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OPTIMAL SUBSIDY PROBLEM FOR THE PUBLIC TRANSIT SYSTEM: A RAMSEY PRICE EQUILIBRIUM MODEL APPROACH

TAKAJI SUZUKI
Chukyo University
Department of Economics
Yagoto Honmachi 101-2, Showa-ku, 4668666 NAGOYA, JAPAN

TOSHIHIKO MIYAGI
Gifu University
Faculty of Regional Studies
Yanagido 1-1, 5011193 GIFU, JAPAN

Abstract

This paper focuses on urban transit pricing policies including financial support system, where the government gives transportation agency subsidies collected from fuel tax paid by automobile users. To consider the effects of shortening travel times on road network with introducing an urban transit, we have already formulated as a bilevel programming problem which consists of Ramsey pricing rule as an upper problem and the binary mode choice/assignment model as a lower problem. In this paper, we extend previous model to take the relation between the subsidy and automobile-taxes into account and to determine optimal subsidy level for the costs of urban transits.

INTRODUCTION

Urban transportation policies of changing the main transportation mode from automobiles to public transits may contribute to improvements of urban environmental problems like a reduction of Co_2, or to revitalization in CBD. However, it is difficult for urban transit agency to pay the costs of introducing a urban transit system by their own profits because of the lack of sufficiently large demand and huge construction cost, especially in the Japanese middle or small size of cities. In this situation, to make the introduction of a urban transit system feasible, the central or local government gives some amount of subsidies to the urban transit agency.

This paper focuses on urban transit pricing policies including financial support system, where the government gives transportation agency subsidies collected from fuel tax paid by automobile users. This type of policy-making is playing an important role in improvements of urban transportation systems in European and North American countries. In Japan, automated guideway transit (AGT), light rail transit (LRT), mono-rail and guideway bus systems are partly subsidized from the earmarked funds consisting of mainly automobile taxes such as a fuel tax to reduce road congestion in urban areas. Since one of the major significances of introducing new transit services is to operate urban transportation systems efficiently, it is a natural thought that the costs of introduction of the new service should be paid by all beneficiaries from the usage of the urban transportation systems. This problem may be formulated as one of the optimal pricing problems where the burden of the construction costs by each mode user is decided to maximize the social welfare associated with the whole of urban transportation systems.

To consider the effects of shortening travel times on road network with introducing an urban transit, we have already proposed the model in which the Ramsey pricing rule is harmonized with the combined modal split and assignment model proposed by Florian and Spiess (1983), to take account of the influence of traffic congestion to transit demands. We call this model the Ramsey price equilibrium (RPE) model (Miyagi *et al*, 1992). The model was formulated as a bilevel programming problem which consists of Ramsey pricing rule as an upper problem and the binary mode choice/assignment model as a lower problem. Suzuki and Miyagi (1997) showed that in comparison between RPE model and the original Ramsey pricing rule, the social welfare obtained from the RPE model is bigger than that of the original Ramsey pricing. If we consider the effects of shortening travel times on road network, it can be said that the RPE model gives more efficiency pricing rule than the original one: the RPE model includes the user's behavior where users are assumed to forecast road congestion, and to change their mode and path to maximize their own utility.

For the RPEP, Miyagi and Suzuki (1996,1997) proposed solution algorithms with nonlinear sensitivity analysis offered by Fiacco (1983), Tobin and Friesz (1988) and Friesz *et al.* (1990), and further investigated the efficiency of pricing of urban transit by RPE through a numerical example: increasing subsidy for construction costs of transit system lowers its fares, and brings about higher automobile-users benefit through the realization of optimal modal split. In this paper we discuss about optimal subsidy level, that is, the reasonable payment of automobile users when an urban transit is introdued into the existing urban transportation systems.

This paper is organized by following four chapters. In the second chapter, we first refer to

Japanese financial system for AGT system. The institution is regarded as the financial system that automobile users load the costs for introduction of urban public transits, partly. In the third chapter, to deal with the optimal load of the construction costs of AGT system by automobile users, we extend the RPE model to the more comprehensive model with taking the relation between the subsidy and automobile-taxes into account while in the previous model. Two numerical analyses based on the extended RPE model are carried out in the fourth chapter. The first is the sensitivity analysis in which we examine how social welfare is affected by changing the subsidy from central government. The second aims at the establishment of a new tax system associated with the optimal subsidy level in terms of taxation for automobile users. The last chapter concludes this paper.

THE CONSTRUCTION INSTITUTION FOR URBAN TRANSITS IN JAPAN

The costs of AGT constructions are partly covered by subsidy from earmarked funds of central government for road construction, which are collected from road users in Japan (JSCE, 1990). The criteria of applying subsidies are

(1) the AGT system substitutes for traffic function of the road,

(2) the joint development of the AGT and road system is recognized to be efficient by the road administrator,

(3) the management and operation of the AGT system is demonstrated by local government or the third sector.

The details of the institution currently performed are as follows:

(1)The infrastructures of AGT system consisting of props and girders are constructed as a part of road, being subsidized using earmarked funds for road constriction, of which costs are partly covered by subsidy from central government. The construction costs of infrastructure must be within 55% of the total construction costs of the AGT system.

(2)The upper limit of the standard subsidy ratio from central government is 54.4% of all the construction costs of AGT.

At the beginning of the AGT construction system, practical subsidy ratio is kept the low level because the upper limit of subsidy ratio was set to the low level. Even though the upper limit was relaxed, the subsidy ratio have been still kept the low level because the subsidy ratio decreased from 66% to 55%.

THE RAMSEY PRICE EQUILIBRIUM MODEL FOR DETERMINATION OF OPTIMAL SUBSIDY LEVEL

If a multiproduct firm is a natural monopoly, then pricing goods at their marginal cost can result in the firm losing money. If the firm cannot be subsidized, to make them sustainable, transits fares must be set sufficiently above marginal cost to break-even, that is, earn zero profit. In one-good situation, the requirement of zero profit is sufficient to set price equal to average cost. However, with more than one good, many different price combinations result in zero profit. Baumol and Bradford (1970) have pointed out that optimal taxation rules proposed by Ramsey (1927) are directly applicable for determining second-best prices that is maximizing social welfare subject to zero profit for multiproduct natural monopolies. Train (1977) has conducted an application of Ramsey rule to pricing for the AC transit and Bart.

Miyagi *et al.*(1992) and Miyagi and Suzuki (1996) have been extended Ramsey pricing rule for optimal transit pricing to a more general model within the framework with multi-modal network equilibrium to consider travelers' behavior affected by the road traffic congestion. The model was formulated as a bilevel programming problem which puts Ramsey pricing problem in the upper problem and the binary mode choice/assignment model in the lower problem, respectively. We called this problem Ramsey price equilibrium model to distinguish from the original Ramsey rule. In this model the public transportation agency decides transits fares in the upper problem and urban transportation users choose their modes with taking transit costs into account. While the demand for transit is affected by transit services, which is defined as the generalized cost combining of fares with travel times between origin-destination pairs, it influences both the revenue and the variable cost of urban transportation agency. Thus, the profit maximization behavior of transit agency and the optimal choice behavior of transportation users are interactively connected. The behavioral structure of such a problem is effectively formulated by a bilevel programming problem (Shimizu, 1982 and Yang and Yager, 1994) or Stackelberg problem (Stackelberg, 1934). If the lower problem is defined as the VI : variational inequality, then the bilevel programming problem is called mathematical programming with equilibrium constraints (MPEC) by Lou *et al.* (1996).

The assumption on transportation agents in our formulation are as follows:
(1)Transportation users choose their travel mode between AGT, bus and automobile.
(2)A public transportation sector of local government constructs AGT system and operates all public transits which are bus and AGT.
For a simplicity, we pay attention to a single OD pair connected by three modes mentioned in the assumption (1) as like Fig. 1. Mutual exclusive transit networks are assumed to handle a multimodal network equilibrium problem within the context of the binary modal choice formulation. While the share of demand between private automobile and public transit systems are determined by the logit modal-split function, path flow on routes within each transit depends on user equilibrium mechanism. The break-even constraints are imposed on public transportation sector. The local government levies uniform-automobile tax from all residents in this region to subsidize the public transport sector.

Algebraically, Ramsey Price Equilibrium model for single OD network can be written as follows:

[RPEP]
U1)

$$Max.\,\Pi(\mathbf{q},\mathbf{p}) = \theta q \ln\sum_m \exp\left(\frac{y-\omega t^m\left(q^m(\mathbf{p})\right)-p^m}{\theta}\right)+(y-g)(\tilde{q}+q)+\sum_m\left(p^m q^m(\mathbf{p})-VC^m\left(q^m(\mathbf{p})\right)\right) \quad (1)$$

$$s.t.\ \sum_m\left(p^m q^m(\mathbf{p})-VC^m\left(q^m(\mathbf{p})\right)-F_m\right)+g\left(\dot{q}+q\right)=0 \quad (2)$$

L1) (**q***, **h***) is the solution for the following VI:

$$\mathbf{C}\left(\mathbf{h}^*\right)^T\left(\mathbf{h}-\mathbf{h}^*\right)-\mathbf{w}\left(\mathbf{q}^{1*}\right)\left(\mathbf{q}^1-\mathbf{q}^{1*}\right)\geq 0,\forall\left(\mathbf{h},q\right)\in\Omega \quad (3)$$

$$\Omega=\left\lfloor \mathbf{h}:q=\Lambda\mathbf{h},\ \mathbf{h}\geq 0\right\rfloor \quad (4)$$

$$\Omega'=\left\lfloor \mathbf{x}:\mathbf{x}=\Delta\mathbf{h},q=\Lambda\mathbf{h},\ \mathbf{h}\geq 0\right\rfloor \quad (5)$$

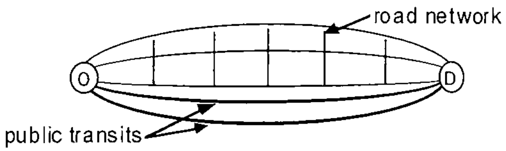

Figure 1 - Multi-mode network representation for a single OD pair

where

q: total demand between OD,

$\tilde{q}$: residents outside of the city area,

q^m: demand using mode m (=1 automobile ,=2 public transit),

p^m, t^m : the fare and travel time using mode m,

g : automobile tax,

ω : time value,

y : average income of residents per a day,

VC^m,F^m : variable costs and construction cost supplying mode m,

$\mathbf{x}, \mathbf{h}, \mathbf{C}$: link flow, path flow, path cost (all letters are vectors),

$g\left(\tilde{q}+q\right)$: subsidy from central government,

$\mathbf{\Delta}, \mathbf{\Lambda}$: link-path, OD-path incident matrix,

θ : parameter

$w\left(q^1\right)$ is a function which represents difference of travel cost between automobile and public transit with demand for each mode. In here following logit type function is translated into eqn.(6).

$$q^1 = q \Big/ \left(1+\exp\left(C^1 - C^2\right)\right),$$

$$w\left(q^1\right) = C^1 - C^2 = \left(q - q^1\right) \Big/ q^1 \qquad (6)$$

The first and second terms in the right hand side of eqn. (1) represent consumer's surplus and the third term denotes producer's surplus. The eqn. (2) is a break-even constraint for public transportation sector. The inequality (3) describes the conditions of network equilibria as variational inequality (Florian and Spiess, 1983). Eqns. (4) and (5) represent the flow-conservation law with path and link variables, respectively.

THE IMPLICATION OF THE RPEP FOR AGT CONSTRUCTION INSTITUTION

In this chapter, we investigate determination of the optimal subsidy level using the RPEP. It is not easy tasks to carry out the comparative-static analysis for the RPEP because the RPEP is formulated as MPEC. To get more insight for characteristics of RPEP, numerical analyses are demonstrated in the following sections.

A RPE model for numerical analyses

Consider a region with 250,000 inhabitants. We assume that a city with 50,000 people is included there. For the simplicity the urban transportation systems of the city are represented by a network which consists of four centroids connected by six links. The centroid 1, 2 and 3 are suburb areas and 4 is a central business district. It is assumed that 20,000 people are traveling between OD pairs, 2-4 and 1-4, and 10,000 people between 3-4. No inflow to CBD from outside of the city is assumed, however, levying automobile tax from people who are included living in outside of the city is assumed. The introduction of AGT system is planed by local government. If the system will be completed, the OD pair from 1 to 4 is connected by AGT and automobile routes. The OD pair from 3 to 4 connected by bus and automobile ones. As for the OD pair from 2 to 4 there are two paths of automobile. Before the introduction of AGT system a bus system was operated on the same route as the projected AGT. After the introduction of AGT system, the bus route will be abolished. The bus and automobile flow mutually independent on link 3 and 4. The RPEP corresponding to Fig. 2 is described below.

The following link cost functions are used in the succeeding analysis.

$$c_a(x_a) = \omega t_{a0}\left\{1 + 0.15(x_a / Q_a)^4\right\} + p_a, a \in 1, \cdots, 4, \tag{7}$$

$$c_a(x_a) = \omega t_{a0} + p_a, a \in 5, \tag{8}$$

$$c_a(x_a) = \omega t_{a0} + 0.0225(x_a / Q_a) + p_a, a \in 6. \tag{9}$$

Cost functions of paths designated in Fig. 2 are defined as:

$$C_1 = c_1(x_1) + c_3(x_3), \tag{10}$$

$$C_2 = c_2(x_2) + c_3(x_3), \tag{11}$$

$$C_3 = c_4(x_4), \tag{12}$$

$$C_4 = c_3(x_3), \tag{13}$$

$$C_5 = c_5(x_5), \tag{14}$$

$$C_6 = c_6(x_6), \tag{15}$$

and the flow conservation equations are given by

$$x_1 = h_1, \tag{16}$$

$$x_2 = h_2, \tag{17}$$

$$x_3 = h_1 + h_2 + h_4, \tag{18}$$

$$x_4 = h_3, \tag{19}$$

$$x_5 = h_5, \tag{20}$$

$$x_6 = h_6, \tag{21}$$

$$h_1 + h_5 = q_{14}, \tag{22}$$

$$h_2 + h_3 = q_{24}, \tag{23}$$

$$h_4 + h_6 = q_{34}, \tag{24}$$

where

c_a, C_k : travel cost on link a and path k,

t_{a0}: travel cost with zero flow on link a,

Q_a: capacity of link a.

It is assumed that the modal split between any OD pair is described by the logit function and the travel costs using the same mode between any OD pair satisfy Wardrop's user equilibrium condition:

$$C_1 = C_5 + \theta \ln \frac{h_5}{q_{14} + h_5}, \tag{25}$$

$$C_4 = C_6 + \theta \ln \frac{h_6}{q_{34} + h_6}, \tag{26}$$

$$C_2 = C_4, \tag{27}$$

The total benefits of users for OD pair from 1 to 4 and from 3 to 4 are defined as consumer's surplus derived from logit demand function as shown in eqns (28) and (29).

$$CS_{14} = yq_{14} - \theta q_{14} \ln \sum_{k=1,5} \exp\left(-C_k / \theta\right), \tag{28}$$

$$CS_{34} = yq_{34} - \theta q_{34} \ln \sum_{k=4,6} \exp\left(-C_k / \theta\right). \tag{29}$$

As for OD pair from 2 to 4 total benefit of users cannot be defined by the logit-function because the OD pair is connected by only road network. The change of benefit is difference of total travel costs between with and without AGT system is formulated as

$$\Delta CS_{24} = \left(yq_{24} - C_2 q_{24}\right)_{with} - \left(yq_{24} - C_2 q_{24}\right)_{without}. \tag{30}$$

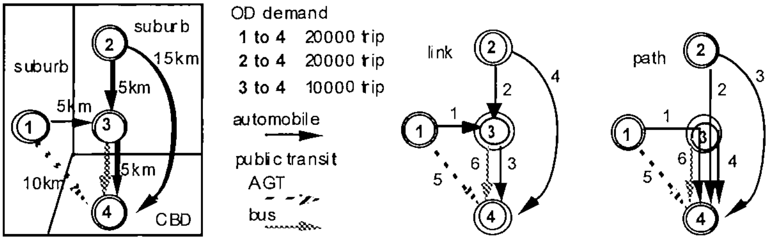

Figure 2 - Example network and regional demand

Table 1 - The characteristic of urban transits

	AGT	bus
Route Distance	10km	5km
Speed	20km/hr	Increase for transit volume
Frequency	8 times/hr (one way)	4times/hr (one way)
Operation Times	7:00 - 22:00	7:00 - 22:00
Total Service Dis.	2400km/day	600km/day
Constraction Cost	30.8million u.s.$/km	——
Subsidy Ratio	54.4% for cons.cost	——

The operational characteristics concerned with AGT and bus are shown in Table 1. The cost of producing services for both of AGT and bus are described by the following Cobb-Dauglus function (Miyagi and Nakatsuhara, 1995):

$$T\left(h_5, h_6\right) = \left(FC_B + FC_N\right) + VC = \left(FC_B + FC_N\right) + 0.001P^{02}H^{2.0}L^{0.5} \tag{31}$$

where

FC_B : fixed cost for bus (= 0 is assumed)
FC_N : fixed cost for AGT (= Construction cost for AGT)
VC : variable cost
P : fuel cost
H : passengers (= $h_5 + h_6$)
L : total operating distance

The break-even constraint for supplier is as follows:

$$p_5 h_5 + p_6 h_6 + p_3\left(h_1 + h_2 + h_3 + h_4\right) - T\left(h_5, h_6\right) + g\left(\dot{q} + q_{14} + q_{24} + q_{34}\right) = 0 \tag{32}$$

where

p_5, p_6 : AGT and bus fare,
p_3 : urban transportation tax (mentioned after)

The optimal pricing for AGT system

In this section we consider the case of subsidization by central government. The major purpose of analysis aims at the sensitivity analysis about the changes in social welfare related to subsidy ratio. The subsidy from central government is collected as a uniform-automobile-tax from all residents in the region uniformly.

< case A >
The public transit sector pays the balance subtracting subsidy form the construction cost and the variable cost by the revenue of transits fares. The case corresponds to the second best pricing for AGT system within the present institution in Japan where the ceiling of the upper limits the subsidy ratio for the AGT construction cost is assumed to be 54.4% of its total construction costs. We assume that all residents have an automobile and pay the same amount of automobile tax to the central government.

< case B >
The case B is set to compare with the case A. In this case, the subsidy ratio is set to 70% for the construction costs with the other conditions being remained.

Optimal equilibrium for the case A and B

The Fig. 3 represents the link flows and path travel-costs at the optimal equilibrium solution in the case A. The optimal AGT and bus fares are 3.03 US dollar and 2.50 US dollar. The travel costs of links show the section of road between 3 to 4 is the bottle-neck. If the congestion of this section were reduced, the urban transportation system would become efficient, extremely.

The Fig. 4 shows the link flows and the travel-costs at the optimal equilibrium in the case B. The optimal fares are 2.65 US dollar in AGT and 2.16 US dollar in bus, respectively. These fares are lower compared with the case A.

The variation of social welfare corresponding to each case are 111,751 US dollar for the case A and 134,543 US dollar for the case B, respectively. We can say that the subsidy ratio in present Japanese institution is too small in this case from the view point of maximizing of the social welfare of the systems. Additional numerical analyses with increasing the subsidy ratio indicate that these exists the peak of social welfare with respect to the subsidy ratio. It implies that the optimal subsidy ratio which maximizes the social welfare may exist.

In case B, the all travel costs are getting lower than in case A, in particular, the travel costs of transit lines show relatively greater changes. The results are explained by the fact that the efficient improvement of urban transportation systems results in reducing automobile volume of section between centroid 3 and 4 because of transfer of auto-user to transit, which in turn brings about the lowering transit fares. In consequence the costs of all users are decreased. However, this policy isn't Pareto improvement because the people of outside of the area bear a part of increasing subsidy as the automobile tax.

For the results of this analysis, we may be found that the better way of improving urban transportation systems is to impose tax on automobile users because that they are direct beneficiaries of saving travel-times by introduction of the urban transit. This observation indicates that there is a new, efficient tax system for AGT system different from the prevailing Japanese system.

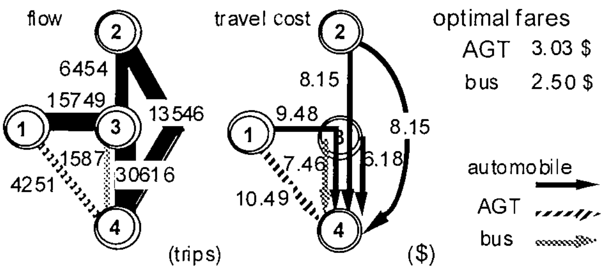

Figure-3 Flow pattern and travel-costs for Case A

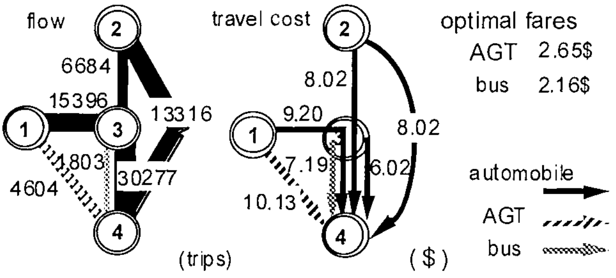

Figure-4 Flow pattern and travel-costs for Case B

The optimal subsidy analysis for AGT system

The subsidy for AGT construction is collected as automobile tax in the previous example. In this section we examine the optimal pricing including taxation for automobile users. Two king of automobile taxes are collected by central government and local government. The main purpose of this section is to compare folowing two financial institutions. The first is the present subsidy institution in Japan. The second is a new tax system that local gevernment imposes additional optimal payment for introduction of AGT system on automobile users only traveling the city area.

The proposal of payment of a new tax system for automobile users

In Japan, subsidy ratio for the construction costs of AGT system is decided as 54.4% of the total construction cost so as to be compatible with the subway construction system: the financing system has no economical significance. On the other hand, in European countries, nearly all the construction costs of urban transit operated by public agencies are subsidized. The reason is that a transit operation agency cannot offset the high construction costs by only own revenues. In some countries the subsidies are collected from automobile users as fuel tax in a similar way as Japan, but the ratio is higher than in Japanese institution.

Essentially, the ratio must be .determined to realize optimal share of demand between road network and public transits to maximize a social welfare. The present Japanese subsidy institution is not clear in the sense who loads for AGT construction and who enjoys the benefits with reduction of road congestion because earmarked funds is collected uniformity from all automobile users. The reduction of road congestion which is caused by introduction of urban transits, is generally restricted to only the urban area. In other wards, the beneficiaries of automobile user are limited to travelers in the city area.

From the above point of view we propose a new taxation system, "urban transportation tax", to improve Japanese financial institution. The tax is levied by the local government from automobile users only who travel the city area as fuel tax, and which is separately collected from the automobile tax levied by the central government. The system is outlined in Fig. 5. In this situation the public transportation sector who operates AGT system is subsidized by both local and central government. If this financial system can be combined with the RPE model, we can obtain the optimal balance between subsidies paid by automobile users traveling city area and the surburb area in the region, and fares paid by transit users at once.

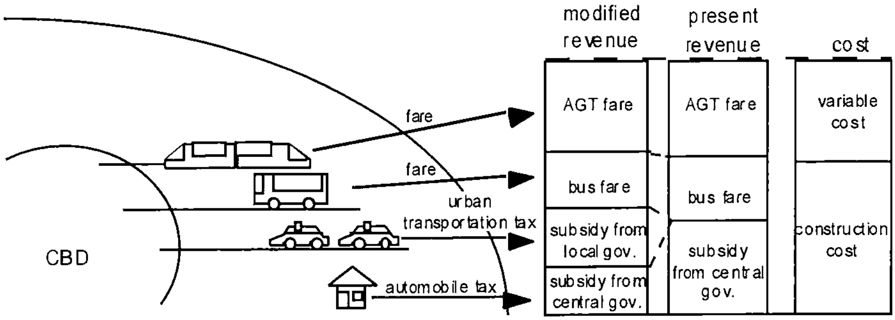

Figure-5 The AGT construction system with urban transportation tax

A numerical example corresponding to this tax system is termed as case C, which is used in the next subsection to compare with the prevailing financing system for AGT in Japan : case A in the previous section.

< case C >

In this case, the balance subtracting subsidy of central government from construction cost and the variable cost is paid by all urban transportation users. The public transit sector collects fares from transits users. The central government keeps to the present financial system. The local government levies the urban transportation tax from automobile users traveling the own city area and subsidize public sector as earmarked fund based on the urban transportation tax. The new tax system is taken into account in RPEP. The case is regarded as a extended model of the case A, and looks for optimal burden of automobile users traveling city area. We assume that the usage of fuel per one automobile trip is fixed and that then the urban transportation tax is uniformly levied on one automobile-trip. The other conditions are remained the same as the case A.

The result of optimal subsidy analysis

The results of optimal equilibrium for case C is illustrated in Fig. 6. The AGT and bus fares are 2.52 US dollar and 2.21 US dollar and optimal urban transportation tax is 0.08 US dollar. These fares are lower than the case A. The reasons are explained as follows: Even though the urban transportation tax per each vehicle is really cheap, the total amount of tax becomes very large amount because that the automobile users occupy 90% in total demand. Thus the public transportation sector gets the lots of subsidy from local government, and the break even constraint is satisfied by even small revenue from transits users comparing with case A.

Taking notice of the variation of travel cost per an auto-user, all travel costs of paths available in the case of subsidization by the urban transportation tax become lower than the case A. In particular, the travel costs of OD pair from 1 to 4 and from 3 to 4 are decrease exceedingly and the travel costs of public transit decrease greatly. Therefore the new tax system brings about a Pareto improvement and is an effective policy in this example case.

The total number of users of 777 change their mode from automobile to public transits in the city. The increase of 13% in the public transit compared with the case A, which accounts for 2% of total demand, is very small, however, the effects spread over all urban transportation system through the cut of fares and through the reduction of the traffic congestion at bottle-necks.

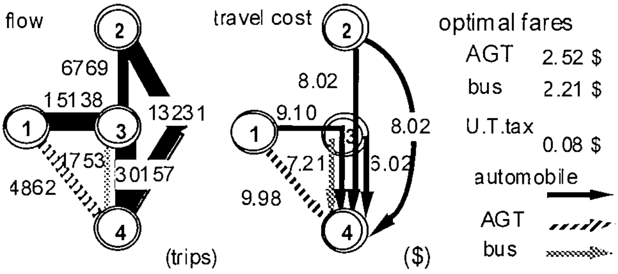

Figure-6 Flow pattern and travel-costs for Case C

Comparative analysis based on benefit incidence matrix

Benefit incidence matrix (Morisugi and Ohno, 1995) is a very useful tool for evaluating different projects. We use the method to compare the difference between the case A and the case C. The table 2, 3 correspond to the case A and C, respectively. Uer's benefit by each mode is defined as the difference of gross surplus between with and without AGT system and derived from applying eqns. (28)-(29) to each mode. The introduction of AGT is economically justified because that while the cost benefit ratio is 3.8 in the case A, the ratio of the case C is 3.1. The total benefit indicating in the lower right corner in the table goes up to 28,274 US dollar by executing the modified AGT construction institution. The case C is superior to the case A.

The first column shows the profits of the public sector. As the local government levies the urban transportation tax in the case C, the subsidy obviously increases compared with the case A. The variable cost of the case C is also increasing. The public transit sector can provide low-priced transit service with lots of customers. More precisely, since the subsidy based on 'urban transport tax' is allocated to the part of construction cost, the load of transits users for the construction cost of AGT is decreasing. In the case C the variable cost increases owing to increasing transit users. The total profits still remain the same value after modification because of the break even constraint.

The sum of subsidy ratio from local and central government is 74% for the construction cost of AGT. In the another example without subsidy from central government, the subsidy ratio is higher than the present subsidy ratio, 73% . The subsidy ratio of present institution is judged to be too small in these example.

The next five columns included in table 2 and 3 show that although total benefits of the AGT and bus users are increased, automobile user's benefit is decreased compared with before the modification. The reason is that as automobile users changes their mode to the public transit, the total benefits are decreased in spite of the increasing benefit in each automobile users.

As a conclusion of this section, it can be said that the public transits may not be functioned efficiently from the view point of total urban transportation system under the present institution.

CONCLUDING REMARKS

In this paper we applied the RPEP to the determination of optimal subsidy level for AGT system and proposed a new tax system to maximize a social welfare of total transportation system including users and producers of transport services.

The major conclusions are follows:

(1) Increasing the subsidy for AGT construction, the social welfare is increasing. The subsidy ratio in the present system in Japan bears no relation to efficiency of total urban transportation systems. We confirm the peak of social welfare associated with increasing subsidy. This implies that the optimal subsidy ratio maximizing social welfare of the system can be defined.

Table 2 The Benefits incidence matrix <case A>

agent item	public trans. sector	AGT users	bus users	automobile users			residents of outside area	local government	central government	total
				OD1-4	OD2-4	OD3-4				
construction cost	-33720	-	-	-	-	-	-	-	-	-33720
variable cost	-5462	-	-	-	-	-	-	-	-	-5462
transit fare	20913	-23563	2650	-	-	-	-	-	-	0
urban trans. tax	-	-	-	-	-	-	-	-	-	0
general tax	-	-311	-116	-1151	-1462	-615	-14615	-	18269	0
User's benefit	-	369931	-259325	-204241	11915	232724	-	-	-	151005
subsidy	18269	-	-	-	-	-	-	-	-18269	0
total	0	346058	-256791	-205392	10454	232109	-14615	0	0	111823

(u.s. $)

Table 3 The Benefits incidence matrix <case C>

agent item	public trans. sector	AGT users	bus users	automobile users			residents of outside area	local government	central government	total
				OD1-4	OD2-4	OD3-4				
construction cost	-33720	-	-	-	-	-	-	-	-	-33720
variable cost	-10666	-	-	-	-	-	-	-	-	-10666
transit fare	19442	-22259	2817	-	-	-	-	-	-	0
urban trans. tax	-	-	-	-2329	-3077	-1269	-	6675	-	0
general tax	-	-355	-128	-1106	-1462	-603	-14615	-	18269	0
User's benefit	-	436166	-240713	-247766	17443	219353	-	-	-	184482
subsidy	24944	-	-	-	-	-	-	-6675	-18269	0
total	0	413552	-238025	-251202	12904	217481	-14615	0	0	140096

(u.s. $)

(2) The new tax system, levying the urban transportation tax, improves urban transportation systems effectively. In this example, the modified tax system achieves a Pareto improvement. The proposed financing system is justified by the pointing of social-welfare view and the benefit principle for automobile users. The pricing rule based on the RPE give a tool for evaluating policies that relate the investment of urban transit with road congestion level.

Conclusions obtained in this paper is restricted in the sense that those are derived from limited numerical examples, we need a more generalized formulation to confirm the conclusion mentioned above.

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