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Abstract

This article reviews some of the important aspects of Japanese environmental problems caused by road transport and policies that have been proposed against them.   We also report preliminary results of our research on the evaluation of various policy measures aimed at reducing CO_2 emissions by automobiles. Our simulation results indicate that the 'Green' tax introduced in Japan in 2001 may not be effective in reducing CO_2 emission while imposing large welfare costs on automobile users.   The fuel tax is more cost effective than ownership and acquisition taxes.   Furthermore, a revenue neutral tax policy that increases the fuel tax and reduces the ownership tax performs better than raising the ownership and the acquisition taxes.

Key Words: Global warming; Road transport; Air pollution; Green tax; Environmental policy

JEL classification: H2, Q21, Q25, Q28, R48

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Introduction

Because of extremely high density of population and economic activities, environmental problems in Japan are acute and policy measures against them are very costly. This means that we have to take extra care in designing a cost effective policy package. Most serious of all are those caused by road transport. First, noise and air pollution caused by road transport are so severe that there have been court rulings that require the government (the road administrator) to pay compensation for damages. Second, road transport is one of the major sources of CO_2 emissions and its share has been increasing. Third, some of the proposed policy measures (such as creating buffer zones between roads and residential areas) are extremely costly for taxpayers.

This article reviews some of the important aspects of Japanese environmental problems caused by road transport and policies that have been proposed against them. We also report preliminary results of our research on the evaluation of various policy measures aimed at reducing CO_2 emissions by automobiles.

In section 2, we look at local environmental problems such as traffic noise and air pollution caused by suspended particulate matters (SPM) and nitrogen oxides (NOx). Section 3 reviews policy issues concerning global warming. Section 4 reports some preliminary results of our research project on the evaluation of cost-effectiveness of alternative tax policies to reduce CO_2 emission in road transport. Finally, section 5 contains brief concluding remarks.

Air Pollution and Traffic Noise

- Particulate Matters

Until recently, more attention had been paid to NOx than SPM in Japan. This has changed however as more evidence has been gathered on the link between SPM and asthma. Early last year (January 2000), Kobe District Court recognized causal relationship between SPM and health damages by asthma, and ruled that the Japanese government as the road administrator pays compensation to 50 plaintiffs in Amagasaki who lived in or commuted to the area within 50 meters from Route 43 when they contracted asthma. It also ruled that SPM emissions must be below 0.15mg/m^3 (one day average value of hourly data). Although the court ruling is for the Osaka Metropolitan Area, the problem is more

serious in the Tokyo Area, where SPM densities exceed 0.15mg/m^3 (the standard set by Kobe District Court) at many stations.

The environmental standard for SPM is to keep the one-day average of one-hour values below 0.10mg/m^3 and one-hour values below 0.20mg/m^3. In the Tokyo Metropolitan Area, the standard is satisfied only at 3 metering stations out of 96. Even outside Tokyo and Osaka Metropolitan Areas, the standard is satisfied at only about a half of the stations.

Exhibit 1.   Environmental quality standard compliance: SPM (1998)

	Stations that meets the standard (%)	Total number of stations
Nation	95 (36%)	269
Tokyo MA	3 (3%)	96
Osaka MA	14 (34%)	41
Other	78 (59%)	132

Source: Environment Agency

Road transport is not the only source of SPM. In the Tokyo Metropolitan Area, SPM emissions from road transport are about 35% of the total. Factories and offices have a larger share of 41% and the nature produces 24% of the SPM.

Even on weekends when there is much less road traffic than on weekdays, we do not observe significant reduction in SPM. On Sundays, PM emission is less than a half of weekday levels, but SPM density is more than 80% of weekday levels at general air pollution monitoring stations and about 75% at roadside stations. This may indicate that other sources may be more important. Smaller size particulates (e.g., PM2.5) are more hazardous to health, however, and road transport may cause a larger share of them.

In the transportation sector, the major sources of SPM emission are diesel engines, as gasoline cars produce virtually no SPM. Emission standards for SPM were first introduced in 1993. The standards apply only to new vehicles, and about 80% of trucks in use are not subject to the regulation.

Emission standards were 0.7g/kWh for heavy trucks in 1993. In 1997, the standards were tightened to 0.25g/kWh for heavy trucks with weights between 2.5 and 3.5 tons. The standards were extended to heavier trucks in 1998 and 1999. From 2003, the standards will become 0.18g/kWh and a further reduction by half (called the New Long-Term Regulation) is expected in around 2005. If all vehicles meet the New Long-Term Regulation, the environmental quality standard of 0.10mg/m^3 will be

satisfied even along major trunk roads.   It will take a long time however to reach the point because the average lifetime of trucks is very long.   In the meantime, we are faced with a difficult policy problem.

According to the estimates by the Road Bureau of the Ministry of Land, Infrastructure and Transport, the SPM density does not decrease much with distance from a trunk road.   This means that creating buffer zones is not a cost effective policy.   An alternative policy would be to reduce traffic of diesel-powered vehicles by direct regulation or some sort of pricing measures.   Tokyo prefecture passed an ordinance to prohibit traffic of diesel vehicles that does not meet its SPM emission standards.   This ordinance will become effective in 2003.

With a long lifetime of trucks, policy measures aimed at existing vehicles are necessary.   New vehicles that meet the environmental standards tend to be more costly, which would lengthen the lifetime of old vehicles further.   Heavier ownership taxes for vehicles that do not meet the environmental standards would be a natural choice.   In 2001, a reform of automobile taxation called 'Green' Taxes is introduced, which differentiate acquisition and ownership taxes according to emission levels of NOx, PM, and CO_2 of vehicles.   This reform is a step in the right direction but its effectiveness is not clear.

- NOx

According to the environmental standard for NO_2, the one-day average of hourly values must be within the zone between 0.04ppm and 0.06ppm, or below.   Exhibit 2 shows that the standard for NO_2 is satisfied more often than that for SPM.   In Tokyo metropolitan area, however, the situation is still quite bad.

Exhibit 2.   Environmental quality standard compliance: NO_2 (1998)

|	Stations that meets the standard (%)	Total number of stations
Nation	267 (68%)	392
Tokyo MA	31 (27%)	113
Osaka MA	30 (52%)	58
Other	206 (93%)	221

Source: Environment Agency

As in the case of SPM, sources of NOx are diverse: those coming from the transport sector are about 46% of the total.   Policy measures to deal with the NOx problem are similar to those for SPM.

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- Noise

Traffic noise is also a big problem in Japan. In 1995, the Supreme Court ruled that the national government as the road administrator is partly responsible for traffic noise along Route 43. The situation has not improved much since then. As shown in Exhibit 3, noise levels exceed the national environmental quality standard at about a half of the monitoring points.

Exhibit 3. Environmental quality standard compliance: Noise (1999)
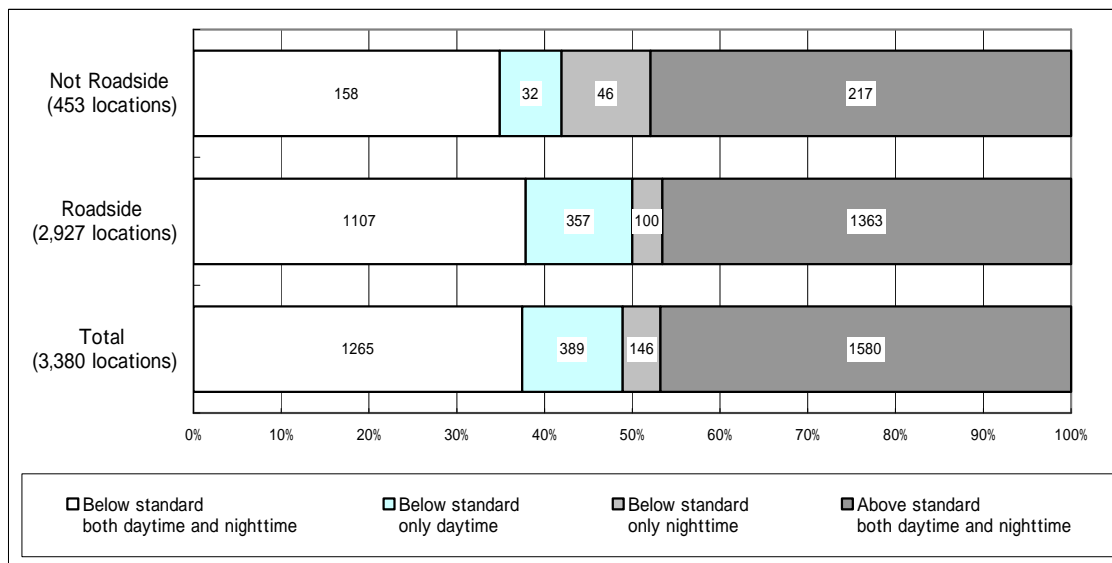
Policy measures taken against traffic noise are mainly on the structural side of roads such as low-noise pavement, noise barriers, and buffer zones.

Global Warming

Although CO_2 is not the sole cause of global warming, it accounts for the largest portion of greenhouse gas, with a notable significance in the area of transport. For this reason, we focus on CO_2 in this article.

- International Comparison

Exhibit 4 makes an international comparison of per-capita CO_2 emission between the transport and other sectors. It shows that Japan has the lowest level of CO_2 emission in the transport sector. However, Japan registers the highest rate of increase at 22.2% between 1990 and 1997. (The United States records a 10.3% increase, U.K. 6.0%, Germany 7.8%, Canada 18.4%, and France 12.7%.)

Exhibit 4:   International Comparison of Per-Capita CO_2 Emission (1997)
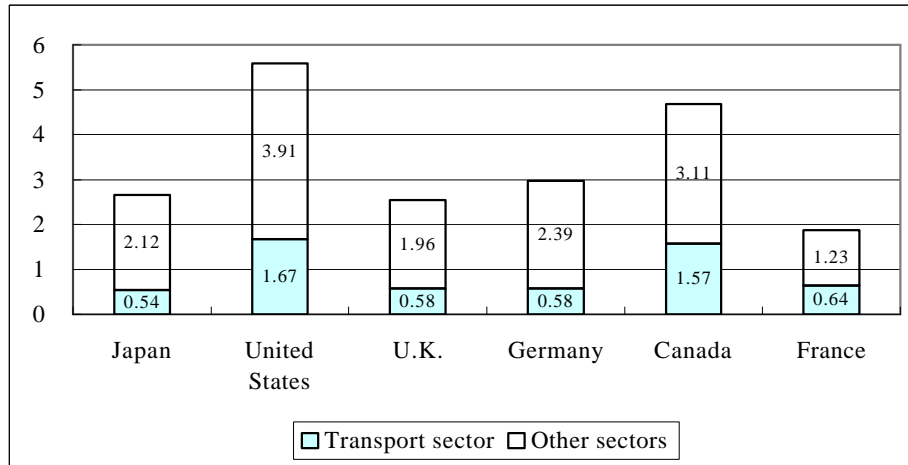
Source: Greenhouse Gas Inventory Data, United Nations Framework Convention on Climate Change.
Note: The figures are in the ton of carbon.   The emission for the transport sector represents CO_2 resulting from fuel combustion.

Automobiles are the largest source of CO_2 emission in the transport sector, posting a high rate of increase each year.   As shown in the next tables, the rate of increase is especially high among passenger cars at 25% in 5 years.   Automobiles represent a major source of CO_2 emission in other countries as well. Energy consumption by automobiles is on the rise in the United States, although not as much as in Japan, reporting a 10% increase in 5 years when trucks and passenger vehicles are combined.   One of the characteristics of the U.S. figures is that energy consumption has decreased for passenger vehicles, while it has risen significantly for light trucks.   This is partially attributable to the fact that the U.S. definition of light trucks includes SUVs (Sports Utility Vehicles).   Light trucks are subject to lower fuel efficiency regulations compared to passenger vehicles.

Exhibit 5:   Transport Sector Energy Consumption by Usage (Japan)   (million kl of crude oil)

	FY1990	FY1995	Rate of increase
Passenger vehicles	39.1	48.8	25%
Passenger-use aircraft	3.1	4.0	29%
Passenger transport total	48.6	58.6	21%
Freight vehicles	27.3	30.2	11%
Freight aircraft	0.4	0.6	50%
Freight transport total	31.9	35.0	10%

Source: Q&A on Global Warming and COP3, Ministry of International Trade and Industries, 1997.

Exhibit 6:   Transport Sector Energy Consumption by Usage (United States)   (trillion Btu)

Year	Autos	Light trucks	Other trucks	Highway subtotal	Air	Non-highway subtotal	Total transportation
1990	8,707	4,467	3,329	16,690	2,059	4,966	21,656
1995	8,519	5,717	3,950	18,390	2,117	5,175	23,565
Rate of increase	-2%	28%	19%	10%	3%	4%	9%

Source: TRANSPORTATION ENERGY DATA BOOK: EDITION 19, Stacy C. Davis, Oak Ridge National Laboratory, September 1999.   Table 2.7.

- Japanese Policy Plan for CO_2 Emission Reduction

The Kyoto Protocol, adopted in the 1997 COP3 (3rd Conference of the Parties to United Nations Framework Convention on Climate Change), sets targets for reduction in greenhouse gas emission.   The Protocol calls on Japan to achieve a 6% reduction against the 1990 figure between 2008 and 2012.   It allows a 17% increase for the transport sector, but mandates a 0% increase for the residential and commercial sector and a 7% reduction for the industrial sector.   However, as shown in Exhibit 7, the CO_2 emission actually rose by 21.3% in the transport sector, 13.4% in the residential and commercial sector, and 0.6% in the industrial sector between 1990 and 1997.   To achieve the Kyoto targets, the transport sector must reduce the emission by approximately 3%, the residential and commercial sector by 11%, and the industrial sector by 7% over the next 10 years.

Exhibit 7: CO_2 Emission by Sector (Japan) (unit: million tons of carbon)
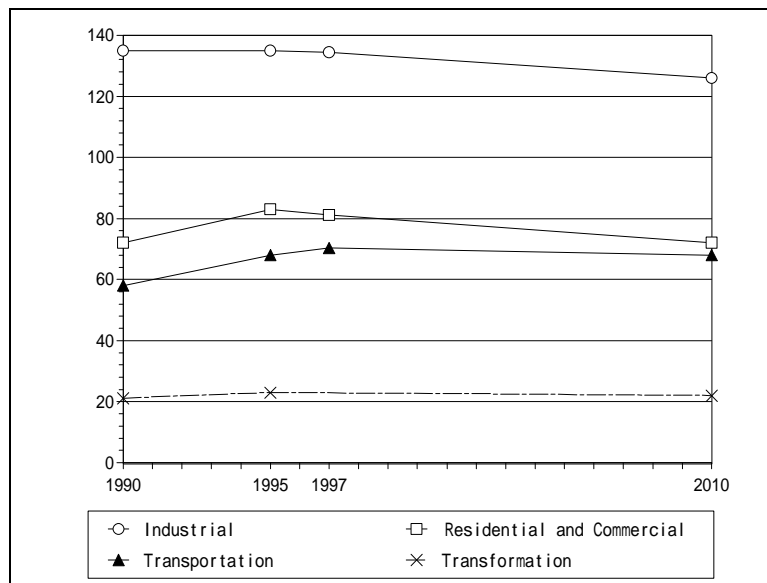
Note: The 2010 values are target figures.

The Japanese government's official plan for CO_2 emission in the transport sector puts heaviest emphasis on improvements in road networks.   As shown in Exhibit 8, the prediction by the government is that road improvements reduce CO_2 emission by 10 million t-C and other policies by 13 million t-C. The premise is that road improvements raise the average speed of traffic and consequently reduce fuel consumption.   Improvements in traffic conditions increase automobile use, however, and it is doubtful that this prediction will be achieved.   Other policies are: improvements in energy efficiency of individual vehicles (4.9 million t-C), improvements in efficiency of physical distribution (2.5 million t-C), promotion of public transportation use (1.6 million t-C), and others (4 million t-C).   It is not clear whether these policies are as effective as the government predicts.

Exhibit 8. CO_2 Emission Reduction Plan in the Transport Sector
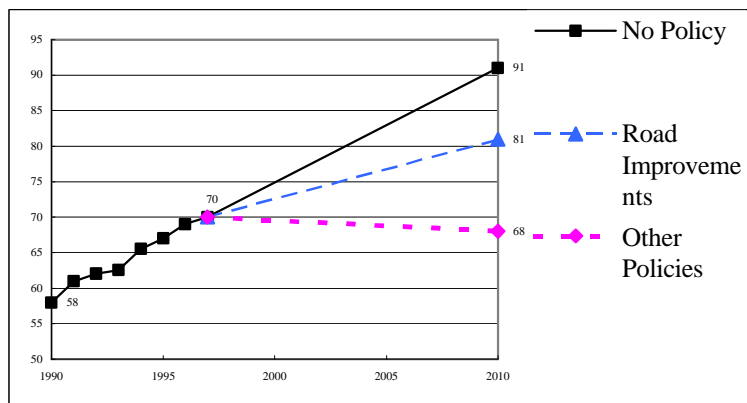
Welfare Comparison of Tax Policies for CO_2 Emission Reduction

This section reports some preliminary results of our research on the evaluation of cost-effectiveness of various policy measures, focusing on the road transport sector.

Our approach is to build a simple but reasonably realistic general equilibrium model to evaluate welfare consequences of policy packages.   We adopt a nested CES framework that is often used in computable general equilibrium (CGE) models.   Studies in EU (reported in Denis and Koopman (1998) and Koopman (1995)) are applications of such a framework to the transport sector.   More recent attempt in this direction is Proost and Van Dender (2001) that builds a Brussels region model with substitutability between private and public transportation.   Our model is much smaller than these, but the consumer's decision on scrapping old cars is fully dynamic and rational.

In 2001, a reform of automobile taxation called 'Green' Taxes is introduced, which differentiates acquisition and ownership tax rates according to environmental cleanliness (i.e., emission levels of NOx, PM, and CO_2) of cars. Although data availability so far does not permit us to evaluate 'Green' Taxes, our aim is to build a model that is capable of evaluating them in comparison with other policies such as a carbon tax levied on fuel consumption.

Ueda, Muto and Morisugi (1998) analyzed welfare impacts of environmental policies in static and dynamic applied general equilibrium models. In their model, the scrapping decision is exogenous and the effects of revenue neutral tax policies (Green taxes) are difficult to analyze. Another difference from our model is that they use the Logit formulation, whereas our model uses the CES form. Hayashi, Kato and Ueno (1999) explicitly considers the vintage structure and scrapping decisions, but their model is not suitable for welfare analysis.
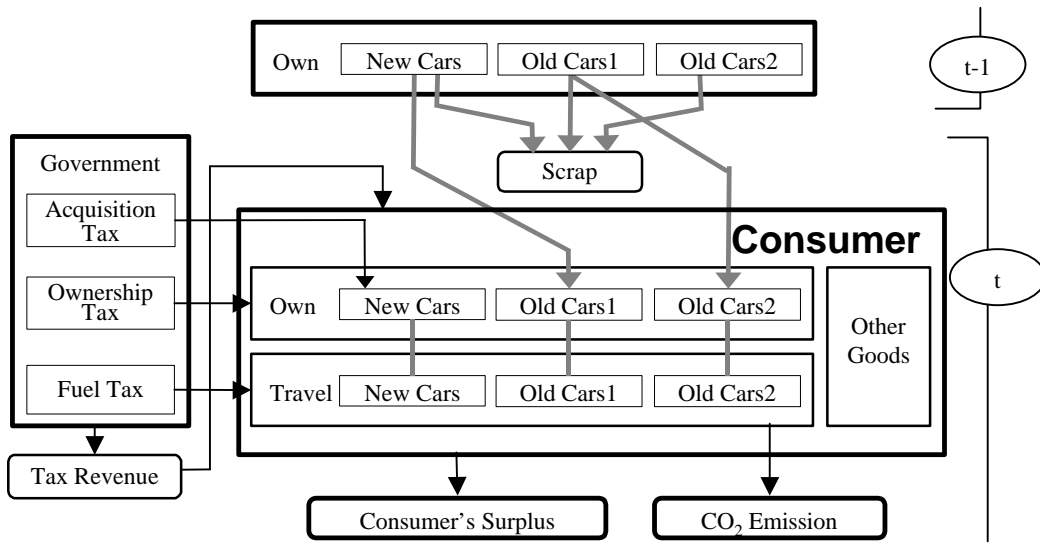
- The Structure of the Model

We restrict our attention to passenger cars. Because of data availability, we consider only two types of cars, Large and Small. Each type has three vintages, New Cars with 0 to 4 years of age, Old Cars 1 with 5 to 9 years, and Old Cars 2 with 10 years and older. A representative consumer owns all the cars. The main decision for the consumer is to choose how many cars of each type and vintage to own and how much to drive them. That is, the consumer chooses the number of New Cars to buy, the survival rates of Old Cars, and the vehicle travel of each type and vintage.

Each time period consists of five years. The first period of our simulation is from the beginning of 2000 fiscal year to the end of 2004 fiscal year. The target for CO_2 emission is set for the third period (2010 to 2014) because the COP3 target year is 2010. In order to account for vehicle stocks that remain after the third period, our model runs to the fifth period. There will be no decisions taken (i.e., all variables are exogenously determined) in the last two periods.

Prices of New Cars and fuel are fixed exogenously, assuming a small country case. There will be no international trade of Old Cars, however.
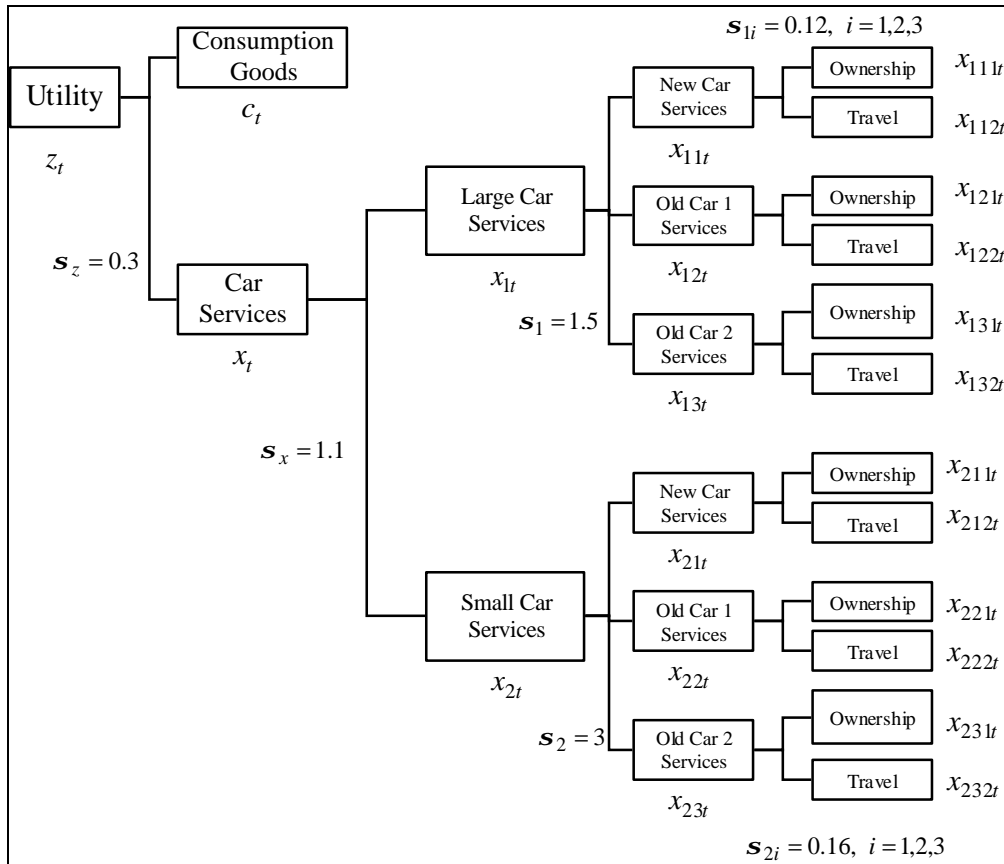
Major policy variables are three types of taxes: fuel, acquisition, and ownership taxes.

Exhibit 9.　Basic Structure of the Model

| Own | New Cars | Old Cars1 | Old Cars2 |

t-1

Scrap

Consumer

Government

Acquisition Tax

Ownership Tax

Fuel Tax

| Own | New Cars | Old Cars1 | Old Cars2 |

Other Goods

t

| Travel | New Cars | Old Cars1 | Old Cars2 |

Tax Revenue

Consumer's Surplus

CO_2 Emission

The utility function of the consumer is of the nested CES type.　Its structure is illustrated in Exhibit 10.

Exhibit 10.　Structure of the Nested CES Utility Function

Utility z_t

Consumption Goods c_t

$s_z = 0.3$

Car Services x_t

$s_x = 1.1$

Large Car Services x_{1t}

$s_1 = 1.5$

Small Car Services x_{2t}

$s_2 = 3$

$s_{1i} = 0.12,\ i = 1,2,3$

New Car Services x_{11t} — Ownership x_{11lt} / Travel x_{112t}

Old Car 1 Services x_{12t} — Ownership x_{12lt} / Travel x_{122t}

Old Car 2 Services x_{13t} — Ownership x_{13lt} / Travel x_{132t}

New Car Services x_{21t} — Ownership x_{21lt} / Travel x_{212t}

Old Car 1 Services x_{22t} — Ownership x_{22lt} / Travel x_{222t}

Old Car 2 Services x_{23t} — Ownership x_{23lt} / Travel x_{232t}

$s_{2i} = 0.16,\ i = 1,2,3$

At the first stage, the utility level in each period is given by a CES function of the consumer good c_t and car services x_t:

$$(1) \qquad z_t = \left(a_c^{\frac{1}{s_z}} c_t^{\frac{s_z-1}{s_z}} + a_x^{\frac{1}{s_z}} x_t^{\frac{s_z-1}{s_z}} \right)^{\frac{s_z}{s_z-1}}.$$

Car services in turn are given by a function of large car services x_{1t} and small car services x_{2t}:

$$(2) \qquad x_t = \left(a_1^{\frac{1}{s_x}} x_{1t}^{\frac{s_x-1}{s_x}} + a_2^{\frac{1}{s_x}} x_{2t}^{\frac{s_x-1}{s_x}} \right)^{\frac{s_x}{s_x-1}}.$$

The two types of car services are functions of three vintages of car services, x_{ijt}, $t=1,2,3$:

$$(3) \qquad x_{it} = \left(\sum_{j=1}^{3} a_{ij}^{\frac{1}{s_i}} x_{ijt}^{\frac{s_i-1}{s_i}} \right)^{\frac{s_i}{s_i-1}}, \quad i=1,2.$$

Finally, car services of each type and vintage consist of the number of vehicles (in million cars) owned x_{ij1t} and the vehicle travel (in billion kilometers) x_{ij2t}:

$$(4) \qquad x_{ijt} = \left(\sum_{k=1}^{2} a_{ijk}^{\frac{1}{s_{ij}}} x_{ijkt}^{\frac{s_{ij}-1}{s_{ij}}} \right)^{\frac{s_{ij}}{s_{ij}-1}}, \quad i=1,2, \; j=1,2,3.$$

We assume that intertemporal consumption choice is of the fixed-coefficient type so that the utility level rises at a constant rate r:

$$(5) \qquad z_t = z(1+r)^t, \; t=1,2,...,$$

where z is the utility level evaluated at period 0. This Leontief type assumption is imposed because otherwise numerical solutions are difficult to obtain in our model.

The consumer determines the survival rates of Old Cars.   The stock of Old Cars 1 in period t is given by

$$(6) \qquad x_{i21t} = s_{i2t} x_{i11,t-1},$$

where s_{i2t} is the proportion of New Cars purchased in period t that is used in period t+1.   The stock of Old Cars 2 is

$$(7) \qquad x_{i31t} = s_{i3t} x_{i21,t-1} = s_{i3t} s_{i2,t-1} x_{i11,t-2},$$

where s_{i3t} is the survival rate of Old Cars 2 in period t.

The prices of vehicle ownership and travel are denoted by p_{ijkt}. The 'price' of vehicle travel p_{ij2t} is the fuel cost including fuel taxes, which is assumed fixed. Because Large Cars consume more fuel, the 'price' is higher for them. We ignore intertemporal and cross-vintage variations and assume that the price of vehicle travel is

$$(8) \qquad p_{ij2t} = \frac{fuel + tax}{effic_i},$$

where *fuel* and *tax* are the fuel cost and fuel tax per liter, and $effic_i$ is the average fuel efficiency for cars of type i ($i = 1$ for Large Cars and $i = 2$ for Small Cars).

The 'price' of a new car p_{i11t} is also fixed but includes taxes and maintenance costs in addition to purchase costs. The 'price' of an old car is endogenous and depends on the survival rate:

$$(9) \qquad p_{i21t} = R_{i2t}(s_{i2t})$$

$$(10) \qquad p_{i31t} = R_{i3t}(s_{i3t}).$$

This reflects the fact that certain proportions of older cars are scrapped because repair and maintenance costs are too high to keep using them.

The expenditures on cars in each period are

$$(11) \qquad E_1 = \sum_{i=1}^{2}\left(p_{i111}x_{i111} + R_{i21}(s_{i21})s_{i21}\overline{x}_{i110} + R_{i31}(s_{i31})s_{i31}\overline{x}_{i120} + \sum_{j=1}^{3} p_{ij21}x_{ij21} \right)$$

$$(12) \qquad E_2 = \sum_{i=1}^{2}\left(p_{i112}x_{i112} + R_{i22}(s_{i22})s_{i22}x_{i111} + R_{i32}(s_{i32})s_{i32}s_{i21}\overline{x}_{i110} + \sum_{j=1}^{3} p_{ij22}x_{ij22} \right)$$

$$(13) \qquad E_3 = \sum_{i=1}^{2}\left(p_{i113}x_{i113} + R_{i23}(s_{i23})s_{i23}x_{i112} + R_{i33}(s_{i33})s_{i33}s_{i22}x_{i111} + \sum_{j=1}^{3} p_{ij23}x_{ij23} \right)$$

$$(14) \qquad E_4 = \sum_{i=1}^{2}\left(p_{i114}\overline{x}_{i114} + R_{i24}(\overline{s}_{i24})\overline{s}_{i24}x_{i113} + R_{i34}(\overline{s}_{i34})\overline{s}_{i34}\overline{s}_{i23}x_{i112} + \sum_{j=1}^{3} p_{ij24}x_{ij24} \right)$$

$$(15) \qquad E_5 = \sum_{i=1}^{2}\left(p_{i115}\overline{x}_{i115} + R_{i25}(\overline{s}_{i25})\overline{s}_{i25}\overline{x}_{i114} + R_{i35}(\overline{s}_{i35})\overline{s}_{i35}\overline{s}_{i24}x_{i113} + \sum_{j=1}^{3} p_{ij25}x_{ij25} \right)$$

where $\overline{x}_{i110}$ and $\overline{x}_{i120}$ are the stocks of New Cars and Old Cars 1 in period 0 (i.e., the period before our starting period 1). In the fourth and fifth periods, there is no decision taken by the consumer. In

particular, the vehicle travel of each vehicle type is a fixed proportion of the number of vehicles.

The consumer maximizes utility z subject to the budget constraint,

(16) $$\sum_{t=1}^{5} \frac{1}{(1+r)^t}(c_t + E_t) \leq W$$

and constraints (1) - (16), where the price of the consumer good in each period is 1 (one) and W is the present value of total expenditures for the five periods which is assumed to be fixed.

- Parameter Calibration

The parameters in the model are calibrated so that the model replicates the actual data as closely as possible and yields price elasticities that are in line with estimates obtained in earlier studies.

The first task is to set prices and costs that the consumer is faced with. We assume that fuel costs including taxes are 100 yen per liter based on recent data. The average fuel efficiency is about 8.4 km/liter. This number includes both large and small cars and no separate data are available for the two types. Assuming that Small Cars are 1.5 times more fuel-efficient than Large Cars, we set fuel efficiency parameters as 6.6 km/liter for Large Cars and 9.9 km/liter for Small Cars. The 'price' of vehicle travel is then $p_{1j2t} = 15.1$ yen/km for Large Cars and $p_{2j2t} = 10.1$ yen/km for Small Cars.

The calibration of ownership prices is based on Exhibit 11. If we divide the initial purchase price simply by five to obtain the price per year, the 'price' of owning a new large car is $p_{111t} = 889.2$ thousand yen per year and that for a new small car is $p_{211t} = 510.0$ thousand yen per year.

Exhibit 11. Ownership Costs (unit: thousand yen)

	Purchase Price	Repair and Maintenance (per year)	Parking (per year)	Insurance (per year)	Taxes (per year)	Total (per year)
Large Cars						
New	3000	30.2	21.4	101.4	136.2	889.2
Old 1 & Old 2		30.2	21.4	101.4	76.2	229.2
Small Cars						
New	1500	30.2	21.4	75.0	83.4	510.0
Old 1 & Old 2		30.2	21.4	75.0	53.4	180.0

The average ownership prices of Old Cars are in the last column in Exhibit 11. Some of the Old Cars have high costs of maintenance and repair so that they are scrapped. In order to represent this, we assume that the repair and maintenance costs have a lognormal distribution. Ownership prices for Old

Cars are then

$$(17) \qquad R_{ijt}(s_{ijt}) = R_{ijA} + \text{logninv}(s_{ijt}, \boldsymbol{m}_{ij}, SD_{ij}), \quad i = 1, 2, \quad j = 2, 3$$

for type i and vintage j, where $\text{logninv}(s_{ijt}, \boldsymbol{m}_{ij}, SD_{ij})$ is the inverse of lognormal distribution with mean $\boldsymbol{m}_{ij}$ and standard deviation SD_{ij}. The constant term is the ownership costs excluding repair and maintenance: $R_{1jA} = 199.0$ and $R_{2jA} = 149.8$. The mean and the standard deviation of the lognormal distribution are determined so that the value of $\text{logninv}(s_{ijt}, \boldsymbol{m}_{ij}, SD_{ij})$ equals the observed average cost of repair and maintenance, 30.2, at the average survival rate observed between 1995 and 1999, and the shadow prices of old cars are equal to those of new cars. Exhibit 12 shows the means and standard deviations obtained in this way and Exhibit 13 reports the average survival rates between 1995 and 1999.

Exhibit 12. The means and standard deviations of lognormal distributions

	Large Old 1	Large Old 2	Small Old 1	Small Old 2
$\boldsymbol{m}_{ij}$	0.22	2.06	1.27	9.27
SD_{ij}	2.15	6.90	3.09	8.12

Exhibit 13. Stocks of Cars and Survival Rate in 1995-1999

	Number of Cars			Survival Rate	
	New Cars	Old Cars 1	Old Cars 2	Old Cars 1	Old Cars 2
Large Cars	7,514	4,752	573	93.1%	57.8%
Small Cars	11,635	11,825	4,436	75.5%	23.5%

The most important parameters are elasticities of substitution. Exhibit 10 show the values of these parameters that we use: $\boldsymbol{s}_z = 0.3$ between car services and other consumer goods; $\boldsymbol{s}_x = 1.1$ between large and small car services; $\boldsymbol{s}_1 = 1.5$ and $\boldsymbol{s}_2 = 3$ between different vintages of Large and Small Cars respectively; and $\boldsymbol{s}_{1j} = 0.12$ ($j = 1, 2, 3$) and $\boldsymbol{s}_{2j} = 0.16$ ($j = 1, 2, 3$) between ownership and travel for Large and Small Cars respectively. The fuel price elasticity of vehicle travel implied by these parameter values is about 0.19. This is in line with empirical estimates ranging from 0.11 to 0.23 in Goodwin (1992), Oum, Waters and Yong (1992), Futamura (1999), and Hayashi, Kato and Ueno (1999).

If the consumer is a price taker, the share parameters satisfy

$$(18) \qquad a_{ijk} = \left(p_{ijk} x_{ijk}^{1/s_{ij}} \middle/ \sum_{k=1}^{2} p_{ijk} x_{ijk}^{1/s_{ij}} \right)^{s_{ij}}$$

$$(19) \qquad a_{ij} = \left(p_{ij} x_{ij}^{1/s_i} \middle/ \sum_{j=1}^{3} p_{ij} x_{ij}^{1/s_i} \right)^{s_i}$$

$$(20) \qquad a_i = \left(p_i x_i^{1/s_x} \middle/ \sum_{i=1}^{2} p_i x_i^{1/s_x} \right)^{s_x}$$

$$(21) \qquad a_x = \left(p_x x^{1/s_z} \middle/ \left(p_x x^{1/s_z} + p_c c^{1/s_z} \right) \right)^{s_z}$$

$$(22) \qquad a_c = \left(p_c c^{1/s_z} \middle/ \left(p_x x^{1/s_z} + p_c c^{1/s_z} \right) \right)^{s_z}.$$

We calibrate the share parameters by substituting price and quantity data into these equations. There are three complications. First, the 'prices' of Old Cars are endogenous and these relationships hold for marginal prices rather than average prices. We assume that the marginal prices of Old Cars equal the 'prices' of New Cars, which are exogenous. Second, the stocks of old cars in the 1995-99 period do not represent the steady state implied by the utility function, because a big change in the tax structure favoring large cars occurred in 1989. We therefore compute a fictitious steady state ownership structure: the number of new cars are taken from 1999 data and the number of old cars are computed by applying the survival rates in Exhibit 13. Third, the average vehicle travel data is available only for the total and we do not have separate data for Large and Small Cars. Based on used car market samples, we assume that the average vehicle travel of Large Cars is 1.2 times that of Small Cars. This yields 11.4 thousand km/year for Large Cars and 9.5 thousand km/year for Small Cars.

Finally, the interest rate r is 20% for five years (approximately 4% per year), the rate of increase of utility z is 5% for five years (approximately 1% per year), and the present value of total expenditures for the five periods W is 997,971.6 billion yen.

- Policy Simulations

Policy simulations solve the maximization problems for the representative consumer with different assumptions on automobile taxation. The benchmark case assumes the current tax system. Exhibit 14 shows stocks of cars, vehicle travel, and CO_2 emission in each period. The values in Period 0 are exogenous and taken from 1999 data. All the actions take place from Period 1 to Period 3. Periods 4 and 5 are added to account for vehicle stock that remains at the end of Period 3.

Exhibit 14.   The Benchmark Case

	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Rate of increase between Period 0 and Period 3
Large Cars							
Number of cars	12.8	17.2	16.9	16.1	15.0	16.3	25%
Vehicle Travel	146.3	194.1	195.1	189.2	171.2	185.7	29%
Travel per car	11.4	11.3	11.5	11.8	11.4	11.4	3%
Small Cars							
Number of cars	27.9	22.6	23.9	26.8	31.3	35.1	- 4%
Vehicle Travel	265.0	212.7	227.0	254.6	323.3	363.9	- 4%
Travel per car	9.5	9.4	9.5	9.5	10.3	10.4	0%
Total							
Number of cars	40.7	39.8	40.8	42.9	46.4	51.4	5%
Vehicle Travel	411.3	406.8	422.1	443.8	494.5	549.5	8%
Travel per car	10.1	10.2	10.4	10.4	10.7	10.7	3%
CO_2 emissions	31.5	32.7	33.8	35.0	37.7	41.7	11%

Our benchmark case has a higher rate of increase of CO_2 emission than other studies.   This is mainly due to a large increase in Large Cars between Period 0 and Period 1, which is caused by the fact that the number of Large Cars increased dramatically in the preceding period due to a change in the tax system, as can be seen from Exhibit 13.

Now, let us examine the effects of an increase in each of the three taxes.   Exhibit 15 shows the effects of increasing the fuel, ownership, and acquisition taxes, respectively.   Welfare costs are calculated ignoring the distortionary effects of existing taxes.   That is, we implicitly assume that the current levels of taxes are first best optimal.   The fuel tax is currently 57.8 yen per liter for gasoline including 4 yen of the consumption tax.   If the tax is raised by 10 yen per liter, CO_2 emission will decrease by about 1.68% and the consumer incurs the welfare cost of about 3.12 billion yen per year. The welfare cost increases rapidly as the tax rate is raised further.   If the tax is 50 yen per liter, CO_2 emission is reduced by about 7.11% but the welfare cost is about 64 billion yen per year.

The ownership tax is 76.2 thousand yen for Large Cars and 53.4 thousand yen in the benchmark case.   Increasing these by 50% to 114.3 and 80.1 reduces CO_2 emission only by 0.81%.   The welfare cost is about 8.5 billion yen.   For the same level of CO_2 emission reduction, the welfare cost is much higher in the ownership tax case than in the fuel tax case.

The welfare cost is even higher in the acquisition tax case.   The current level of the acquisition tax is 10 % of the purchase price including the consumption tax of 5%.   This means that the tax is 300 thousand yen for Large Cars and 150 thousand yen for Small Cars in our model.   In order to reduce CO_2

emission by 0.81%, which is achieved by 50% increase in the ownership tax, the acquisition tax must be raised by more than 250%.

Exhibit 15.   The effects of raising the fuel, ownership, and acquisition taxes independently
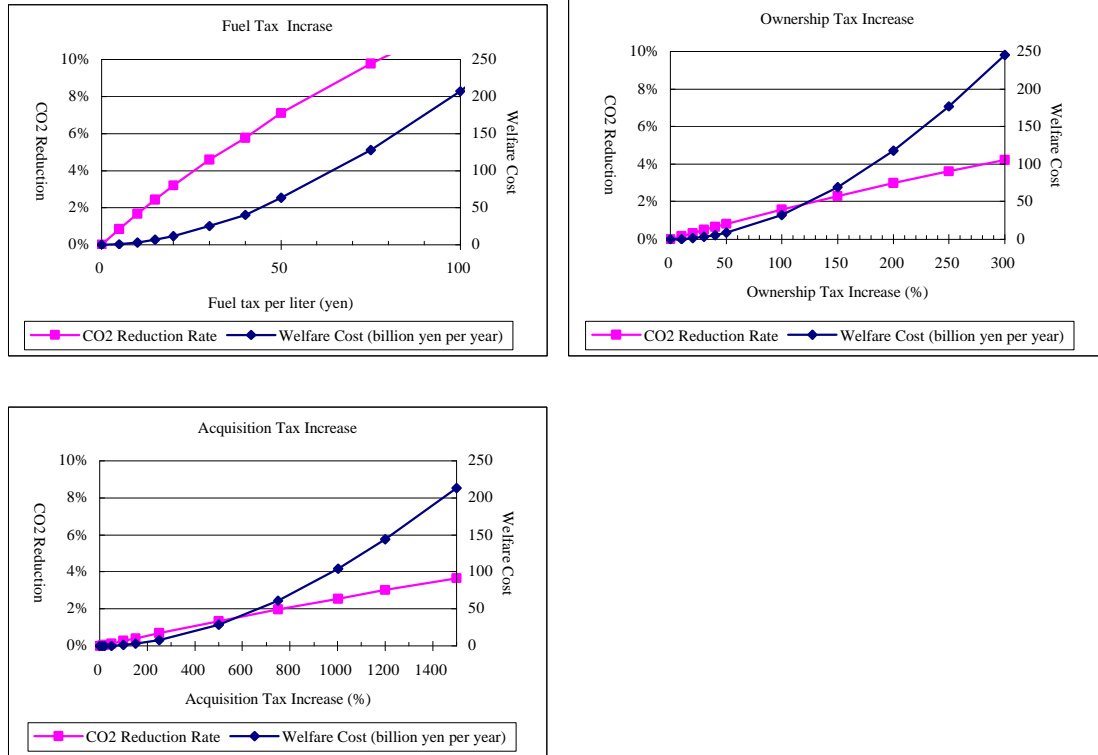

Next, we examine revenue neutral changes in taxes.   First example is to raise the ownership tax of Large Cars and reduce that of Small Cars, keeping the total revenue constant.   Exhibit 16 shows a surprising result that the revenue neutral change *increases* CO_2 emission.   Furthermore, the welfare cost of this policy is quite high: a 100% increase in the tax on Large Cars results in the welfare cost of 87 billion yen in the revenue neutral case whereas the welfare cost is only about 32 billion yen if the ownership tax on both Large and Small Cars are increased by the same percentage.

The reason for this counter-intuitive result is that, although an increase in the tax on Large Cars has the expected effect of reducing them, an accompanying reduction in the tax on Small Cars increases their purchase to more than compensate the effects on Large Cars.   For example, when the tax rate increase is 100%, new large cars decrease by 0.93 million but new small cars increase by 1.6 million in the first period.   The difference becomes larger in periods 2 and 3: in period 2 the decrease in Large Cars and the increase in Small Cars are 0.54 million and 1.48 million respectively, and in period 3 they are

0.56 million and 2.10 million.   This result of course depends on our parameter values but points up a possibility that a revenue neutral change does not achieve the intended policy goal.

Exhibit 16.   The effects of revenue neutral changes in the ownership tax and the acquisition tax
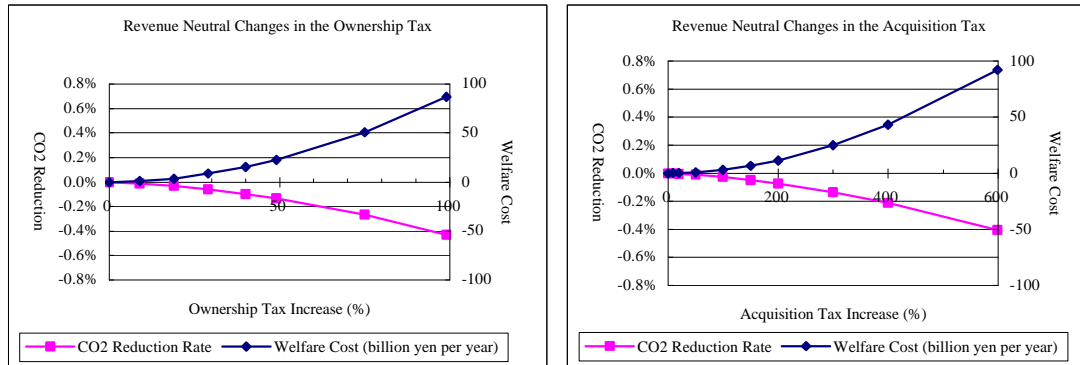
Revenue neutral changes in the acquisition tax also increase CO_2 emission as shown in Exhibit 16.

Exhibit 17 depicts the effects of increasing the fuel tax with a revenue-neutral decrease in the ownership tax.   Considering high ownership taxes in Japan, this option is worth serious attention. Although the effects on CO_2 emission are smaller than the fuel tax increase case, the difference is not very large.   The higher welfare cost reflects the assumption that the present high ownership tax is first best optimal.   In the likely case where the ownership tax rate is too high, the welfare cost may even be negative.

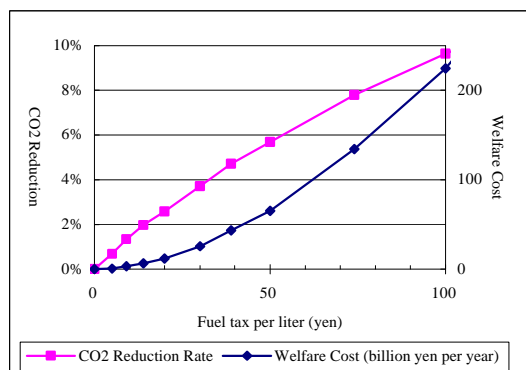Exhibit 17.   The effects of revenue neutral changes in the fuel and ownership taxes

Exhibit 18 summarizes all the cases.   For a given reduction in CO_2 emission, the welfare cost is lowest in the fuel tax increase case, followed by revenue neutral changes in fuel and ownership taxes.

Revenue neutral changes in ownership or acquisition taxes (called ownership green and acquisition green in the graph) that are similar to the 'Green' tax introduced in Japan have adverse effects on CO_2 emission while imposing high welfare costs.

Exhibit 18. Comparison of cost effectiveness of alternative tax policies
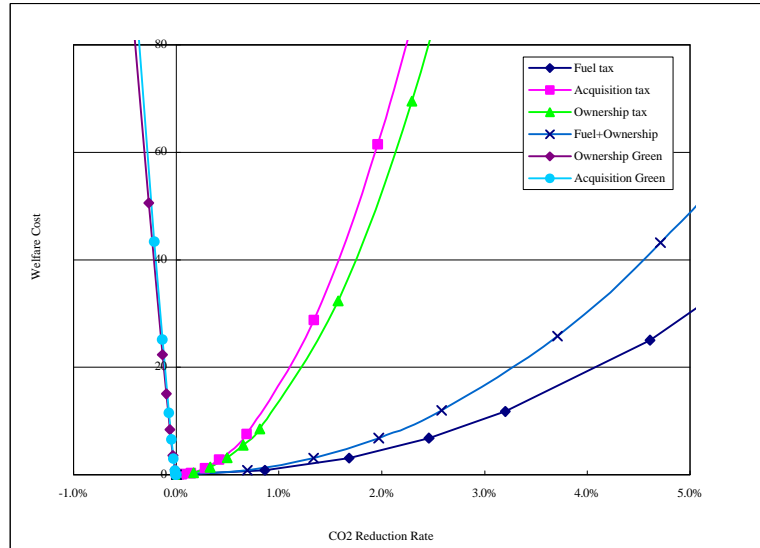
So far we have computed welfare costs assuming that CO_2 emission reduction has zero social value. Exhibit 19 computes net benefits of increasing the fuel tax assuming various social marginal costs of CO_2 emission. This graph shows that the optimal level of emission reduction is rather small. Even if the marginal cost is as high as 30 thousand yen per t-C, the optimal reduction rate is about 4%.

Exhibit 19. Net welfare changes with different social values of CO_2 emission reduction: The fuel tax case
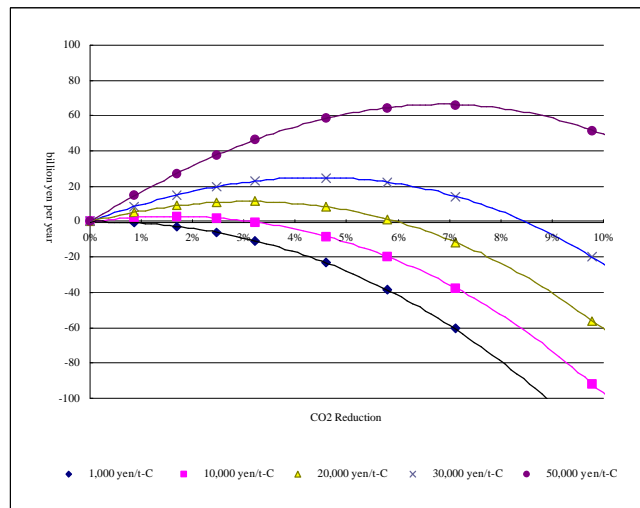
Concluding Remarks

We have reviewed some of the major policy issues concerning environmental problems caused by the road transport sector. We also presented preliminary results on the welfare evaluation of alternative tax policies to reduce CO_2 emission.

Although our model is still very primitive, our analysis indicates that the 'Green' tax introduced in Japan in 2001 may not be effective in reducing CO_2 emission while imposing large welfare costs on automobile users. It also shows that a fuel tax is more cost effective than ownership and acquisition taxes. Furthermore, a revenue neutral tax policy that increases the fuel tax and reduces the ownership tax performs better than raising the ownership and the acquisition taxes.

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