REGIONAL COMPARISON OF ENVIRONMENTAL IMPACTS OF CAR USAGE IN JAPAN

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Abstract

This paper aims to explain the regional and temporal changes of car ownership and car usage with respect to socio-economic variables and to compare environmental impacts of car usage in each region in Japan. To do so, we build a car ownership model and a gasoline consumption model for car usage using socio-economic data of each prefecture for each year from 1965 to 1993. Then we make a simulation system to estimate environmental indices of car usage such as NOx, CO and CO_2 emissions in each prefecture. This paper provides a model to explain the regional and temporal changes of car ownership and car usage in Japan and findings to show the regional differences in environmental impacts of car usage.

INTRODUCTION

The United Nations Framework Convention on Climate Change was held in Kyoto in December 1997. Based on the protocol established in Kyoto, Japan should achieve its qualified emission limitation which is 6 % reduction of carbon dioxide (CO_2) emission from base year 1990. In this background, the transport sector also faces the challenge of reducting carbon dioxide emission from automobiles. In Japan there are individual measures such as improvement of car engine and transport demand management (ex. campaign on car use reduction, promotion of public transport use and so on) . However, significant improvement in pollutant reduction has not resulted because the traffic volume of vehicles has been increasing. It is necessary to change the demand structure of car travel fundamentally. It is the only measure that can reduce CO_2 emission volume back to the 1990 levels.

There were some studies to evaluate aggregate pollutant emission volume in consideration of car demand structure in Japan. Morisugi, Ohno and Kawamata (1990) estimated NOx emission volume based on the ratio of diesel to gasoline cars. As they estimated the number of cars by using Corhort Analysis, they could estimate the entire country's value but not specific regional value. Concerning regional estimation of pollutant from vehicles, Kurokawa, Ishida and Taniguchi (1993) estimated that for the Tokyo Metropolitan area. They calculated the traffic volume and travel speed of each link of the road network by using traffic assignment simulation and calculated pollutant volume with emission rate per vehicle km by velocity. Then aggregate pollutant emission volume of each link in the whole Tokyo Metropolitan area was calculated. However, there were some problems with this approach. It can only consider a few policy variables such as car trip generation and road network because it uses the 4 step-estimation method of traffic demand forecast. Thus it cannot consider other transport and it is hard to expand the analysis area to the whole country. Hayashi et. al (1995) estimated carbon dioxide emission per city based on the modal share difference. They analyzed many cities but focused only a single measure which is change in modal share.

This paper aims to explain the regional and temporal changes of car ownership and car usage with respect to socio-economic variables and to compare environmental impacts of car usage in each region. To do so, we build a car ownership model and a gasoline consumption model for car usage using socio-economic data of each prefecture in Japan for each year from 1965 to 1993. Then we make a simulation system to estimate environmental indices of car usage such as NOx, CO and CO_2 emissions in each prefecture. Also, we examine the predicted emissions of pollutants in the year 2000 to find policies that can reduce emission levels back to 1990 values.

REGIONAL DEMAND STRUCTURE OF CAR OWNERSHIP AND USAGE

There are various factors that influence car ownership and car usage. In this paper, we focus on regional attributes and transport policies that are related to growth in car ownership and usage. This is in order to consider the regional policies that can have positive effects on the environment.

One of the reasons why there is an increase in car ownership and usage is suburbanization of housing and commercial districts in recent years. Suburbanization expands urban areas and low density areas. While this expansion of low density areas accounts for an increase in car ownership, people depend on cars exclusively as public transport becomes less convenient. We may say that improvement of population distribution and density structure is one of the important regional measures which can change car usage.

It is widely believed that road development is another strategic measure which increases or decreases car ownership and usage. Conventional road planning has been intended to satisfy road traffic demand. However, car ownership and road traffic demand also usually increase once road service level becomes higher. As a result, more road construction is required to satisfy increased demand. But road construction is never adequate to meet growing traffic demand thereby resulting in congestion. On the other hand, road development has another aspect which eases congestion and improves fuel efficiency of cars. Therefore it is important to consider how road construction in the future may affect the environmental load of car usage.

Furthermore, car usage is sensitive to gasoline price. Gasoline price control is directly measured to manage car traffic demand. However, recent gasoline prices in Japan have tended to be cheaper than they were previously. Thus, gasoline price control may become one effective measure to reduce traffic demand.

To focus the three main measures mentioned above, we must examine how such regional measures may affect the environmental load of car usage. To do so, we developed a car ownership and car usage models that can show the relationship between car demand and socio-economic attributes on a regional basis. Then, we estimated pollutant emission volumes in each prefecture in Japan. This is discussed in the following chapter.

ESTIMATION MODEL FOR ENVIRONMENTAL IMPACT DUE TO CAR USAGE

Outline of Estimation System

Indices related to environmental impact of car usage is calculated using the estimation system shown in Figure 1. Based on the regional attribute, car ownership and car usage are estimated. Considering the availability of data, car usage is represented by gasoline consumption. These models of car ownership and usage refer to Itoh and Ishida (1993, 1996 and 1997). In this system, the three measures that were used to manage traffic demand were road service level, population density and gasoline price. These are introduced as explanatory variables of car ownership and car usage models. Using the estimated value of the number of cars and gasoline consumption, pollutant emission volume due to car usage is calculated. Thus, this system can compare these measures' influences on the environmental impact.

Car Ownership Model

Our target of analysis is environmental management related to personal transportation behavior. Thus, we define car as passenger car for personal use and light vehicle. These cars have a 77.7% share in all vehicles in 1995. We build a car ownership model in which the independent variable is the number of cars per household and the dependent variables are the following factors which affect causal relations and which are related to demand management policy.

1) Income per household : This is the most important factor affecting the decision for car purchase. We calculated average income per household in each prefecture using data from the Economic Planning Agency. In order to compare along a designated time period, income variable was standardized by income deflator coefficient.

2) Road length per person : The length of constructed or improved road according to road design standard is divided by the population. This excludes expressways. This index represents the road service level for daily car trips.

3) Population density of the Densely Inhabited District (DID) : DID is defined as an area with more than 4,000 people per square kilometer based on the Japan National Census.

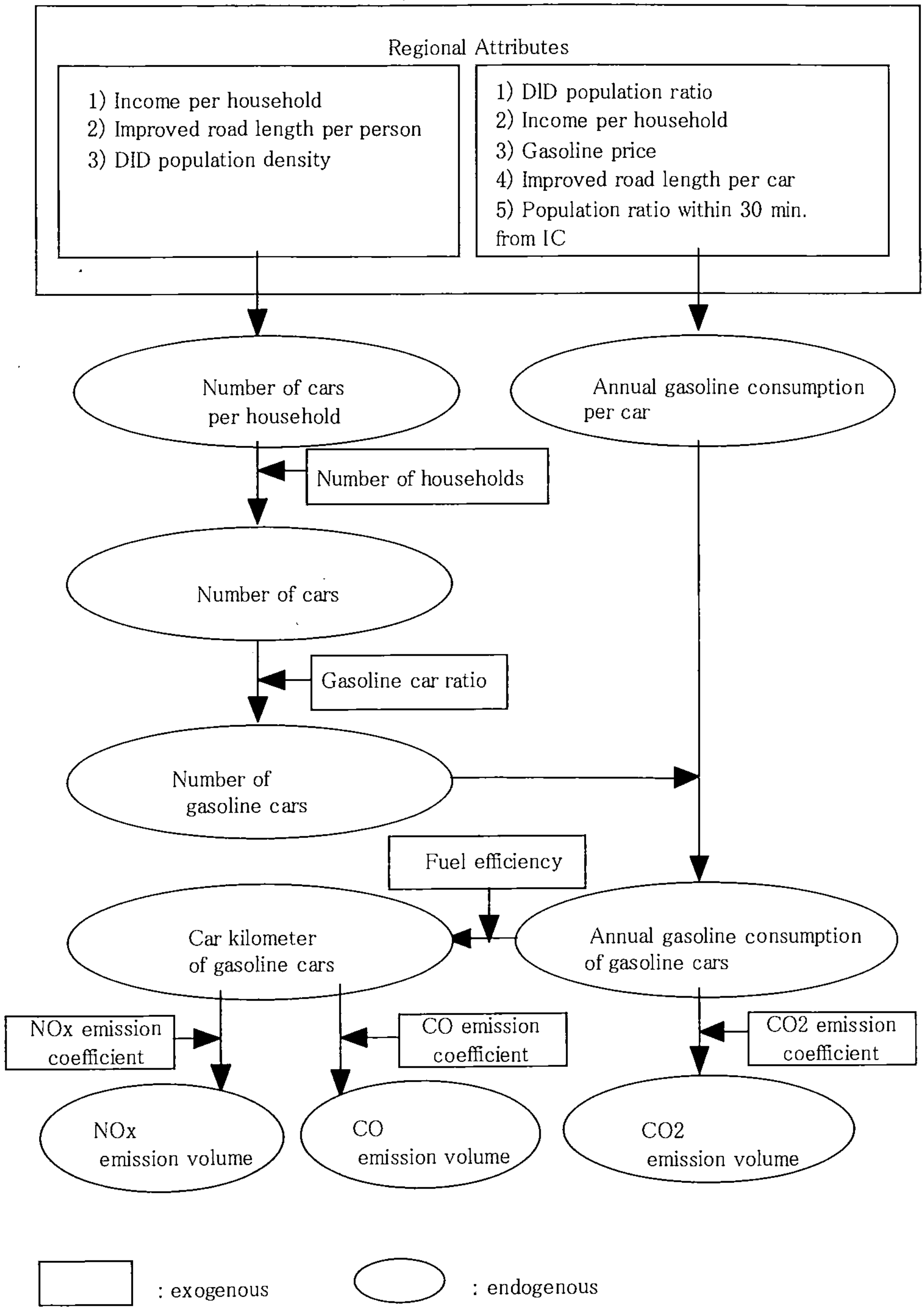

Figure 1 - Flowchart of Estimation System for Environmental Load due to Car Usage

Using data of 46 prefectures in Japan from 1965 to 1993 (1,334 samples), we apply a panel model as the Temporal Coefficient Model that takes the temporal difference of influence factors into consideration (Hsiao 1986). In this model, we apply 4 period classifications based on the preliminary analysis of car ownership and factors to describe a difference of influence from factors.

The Temporal Coefficient Model is shown as follows:

$$\underset{N\times 1}{\mathbf{y}_t} = \left(\underset{N\times(K+1)G}{[\mathbf{e}_N \mid X_t]\otimes \mathbf{p}_t}\right)\underset{(K+1)G\times 1}{\beta} + \underset{N\times 1}{\mathbf{u}_t}\ ,\quad t=1,\cdots,T. \qquad (1)$$

Where,

y : dependent variable, X : independent variable, β : coefficient, u : error term,
K : number of variables, G : number of group,
T : number of time, N : number of prefecture,
P : correspondent matrix (period and year),

$$\underset{N\times 1}{\mathbf{e}_N} = \begin{bmatrix}1\\ \vdots\\ 1\end{bmatrix},\qquad \underset{T\times G}{P} = \begin{bmatrix}\mathbf{p}_1\\ \mathbf{p}_2\\ \mathbf{p}_3\\ \vdots\\ \mathbf{p}_T\end{bmatrix} = \begin{bmatrix}1 & 0 & \cdots & 0\\ 1 & 0 & \cdots & 0\\ 0 & 1 & \cdots & 0\\ \vdots & \vdots & & \vdots\\ 0 & 0 & \cdots & 1\end{bmatrix},\qquad \underset{N\times K}{X_t} = \begin{bmatrix}x_{11t} & \cdots & x_{K1t}\\ \vdots & & \vdots\\ x_{1Nt} & \cdots & x_{KNt}\end{bmatrix},$$

and here we define $[\mathbf{e}_N \mid X_t]$ as,

$$[\mathbf{e}_N \mid X_t] = \begin{bmatrix}1 & x_{11t} & \cdots & x_{K1t}\\ \vdots & \vdots & & \vdots\\ 1 & x_{1Nt} & \cdots & x_{KNt}\end{bmatrix}.$$

In equation (1) , a group has more than one year. As there is a time series correlation between each error term, we must estimate these equations using generalized least squares (GLS). Equation (1) can be rewritten as,

$$\underset{NT\times 1}{\mathbf{y}} = \underset{NT\times(K+1)G}{[XP]}\cdot \underset{(K+1)G\times 1}{\beta} + \underset{NT\times 1}{\mathbf{u}}, \qquad (2)$$

where

$$\mathbf{y} = \begin{bmatrix}\mathbf{y}_1\\ \vdots\\ \mathbf{y}_T\end{bmatrix},\quad [XP] = \begin{bmatrix}[\mathbf{e}_N \mid X_1]\otimes \mathbf{p}_1\\ \vdots\\ [\mathbf{e}_N \mid X_T]\otimes \mathbf{p}_T\end{bmatrix},\quad \mathbf{u} = \begin{bmatrix}\mathbf{u}_1\\ \vdots\\ \mathbf{u}_T\end{bmatrix}.$$

Using GLS, the estimator of coefficient β is,

$$\hat{\beta} = \left([XP]'\Omega^{-1}[XP]\right)^{-1}[XP]'\Omega^{-1}\mathbf{y}, \qquad (3)$$

where

$$\Omega = \Sigma\otimes I_N = \begin{bmatrix}\sigma_{11} & \cdots & \sigma_{1T}\\ \vdots & & \vdots\\ \sigma_{1T} & \cdots & \sigma_{TT}\end{bmatrix}\otimes I_N, \qquad (4)$$

therefore

$$\Omega^{-1} = \Sigma^{-1}\otimes I_N. \qquad (5)$$

Since the variance-covariance matrix Σ is unknown, we use efficient estimator of σ (Zellner 1962) as,

$$\hat{\sigma}_{ts} = \frac{1}{N}\left(\mathbf{y}_t - \left([X_t \mid \mathbf{e}_N]\otimes \mathbf{p}_t\right)\hat{\beta}_{OLS}\right)'\left(\mathbf{y}_s - \left([X_s \mid \mathbf{e}_N]\otimes \mathbf{p}_s\right)\hat{\beta}_{OLS}\right), \qquad (6)$$

where

$$\hat{\beta}_{OLS} = \left([XP]'[XP]\right)^{-1}[XP]'\mathbf{y}. \qquad (7)$$

Table 1 shows an estimation result of the temporal coefficient model for car ownership. Variable coefficients of each period reflect the degree of the factors' influence. For example, income influence was high in the first period then became lower in the following periods. However, income influence became high again because peoples' income may be high enough to own more than two cars per household in a later period.

Car Usage Model : Gasoline Consumption Model

Vehicle kilometer as a representative of traffic demand has been surveyed by the Ministry of Construction and the Ministry of Transport in Japan. However, as these surveys use sampling methods, vehicle kilometers traveled in each prefecture for each year cannot be captured precisely.

On the other hand, gasoline consumption data is surveyed every year in each prefecture by the Ministry of International Trade and Industry. Fuel sources of passenger cars are gasoline, diesel oil and LPG gas. In Japan, about 90 % of passenger cars used gasoline fuel in 1990. As fuel efficiency has been stable in each region so far, gasoline consumption can be regarded as proxy for vehicle kilometer to represent car usage.

Therefore, we build a gasoline consumption model with annual gasoline consumption per car on independent variable and the following five factors which have causal effect and relate demand management policy as dependent variable.

1) DID population ratio : Population in DID is divided by the whole population. It presents the degree of population concentration as the regional structure.

2) Income per household : It is the same variable as for the car ownership model. The economic status of the household affects both car ownership and usage.

3) Gasoline price : Car usage is very sensitive to gasoline price. Regular gasoline price per liter is used.

4) Road length per car : This road length is the same as in the car ownership model. However, road service level in car usage may be affected by road space per car. Thus, road length is divided by the number of cars.

5) Ratio of population to provided expressway service : This index represents the extent of expressway service. It is measured as the population within 30 minutes from an interchange (IC) of an expressway. This aggregated population within 30 minutes from an IC is divided by the whole population.

Using data from 46 prefectures in Japan from 1965 to 1993, we again apply temporal coefficient modeling technique. In the gasoline consumption model, 5 period categories are adopted based on the preliminary analysis of gasoline consumption and factors. Table 2 shows an estimation result of the temporal coefficient model for gasoline consumption.

Estimation of Gasoline Consumption

The total number of cars is calculated from the number of cars per household (estimated from the car ownership model) and the number of households. The focus of the study is on gasoline cars, which are assumed to be 90 % of the total number of cars, the other 10% being diesel. Then, we calculate the annual gasoline consumption of gasoline cars as the product of the number of gasoline cars and gasoline consumption per car estimated from the model.

Table 1 - Estimation Result of Car Ownership Model

Car Ownership Model	Temporal Coefficient Model Coefficient	t-Value
Intercept	—	—
1965-71	0. 016	0. 536
1972-77	0. 622	13. 295
1978-82	0. 980	21. 247
1983-93	1. 062	23. 662
Income per HH	—	—
1965-71	0. 099	30. 075
1972-77	0. 059	13. 003
1978-82	0. 063	13. 689
1983-93	0. 098	27. 431
Road length per person	—	—
1965-71	0. 038	7. 188
1972-77	0. 036	6. 826
1978-82	0. 030	7. 944
1983-93	0. 027	8. 363
Population Density in DID	—	—
1965-71	-0. 029	-11. 831
1972-77	-0. 062	-15. 147
1978-82	-0. 096	-21. 623
1983-93	-0. 125	-27. 510
R bar square	0. 937	

Table 2 - Estimation Result of Gasoline Consumption Model

Gasoline Consumption Model	Temporal Coefficient Model Coefficient	t-Value
Intercept	—	—
1965-67	0. 726	2. 879
1968-74	0. 752	7. 508
1975-82	0. 992	17. 553
1983-85	0. 611	8. 433
1986-93	0. 782	8. 743
Population Ratio of DID	—	—
1965-67	0. 391	4. 633
1968-74	0. 412	8. 356
1975-82	0. 387	13. 248
1983-85	0. 333	11. 347
1986-93	0. 279	10. 882
Income per HH	—	—
1965-67	0. 000	0. 009
1968-74	0. 018	2. 247
1975-82	0. 007	1. 262
1983-85	0. 012	2. 304
1986-93	0. 010	2. 759
Gasoline Price	—	—
1965-67	-0. 058	-0. 461
1968-74	-0. 156	-3. 092
1975-82	-0. 187	-9. 282
1983-85	-0. 006	-0. 193
1986-93	-0. 107	-1. 717
Road length per person	—	—
1965-67	5. 623	12. 604
1968-74	11. 192	14. 140
1975-82	8. 494	9. 977
1983-85	5. 089	4. 929
1986-93	2. 025	2. 005
Population Ratio within 30min. from IC	—	—
1965-67	-0. 088	-1. 829
1968-74	0. 026	0. 999
1975-82	0. 027	2. 025
1983-85	0. 024	1. 529
1986-93	0. 045	2. 712
R bar square	0. 527	

Estimation of Pollutant Emission Volume

We estimate three pollutant emission volumes : CO_2, NOx and CO. CO_2 volume is calculated from the amount of gasoline consumption and unit calorific value of CO_2. We adopt a unit emission volume per gasoline consumption : 2.253 kg/liter.

Calculation of emission volumes of NOx and CO is based on car kilometers. The number of car kilometers is calculated from gasoline consumption and fuel efficiency. Then using each unit emission volume of NOx (0.510 g/car·km) and CO (3.280 g/car·km) at 30 km/h which is the average running speed, each emission volume is estimated.

REGIONAL COMPARISON OF ENVIRONMENTAL IMPACT DUE TO CAR USAGE

Policy Conditions

In this comparative study, we focus on the following regional policies to manage car usage.

1) Demand management of car usage by gasoline price control

2) Demand management by changing regional population structure

3) Positive influence of road construction on car usage

Specific conditions of each policy are shown in Table 3. The base case is in the year 1990 and a future estimate will be in the year 2000. There is an environmental target that CO_2 emission volume in 2000 will be kept at 1990 levels. The basic case is the ' do nothing ' case where current emission trends will continue. Policy cases vary each of the three values independently to evaluate each policy.

Table 3 - Policy Cases and Each Conditions

	Gasoline Price (yen/litter)	Population in DID (million) / Area of DID (square km)	Population Ratio in DID / Density in DID (population/km²)	Length of Improved Road (million km)
Standard Year (1990)	129	78. 1	63. 2%	0. 55
		11, 732	6, 661	
Basic Case : change with trend in 2000	100	87. 7	68. 8%	0. 68
		14, 065	6, 232	
Gasoline Price 1 : level in 1990	129			
Gasoline Price 2 : double raise	200			
Density Renovation 1: fixed level in 1990		11, 732	7, 471	
Density Renovation 2: fixed level in 1980		10, 028	8, 741	
Road Improvement 1: fixed level in 1990				0. 55
Road Improvement 2: all roads in 1990				1. 10

Effects of Each Policy Case

Trends for Whole Country

Table 4 shows the change in value of each environmental index for each policy. In the basic case which assumes that trends will continue through 2000, a 14.6% increase in the number of cars and 19.6% increase in gasoline consumption are expected. As a result, each pollutant emission volume increases by 19.6% compared to 1990 levels. This increase is about 1.5% increase in the total emission volume of CO_2 in Japan. We now examine the changes in emission volumes through various policies in the following.

Let us assume that we reduce gasoline consumption directly by raising of gasoline prices. Even if we double the gasoline price increase in from the present 100 yen/liter to 200 yen/liter, a 6.9% increase in emission from 1990 level is expected. It can be said that a lager raise in gasoline prices is needed to reduce emission to 1990 levels.

For the effect of population distribution and density structure, maintaining the expansion of DID areas at 1990 levels will result in 5.3 % increase in emission. Reverting the expansion of DID areas to 1980 levels which means more densely structured areas, a 10.1 % decrease in emission is expected. This scenario assumes improved public transportation and abandoning car use.

On the other hand, an increase in improved road length creates a 19.6% increase in CO_2 emission. If all existing roads in 1990 (1.1 million km) are improved, there will be a 29.5% increase in emission. Even if road improvements cease in the future, a 15.3% emission increase will still be expected. Though actual values vary because congestion is not considered in this study, it may be said that it is difficult to control emission volumes only by stopping constructing of roads. If plans for road construction materialize in the future, CO_2 emission will certainly increase. Therefore, other policies such as change in density structure need to be implemented simultaneously.

Regional Difference by Policy Case

Figures 2, 3 and 4 show regional differences in CO_2 emission for each policy case. Looking at the basic case in 2000, prefectures around Tokyo are relatively low in their rate of increase of emission.

Table 4 - Results of Environmental Indices by Policy Case (Value of Whole Country)

	Number of Cars (thousand)		Gasoline Consumption (thousand kl)		Car Kilometer (million car km)	
Standard Year (1990)	48, 566	-	43, 170	-	346, 971	-
Basic Case : change with trend in 2000	55, 666	14. 6%	51, 647	19. 6%	415, 115	19. 6%
Gasoline Price 1 : level in 1990	55, 666	14. 6%	50, 051	15. 9%	402, 295	15. 9%
Gasoline Price 2 : double raise	55, 666	14. 6%	46, 142	6. 9%	370, 875	6. 9%
Density Change 1: fixed level in 1990	49, 009	0. 9%	45, 459	5. 3%	366, 025	5. 5%
Density Change 2: fixed level in 1980	41, 812	-13. 9%	38, 830	-10. 1%	313, 428	-9. 7%
Road Improvement 1: fixed level in 1990	53, 928	11. 0%	49, 781	15. 3%	399, 851	15. 2%
Road Improvement 2: all roads in 1990	59, 643	22. 8%	55, 903	29. 5%	449, 210	29. 5%

Table 4 - Results of Environmental Indices by Policy Case (continued)

	CO2 Emission (thousand ton)		NOx Emission (ton)		CO Emission (ton)	
Standard Year (1990)	97, 263	-	176, 955	-	1, 138, 065	-
Basic Case : change with trend in 2000	116, 360	19. 6%	211, 709	19. 6%	1, 361, 577	19. 6%
Gasoline Price 1 : level in 1990	112, 766	15. 9%	205, 170	15. 9%	1, 319, 527	15. 9%
Gasoline Price 2 : double raise	103, 957	6. 9%	189, 146	6. 9%	1, 216, 470	6. 9%
Density Change 1: fixed level in 1990	102, 419	5. 3%	186, 673	5. 5%	1, 200, 561	5. 5%
Density Change 2: fixed level in 1980	87, 483	-10. 1%	159, 848	-9. 7%	1, 028, 044	-9. 7%
Road Improvement 1: fixed level in 1990	112, 159	15. 3%	203, 924	15. 2%	1, 311, 510	15. 2%
Road Improvement 2: all roads in 1990	125, 949	29. 5%	229, 097	29. 5%	1, 473, 409	29. 5%

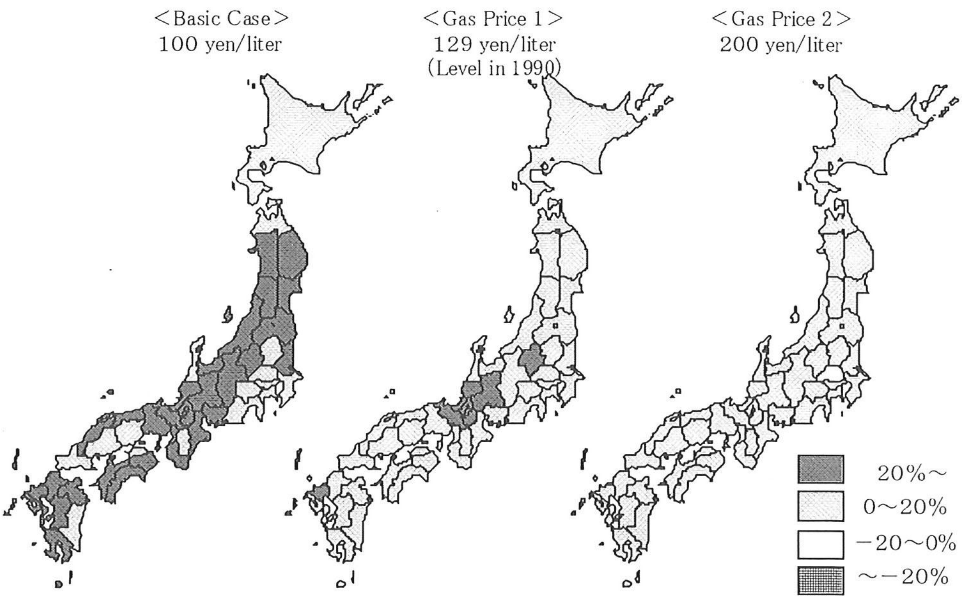

Figure 2 - Regional Differences in Increase Rate of CO_2 Emission - Gasoline Price Control Case -

This is because these prefectures are high density areas and have a tendency to go through population density transition. On the other hand, prefectures where population density is low tend to have increasing emission rates.

The gasoline price policy case is supposed to raise gasoline price so it becomes uniform throughout the whole country. The most sensitive prefecture to gasoline prices is Saitama near Tokyo. Here, gasoline prices are the cheapest in Japan. If the price doubles, only Saitama prefecture will have emissions lower than 1990 levels.

In the density structure change case, prefectures where there is only a gradual increase in population

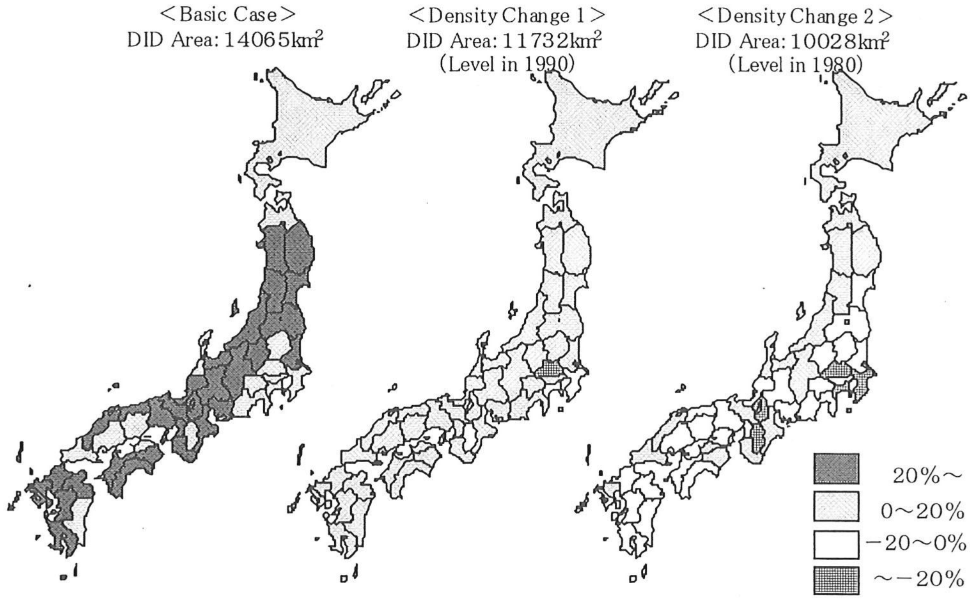

Figure 3 - Regional Differences in Increase Rate of CO_2 Emission - Density Structure Change Case -

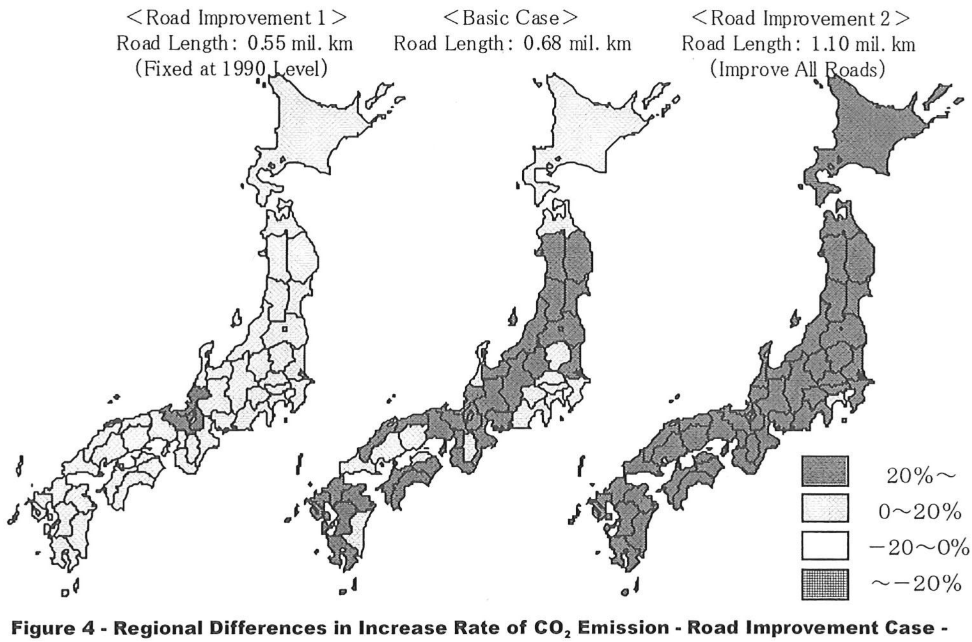

Figure 4 - Regional Differences in Increase Rate of CO_2 Emission - Road Improvement Case -

density and where population density is over 10,000 people per square km tend to increase slightly in emission. If the DID area will be fixed in the area of 1990, only 4 prefectures would decrease in emission. If the DID area will be fixed in the area of 1980, over half of the prefectures could decrease in emission.

For the road improvement case, almost all prefectures would have less than 20 % emission if road improvement were to stop at 1990 levels. If all existing roads in 1990 were to improve, all the prefectures would increase emission by more than 20 %. Since it is not realistic to stop constructing or improving roads, a combination of other measure should be implemented to reduce emission to desirable levels.

CONCLUDING REMARKS

This study proposes a method to estimate regional car usage using a car ownership and gasoline consumption model and builds an estimation system for environmental indices for car usage. This system can compare regional environmental impacts as long as the policies are related to car ownership and car usage.

The car ownership model and gasoline consumption model are explained by regional attributes that are related to car ownership and usage factors and that have a possibility of influencing car ownership and usage. In this study, we focus on gasoline price, population structure and road improvement. In addition, this estimation system can consider other measures such as a change in gasoline car ratio, improvement of fuel efficiency, engine improvement of pollutant emission and others by manipulating corresponding parameters.

In estimating the future situation, car usage will increase by 20% from 1990 levels if all factors follow the same trend through the year 2000. If CO_2 emission volume is to be kept at 1990 levels, it would be most effective to keep DID population density at a higher level than in 1990.

This estimation system has some limitations. For example, if gasoline prices rise, the number of cars is not affected. Thus, not all of the correlation between variables can be explained. However, this estimation system aims to compare regional differences in environmental impact due to car usage and to compare the results of the policies related to environment. In this sense, this system could indicate sufficient correlation results between regional environmental impacts due to the car usage and policies.

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