMPENSATION TESTS

Since the original Kaldor and Hicks test have been proposed for the world composed of only private goods x [Kaldor (1938), Hicks (1940)], we will extend their original idea to our more complex world composed of not only private goods, but also time requirement vector t and environmental quality vector E. These extended compensation tests are as follows:

<u>Kaldor Test (KT)</u> : For any proposed social change, if output of private goods after the change X^1 could be redisributed in lump sum so as to make the modified new situation Pareto superior to the original, under the condition that required time and environment quality remain at the final level t^1 and E^1, then accept the proposed change.

<u>Hicksian Test (HT)</u> : For any proposed social change, if output before the change X^0 could not be redisributed in lump sum so as to make the modified new situation Pareto-superior to the final position, under the condition that time requirement and environmental quality remain at the original level t^0 and E^0, then accept the proposed change.

These two tests can be stated formally by introducing the following aggregate notation. Let:

$$S^0(t^1,E^1) = \{Z=\sum_i z_i \mid z_i \in s_i^0(t^1,E^1),\ i \in I\} \qquad (15)$$

$$S^1(t^0,E^0) = \{Z=\sum_i z_i \mid z_i \in s_i^1(t^0,E^0),\ i \in I\} \qquad (16)$$

denote the vector sums of the collections of sets $\{s_i^0 \mid i \in I\}$ and $\{s_i^1 \mid i \in I\}$, respectively. Then S^0 and S^1 denote the sets of aggregate commodity bundle vectors which could be distributed in such a way as to be weakly Pareto-superior to the individual equilibrium levels $x^0 = [x_i^0 \mid i \in I]$ and $x^1 = [x_i^1 \mid i \in I]$, for society I, respectively. As can be seen from Figure 1, these sets consist of all points on or above the "Scitovsky community indifference curves" (i.e., Scitovsky contours) through X^0 and X^1 (which correspond to the associated aggregated commodity vectors for x^0 and x^1, respectively).

Using the concept of S^0 and S^1, the two compensation tests can be now reformulated as follows (see Figure 1):

Kaldor Test (KT) : The proposed social change should be accepted if and only if $X^1 \in S^0$.

Hicksian Test (HT) : The proposed social change should be accepted if and only if $X^0 \notin S^1$.

At this moment it might be helpful to interpret the difference between the Kaldor and Hicksian tests. The former test focuses on whether or not the gainers could compensate the losers by redistributing the after-change community bundle X^1 so as to make everyone better off than he was in X^0. Hence the question here is whether or not X^1 is in the set S^0. If the gainers could compensate the losers, i.e., if $X^1 \in S^0$, then the change passes the Kaldor test. On the other hand, the latter test focuses on whether or not potential losers could bribe the gainers by redistributing the before-change community bundle X^0 so as to make everyone better off than he would be in X^1. Thus the question here is whether or not X^0 is in the set S^1. If the potential losers could not bribe gainers, i.e., if $X^0 \notin S^1$, then the change passes the Hicksian test.

First, note that, given the value of t and E, unlike individual indifference curves, Scitovsky contours can intersect one another. For example, the intersections A^0 and A^1 of the Scitovsky contours for X^0 and X^1 shown in Figure 2 identifies a combination of goods which can be distributed in such a way that all the members of society can jointly realize the same utility levels as those under some distribution of X^0 or X^1, respectively.

Second, notice that if we adopt either Kaldor or Hicksian test only, we have the possibility of contradiction for such a case as shown in the Figure 2. For according to the Kaldor test, $X^1 \in S^0$ implies that the proposed change from X^0 to X^1 should be adopted. Now consider the reverse change from X^1 to X^0. Since $X^0 \in S^1$, it follows that if this change were to be subsequently proposed, then it would be adopted, and one obtains a 'cycle' or 'contradition' as shown in Figure 2(a). The same type of contradition is possible for the Hicksian test in the case shown by Figure 2(b). The situations in both Figure 2(a) and 2(b) are designated as Scitovsky paradoxes in honor of Scitovsky (1941) who first pointed them out and advocated the Scitovsky test in order to avoid such contradictions. This test avoids such contradictions by requiring that both $X^1 \in S^0$ and $X^0 \notin S^1$ hold in order that the proposed social change be accepted.

If we now define a given proposed social change to be paradox free if and only if both ($X^0 \epsilon S^1$, $X^1 \epsilon S^0$) and ($X^0 \notin S^1$, $X^1 \notin S^0$) fail to hold, then following equivalence theorem can be easily proved [see Morisugi (1983a) for proof].

Proposition 1 (Equivalency of Kaldor and Hicksian Tests)
The Kaldor test and the Hicksian test are equivalent for a given proposed social change if and only if the proposal change is paradox free.

This result yields important consequences for welfare implications of cost benefit analysis. In particular, if we wish to employ either the Hicksian or Kaldor tests in evaluating a project, then we are obliged to confine ourselves to proposed social changes which are paradox free. But, within this framework, the Kaldor test is necessarily equivalent to the Hicksian test. Hence, we may as well adopt the Hicksian test whenever this test is easier to carry out than the Kaldor test. Indeed, this is precisely what we shall do in the present paper.

5. SUFFICIENCY OF THE EQUIVALENT VARIATION CRITERION FOR KALDOR AND HICKSIAN COMPENSATING TESTS

In this section it is shown that the equivalent variation criterion ΣEV is a sufficient condition for the Hicksian test, (and also the Kaldor test, when the proposed social change is free of Scitovsky paradoxes).

Proposition 2 (sufficiency of the Equivalent Variation Criterion)
The equivalent variation criterion is sufficient for the Hicksian test.

Proof: First recall from (11) that, by definition, $p^0 f_i \leq p^0 z_i$ holds for all consumers i and all $z_i \epsilon s_i^1$: Hence for any $Z = \sum_{i=1}^{I} z_i \epsilon S^1$,

$$p^0 Z = \sum_i p^0 z_i \geq \sum_i p^0 f_i = p^0 \sum_i f_i = p^0 F \qquad (17)$$

But if the ΣEV criterion is satisfied for X^0, p^0 and F, then from (13)

$$\Sigma EV > 0 \quad p^0 F > p^0 X^0 \qquad (18)$$

Thus (17) and (18) together imply that X^0 cannot be an element of S^1, and hence that HT holds. End of Proof.

Combining Propositions 1 and 2 we obtain the following immediate consequence:

Proposition 3 (Sufficiency of Equivalent Variation Criterion for the Kaldor and Hicksian Tests)
For any proposed social change, which is paradox free, the equivalent variation criterion is sufficient for both the Kaldor and Hicksian tests.

This result shows the second statement in section 1 above that if social costs and benefits are measured in terms of the equivalent variation index ΣEV, then any proposed social change which satisfies the resulting cost benefit criterion is guaranteed to improve economic efficiency in both the Kaldor and Hicksian sense -- whenever these concepts are both well defined. Hence, from an economic efficiency viewpoint, it may be argued that ΣEV is more appropriate for measuring social costs and benefits than ΣCV.

Finally, it should be noted that ΣCV criterion fails to be sufficient for the Kaldor test [Boadway (1974)]. Hence even in cases where the Kaldor and Hicksian tests are equivalent, i.e., even when no Scitovsky paradoxes are present, it follows at once that this criterion also fails to be sufficient for the Hicksian test. Failure of sufficiency in this case is illustrated by the counterexample in Figure 1(a) where the after-change equilibrium is located at $\bar{X}^1$.

6. MEASURABILITY of EQUIVALENT VARIATION

The measurability of EV from the observation of people's daily activities can be derived again from the fact that EV is a kind of utility function itself. It will be illustrated by assuming a simple situation. We assume that there are five private commodities (or activities): composite good z with price 1 and zero required time, transport activity x with cost p and time t per unit of activity, labor time tw with wage w (net of tax), leisure time l with zero price, and fixed own land L with rent r (net of tax), and there is an environmental quality index E. Therefore an individual with income (wtw+rL) and total available time T maximizes his utility u(z, x, tw, l, E) by controlling z, x, tw and l under the budget and time constraints:

$$\max_{z,x,tw,l} u(z, x, tw, l, E) ,$$
$$\text{s.t.} \quad z + px = wtw + rL , \quad tx + tw + l = T \qquad (19)$$

The two constraints can be combined into :

$$z + (p + wt)x + wl = rL + wT \equiv \Omega \qquad (20)$$

Given values of parameters, p, w, t, r : E, L, T, we will derive his optimal composite good z(p, w, t, r : E, L, T), transport demand x(p, w, t, r : E, L, T), his labor hours tw(p, w, t, r : E, L, T), leisure time l(p, w, t, r : E, L, T) and his maximized utility level v(p, w, t, r: E, L, T), which is called an indirect utility function.

Suppose that a transport project induces a change in parameters from p^0, w^0, t^0, r^0, E^0 to p, w, t, r, E with L and T constant. Then his attainable utility v changes from $v^0 = v(p^0, w^0, t^0, r^0, E^0, L, T)$ to $v = v(p, w, t, r, E, L, T)$.

From the definition of EV of eq. (5) his equivalent variation EV can be formulated as :

$$EV = e(p^0, w^0, t^0, r^0, E^0, L, T, v(p, w, t, r, E, L, T))$$
$$- e(p^0, w^0, t^0, r^0, E^0, L, T, v^0) \qquad (21)$$

where e( ) is the expenditure function.

Eq. (21) can be approximated by a Taylor's series:

1st order

$$EV = \{(\partial e/\partial p)\Delta p + (\partial e/\partial w)\Delta w + (\partial e/\partial t)\Delta t + (\partial e/\partial r)\Delta r + (\partial e/\partial E)\Delta E\}$$

2nd order

$$+ (1/2)\{(\partial^2 e/\partial p^2)\Delta p^2 + (\partial^2 e/\partial w^2)\Delta w^2 + (\partial^2 e/\partial t^2)\Delta t^2$$

$$+ (\partial^2 e/\partial r^2)\Delta r^2 + (\partial^2 e/\partial E^2)\Delta E^2 + 2(\partial^2 e/\partial p\partial w)\Delta p\Delta w$$
$$+ 2(\partial^2 e/\partial p\partial t)\Delta p\Delta t + 2(\partial^2 e/\partial p\partial r)\Delta p\Delta r + 2(\partial^2 e/\partial p\partial E)\Delta p\Delta E$$
$$+ 2(\partial^2 e/\partial w\partial t)\Delta w\Delta t + 2(\partial^2 e/\partial w\partial r)\Delta w\Delta r + 2(\partial^2 e/\partial w\partial E)\Delta w\Delta E$$
$$+ 2(\partial^2 e/\partial t\partial r)\Delta t\Delta r + 2(\partial^2 e/\partial t\partial E)\Delta t\Delta E + 2(\partial^2 e/\partial r\partial E)\Delta r\Delta E$$
$$+ \cdots \qquad (22)$$

where indicates the change in parameters, and all the derivatives are evaluated at the intial situation with superscript 0.

We use a famous envelope theorem [see Varian (1978) for example]:

$$(\partial e/\partial p) = -x \;,\; (\partial e/\partial w) = -tx - 1 + T = tw \;,$$
$$(\partial e/\partial t) = -wx \;,\; (\partial e/\partial r) = L \qquad (23)$$

Substituting the above eq. (23) to (22) we obtain :

1st order

$$EV = \{ -x^0(\Delta p + w^0\Delta t) + (\partial e/\partial E)\Delta E + tw^0\Delta w + L\Delta r \}$$

2nd order

$$(1/2)\{ -(\partial x/\partial p)\Delta p^2 + (\partial tw/\partial w)\Delta w^2 - (\partial(wx)/\partial t)\Delta t^2$$
$$+ (\partial^2 e/\partial E^2)\Delta E^2 - 2(\partial x/\partial w)\Delta p\Delta w - 2(\partial x/\partial t)\Delta p\Delta t$$
$$- 2(\partial x/\partial E)\Delta p\Delta E + 2(\partial tw/\partial t)\Delta w\Delta t + 2(\partial tw/\partial E)\Delta w\Delta E$$
$$- 2(\partial(wx)/\partial E)\Delta t\Delta E \} + \qquad (24)$$

Since x, tw, $(\partial e/\partial E)$ can be in principle observable from his behavior except for the practical difficulty of how actually these demand and supply functions might be estimated from the existing data, it can be said from (24) that EV is measurable from his revealed activities.

7. UNCERTAINTY

Whenever some of the parameters ; price p, time t, and environmental quality E have a kind of uncertainty, we assume that individuals and firms maximize their expected utilities. And if necessary, the term expenditure function is replaced by the expected expenditure function. This assumption which follows Neumann and Morgenstern's axiom, does not change any conclusions derived above except for; first, that the relevant compensation for defining EV and CV become the contingent type depending on the probablistic state of nature; second, practical tools to evaluate EV for the change in uncertainty level of parameters, which will be discussed in the next section [for a more formal discussion of cost benefit analysis under uncertainty, see Graham (1981)].

8. MEASUREMENT OF EV

First, it is critically important to follow all the impact incidences which end up as the change in utility levels of affected people. Although we might expect to find a short-cut for measuring ΣEV by using only available information from the direct output of transport project (i.e., transport market itself), unfortunately at the prsent stage of theory it is necessary to obtain all the impact incidences so that the impact analysis of a transport project should be oriented to measure the individuals' atainable utility level.

It can be said, therefore, that the distinction between private (individual) and business trips is extremely important because the change in business trip conditions incidentally means an increase in production efficiency and this results in profit increase which in turn through competition resolves into the increase in factor prices such as wage, capital, and land rent and/or dividends of stocks. Notice that this conceptual distinction between individuals and firms is also applicable to the case of other private goods and environmental quality.

In view of the above discussion on the incidences of various impacts, we assume that all the direct and indirect effects of a transport project could be known through a kind of general equilibrium model in the form of the change in parameters which influences the attainable utility levels of all the affected individuals. This way of thinking leads us to the proper classification of transport impacts for which we can take into account only the parameters of indirect utility function. Thus the impact can be classified into the following five items: (1) change in transport conditions in terms of price and time from the viewpoint of non-business trips including commuting, (2) change in price and required time of goods other than transport services, (3) change in (lump sum) income which means change in prices of fixed factors such as land rent, capital rent, and wage of the fixed hour labor which includes all the direct and indirect income change due to the change in production environment such as business trip conditions, production oriented public goods, taxes, subsidies, (4) change in environmental qualities of individuals (excluding those for business firms), (5) change in uncertainty level of the houeshold's environment (excluding firms' environment).

We shall discuss the practical methods of EV for each of the items mentioned above.

(1) <u>Transport condition of private purpose trips</u>

Conventionally the users' benefits have been measured by the consumers' surplus for aggregate ordinal demand function but theoretically this method has two problems. First, business and private trips should be distinct. For the former is an input for producing some outputs; therefore, the change in transport conditions might induce the price changes of outputs and/or fixed factors. These indirect effects again change the attainable utility level of which the EV seems to be not necessarily identical to the users' surplus of their demand functions. But fortunately it can be shown that except for output price change, this lump sum income change due to price changes of fixed factors is equivalent to the users' surplus of transport demand [see Morisugi (1983b)].

Second the users' benefits of private trips, on the other hand, measured by EV, does not necessarily coincide with the consumers' surplus of ordinal demand function. As one can see from the eq. (24), the EV of price and time change should be measured by Taylor's series of ordinal demand function.

(2) <u>Price and time change of goods other than transport</u>

The basic method for measuring EV is the same as the case for the transport condition above. Notice, however, that items which should be accounted are only final consumption goods.

(3) Lump sum income change

For an individual, the lump sum income change is equivalent to the change in the price of fixed own factors. These changes are generally indirect effects of a transport project because they are the result of changes in production environment such as business trip condition, production oriented public goods, and uncertainty level except for taxes and subsidies levied directly on individuals. It can also be shown that the total lump sum income change itself is a portion of EV and can be measured by either the consumers' surplus of some appropriate input demand function of firms, such as business trip demand (for the case of transport condition), or the producers' surplus of output supply function (equal to marginal cost function) for such a case of environmental deterioration [Morisugi (1983b)]. As a consequence, if one evaluates an economic efficiency of a project measured by ΣEV, the consumers' surplus approach is useful. If one seeks to know the distributional aspects of EV, on the other hand, it is necessary to follow all the incidences of income distribution through a kind of general equilibrium approach.

(4) Environmental Impacts for Individuals

Again it is important to make a distinction between the business and household environment, although both refer mainly to natural and local environmental deterioration such as air, water, and noise pollution. As mentioned above, the change in production environment is transformed to the change in lump sum income of individuals of which EV can be measured by an appropiate cost function of affected firms.

For the case of household environmental change, on the other hand, some difficulty arises because it does not have any direct market, i.e. it is a variable of utility function but it cannot be controlled directly nor included in the budget constraint.

When we pay attention to the characteristics of environmental impacts derived from a transport project as a local public good, it becomes apparent that the household has a kind of indirect controllability over them by choosing their residential places. Thus the preference on local environmental qualities is revealed by the residential choice. At the present stage of development on the methodology for measuring EV of local environmental quality change, there are two approaches: multiattribute utility function approach and property value analysis. The former is a kind of survey method by estimating an indirect utility function with special attention to residential choice in which some residential attributes reflect the environmental qualities [Morisugi and Katoh (1981), and Morisugi (1982)]. The latter is called a hedonic price approach and usually uses reggression analysis, but theoretically it can be applied only for the case where the affected area is relatively small compared with the rest of the area [for a critical analysis see Mäler (1974) and for full survey on this field see Freeman (1979)].

(5) Uncertainty for Individuals

First, it is again important to make a distinction for those between business and household for the same reason mentioned above. Also the same difficulty as the environmental quality issue arises in terms of measuring individual preference over uncertainty. For the case of a transport project, three typical uncertainties should be analyzed: that is; the traffic accidents; reliability of arrival time; and the environmental quality. The former two have been analyzed by the so - called disaggregate demand analysis in which uncertainty is taken into account explicitly [see Ben-Akiba and Lerman (1979), Bruzelius (1979) and Sasaki (1982) for theoretical basis, and see Manheim (1980) and Domencich and McFadden (1975) for introduction]. The basic method for measuring EV of uncertainty in environmental quality is the same as for the individual environmental impact mentioned above (4). A typical example can be seen in MRI (1981). The last problem concerns the statistical errors of EV. The estimated EV has many uncertain factors such as transport demand, population, etc. For evaluating these types of uncertainties, again it should be based on the concept of EV for uncertainty although there are very few developments at the present situation.

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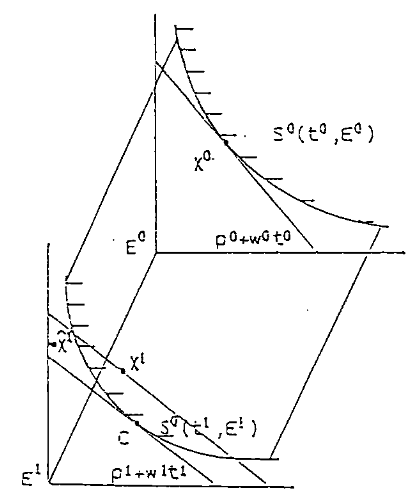


Note. w indicates the wage per unit of labor hour.

FIGURE 1 (a). Compensation Test (Kaldor Test)

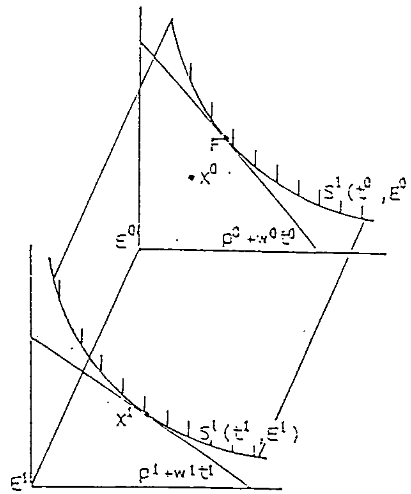
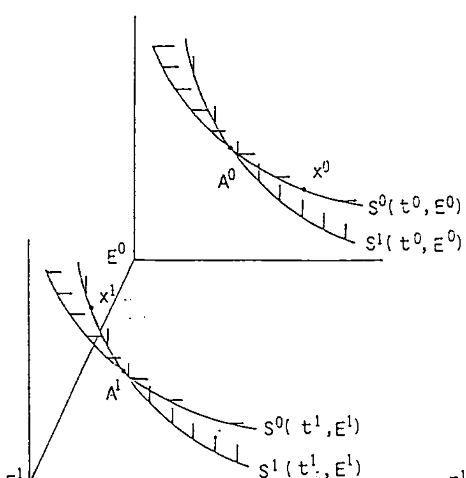
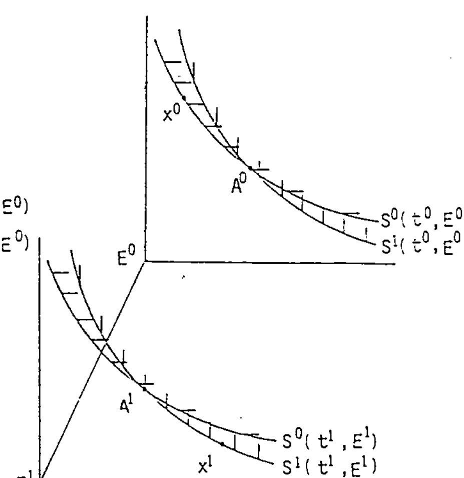


FIGURE 1 (b). Compensation Test (Hicksian Test)



Note. $x^1 \in S^0$ and $x^0 \in S^1$.

FIGURE 2 (a). Scitovsky Paradoxes: Contradiction of Kaldor Test



Note. $x^0 \notin S^1$ and $x^1 \notin S^0$.

FIGURE 2 (b). Scitovsky Paradoxes: Contradiction of Hicksian Test