

Miyoshi, Hiroaki

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Externalities and Taxation/Subsidization Policy of Vehicle Information and Communication System

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Externalities and Taxation/Subsidization Policy of Vehicle Information and Communication System

Hiroaki Miyoshi

Institute for Technology, Enterprise and Competitiveness
Doshisha University

Summary

VICS (Vehicle Information and Communication System) is a digital data communication system which promptly provides the latest necessary road traffic information via car navigation equipment.

In this paper, we first classified benefits of using VICS and showed that VICS unit is a good with network externality. There are two patterns for its sign of externality; it can be negative or change from positive to negative.

We then developed a simulation model based and actually measured the optimal penetration level of VICS and the level of tax/subsidy required to realize that level.

The result showed that it would be highly necessary to impose a tax on VICS units in order to realize the optimal penetration level.

1. Introduction

VICS (Vehicle Information and Communication System) is a digital data communication system which promptly provides the latest necessary road traffic information such as traffic congestions, accidents or link-travel-time to drivers via car navigation equipment. Drivers can receive real-time road traffic information about congestion and regulation 24 hours a day, 7 days a week. The world's first VICS service started in Japan in April 1996.

Researchers from various countries have conducted a number of computer simulations in order to examine the extent to which such provision of traffic information can save travel-time of users of information and non-users. Many studies aimed at measuring the impact of traffic congestions, information penetration level or quality of information and etc. on the travel-time, by setting hypothetical O-D pair as well as road network and formulating route choice behaviors both for users and non-users¹.

Among such studies, Ben-Akiva et al.(1991), Emmerink et al.(1995), Koutsopoulos and Lotan(1990), Mahmassani and Jayakrishnan(1991), Yang (1999) have focused on the impact of traffic information penetration level on travel-time, which will be examined in this paper. In these studies, various penetration levels have been exogenously set and the impact on travel-time for both users and non-users has been measured and it has been concluded that the penetration level has a large impact on travel-time for both users and non-users.

As studies aiming at measuring the market penetration level of traffic information as the endogenous variable of model, by formulating the demand curve and the supply

curve for traffic information, Emmerink et al.(1994) was the first study which discussed its framework. Yang (1998), Yang (1999), Yang and Meng (2001), Yin and Yang (2003) have then conducted its actual modeling.

In Yang (1998), it has been indicated that service users deterministically travel along the shortest route to their destination based on the traffic information provided, while non-users stochastically choose travel routes based on the logit choice. The benefit for users is the margin between the travel-time of users and that of non-users and the demand curve for traffic information has been formulated as a logit model whose explanatory variable is the margin of travel-time. Yang and Meng (2001) has modified this model to a dynamic model and Yin and Yang (2003) has extended its research targets to cases where users choose their routes by considering the quality of information.

On the other hand, Emmerink et al.(1996) and Zang and Verhoef (2005) have argued about the traffic information in terms of economic welfare. Zang and Verhoef (2005) employed a model which has been developed from the model studied in Emmerink et al. (1996). In their study, benefits of traffic information have been classified into two categories of benefits, which are the decision-making benefit and the travel-time saving benefit (the decision-making benefit is the benefit which drivers can enjoy when he/she can obtain complete information on traffic congestion ahead of travel and can thus make an appropriate decision in deciding to travel or not. The travel cost benefit is the benefit of reduction of travel-time) and the demand curve for information has been derived under the assumption that the former being benefits belong to users. Meanwhile, the supply curve for information has been derived under the assumption that the information is provided by a monopoly firm. The information penetration level has been calculated as the point at the intersection of the demand curve and the supply curve. Based on that, they have calculated the economic welfare level (decision-making benefit and travel-time saving benefit) and analyzed the impact of the provision of subsidies to the monopoly firm on the economic welfare.

As explained above, there have been several researches on the penetration level of traffic information. However, the penetration level analyzed in researches above is the purchase rate of the traffic information on specific route, under the assumption that traffic information on certain O-D pairs and road networks are onerously provided by a private company.

In this paper, we will discuss about the optimal penetration level of VICS in terms of economic welfare as discussed in Emmerink et al. (1996) and Zang and Verhoef (2005). However, our focus will be put on the penetration level of VICS-enabled car navigation system to receive traffic information from VICS (hereinafter, 'VICS unit'). It is because, as explained below, if a driver purchased a VICS unit, he or she will be able to receive traffic information for free and there is no point to consider the problem of penetration levels for individual routes. In analyzing the penetration level of VICS unit, two points of view, which are different from those in previous studies, will be important. The first point is the network externality that VICS unit has and the second is the problem of dynamic stability of penetration level, attributed to its network externality.

In this paper, we will first classify benefits of using VICS and show that the VICS unit is a good with network externality and there are two patterns for its sign of externality, which are negative or positive to negative.

We will then develop a simulation model and calculate the optimal penetration level and the amount of taxes and subsidies required to accomplish that standard.

2. Outline of VICS and benefits from VICS

In this section, we will review the outline of VICS and characteristics of benefits of this service.

2.1. Outline of VICS service

As explained above, VICS (Vehicle Information and Communication System) is a system to provide traffic information such as traffic jams, accidents or link-travel-time to drivers in real time, through on-board car navigation system. Information will be displayed on the map of the car navigation screen, as overwriting. This system is managed by VICS center, which has been jointly established by National Police Agency, Ministry of Posts and Telecommunications, Ministry of Construction and private firms in 1995. Its service started in 1996, first in the metropolitan area. Its service has been gradually extended to other areas and the service has been provided throughout Japan since February 2003.

There are three methods for providing traffic information edited and processed in VICS center; 1) information transmission through radio beacons, devices installed on highways, 2) information transmission through infrared beacons, devices on major open roads and 3) FM multiplex broadcasting by FM stations. Among them, information on traffic jams and travel-time on open roads is provided through infrared beacons and FM multiplex broadcasting. While the latter provides wide-area information covering the whole prefectural area where the FM station concerned is located, infrared beacons can provide high-precision information as far as 30 km ahead and 1 km behind from the car.

VICS unit needs to be installed in order to receive traffic information by VICS. Two types of VICS units are currently sold on the open market. One receives only FM multiplex broadcasting and the other can receive information from beacons (radio/optical) all together (this kind of device is called ‘three-media-receiver’).

Traffic information for VICS is collected through devices installed on roads, such as vehicle detectors. It should be noted that the infrared beacon explained above not only has the function to transmit information to VICS units but also has the function as vehicle detector. The characteristic of the infrared beacon is that it can identify individual vehicles by receiving information on ID numbers from vehicles equipped with three-media-receiver, while other vehicle detectors, such as ultrasonic vehicle detectors and microwave vehicle detectors, merely detect every vehicle and its speed cross-sectionally. It will be thus possible for the infrared beacon to provide information with higher-precision on link-travel-time, as it can calculate the time required to travel between one infrared beacon and the next one.

Users can receive information by VICS if they have purchased a VICS unit and paid 315 yen (consumption tax of 15 yen included) as reception fee. Apart from that, users do not need to pay additional charges to use VICS.

2.2 Benefits from VICS and its feature

We will now explain about benefits which will be brought to the society by using VICS.

2.2.1 Categories of benefits and their attributions

Benefits of VICS will be categorized into two benefits, which are benefits belonging to drivers and benefits of environment improvement.

Among benefits belonging to drivers, the travel-time saving benefit, which can be realized by avoiding traffic congestions temporally and spatially, is the most important. In the same time, when the traveling speed has been increased by avoiding traffic congestions, we can also have benefits of energy reduction (Travel cost saving benefits).

Such benefits can be enjoyed not only by vehicles equipped with VICS unit but also by vehicles without VICS unit, as traffic congestions that vehicles without VICS suffer will be relieved when vehicles equipped with VICS unit disperse their travel time and routes. In addition, there will be also the decision-making benefit for vehicles equipped with VICS unit, that will allow drivers to make an appropriate decision in deciding to travel or not.

Concerning to benefits of environment improvement, there are two types of benefits, which are the benefit of reducing air-pollution substances such as NO_x or PM and the benefit of reducing emissions of carbon. The former means the decrease of health damages of city populations residing along major roads or the reduction of acid rain. The latter means the prevention of global warming.

2.2.2 Feature of travel-time saving benefits

We will then clarify the feature of VICS benefits, focusing on its travel-time saving benefits.

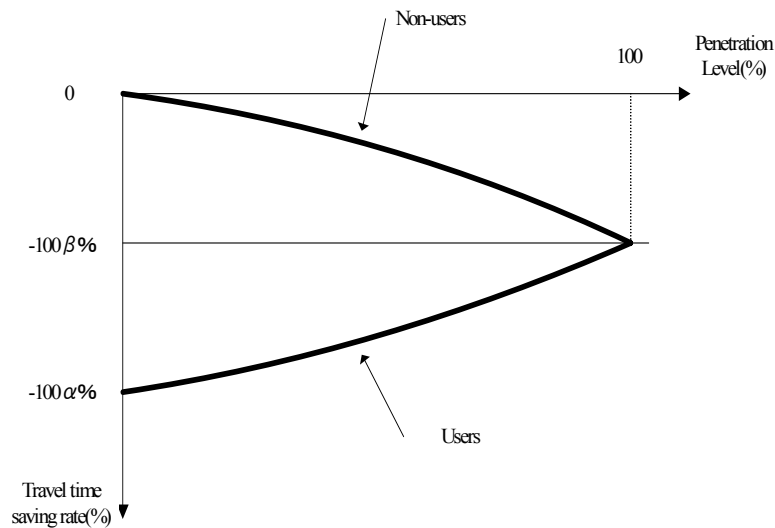
a) Relation between the penetration level and the travel-time saving rate

As explained above, many studies have been done as to the relation between the penetration level of traffic information and the travel-time saving rate for information users and non-users. Here, we will study the relation between the penetration level and the travel-time saving rate in two cases as in Figure 1 and Figure 2, in accordance with Emmerink et al. (1994).

Concerning non-users, both in Figure 1 and Figure 2, the travel-time saving rate increases, as the penetration level of traffic information increases. This is because the traffic will be temporally and spatially dispersed as the number of information users increases, and traffic congestions on routes or hours that non-users choose will be gradually relieved.

Regarding information users, in Figure 1, the travel-time saving rate decreases as the penetration level increases. Let's throw a short look at an example where there are two

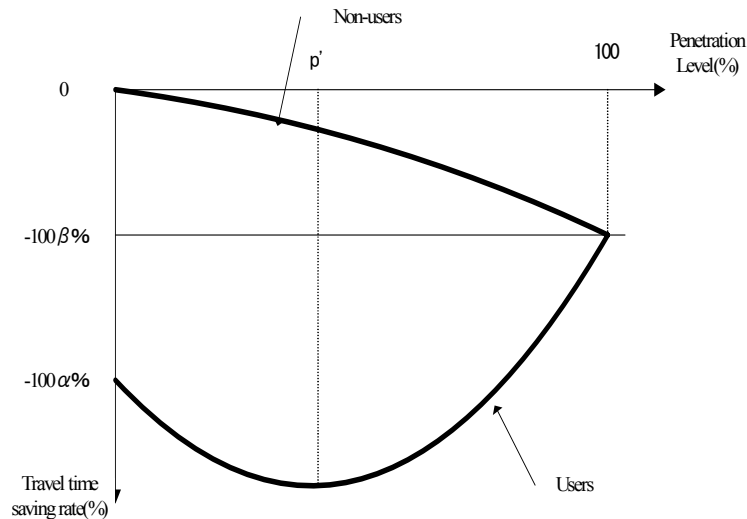
routes, A and B, to travel from a departure point to a destination and the route A is more congested than the route B. In such case, information users will choose the route B, based on traffic information. However, the number of vehicles choosing the route B will be more numerous as the number of information users increases. As a result, the route B will be gradually congested. The maximum travel-time saving rate for information users will be thus realized when the number of other users is zero and the travel-time saving rate will decrease as the number of information users increases. Figure 1 shows such phenomenon.



Prepared by authors, referencing Emmerink et al. (1994)

Figure 1 Relation between the penetration level and the travel-time saving rate (1)

On the other hand, in the case in Figure 2, the slope of the curve for the travel-time saving rate for information users turns from positive to negative at the penetration level p' . This will occur when traffic information is collected through on-board devices. It is because, when the penetration level of on-board device remains low, traffic information will more precise when the penetration level of device augments and information from on-board devices increases. However, when the penetration level became higher than the boundary penetration level, further increase in number of users will have an effect to cause traffic congestions on alternative routes, rather than the improvement of precision of traffic information. It is thus considered that, in such case, the travel-time saving level for information users will decrease, as the penetration level increases.



Prepared by authors, referencing Emmerink et al.(1994)

Figure 2 Relation between the penetration level and the travel-time saving rate (2)

For the relation between the penetration level of VICS and the travel-time saving rate, these will be also two cases as in Figure 1 and Figure 2. ⁱⁱ

As explained above, in VICS, infrared beacons estimate precise travel-time by uplink information from three-media-receiver VICS units.

With regard to this link-travel-time, as the number of three-media-receiver VICS units increase, it will be possible to collect more information covering wide areas and traffic information by VICS will be thus more precise. If infrared beacon contributes the most to the reduction of travel-time among three VICS Medias, the relation between the penetration level of VICS unit and the travel-time saving rate will be generally indicated like in Figure 2.

On the other hand, 70-80% of VICS currently used are said to be one-media-receiver VICS, which receive only FM multiplex broadcasting. In that case, the contribution of infrared beacons to the reduction of travel-time will not be that important and it will be highly possible that relation between the penetration level of VICS unit and the travel-time saving rate will be generally indicated like Figure 1.

b) Classification of travel-time saving benefits based on attributions

We will then classify travel-time saving benefits by VICS, based on their attributions. Figure 3 classified travel-time saving benefits under the assumption that the relation between the penetration level of VICS and the travel-time saving rate is as in Figure 1. First of all, two heavy-line curves in Figure 3 show the travel-time saving benefit for one vehicle equipped with VICS unit compared to the penetration level of 0% and the travel-time saving benefit for one vehicle without VICS unit. In order to simplify the discussion, travel-time and time value is set as equal for all drivers. The travel time saving rate for vehicles equipped with VICS unit decreases as the penetration level increases. Therefore, the travel-time saving benefit for one vehicle equipped with

VICS unit will gradually decrease. On the other hand, as the travel time saving rate for vehicles without VICS unit increases as the penetration level increases, the travel-time saving benefit for one vehicle without VICS unit will gradually increase.

The travel-time saving benefits for the society at the penetration level of p will be classified into 3 categories; 2 benefits belonging to vehicles equipped with VICS unit (Figure 3: '(i)Benefit for vehicles equipped with VICS, which will be evaluated in the market', '(ii)Benefit for vehicles equipped with VICS, which will not be evaluated in the market') and 1 benefit belonging to vehicles without VICS unit (Figure 3: '(iii)Benefit for vehicles without VICS unit').

Firstly, concerning the benefits belonging to vehicles equipped with VICS unit, the total amount is equal to the product of the travel-time saving benefit for one vehicle equipped with VICS unit compared to the penetration level of 0%, the penetration level and the number of vehicles in the whole society. This benefit is composed of two categories of benefits, which are 1) the benefit which will be a subject of market's evaluation and 2) the benefit which will not be subjected to the market's evaluation. '(i)Benefit for vehicles equipped with VICS, which will be evaluated in the market' will be indicated as the product of the margin between the travel-time saving benefit for one vehicle equipped with VICS unit and that for one vehicle without VICS, the penetration level and the number of vehicles in the whole society. It is because the market value of VICS unit is assessed by the travel-time saved by vehicles equipped with VICS in comparison with that of vehicles without VICS and it will not be assessed by the margin compared to the penetration level of 0%. As the relation between the penetration level of VICS and the travel-time saving rate is assumed as Figure 1, the margin between the benefit for a vehicle with VICS and one without VICS will decrease in a monotone and the margin attains its maximum level when the penetration level is zero and the margin became zero when the penetration level is 100%. However, if the relation between the penetration level of VICS and the travel-time saving rate is assumed as Figure 2, the margin between the benefit for one vehicle equipped with VICS and that of one vehicle without VICS will increase up to a certain penetration level (boundary penetration level) and will then decrease in a monotone and the margin will become zero when the penetration level is 100%.

Secondly, among benefits belonging to vehicles with VICS unit, '(ii)Benefit for vehicles equipped with VICS, which will not be evaluated in the market' will be indicated as the product of the travel-time saving benefit for one vehicle without VICS unit compared to the penetration level of 0%, the penetration level and the number of vehicles in the whole society. It is because vehicles equipped with VICS unit can enjoy not only the benefit in (i) but also travel-time saving benefits that vehicles without VICS enjoy. This benefit increases in a monotone as the penetration level augments.

Finally, as to '(iii) Benefit for vehicles without VICS unit', this is equal to the product of the travel-time saving benefit for one vehicle without VICS unit compared to the penetration level of 0% , (1-penetration level) and the number of vehicles in the whole society.

As discussed above, travel-time saving benefits for the society by VICS can be classified into 3 categories.

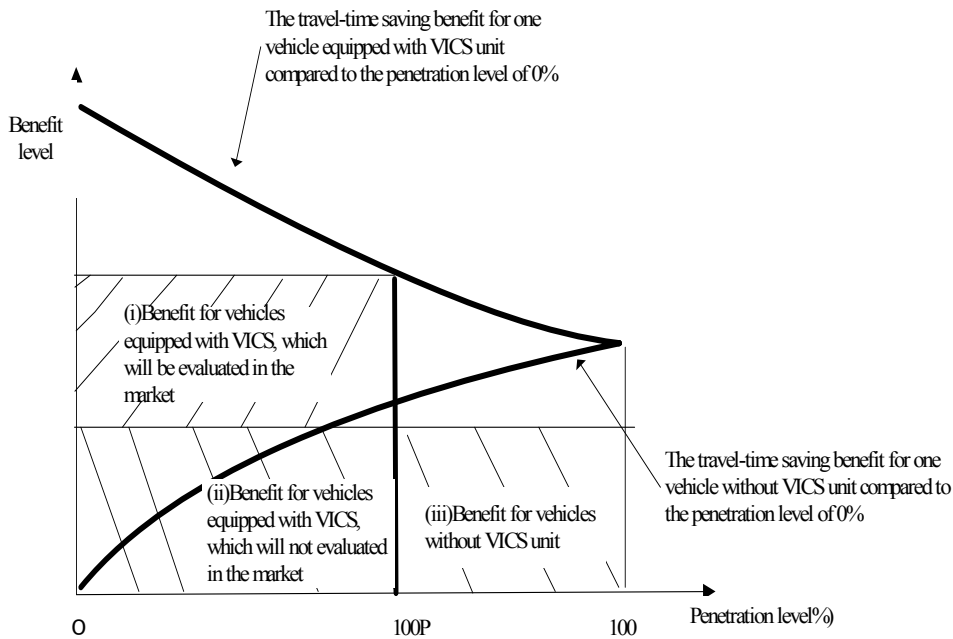


Figure 3 Penetration level of VICS and travel-time saving benefits

c) Travel-time saving benefits and network externality

When the benefit that individuals can enjoy from a good or a service depends on the number of individuals consuming the good or service, the good or service concerned has network externalityⁱⁱⁱ. The network externality is a notion used normally when the sign of externality is positive, c'est-a-dire, when the benefit that individuals can enjoy from a good or a service increases as the number of individuals consuming the good or service augments. However, in this paper, we will use this notion regardless of its sign of externality.

Among benefits belonging to vehicles equipped with VICS, the first benefit, that is, '(i)Benefit for vehicles equipped with VICS, which will be evaluated in the market' is the benefit related to the network externality of VICS unit. If the relation as in Figure 1 can be established between the penetration level of VICS unit and the travel-time saving rate, the benefit by VICS evaluated in the market (margin between the travel-time saving benefit for one vehicle equipped with VICS unit and that for one vehicle without VICS) will decrease in a monotone as the penetration level increases. In such case, VICS unit is a good with network externality whose sign of externality is negative. In contrast, if the relation as in Figure 2 can be established between the penetration level of VICS and the travel-time saving rate, the benefit by VICS evaluated in the market (margin between the travel-time saving benefit for one vehicle equipped with VICS unit and that for one vehicle without VICS) will increase up to the boundary penetration level and will then decrease in a monotone and it will become zero when the penetration level attains 100%. In such case, VICS unit is a good with network externality whose sign of externality turns from positive to negative at the boundary penetration level.

In ‘3 Simulation of the optimal penetration level of VICS and the level of tax/subsidy’, we will run a simulation on the penetration level of VICS unit and the travel-time saving rate based on the pattern in Figure 1, assuming the sign of externality is negative.

3. Simulation of optimal penetration level of VICS and the level of tax/subsidy

In this section, we will simulate how benefits of VICS, the market penetration level, the optimal penetration level and the tax/subsidy rate required to realize the optimal penetration level change, depending on travel-time saving effects of VICS. First of all, we will explain about the framework of the simulation model.

3.1 Simulation model

3.1.1 Framework

a) Target benefits of simulation

Among benefits explained in the section 2 ‘Outline of VICS and benefits from VICS and its feature’, the travel-time saving benefit enjoyed by both of vehicles equipped with VICS unit and vehicles without VICS unit will be the object of this simulation.

b) Types of vehicle

We have categorized vehicles into 4 types, which are passenger vehicles, mini trucks, small trucks and standard trucks, and set different travel distance distributions and time values for each category of vehicle to calculate the travel-time saving benefit. In principle, we have referred to the Japanese statistical data of 2002 and 2003 in setting travel distance distributions and times values.

c) Relation between the penetration level of VICS unit and the travel-time saving rate

We assume that the reduction of travel-time would be realized only when vehicles equipped with VICS unit drive on the general roads of urban areas^{iv}, and it would not be realized in other areas. As to the relation between the penetration level of VICS unit and the travel-time saving rate, under the assumption that the sign of externality is negative as in Figure 1, we have set several values for α and β as well as for curvatures to conduct our simulation. It should be noted that the travel-time saving rate in Figure 1 shows the expected value of travel-time saving and the actual travel-time saving rate will be distributed stochastically.

d) Decision making in purchasing the VICS unit

We assume that each individual has complete information on the relation between the penetration level of VICS unit and the expected value of travel-time saving and purchases a VICS unit when the expected value of personal benefit by the vehicle equipped with VICS (‘Benefit for vehicles equipped with VICS, which will be evaluated in the market’ in Figure 3) exceeds the cost of purchasing a VICS unit.

e) **Change in the traffic volume by the penetration of VICS unit**

As VICS reduces the generalized cost of travel, it can be reasonably considered that the penetration of VICS increases the traffic volume. In this paper, however, in order to simplify the model, we will conduct a simulation under the assumption that VICS does not affect the traffic volume.

3.1.2. Model

The simulation model and values of parameters are as follows.

a) **Distribution of travel-time costs in urban areas**

We assume that the distribution of travel-time costs in urban areas of vehicles j ($j \in \{c, l, s, b\}$ c : passenger vehicles, l : mini trucks, s : small-sized trucks, b : standard trucks) are lognormally-distributed as follows.

Passenger vehicles

We assume that the travel distance of a passenger vehicle ($j=c$) and the time value of an individual are independent and lognormally-distributed. Under this assumption, the travel-time cost of passenger vehicle in urban is lognormally-distributed as below.

$$d_c(x_c) = \frac{1}{\sigma_{x_c} x_c \sqrt{2\pi}} \exp\left[-\frac{(\ln x_c - \mu_{x_c})^2}{2\sigma_{x_c}^2}\right] \dots \dots (1)$$

$$\mu_{x_c} = \eta_{d,c} + \ln \lambda_c - \ln v + \eta_{w,c}$$

$\eta_{d,c}$: Calculated from the national average and median of monthly travel distance^v, under the assumption that monthly travel distance is lognormally-distributed.

λ_c : National average of the percentage of travel on general roads of urban areas in the whole travel distance^{vi}.

v : The average traveling speed on general roads in urban areas^{vii}.

$\eta_{w,c}$: Calculated from the national average and median of time value under the assumption that the time value is lognormally-distributed. We have calculated the average and the median of time value based on the distribution of annual income^{viii} and the average annual working hours^{ix} across the country.

$$\sigma_{x_c} = \sigma_{d,c_i} + \sigma_{w,c}$$

σ_{d,c_i} : Calculated from the national average and median of monthly travel distance, as $\eta_{d,c}$.

$\sigma_{w,c}$: Calculated from the national average and median of time value, as $\eta_{w,c}$.

Table 1 Values used for the calculation of parameters of the distribution of travel-time costs for passenger vehicles.

μ_{x_c}	$\eta_{d,c}$	$\eta_{w,c}$	λ_c	v	σ_{x_c}	σ_{d,c_i}	$\sigma_{w,c}$
9.725	5.659	8.033	0.423	22.343	1.422	0.909	0.513

Mini trucks, small trucks and standard trucks

We assume that the travel distance of each truck ($j \in \{l, s, b\}$) is lognormally-distributed. Under this assumption, the travel-time cost in urban areas follows a lognormal distribution as below. While we have assumed that the time value is lognormally distributed for passenger vehicles, we set a certain time value for each type of truck.

$$d_j(x_j) = \frac{1}{\sigma_{x_j} x_j \sqrt{2\pi}} \exp\left[-\frac{(\ln x_j - \mu_{x_j})^2}{2\sigma_{x_j}^2}\right] \quad j \in \{l, s, b\} \dots \dots (2)$$

$$\mu_{x_j} = \eta_j + \ln \lambda_j - \ln v + \ln w_j$$

η_j : Calculated from the national average and median of monthly travel distance^x, under the assumption that the monthly travel distance for vehicle j is lognormally-distributed.

λ_j : National average of the percentage of travel on general roads of urban areas in the whole travel distance which is assumed to be common to each vehicle type.

v : Traveling speed. (Same of passenger vehicles)

w_j : Time value. We have employed the value in ‘Cost-Benefit Analysis Manual’ by Ministry of Land, Infrastructure and Transport^{xi}, under the assumption that the time value is common for all vehicles of the same type.

σ_{x_j} : Calculated from the national average and median of monthly travel distance for vehicle j , as η_j .

Table 2 Values used for the calculation of parameters of the distribution of travel-time costs for trucks

Type of vehicle	μ_{x_j}	η_j	λ_j	v	w_j	σ_{x_j}
Mini truck ($j=l$)	10.219	6.166	0.377	22.343	3,409	1.233
Small truck ($j=s$)	10.782	6.729	0.377	22.343	3,409	1.023
Standard truck ($j=b$)	12.638	8.183	0.367	22.343	5,246	0.339

b) The travel-time saving rate

We have formulated the expected value of the travel-time saving rate for vehicles equipped with VICS unit $rt_{with}(p)$ as a following quadric.

$$rt_{with}(p) = 2(\alpha - \beta)(1 - 2\theta_{with})p^2 + (\beta - \alpha)(1 - 4\theta_{with})p - \alpha : \alpha > \beta \dots\dots(3)$$

Under this formulation, the travel-time will be reduced by $100\alpha\%$ at the penetration level 0, $100(\alpha - (\alpha - \beta)\theta_{with})\%$ at the penetration level 0.5 and $100\beta\%$ at the penetration level 1.

On the other hand, we have formulated the expected value of the travel-time saving rate for vehicles without VICS unit $rt_{without}(p)$ as below.

$$rt_{without}(p) = 2\beta(2\theta_{without} - 1)p^2 + \beta(1 - 4\theta_{without})p \dots\dots(4)$$

Under this formulation, the travel-time will not be reduced at the penetration level 0 but will be reduced by $100\beta\theta_{without}\%$ at the penetration level 0.5 and $100\beta\%$ at the penetration level 1 (the same rate as vehicles with VICS).

θ_{with} and $\theta_{without}$ are parameters which respectively determine the curvatures of $rt_{with}(p)$ and $rt_{without}(p)$. Here, we set a standard case where $rt_{with}(p)$ and $rt_{without}(p)$ became liner and 8 other cases for comparison. Table 3 shows values of θ_{with} and $\theta_{without}$ for the standard case as well as for comparative cases. In the interval of $0 \leq p \leq 1$, $rt_{with}(p)$ will be a monotonically increasing function and $rt_{without}(p)$ will be a monotonically decreasing function for all cases.

Table 3 Values of θ_{with} and $\theta_{without}$ for the standard case and comparative cases

		Value of θ_{with} for $rt_{with}(p)$		
		1/4(concave)	2/4(liner)	3/4(convex)
Value of $\theta_{without}$ for $rt_{without}(p)$	1/4(convex)	Comparative case8	Comparative case4	Comparative case6
	2/4(liner)	Comparative case2	Standard case	Comparative case1
	3/4(concave)	Comparative case7	Comparative case3	Comparative case5

Note: Concave means the concave function to the original point and Convex means the convex function to the original point.

c) Benefit for vehicles equipped with VICS

Personal benefit for vehicles equipped with VICS

The expected value of personal benefit for vehicles equipped with VICS unit at the penetration level p ('(i)Benefit for vehicles equipped with VICS unit, which will be evaluated in the market' in Figure 3) can be indicated as the product of the margin between the travel-time saving rate for vehicles with VICS unit and that of vehicles without VICS unit and the travel-time cost.

$$ben_{j,with}(p, x_j) = x_j (rt_{without}(p) - rt_{with}(p)) \quad j \in \{c, l, s, b\} \dots\dots(5)$$

Expectation equilibrium demand curve

Under a given penetration level p , the expected value of marginal personal benefit for vehicles equipped with VICS unit is common among vehicles of all types. From the formula (5), it means that, under a given penetration level p , the marginal travel-time cost for vehicles equipped with VICS units is common among vehicles of all types. If the travel-time cost is $x^* = x_c^* = x_l^* = x_s^* = x_b^*$, the expectation equilibrium demand curve LD satisfies the following formula.

$$F(p, x^*) = \frac{1}{\bar{n}} \sum_j \bar{n}_j \int_{x^*}^{\infty} d_j(x_j) dx_j - p = 0 \quad j \in \{c, l, s, b\} \dots \dots (6)$$

$$\text{Where, } \bar{n} = \sum_j \bar{n}_j$$

If we assume that the formula (6) defines implicitly the function $x^* = h(p)$, the height of expectation equilibrium demand curve LD at the penetration level p can be indicated as the function of the penetration level p as below.

$$\begin{aligned} LD(p) &= ben_{c,with}(p, x^*)|_{x^*=h(p)} \\ &= ben_{l,with}(p, x^*)|_{x^*=h(p)} \\ &= ben_{s,with}(p, x^*)|_{x^*=h(p)} \\ &= ben_{b,with}(p, x^*)|_{x^*=h(p)} \dots \dots (7) \end{aligned}$$

However, in this model, we cannot solve for $x^* = h(p)$ algebraically from the formula (6). We have thus solved for x^* with Newton method, by exogenously setting the value of p in the formula (6) and we have derived the height of the expectation equilibrium demand curve LD at the penetration level p , by putting p and corresponding value of x^* in the formula (5).

The number of vehicles \bar{n}_j used in the simulation is as in Table 4^{xii}.

Table 4 Number of vehicles for each type

Types of vehicle	Number \bar{n}_j
Passenger vehicle $j=c$	55,288,124
Mini truck $j=l$	9,600,918
Small truck $j=s$	4,804,780
Standard truck $j=b$	2,471,301

Source: Numbers of motor vehicles owned, in Information and Research Department, Policy Bureau, Ministry of Land, Infrastructure and transport, ‘Statistical Survey on Motor Vehicle Transport (2003)’

Benefits for the whole vehicles equipped with VICS unit

We can consider that the probability distribution of the margin between the travel-time saving rate for vehicles with VICS unit and that for vehicles without VICS unit ($rt_{without}(p) - rt_{with}(p)$) and the probability distribution of the travel-time cost for

each type of vehicle are independent. Therefore, the benefit enjoyed by the whole vehicles of each type $sben_{j,with}$ is equal to the definite integration, from the marginal travel-time cost for vehicles equipped with VICS unit (numeric solution of the formula (6)) to the distance ∞ , of the formula multiplying the expected value of personal benefit for each type of vehicle formulated as (5) by the probability density function of travel-time cost of each type of vehicle in formulas (1) and (2) and the number of vehicles of each type \bar{n}_j . The benefit for the whole vehicles equipped with VICS unit is the total of benefits of 4 vehicle types and will be indicated as below.

$$sben_{with}(p, x^*) = \sum_j sben_{j,with}(p, x^*) = \sum_j \bar{n}_j \int_{x^*}^{\infty} ben_{j,with}(p, x_j) d_j(x_j) dx_j \dots (8)$$

Likewise, the marginal benefit enjoyed by the whole vehicles when the number of vehicles was increased by one $msben_{with}$ (MEB curve) will be indicated as follows.

$$msben_{with}(p, x^*) = \frac{1}{\bar{n}} \sum_j \left(\frac{\partial}{\partial p} sben_{j,with}(p, x^*) - \frac{F_p}{F_{x^*}} \frac{\partial}{\partial x^*} sben_{j,with}(p, x^*) \right) \dots \dots (9)$$

$$\text{Where, } F_p = \frac{\partial}{\partial p} F(p, x^*), \quad F_{x^*} = \frac{\partial}{\partial x^*} F(p, x^*)$$

We have derived values of formulas (8) and (9) by solving for x^* with Newton method, by exogenously setting the value of p in the formula (6) and by putting p and corresponding value of x^* in formulas (8) and (9).

Dynamic stability

When every individual decides on whether he or she uses VICS unit or not every term and there is a discrepancy between the penetration level expected by peoples and the actual penetration level, whether the penetration level converges to a point on the expectation equilibrium demand curve LD depends on the slope of phase diagram.

We assume that peoples estimate a common penetration level p^e for VICS unit. If we indicate the supply price including tax/subsidy (market price of VICS unit) as c' , the travel-time cost x' for marginal VICS unit users under this expected penetration level (common level for all types of vehicle) satisfies the following formula.

$$G(p^e, x') = ben_{c,with}(p^e, x') - c' = 0 \dots \dots (10)$$

If we assume that the formula (10) defines implicitly the function $x' = l(p^e)$, the penetration level realized p can be indicated as the function of the expected penetration level p^e as below.

$$p = k(x')|_{x'=l(p^e)} = \frac{1}{\bar{n}} \sum_j \bar{n}_j \int_x^{\infty} d_j(x_j) dx_j |_{x'=l(p^e)} \dots \dots (11)$$

Then, if we assume that peoples consider the penetration level of the previous term as the expected penetration level of the present term ($p^e = p_{-1}$), the slope of phase diagram can be indicated, as the function of the penetration level in the previous term, as below.

$$\frac{dp}{dp_{-1}} = -\frac{G_{p^e}}{G_x} \frac{d}{dx} k(x') \Big|_{x'=l(p^e)} \quad p^e = p_{-1} \dots \dots (12)$$

We have derived values of formulas (11) and (12) by exogenously setting the value of p^e in the formula (10) and by putting its numeric solution x' in formulas (11) and (12).

d) Benefits commonly enjoyed both of vehicles equipped with VICS unit and vehicles without VICS unit

At the penetration level p , the expected value of the travel-time saving benefit commonly enjoyed by vehicles equipped with VICS and vehicles without VICS ('(ii)Benefit for vehicles equipped with VICS, which will not evaluated in the market' and '(iii)Benefit for vehicles without VICS unit' in Figure 3) is $-x_j rt_{without}(p)$.

We can consider that the probability distribution of the travel-time saving level for vehicles without VICS unit and the probability distribution of the travel-time cost for each type of vehicle are independent. Therefore, the benefit enjoyed by the whole vehicles of each type $sben_{j,together}$ is equal to the definite integration from 0 to ∞ , of the formula multiplying the expected value of this benefit by the probability density function of travel-time cost of each type of vehicles in formulas (3) and (4) and the number of vehicles of each type \bar{n}_j . The whole benefit $sben_{together}$ is the total of benefits of 4 types of vehicle and it will be indicated as below.

$$sben_{together}(p) = \sum_j sben_{j,together}(p) = -\sum_j \bar{n}_j rt_{without}(p) \int_0^\infty x_j d_j(x_j) dx_j \dots \dots (13)$$

Likewise, the marginal benefit enjoyed by the whole vehicles when the number of vehicles was increased by one $msben_{together}$ is as follows.

$$msben_{together}(p) = \frac{1}{\bar{n}} \frac{d}{dp} sben_{together}(p) \dots \dots (14)$$

e) Social benefit and marginal social benefit

The social benefit $smben$ is the total of the benefit for the whole vehicles equipped with VICS unit (the formula (8)) and the benefit commonly enjoyed by vehicles equipped with VICS unit and vehicles without VICS unit (the formula (13)). It will be thus indicated as below.

$$smben(p, x^*) = sben_{with}(p, x^*) + sben_{together}(p) \dots \dots (15)$$

On the other hand, the marginal social benefit $msmben$ (MSB curve) can be indicated as below, from formulas (9) and (14).

$$msmben(p, x^*) = msben_{with}(p, x^*) + msben_{together}(p) \dots \dots (16)$$

f) **Social marginal cost**

Finally, concerning the social marginal cost, as mentioned above, in the case of VICS, costs for users are limited to the cost for purchasing a VICS unit and the reception fee of 315 yen (consumption tax of 15 yen included). Apart from that, users do not need to pay additional charges to use VICS.

If we assume that the cost for a VICS unit, including the reception fee, is 200,000 yen and the tenure of use is 10.99 years^{xiii}, its monthly usage fee will be 1,519 yen. In this paper, we use this value as the social marginal cost, under the assumption of constant returns to scale.

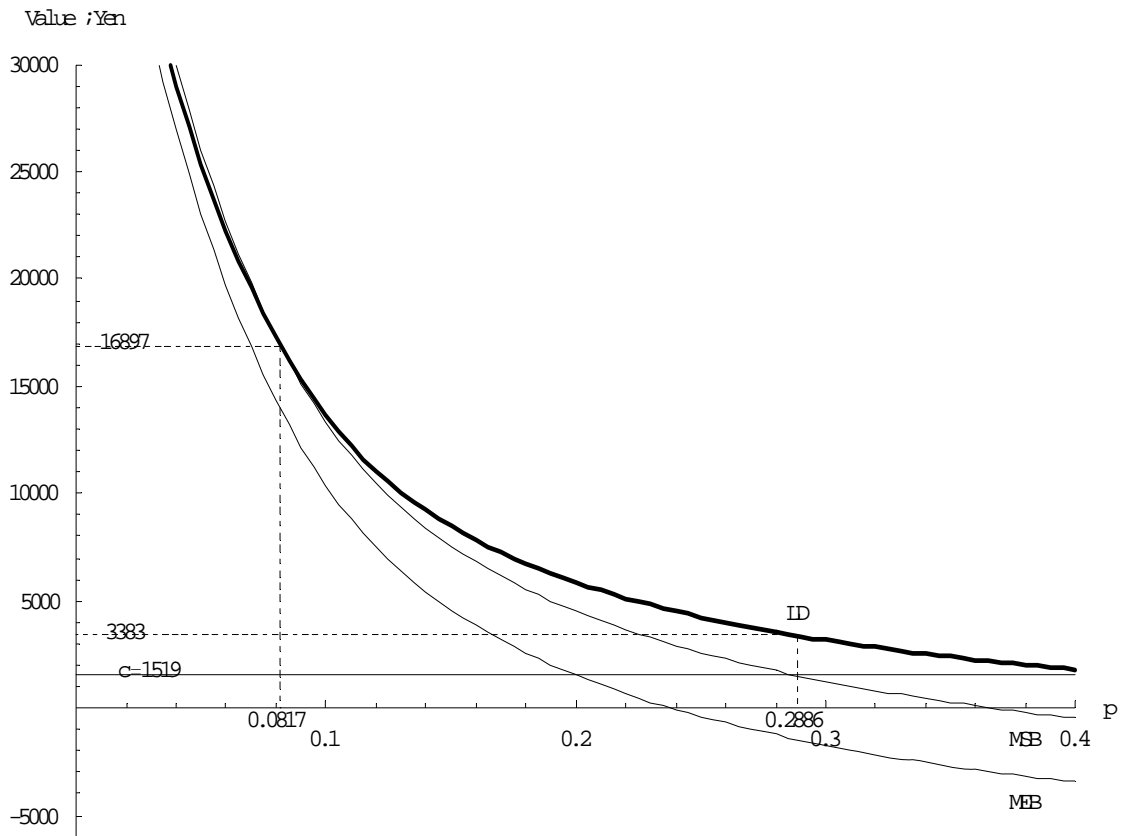
3.2. **Result of Simulation**

In the method explained above, we have simulated how benefits by VICS, the market penetration level and the optimal penetration level, as well as the rate of tax/subsidy required to realize the optimal penetration level change. Here, we will explain about the result of the standard case (case where both $rt_{with}(p)$ and $rt_{without}(p)$ are linear), unless otherwise defined.

3.2.1 **Expectation equilibrium demand curve of VICS, marginal benefit for the whole vehicles with VICS and social marginal benefit**

First of all, in order to confirm forms and the positional relation of the expectation equilibrium demand curve LD , the marginal benefit for the whole vehicles MEB and the social marginal benefit curve MSB , we have drawn their curves by setting parameters of the travel-time saving rate (α, β) as $(0.1, 0.05)$. The result is as indicated in Figure 4^{xiv}.

The intersecting point of the social marginal cost and the social marginal benefit curve MSB is the optimal penetration level. In this case, the optimal penetration level is realized when the penetration level is 28.86%^{xv}. However, at this penetration level, the expectation equilibrium demand curve LD is situated over the social marginal benefit curve MSW . It shows that the market penetration level exceeds the optimal penetration level. In order to realize the penetration level of 28.86% in the market, the user cost must be 3,383 yen. Therefore, in order to realize the optimal penetration level, we have to impose a tax of 1,864 yen, which is equivalent to the gap between 3,383 yen and the social marginal cost (1,519yen), to every VICS unit.



(100 α = 10%、100 β = 5%)

Figure 4 Expectation equilibrium demand curve *LD* , marginal benefit for the whole vehicles and social marginal benefit

3.2.2 Combination of the travel-time saving rate, the optimal penetration level, the market penetration level, the level of tax/subsidy

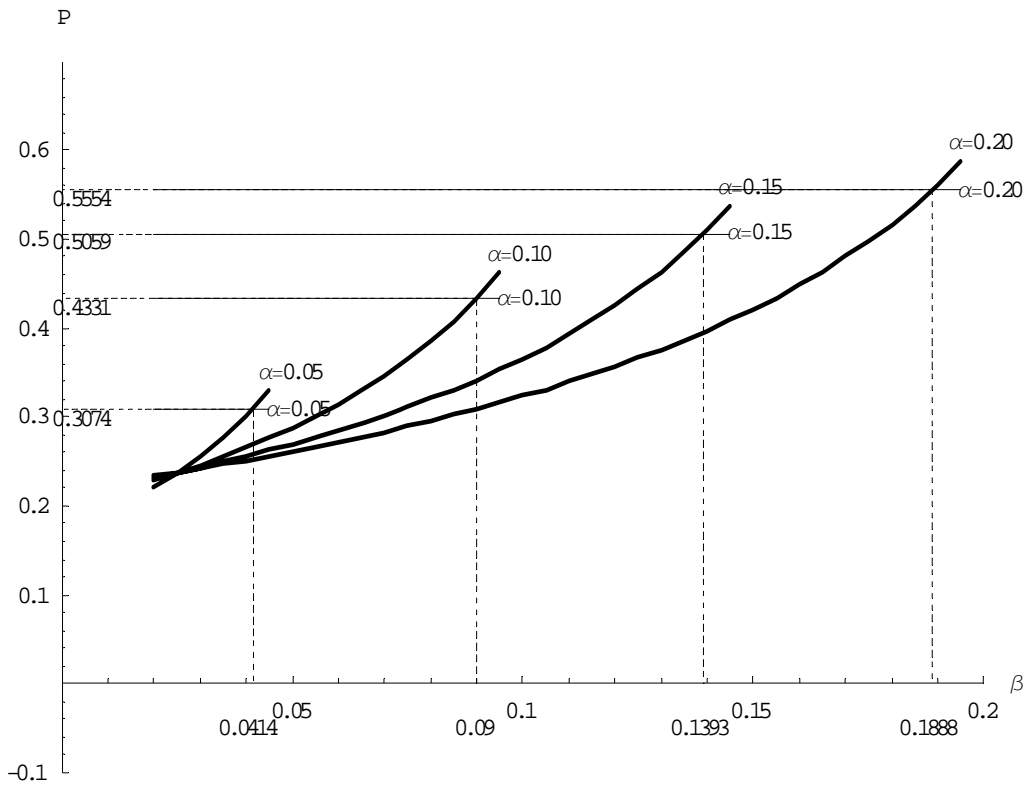
Secondly, we have set several parameters of travel-time saving rate (α, β) and calculated the optimal penetration level and the market penetration level. The result is as indicated in Figure 5. Four thin lines in Figure 5 shows how the market penetration level changes in combination with the value of β , in four cases where values of α are respectively set as 0.05, 0.10, 0.15 and 0.20^{xvi}. On the other hand, four heavy lines shows how the optimal penetration level changes in combination with the value of β , also where values of α are 0.05, 0.10, 0.15 and 0.20^{xvii}.

First of all, with regard to the market penetration level, larger the value of α is, higher the market penetration level becomes. It is because the expectation equilibrium demand curve *LD* shifts to the right side as the value of α gets larger. However, the market penetration level will not be affected by β , because, in the standard case, the margin between the travel-time saving rate for vehicles equipped with VICS unit and that of vehicles without VICS unit is neutral to the value of β . We can see such cases where the market penetration level is neutral to β in comparative cases 5 and 8. On the other hand, in comparative cases 2, 3 and 7, the market penetration level decreases

as β augments and in comparative cases 1, 4 and 6, the market penetration level increases as β augments.

Secondly, concerning the optimal penetration level, like the market penetration level, for the same α , larger the value of β , higher it becomes. It is because the effect of negative network externality weakens and the degree of the negative slope of the marginal benefit for the whole vehicles with VICS *MEB* becomes smaller, as the value of β gets larger. In addition, benefits commonly enjoyed by vehicles with VICS unit and vehicles without VICS unit ('(ii)Benefit for vehicles equipped with VICS, which will not evaluated in the market' and '(iii)Benefit for vehicles without VICS unit' in Figure 3) become larger. However, unlike the market penetration level, for the same β , the optimal penetration level decreases as the value of α augments. It is because as the gap between α and β becomes larger, the effect of negative network externality of VICS increases and the degree of the negative slope of the marginal benefit for the whole vehicles with VICS becomes larger.

Thirdly, as to the relation between the market penetration level and the optimal penetration level, when we indicate points where the market penetration level and the optimal penetration level are identical as (α, β, p) , their values are respectively (0.05,0.0414, 0.3074), (0.10,0.090,0.4331), (0.15,0.1393, 0.5059) and (0.20,0.1888, 0.5554). If the value of β exceeds these levels at each level of α , the optimal penetration level will exceed the market penetration level and we have to provide the subsidy to VICS unit in order to realize the optimal penetration level. In contrary, if the value of β is below these levels at each level of α , the optimal penetration level will be below the market penetration level, and we have to impose a tax to VICS unit in order to realize the optimal penetration level.



Note: Thin lines show the market penetration levels under parameters of travel-time saving level (α, β). On the other hand, heavy lines show the optimal penetration levels under parameters of travel-time saving level (α, β).

Figure 5 Combination of travel-time saving rate, the optimal penetration level, the market penetration level, the level of tax/subsidy

Figure 6 shows the level of tax/subsidy required to realize the optimal penetration level in combination with the value of β , in four cases where values of α are respectively set as 0.05, 0.10, 0.15 and 0.20. The positive domain of vertical line shows the imposition of tax and the negative domain shows the provision of subsidy. From this figure, we can understand that the imposition of tax is necessary to realize the optimal penetration level unless the value of β is similar to the value of α (in other words, unless the negative network externality is weak).

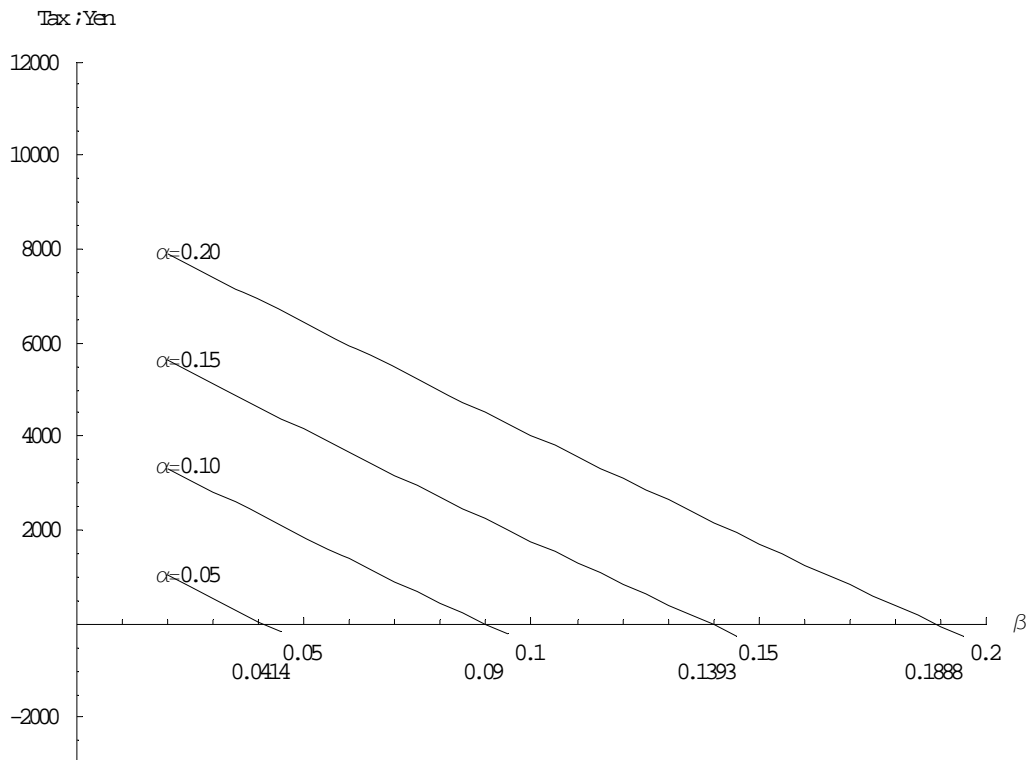


Figure 6 Combination of travel-time saving rate and tax/subsidy required to realize the optimal penetration level(1)

Furthermore, we have calculated values of β , with which the market penetration level and the optimal penetration level become equal, for 37 values of α , varying from the minimum value of 0.02 to the maximum value of 0.20 with an interval of 0.005. The heavy line in Figure 7 was drawn by connecting such points with a straight line. On the other hand, the thin line in Figure 7 is a forty-five degree line, *i.e.*, combinations of α and β where α and β are equal and the network externality becomes zero. In the domain below the heavy line, the imposition of tax is necessary to realize the optimal penetration level and in the area between the heavy line and the thin line, the provision of subsidy will be required to realize the optimal penetration level. As in Figure 6, we can understand that the imposition of tax will be necessary to realize the optimal penetration level unless the value of β is similar to the value of α (*i.e.*, unless the negative network externality is weak).

If we change points of view, combinations of α and β on the heavy line are combinations of α and β where the effect of the negative network externality to depress the marginal benefit for the whole vehicles with VICS unit (the gap between the marginal benefit for the whole vehicles with VICS MEB and the expectation equilibrium demand curve LD) and the marginal value of benefits commonly enjoyed by vehicles equipped with VICS units and vehicles without VICS unit (the gap between the social marginal benefit curve MSB and the marginal benefit for the whole vehicles with VICS MEB) are equal.

In this simulation, we have not measured the benefit of car navigation system belonging to vehicles equipped with VICS unit. However, this benefit does not have network externality. If we assume that a driver gives greater values to the car navigation system when the personal benefit calculated in this paper is larger, even if we includes the benefit of car navigation system, there will be no change in the gap between the marginal benefit for the whole vehicles with VICS MEB and the expectation equilibrium demand curve LD , as well as in the gap between the marginal benefit for the whole vehicles with VICS MEB and the social marginal benefit curve MSB . Therefore, if we include the benefit of car navigation system, three curves indicated in Figure 4 will shift to the upside, without changing relative positional relation among them. This shows the further necessity of tax imposition to realize the optimal penetration level.

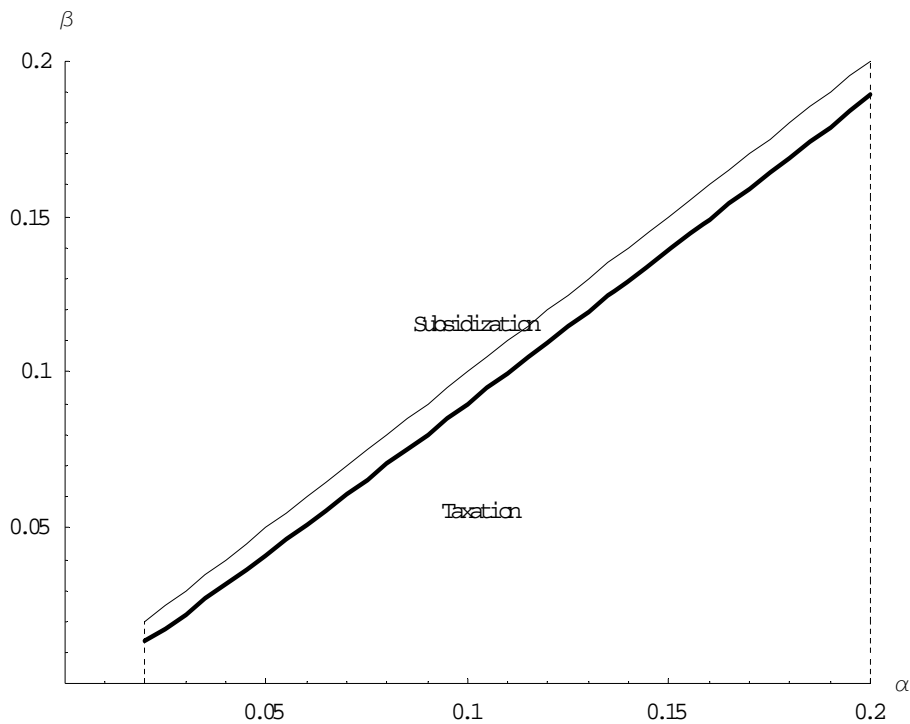


Figure 7 Combination of travel-time saving rate and tax/subsidy required to realize the optimal penetration level (2)

These are the results of the simulation for the standard case. With regard to comparative cases, Table 5 shows combinations of (α, β) for comparative cases, where the market penetration level coincides with the optimal penetration level. Table 5 indicates that, for example, in the comparative case 1, the market penetration level coincides with the optimal penetration level when $\alpha=0.05$ and $\beta=0.0433$ and its level is 30.02%. In all cases, the market penetration level coincides with the optimal penetration level when β has a value similar to α . Therefore, we can draw a same conclusion that the imposition of tax will be necessary to realize the optimal penetration level unless the value of β is similar to the value of α (i.e., unless the negative network externality is weak).

Table 5 Combinations of (α, β) where the market penetration level coincides with the optimal penetration level (Comparative cases)

	$\alpha=0.05$		$\alpha=0.1$		$\alpha=0.15$		$\alpha=0.2$	
Standard case	0.0414	(0.3074)	0.0900	(0.4331)	0.1393	(0.5059)	0.1888	(0.5554)
Comparative case1	0.0433	(0.3002)	0.0909	(0.4259)	0.1389	(0.4993)	0.1873	(0.5494)
Comparative case2	0.0383	(0.3203)	0.0892	(0.4416)	0.1398	(0.5119)	0.1902	(0.5600)
Comparative case3	0.0364	(0.2696)	0.0836	(0.3663)	0.1321	(0.4223)	0.1811	(0.4609)
Comparative case4	0.0448	(0.3573)	0.0927	(0.5018)	0.1415	(0.5801)	0.1907	(0.6310)
Comparative case5	0.0393	(0.2565)	0.0858	(0.3535)	0.1334	(0.4106)	0.1815	(0.4503)
Comparative case6	0.0459	(0.3538)	0.0926	(0.4967)	0.1399	(0.5748)	0.1875	(0.6257)
Comparative case7	0.0323	(0.2919)	0.0813	(0.3830)	0.1312	(0.4351)	0.1813	(0.4712)
Comparative case8	0.0432	(0.3631)	0.0929	(0.5067)	0.1428	(0.5839)	0.1927	(0.6340)

Note: It shows that in the comparative case 1, the market penetration level coincides with the optimal penetration level when $\alpha = 0.05$ and $\beta = 0.0433$ and its level is 30.02%.

3.2.3 Dynamic stability

Now, let's check the dynamic stability of the optimal penetration level. Four curves in Figure 8 show slopes of phase diagram at the optimal penetration level in combination with the value of β , in four cases where values of α are respectively set as 0.05, 0.10, 0.15 and 0.20. They have been derived by putting the optimal penetration level in p^e of the formula (12).

This figure shows whether the market penetration level converges to the optimal penetration level by the imposition of tax/subsidy when the expected penetration level is in the neighborhood of the optimal penetration level.

In Figure 8, for all cases, slopes of topological map are larger than -1. Therefore, when the expected penetration level is in the neighborhood of the optimal penetration level, the market penetration level will converge to the optimal penetration level.

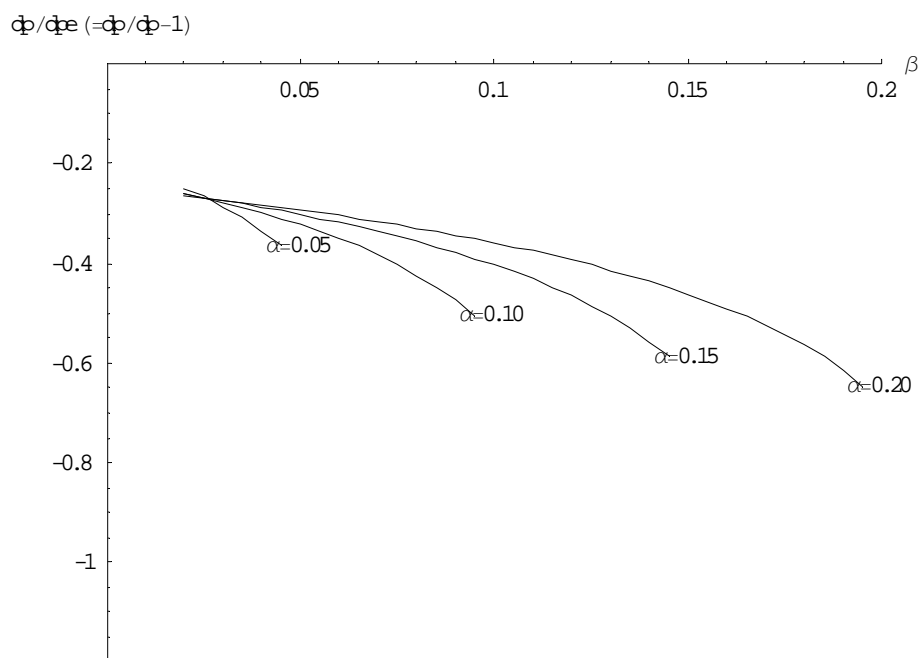


Figure 8 Combinations of travel-time saving rate and the dynamic stability of the optimal penetration level

4. Conclusion and challenges

In this paper, we first classified benefits of using VICS and showed that VICS unit is a good with network externality. There are two patterns for its sign of externality; it can be negative or change from positive to negative.

We then developed a simulation model and actually measured the optimal penetration level of VICS and the level of tax/subsidy required to realize that level. The result showed that it would be highly necessary to impose a tax on VICS units in order to realize the optimal penetration level.

We are to elaborate the measurement of the VICS benefit and its optimal penetration level. In this simulation, we have chosen the travel-time saving benefit as the object of measurement. However, as explained in 2.2.1 ‘Categories of benefits and their attributions’, other benefits, such as the travel-cost saving benefit, arise from VICS both for vehicles equipped with VICS unit and vehicles without VICS unit. Likewise, in this simulation, we have employed the cost for purchasing the VICS unit as the cost. However, in order to discuss the optimal penetration level in comparison with this cost, we have to consider the benefit of the car navigation function. In addition, apart from benefits belonging to drivers, there are benefits for the whole society, which are the benefit of reducing air-pollution substances and the benefit of reducing emissions of carbon. In the future, we need to elaborate the measurement in considering these points. Especially for the measurement of the benefit of car navigation function, we need to carry out an inquiry survey to drivers and measures its value by Contingent Valuation method (CVM).

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Notes

ⁱ Levinson (2003) has studied and summarized related researches.

ⁱⁱ As to travel-time saving by VICS, several driving experiments have been conducted in the past. In the driving experiment conducted by Universal Traffic Management Society of Japan on February 1997 in the Tokyo metropolitan area (From Shinjyuku-Sancyome to Shiba-Gocyome) , it has been reported that travel-time for vehicles with VICS unit had been saved by 4.4%, compared to that of vehicles without VICS unit. (UTMS (1997)) Likewise, in the feasibility study on ITS Model Experiment Plan that ITS Japan started in 1997 , it has been reported that travel-time in Toyota-city (From Toyota-minami to Sakaemachi) has been saved by 20 % at maximum and 10% in daily average.

ⁱⁱⁱ The notion of network externality was first proposed in Libenstein(1950), as consumption externalities such as ‘bandwagon Effect’ (positive consumption externality) and ‘Snob Effect’ (negative consumption externality). Later, it has been formulated as ‘A Theory of Interdependent Demand for a Communications service’ in Rohlfs(1974).

^{iv} ‘DID(Densely Inhabited Districts)’ and ‘other urban areas’ in “Road Traffic Census” by Ex-Road Bureau of Ministry of Construction.

^v Japan Automobile Manufacturers Association, Inc. (2003), “ Passenger Car Market Trends (March 2004)”

^{vi} Calculated based on Ex-Road Bureau of Ministry of Construction(1999), “Road Traffic Census”

^{vii} Ex-Road Bureau of Ministry of Construction (1999), “Road Traffic Census” Chart 2-1

^{viii} ‘Yearly Average of Monthly Receipts and Disbursements per Household in Fiscal Year -All Japan-‘ in Ministry of Internal Affairs and Communications (2003) , “Annual report on the family income and expenditure survey”

^{ix} Calculated from the average monthly working hours in establishments with 5 or more employees, in Ministry of Health, Labour and Welfare,”Annual Report on the Monthly Labour Survey”

^x Japan Automobile Manufacturers Association, Inc. (2002),”Small/Mini Truck Market Trends (March 2003)”and (2002) “Standard Truck Market Trends (March 2003) “

^{xi} City and Regional Development Department, Road Bureau, Ministry of Land, Infrastructure and Transport, Japan, “Draft for ‘Cost-Benefit Analysis Manual’”, August 2003

^{xii} As we can understand from the development of formula described later, the number of vehicles does not affect on the marginal value of the benefit.

^{xiii} It shows the average tenure of use of automobiles. “Trend of Japanese People ’s Possession of Automobiles 2004”, Association Automobile inspection & registration Association,

^{xiv} These curves were drawn by deriving values on the vertical axis for 80 values of p , whose values on the horizontal axis varying from the minimum value of 0.005 to the maximum value of 0.4, with an interval of 0.005 and by connecting such points with a straight line.

^{xv} At this penetration level, penetration levels for each type of vehicle are as follows; passenger vehicles 23.13%, mini trucks 32.76%, small trucks 50.48% and standard trucks 100%. The percentage of the benefit for vehicles equipped with VICS unit in the total social benefit is 81.0%, while the benefit commonly enjoyed by vehicles with VICS unit and vehicles without VICS unit is 19%.

^{xvi} This value of α has been set based on the result on previous works on the penetration level of traffic information and the level of travel-time saving.

^{xvii} We have calculated the optimal penetration level and the market penetration level for 6 patterns of (α, β) ((0.05, 0.02), (0.05, 0.025), (0.05, 0.030), (0.05, 0.035), (0.05, 0.040), (0.05, 0.045) and showed diagrammatically by connecting such points with a straight line. For the case where $\alpha=0.10$, we have calculated market penetration levels for 16 values of β varying from the minimum value of 0.02 to the maximum

value of 0.095, with an interval of 0.005 and showed diagrammatically by connecting such points with a straight line. Likewise, for cases where $\alpha=0.15$ and $\alpha=0.20$, we have calculated market penetration levels respectively for 26 values of β varying from the minimum value of 0.02 to the maximum value of 0.145 and for 36 values of β varying from the minimum value of 0.02 to the maximum value of 0.195 and showed diagrammatically by connecting such points with straight lines. Figure 6 and Figure 8 are diagrammatic representations where values are calculated in the same combinations of parameters and such points were connected with straight lines.

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