A Land-Use Transport Model to Assess the Impact of Urban Policies on Carbon Dioxide Reduction and Sustainability

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Abstract: Urban policies are considered important measures for mitigating global warming. They are estimated to have a substantial positive impact on CO_2 emissions from urban activities, owing to changes in the behavior of actors in the urban system. This means that urban mitigation policies would also affect the quality of life of urban residents. The impact of urban policies should therefore be assessed with regards to both CO_2 emissions and sustainability. This study demonstrates the applicability of a land-use transport model to urban mitigation policy assessment. First, we develop a model in which actors' location decisions and travel behavior are explicitly formulated. Second, this model is applied to two urban policies, road pricing and land-use regulation, to assess their long-term impact on CO_2 emissions and sustainability. The study verifies that the developed model has the capacity, under assumed conditions, to consistently assess urban policies regarding CO_2 emissions and sustainability.

Keywords: global warming mitigation, sustainability, urban policies, land-use transport model

1. INTRODUCTION

Urban policies toward compact cities and modal shift are considered important measures for mitigating global warming by reducing CO_2 emissions from the transport sector. Compact cities or public-transport-oriented cities can be realized through the behavioral changes of actors in the urban system, that is, change of location of residence for households or of office for firms and change of transport modes for a wide range of travel purposes. Urban policies, including the development of public facilities or infrastructure, transport or land-use regulations, and taxes or subsidies, change the conditions of an urban system and induce actors in the system to change their behavior. As a result, urban policies affect CO_2 emissions from urban activities as well as the happiness or quality of life of people in the city, which can serve as a representative index of sustainability.

The policies that decrease city residents' quality of life are not sustainable because they thwart the satisfaction of the needs of current or future generations. When we evaluate urban policies as global warming mitigation measures, we should recognize not only their impact on CO_2 emissions reduction but also their impact on people's lives as an index of sustainability.

A land-use transport (LUT) model is an analytical tool for assessing the impact of urban policies on people's activities and quality of life. This approach assumes the behavioral principles of people and firms with regard to their location choices and travel in the urban system. It analyzes the impact of policies on these urban activities; consequently, their CO_2 emissions can be calculated. With this analytical tool, we can estimate the impact of policies on people's happiness or quality of life in light of their behavior.

The objective of this study is to demonstrate the applicability of an LUT model to the assessment of global warming mitigation measures in urban systems. We developed an LUT model in which people's behavior is explicitly described in order to assess urban policies' impact in reducing CO_2 emissions and their impact on urban sustainability. By using this model, the impact of urban compaction and the modal shift of passengers are analyzed in the assumed virtual city. In section 2, we review urban policies as mitigation measures and studies for urban modeling. Our LUT model is formulated in section 3, and the simulation results for urban compaction policy and modal shift policy are described in section 4.

2. URBAN POLICIES AND ANALYTICAL MODELS

2.1 Urban Policies as Global Warming Mitigation Measures

Some studies indicate that urban policies could have a substantial impact in reducing CO_2 emissions. The National Institute for Environmental Studies in Japan published its vision of the urban lifestyle of the future and future reduction in CO_2 emissions and discussed policy measures to realize its vision (NIES, 2006). It concluded that by 2050, emissions could be reduced by 70% from their 1990 level. Urban policies are responsible for part of the emissions reduction in their model, and their model analysis indicates that it is possible to drastically reduce CO_2 emissions from building, heating/cooling, and transport (Hanaki, 2009). The Intergovernmental Panel on Climate Change (IPCC) compiled a wide range of mitigation measures in the field of land use and transport policy, including urban compaction and modal shift (IPCC, 2007). In order to promote mitigation through urban policies, the Japanese government selected 13 cities to serve as eco-model cities in which policies for a low-carbon society would be implemented (Prime minister of Japan and his cabinet, 2009). In this program, the government will help selected local governments to achieve their emissions reduction targets through urban policies. In the following section, we summarize the features of urban compaction and modal shift of passenger transport from the literature.

Urban compaction

Urban compaction is a policy that aims to reduce CO_2 emissions and energy consumption without loss of residents' welfare by limiting the urban sphere and leading to a higher density of population. Measures that support this policy include land-use regulations such as zoning and development controls, strategic investments in urban infrastructure at the city's center, and a system of property and land value taxes that give preference to location and development at the city's center.

The following positive effects are expected from this policy: reduction in total trip length, a modal shift from private cars to public or non-motorized transport, cost savings from infrastructure and buildings in suburbs, and improved efficiency of area heating/cooling as a result of higher density at the city's center. At the same time, it would cause negative effects such as worsening traffic congestion, a rise in land price, an increase in construction costs, a decline in residence/office space per person, concentration of hazardous risk, and an increase in energy consumption from building maintenance and operations due to intensive vertical development.

Modal shift of passenger transport

Modal shift policy aims to induce modal shift from private cars to public transport or non-motorized transport, which may alleviate road congestion and reduce CO_2 emissions. The following policy measures are considered to be effective: the development of public transport infrastructure, subsidies to public transport operations, fare controls, traffic regulation and pricing for private cars, fuel taxes, and parking fee controls.

These policies are expected to bring social benefits through service improvements and cost reductions for public transport, reduction of CO_2 emissions, and the alleviation of road congestion. However, the following negative impacts are also expected: an increase in fiscal expenditures on public transport and a decline in social welfare due to restrictions on or increased costs of car usage.

Although these two policies may reduce CO_2 emissions from the transport sector, they would have both positive and negative impacts on social benefit. This suggests that we should not only assess the impact of these policies on CO_2 emissions reduction but also on social sustainability. Because the path of impact of urban policies on social sustainability is not simple enough to be understood intuitively, we need an analytical tool to assess the possible effects of urban policies on society.

2.2 Urban Models and Land Use Transport Models

There are various studies of urban models based on different theoretical frameworks, including the optimization model of residential location (Kobayashi and Taguchi, 2001), the life-cycle assessment model for estimating lifetime environmental burden from building and transport (Urban Transport Planning Office *et al*, 2002), and the urban economics model for assessing the impacts of policies on the spatial pattern of economic activities and on social welfare (Safirova *et al*, 2006). Among these studies, only the urban economics models explicitly describe people's behavior in a city and are able to quantify the social sustainability indices, including benefit based on the behavioral principle.

LUT models, which integrate the urban economics model and transport behavior theory, provide a comprehensive analytical framework for the assessment of urban policies (see review papers Wegener, 2003; Miyamoto et al., 2006). For example, Anas and Xu (1999) developed a general equilibrium model of urban activities of households and firms in a city, based on discrete choice theory, to assess urban policies such as road pricing and the provision of public housing. In their study, they divided the urban space into discrete zones, and their model assessed the policy impact by comparing the equilibrium states with and without the policy, where the equilibrium state represents the simultaneous equilibrium of markets, including commodity, labor, land, and transport markets, in every zone.

The purpose of this study is to develop a method of assessing the impact of urban policies on CO_2 reduction and social sustainability, and its model should be applicable to various cities with different population and economic levels. Physical conditions and socio-economic activities reasonably differ among cities; indeed, developed countries and less developed countries look quite different in appearance. However, many cities in arising countries are taking similar urban growth trajectories and they are facing same urban problems in land use and transport. Probably different legal systems or culture bring different urban situations, but the essential drivers to form urban structure and activities, which is derived from behavioral principles of people or firms, can be assumed to common to the liberalism states. Following the literatures of LUT models, this study explains urban formation by the behavior of actors in the urban system under the given population, technologies, and productivity. We consider that people and the other actors have common behavioral principles in the urban activities over the world, especially with regard to the economic aspects; therefore, it is highly expected that our modelling framework is applicable to various cities with different conditions if appropriately tuned.

As we intend to explain the impact path of policy measures, the model is designed to output some basic indicators related to lifestyle, including income, floor area of residence, and commuting time, as social sustainability indices. Our model is based on past studies of LUT models; however, some sub-models such as firm's location and developer's investment behaviors are upgraded for in-depth policy assessment. For the contribution to policy formulation and implementation, our model is aimed to serve as a tool for sharing the vision of policy outcomes between policy makers and other stakeholders. Figure 1 shows the concept of vision sharing using LUT model. Stakeholders involved in urban policies may have their own interests that are sometimes distinctive and may have conflict with the interests of the other stakeholders. LUT model can be designed to analyze those different interests consistently and visualize the outcomes spatially. Those outcomes form a vision of the target urban area and sharing of the vision among stakeholders may support to coordinate planning the policy and building the consensus. This issue is not sufficiently considered in the past studies and sometimes the impact-paths were not explicitly presented. To make the analytical results accountable, we try to keep the modeling framework as general and simple as possible.

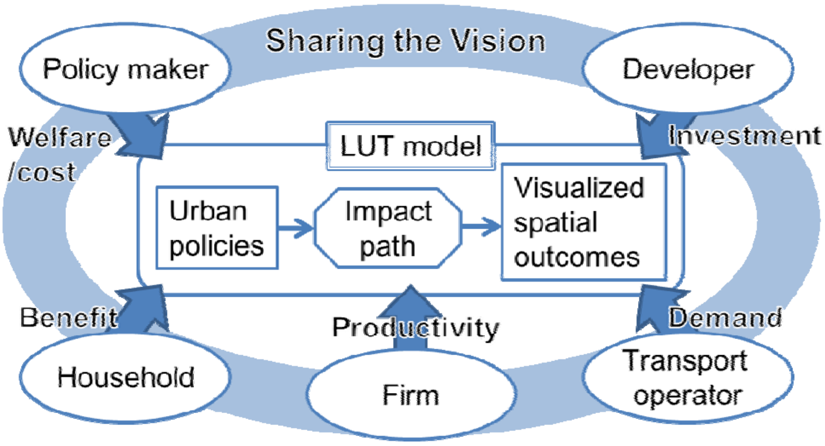

Figure 1. Concept of vision sharing

3. LAND-USE TRANSPORT MODEL

Our model is similar in structure to the model by Anas and Xu (1999), but we introduce an agglomeration economy in the firm's location choice, and we make the floors for residences and offices an endogenous variable by introducing a model of developer's behavior. In addition, we employ the bid-rent theory (Alonso, 1964) for the clearance condition of the floor market to reduce the computational cost of the model. In this study, we consider only passenger transport and neglect freight transport. Furthermore, the car and train are the only transport modes analyzed here.

3.1 Formulation of Behaviors

We assume five classes of actors in a city: employed households, unemployed households, firms, developers, and land owners. The principles of their behavior are formulated as follows.

The employed household

The employed household decides the consumption of goods x, floor A, and leisure hours S so as to maximize its utility u^H under the constraints of time and income. This behavior can be formulated as follows.

$$\max \quad u^H = X_{ij}^{\alpha X} \cdot A_{ij}^{\alpha A} \cdot S_{ij}^{\alpha S} \tag{1}$$

$$\text{s.t.} \quad w_j \cdot T_{ij}^{w} + W = \Sigma_{ik} p_{Hik} \cdot x_{ijk} + r_{ij} \cdot A_{ij} + c_{ij} \cdot T_{ij}^{w} \tag{2}$$

$$T = T_{ij}^{w} + T_{ij}^{c} + S_{ij} \tag{3}$$

$$X_{ij} = (\Sigma_{ik}\, b_k \cdot x_{ijk}^{-\rho})^{-1/\rho} \tag{4}$$

where i, j, k denote the location of residence, work place, and shopping. X is the composite utility of goods, w_j is the wage rate, W is unearned revenue, p_{Hik} is the consumer price of goods, r is floor rent, c is commuting cost, T is available time, T^w is working hours, T^c is commuting hours, and b is the attractiveness of the shopping place. Here the consumer price of goods is defined as the sum of the original price of good p_H and the travel cost for shopping c_{ik} ($p_{Hik} = p_H + c_{ik}$). Solving this problem, x_{ijk}, A_{ij}, T_{ij}^{W}, and r_{ij} are expressed as functions of u^H and w_j.

The unemployed household

The unemployed household decides the consumption of goods x and floor A so as to maximize its utility u^N under the constraints of income. This behavior can be described as follows.

$$\max \quad u^N = X_i^{\alpha X} \cdot A_i^{\alpha A} \tag{5}$$

$$\text{s.t.} \quad W = \Sigma_k p_{Hik} \cdot x_{ik} + r_i \cdot A_i \tag{6}$$

$$X_i = (\Sigma_k\, b_k \cdot x_{ik}^{-\rho})^{-1/\rho} \tag{7}$$

Solving this problem, x_{ik}, A_i, and r_i are expressed as functions of u^N.

Firms

Firms produce goods with inputs of labor, floor, capital, and business meetings so as to maximize their profit. This is expressed as follows.

$$\max \quad \Pi_j = p \cdot q_j - c_j \tag{8}$$

$$\text{Where} \quad q_j = \beta_0 \cdot L_j^{\beta_L} \cdot A_j^{\beta_A} \cdot K_j^{\beta_K} \cdot M_j^{\beta_M} \tag{9}$$

$$M_j = (\Sigma_{j'} (\xi \cdot L_{j'} \cdot m_{jj'})^{-\rho})^{-1/\rho} \tag{10}$$

$$c_j = w_j \cdot L_j + r_j \cdot A_j + \Sigma_{j'} c_{jj'} \cdot m_{jj'} + \kappa \cdot K_j \tag{11}$$

where j is firm location; Π_j is profit; p is producer price; q_j is production quantity; L, A, K, and M are inputs of labor, floor, capital, and business meetings, respectively; $\xi L_{j'}$ is the value of meeting at location j', which is assumed to be proportional to the labor input at j'; $m_{jj'}$ is the number of meetings at j'; w is the wage rate; r is floor rent; $c_{jj'}$ is the travel cost between j-j'; κ is the price of capital; and β_L, β_A, β_K, β_M, and ρ are parameters. Solving this problem, L_j, A_j,

K_j, and $m_{jj'}$ are expressed as functions of w_j and q_j.

Developers

Developers produce floor A with inputs of land G and construction capital K, and they provide it to firms and households so as to maximize their profit Π. This behavior is expressed as follows.

$$\max \Pi_i = r_i \cdot A_i - \kappa_b \cdot K_j - r_{li} \cdot G_j \tag{12}$$

$$A_i = \gamma_0 \cdot G_i^{1-\gamma_k} \cdot K_i^{\gamma_k} \tag{13}$$

where r_i is floor rent, κ_b is the price of construction capital, r_{li} is land rent, and G_i is the given land area. We also assume $0 < \gamma_k < 1$. Here, the bid rents of actors differ from each other. We assume, in light of discrete choice theory (Ben-Akiva and Lerman, 1985), that the developers evaluate their rent in log scale with an error term, following a Gumbel distribution, and provide the floor to an actor in proportion to its probability of bidding the maximum rent among all actors. Employed households bid different rents according to their work place because commuting costs affect their bid rent. Denoting bid rents of firms r_i^B, employed households r_{ij}^H, and unemployed households r_i^N, the proportion of floor supply provided to each actor is expressed as follows.

$$\mathrm{Pr}_i^k = (r_i^k)^\theta / \Sigma_{k'} (r_i^{k'})^\theta \qquad k \in \{B, H, N\} \tag{14}$$

$$\mathrm{Pr}_{ij|H} = \left(r_{ij}^H\right)^{\theta_H} \Big/ \sum_{j'} \left(r_{ij'}^H\right)^{\theta_H} \tag{15}$$

$$r_i^H = \Sigma_j \, \mathrm{Pr}_{ij|H} \cdot r_{ij}^H \tag{16}$$

$$\mathrm{Pr}_{ij}^H = \mathrm{Pr}_i^H \cdot \mathrm{Pr}_{ij|H} \tag{17}$$

where B, H, and N denote firm, employed household, and unemployed household, respectively. The expected floor rent is expressed as follows.

$$r_i = \mathrm{Pr}_i^B \cdot r_i^B + \mathrm{Pr}_i^N \cdot r_i^N + \Sigma_j \, \mathrm{Pr}_{ij}^H \cdot r_{ij}^H \tag{18}$$

Solving equations (12) and (13) under equations (14)–(18), the floor area provided to each actor is calculated.

Land owners

Land owners rent their own land as building area or agricultural area to maximize their profit. Taking the same approach as with the developers' behavior formulation, we assume that land owners decide the proportion of land to supply as building and agriculture area according to the land rent. Assuming a building land rent of r_{li} and an agricultural land rent of r_{ai}, the building land area is calculated by the following equation.

$$G_i = G_{0i} \cdot \left(r_{li}\right)^{\theta_G} \Big/ \left(\left(r_{ai}\right)^{\theta_G} + \left(r_{li}\right)^{\theta_G}\right) \tag{19}$$

where G_{0i} is land area owned by a land owner.

3.2 Equilibrium Conditions

Equilibrium conditions for floor and labor markets

First, when floor demand of firms equals its supply, the production volume q_j can be calculated. Under this condition, labor demand in zone j is given by following equation.

$$L_j^B = (\beta_L / \beta_A)\cdot(r_j^B / w_j)\cdot A_j^B \tag{20}$$

Dividing the floor supply $A_i \cdot \mathrm{Pr}_{ij}^H$ by residential floor demand per employed household A_{ij}^H, the number of employed households n_{ij}^H is calculated. The number of unemployed households n_i^N is calculated similarly. Using these variables, the equilibrium condition of the labor market is expressed as follows.

$$L_j^B = \Sigma_i \, n_{ij}^H \cdot T_{ij}^w \qquad \text{for } \forall j \tag{21}$$

If the total numbers of employed and unemployed households in the urban sphere are given as N^H and N^N, the zonal numbers of households must satisfy the following conditions.

$$\Sigma_{i,j} \, n_{ij}^H = N^H \tag{22}$$

$$\Sigma_i \, n_j^N = N^N \tag{23}$$

Equilibrium conditions are expressed by equations (21)–(23), and they are solved by the utilities of households u^H, u^N, and the wage rate w_j for each zone.

Traffic network equilibrium

The origin-destination (OD) traffic volume between zones i and j is expressed as the sum of travel for commuting, shopping, and meeting. It is given by the following equation.

$$Q_{ij} = 2 \times (n_{ij}^H + \Sigma_i \, n_{ij}^H \cdot x_{ikj}^H + n_i^N \cdot x_{ij}^N + m_{ij}) \tag{24}$$

The first multiplier on the right hand side denotes the round trip. We denote the set of routes between zones i and j as K_{ij}, its generalized cost as c^{ij}, the cost to use route k as c_k^{ij}, and traffic volume on the route as f_k^{ij}. Assuming the Wardrop equilibrium (Wardrop, 1952), which satisfies the equal travel time principle, the following equation is satisfied.

$$f_k^{ij} \cdot (c_k^{ij} - c^{ij}) = 0 \text{ and } (c_k^{ij} - c^{ij}) \geq 0 \quad \text{for } \forall k \in K_{ij}, \ \forall ij \in \Omega \tag{25}$$

where Ω is a set of all OD pairs in the urban sphere. Denoting the traffic volume at link a as z_a and the generalized cost as $c_a(z_a)$ which is a function of traffic volume, the following equations can be derived.

$$c_k^{ij} = \Sigma_i \, \delta_{ak}^{ij} \cdot c_a(z_a) \qquad \text{for } \forall k \in K_{ij}, \ \forall ij \in \Omega \tag{26}$$

$$z_a = \Sigma_{k \in Kij} \, \Sigma_{ij \in \Omega} \, \delta_{ak}^{ij} \cdot f_k^{ij} \qquad \text{for } \forall a \tag{27}$$

$$Q_{ij} = \Sigma_k \, f_k^{ij} \tag{28}$$

where δ_{ak}^{ij} is a variable that equals one if link a is included on the route k in OD-ij, and zero if it is not included. If the vector of link traffic z_a satisfies equations (25)–(28), this traffic pattern satisfies the Wardrop equilibrium condition. This problem can be solved using the Frank-Wolfe algorithm (Frank and Wolf, 1956). In this paper, we use the following US Bureau of Public Road (BPR) function (BPR, 1964) for the link cost function of road.

$$c_a(z_a) = c_{a0} \cdot \left\{ 1 + \eta_1 \cdot (z_a / \chi_a)^{\eta_2} \right\} + c_{a1} \tag{29}$$

where c_{a0} is the time cost at zero traffic, c_{a1} is the monetary cost, χ_a is the daily traffic capacity, and η_1 and η_2 are the parameters. We assume the cost of the rail network is constant, that is, it is not a variable of rail travel demand. Solving this problem, travel time at each road link is calculated. By summing the travel time and cost of the links on the shortest path, travel cost c_{ij} and time T_{ij}^c are calculated. They are used as travel cost in the urban economics model. In addition, total traffic volume can be calculated as sum of products of traffic volume and link-length for all network links.

3.3 Benefit

Benefit B is defined as change in the utility of households by policies in monetary terms. In this model, the benefit can be approximately expressed as follows.

$$B = (u_w - u_o)\cdot(g_w + g_o)/2 \tag{30}$$

$$g_k = \sum_{i,j} \frac{w_{j,k}\cdot\alpha_s\cdot M + T^w_{ij,k}\left(w_{j,k}-c_{ij,k}\right)^2}{\left(w_{j,k}-c_{ij,k}\right)u_k} \cdot \frac{\left(w_{j,k}-c_{ij,k}\right)\left(T-T^w_{ij,k}\right)+M}{\left(w_{j,k}-c_{ij,k}\right)\left(T-T^w_{ij,k}\right)\left(1-\alpha_S\right)-\alpha_S M} \tag{31}$$

where the suffix w in equation (30) denotes “with policy” and o denotes “without policy.” g_k in equation (31) is the partial differentiation of income over utility.

3.4 Linkage among Actors and Markets

A summarized chart of linkage among actors and markets in the above formulation is shown in Figure 2. The arrow direction indicates major variables to represent the interaction among actors that can be interpreted as the flow of goods/services and the counter flow of price/cost.

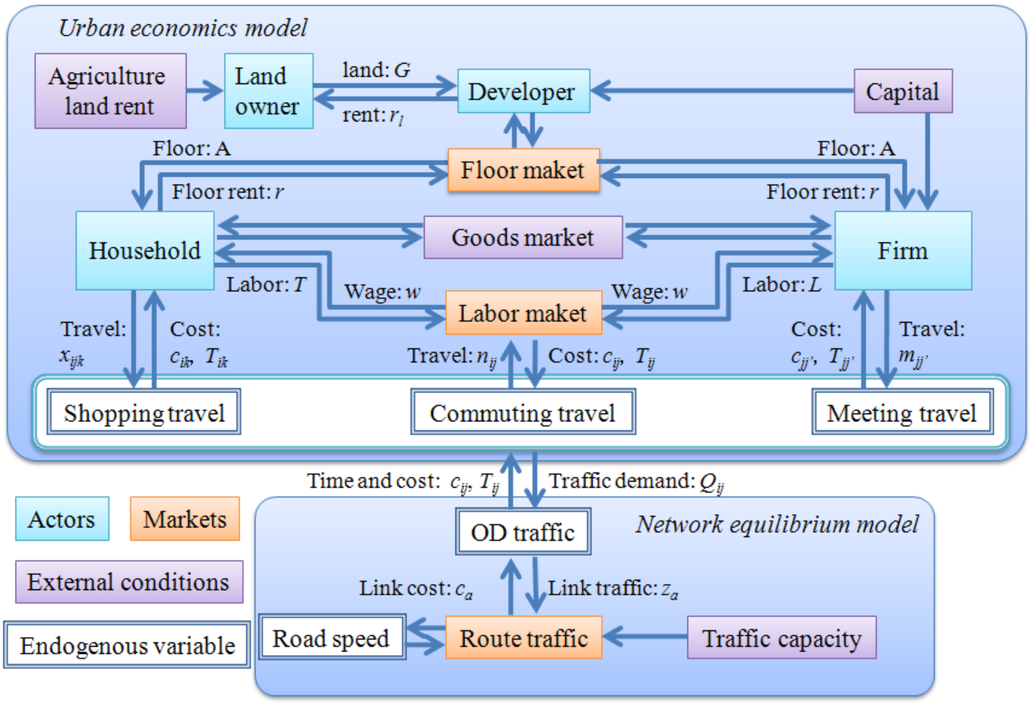

Figure 2. Linkage among actors and markets

The urban economics model and network equilibrium model are solved alternately. The former model outputs OD travel demand, which is an input of the latter model, and the latter model estimates OD trip time and cost, which are inputs of the former model. In this analysis, the system equilibrium is reached when the differences in the travel demand and cost from the preceding calculation are small enough.

4. POLICY ANALYSIS

Road pricing at the city's center and regulation of suburban development of buildings are taken as examples of urban policies in this study. We assume a square area that consists of 7×7 grids, and we assume that each grid is 2 km × 2 km. Two hundred thousand employed households and 100,000 unemployed households are assumed to exist in this area; four railways are supplied from the center to the north, south, east, and west. Road links connect all adjacent grids, with links that are nearer to the center having higher capacity. Each link on the transport network has same length, 2km. The model parameters are set based on various statistics, as shown in Table 1.

Table 1. Model parameters

Actor	Parameters		Value
Employed household	Household size		1.9
	Available time (hours/year)	T	7,538
	Unearned revenue (thousand yen/year)	M	125
	Parameters of utility function	α_X	0.20
		α_A	0.10
		α_S	0.70
Unemployed household	Household size		1
	Unearned revenue (thousand yen/year)	M	911
	Parameters of utility function	α_X	0.73
		α_A	0.27
Shopping place substitution parameter (both for employed and unemployed)		ρ	-0.56
Firm	Parameters of production function	β_0	1.50
		β_L	0.50
		β_A	0.20
		β_K	0.20
		β_M	0.10
	Meeting place substitution parameter	ρ	-0.30
	Rent for capital (thousand yen/year)	κ	90
Developer	Parameters of floor production function	γ_0	1.69
		γ_k	0.73
	Rent for capital (thousand yen/year)	κ_b	76
	Variance parameters	θ_H	1.00
		θ	3.00
Land owner	agriculture land rent (thousand yen/m^2/year)	r_a	5.00
	Variance parameters	θ_G	3.00
Road link cost function		η_1	0.48
		η_2	2.82

Note: These parameter values are estimated based on statistics published by the Japanese government (Statistics Bureau, 2006; Statistics Bureau, 2007; Statistics Bureau, 2003; RIETI, 2008; Land and Water Bureau, 2003)

The road network is assumed to be used only by passenger cars that refueled by gasoline. The fuel economy of a car is given as a function of its driving speed and vehicle weight (Hosoi, 1998) where the speed is calculated for each link in the model and the weight is assumed to be 1.2 ton. We assume the occupancy rate of each car is one, that is, passenger kilometrage and vehicle kilometrage are identical. CO_2 emission from a road link is calculated by multiplying traffic volume, length of a link, fuel economy and CO_2 emission per fuel consumption. In the development regulated areas, train service is not provided and infrastructures are not maintained, i.e. CO_2 emission caused by these activities is reduced. On the other hand, CO_2 emissions from these activities in the unregulated grids are not changed.

Under these assumptions, the estimated location pattern of an employed household's residence and link traffic on the road and railway in the equilibrium state are shown in Figure 3. This figure indicates that the household density is higher as the grid is nearer to the center. It shows that the grids along the railway are relatively attractive for residents as well. The pattern of location of firms is similar to that of the location of households. Reflecting the location pattern of households and firms, heavier traffic is found on the links that are nearer to the center.

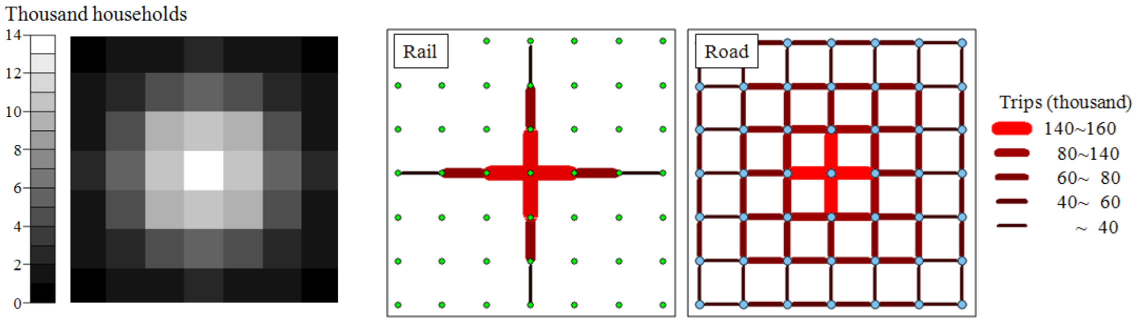

Figure 3. Residential pattern of employed household (left), link traffic of rail (middle) and roads (right)

We define this equilibrium state as the benchmark and estimate the impact of two policy measures. Because a policy measure changes the conditions of location and travel, it brings another equilibrium state. Policy impact is calculated as the difference between the equilibrium state with policy and the equilibrium state without policy. Regarding the dynamics of policy impact, the travel pattern can be changed in the short term. However, the change of location pattern may take more time because the location change of residents or firms requires a higher cost than route/mode change in travel. In the case of Japan, the lifetime of a house is around 30–40 years, and it would allegedly take the same number of years to reach the new equilibrium state for location by policy intervention.

4.1 Impact of Road Pricing

Road pricing will affect the mode or route choice of actors in the short term, while it may affect the location of residence and office to avoid the charge in long term. Here, we analyze the long-term impact of road pricing.

In this analysis, road pricing is instituted in the road links connected to the center grid. If we set a certain value (e.g., 200 yen) as the charge of a toll, we can calculate the toll's effect on CO_2 and traffic. In this model, the road charge is added to c_{a1} in equation (29). The effect is calculated as the differences in CO_2 and traffic between this case and the case of a zero yen toll. We set seven values (200, 400, 600,… 1400) as the toll charges and calculate the effect for each. In the case of a charge of more than 1400 yen, there is no traffic on the charged road links. CO_2 emissions from road transport decline over the range of charges, although the sensitivity is small in the range of charges above 1000 yen (Figure 4). This policy does not affect emission from infrastructure construction and management as well as from railway operation. In total, the road pricing is estimated to reduce 6% of CO_2 at maximum. The total traffic volume declines and the share of railway traffic increases as the charge increases (Figure 5). In the range of charges above 1000 yen, the traffic on the link with road pricing is already so small that the traffic and modal share sensitivities over the charge are small.

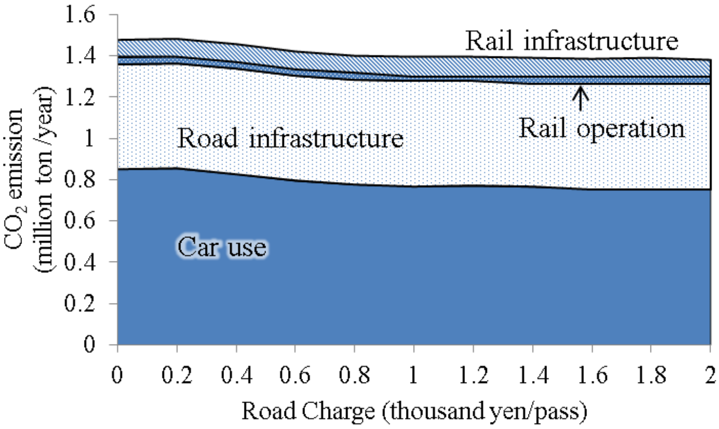

Figure 4. CO_2 emissions change from road transport over the road pricing

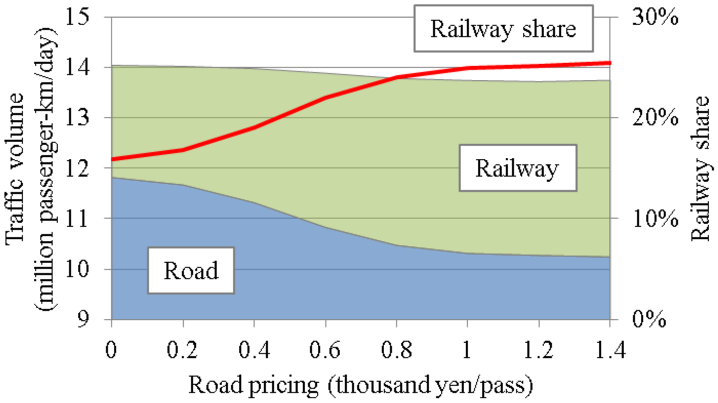

Figure 5. Traffic volume and modal share over the road pricing

Benefit declines as the charge increases (Figure 6). In this study, the benefit is composed of income, floor area of residence, and leisure time, but it does not consider the return of revenue from the road pricing to households, income increases of land owners, as well as profit of railway operator. The revenue from road pricing has a maximum value when the toll is 400 yen, and the revenue is significantly larger than the negative impact on benefit. This indicates that if the cost for road pricing is sufficiently inexpensive and the revenue is adequately returned to households, the road pricing could possibly improve the overall benefit. It is consistent with the findings of transport economics, which suggest that transport charging under the existence of externality of traffic congestion improves the social welfare (Pigou, 1920). When the charge exceeds 1000 yen, its negative impact on benefit is larger than the revenue from the charge. This means that excessive charging decreases the total benefit.

The revenue of land owners from land rent is positive, at 400–600 yen. The rent at the grid of the city's center increases because some households and firms shift their location to the center to avoid the road pricing. In the range above 800 yen, the charge has a negative impact on income of land owners. This reflects the depressed economic activity due to the excessive road pricing. Profit of railway operator increases at 200-800 yen because the railway passengers increase due to the modal shift.

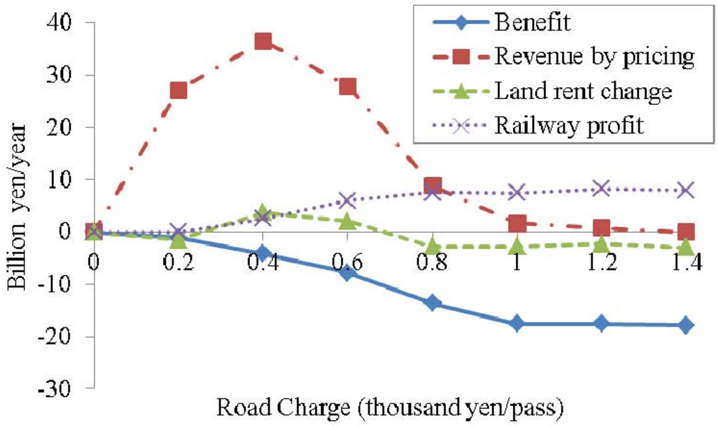

Figure 6. Change of benefit, revenue from charge, and land rent over the road pricing

4.2 Impact of Regulation on Suburb Development

In this analysis, we assume that the location of households and firms at the outer area of the city shown in Figure 3 is prohibited. The usable area is set at 196 km^2 without regulation, although it is 100km^2 if the outermost grids are regulated, and it is 36km^2 under the regulation of the two outermost grids.

CO_2 emissions from road transport decline as the size of the development area decreases (Figure 7). The rate of CO_2 emission reduction is higher under the regulation of two outermost grids. The regulation also reduces emission from construction and maintenance of road and rail infrastructure as well as rail operation, while absolute values of latter two reductions are small. The total CO_2 is reduced 25% at 100km^2 of development area and 57% at 36km^2.

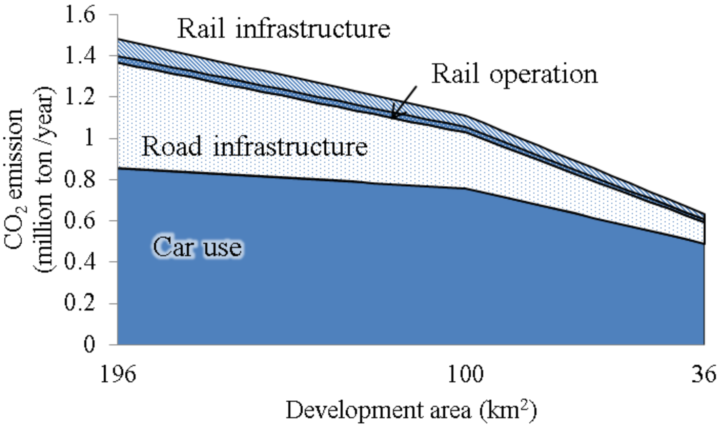

Figure 7. CO_2 emissions change from road transport over development area

Regarding the change in transportation (Figure 8), the total traffic volume declines and the railway's share of traffic increases as the development area is reduced. Regulation is expected to reduce the trip length because it leads small urban area. As shown in this figure, the road traffic significantly declined but volume of railway traffic is almost stable. Assumed regulation increases the chance to access to the railway from origin of a trip; the share of the grids where railway runs is 27% without regulation in this setting but it is 36% and 56% when the outmost and two outmost grids are regulated respectively. It would be applicable to the actual cities. Also the spatial concentration of urban development increases the possibility of congestion on road. The level of service of railway is constant, therefore congestion on road induces modal shift. These changes in transport correlatively affect the increase of railway share and consequent reduction of CO_2 emissions.

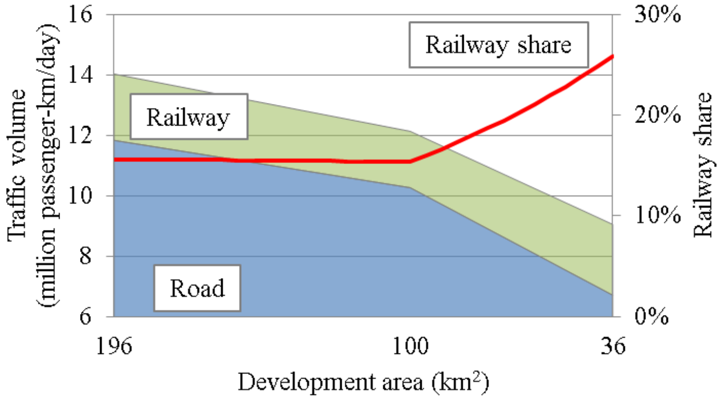

Figure 8. Traffic volume and modal share over development area

Benefit declines especially in the case of regulation of two grids (Figure 9). In this analysis, the reduction of the development area increases the scarcity of land, which induces a rise in floor rent. As a result, it reduces the floor area of houses and offices. The rise in floor rent increases the production cost of firms. It consequently lowers the income of households and leads to longer working hours. The estimated benefit in this study reflects this mechanism of urban economic activity.

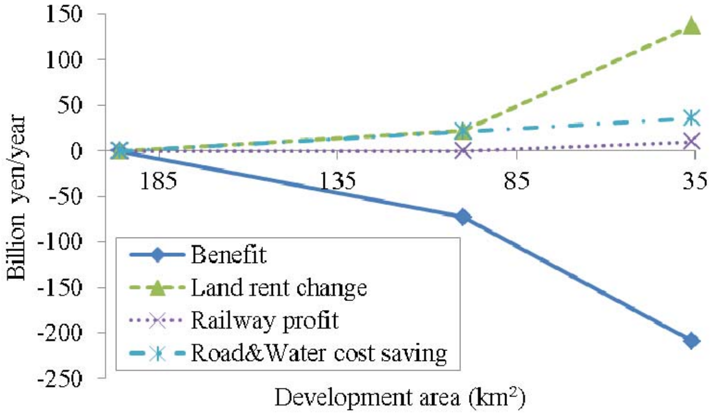

Figure 9. Change of benefit and land rent over development area

On the other hand, a land rent increase raises the income of land owners. If land owners and households in the city are not identical, this result can be interpreted to mean that the policy prompts income transfer from households to land owners. Part of the negative benefit to households is caused by this income transfer. In addition, infrastructure cost can be saved at regulated grids. We assume costs for road, rail, water and sewage are eliminated there. In the figure the cost reduction in railway slightly increases the railway profit. Road and water cost reduction benefits the local government. In this model, tax collection is not considered therefore this cost saving has to be taken into account. The sum of the changes in benefit, land owner income, railway profit, road and water construction and maintenance costs, which cancels the income transfer, indicates the negative figure. It suggests the possibility of social welfare reduction by the land use regulation policy.

4.3 Comparison of Urban Policy Impacts

Road pricing is estimated to possibly bring economic benefit but have quite small impact on CO_2 emission reduction. On the other hand, regulation on suburban development will have drastic impact on CO_2 emission reduction but have negative figure on the economy.

Regarding the CO_2 emission, the pricing reduces emission from car use but its impact is small compare to the land use regulation. The pricing policy induce modal shift to railway for the trip to city center in short term, and it induce relocation of households and firms from city center to not priced girds in long term. Therefore this policy triggers the dispersed urban structure which is negative for CO_2 emission reduction. Land use regulation forces compact urban form that makes trip length shorter and access to railway easier, consequently emission from car use declines. In addition emission from infrastructure construction and maintenance is reduced at regulated grids while pricing does not change the emission from the infrastructures. In combination of these factors land use regulation has much larger impact on the reduction than that pricing does.

Meanwhile, the land use regulation brings negative economic impact substantially as described before. The regulation enforced household to shorten the trip length and commuting time, which is positive factor for benefit, however decline of livable land make household to live smaller house by paying more expensive rent. It is main driver to decline the benefit of household. The average floor declines 5% and 15% when outmost and two outmost grids are regulated. For firms, floor rent increases therefore they shift the input from floor to labor. At the same time, the reduction of commuting time alleviates time constraint. It leads higher supply of labor and decline of wage rate. As a result, this policy brings lower wage rate and longer working hours. Reflexively, the floor rent increase will benefit the land owners. Sum of these factors indicates negative figure, it is -25 to -30 billion yen annually. As explained the pricing has more complex figure. If half of the pricing revenue is used for the system cost for pricing, the sum of benefit, revenue, land rent, and railway profit has maximum value +20 billion yen at charge of 400 yen, and it declines to -13 billion yen at 1400 yen.

Considering the total monetary impact as a cost for CO_2 reduction, the unit cost to reduce emission by the policy can be obtained (Table 2). When 400 yen is charged as toll, the cost is estimated -845,000yen/ton-CO_2; this means CO_2 can be reduced with social monetary benefit. However its reduction potential is only 24,000 ton/year in this setting. If toll is 1400 yen, the reduction potential is 86,000 ton/year but the reduction cost is 150,000yen/ton-CO_2. Land use regulation reduces the emission about 10 times than road pricing does. The unit costs are about 79,000 yen/ton-CO_2 and 30,000 yen/ton-CO_2 for outmost and two outmost regulation respectively. The unit costs are extremely expensive compare to allowance price in

EU-ETS market, it was about 2,000 yen/t-CO_2 in 2011, except in case of the negative cost by road pricing. However, if photovoltaic generation is considered as a measure for CO_2 reduction, its cost can be estimated about 30,000yen/t-CO_2. In this sense, the urban compaction could be a possible option of future countermeasures for climate change with substantial reduction potential.

Table 2. Efficiency of CO_2 reduction

			Net surplus billion yen	CO_2 reduction thousand ton/year	Unit cost 1000yen/tCO_2
Road pricing	Toll(yen)	400	20.3	24	-845.4
		1400	-12.9	86	150.1
Land use regulation	Livable area(km^2)	100	-29.2	371	78.7
		36	-25.2	848	29.7

The climate policy requires integration of existing policy fields to achieve drastic reduction of greenhouse gas emission. Many literatures have studied these policies independently, but analysis in a unified framework should be needed to discuss the policy integration. In addition to these urban policies, technological development in transport and building/construction should be incorporated because they are essential factor to reduce CO_2 emission without declining the social activities. These technological progresses can be reflected in the model by change of cost of housing and transport. Urban conditions including population and income level may affect the policy impact substantially. Some policies may be effective for a city but may be not for the other situation. These conditions can be taken into account as well in this model, and further parameter studies may clarify the effective policies for specific conditions. The LUT model including one proposed here can be a tool for a city wide integrated policy analysis, but further study is needed.

5. CONCLUSION

In this study, we developed a land-use transport model, which explicitly represents the behavior of urban actors like households and firms, and applied it to assess the impact of two policy measures, road pricing and suburban land use regulation, under the virtual urban conditions. In this application of the model, we attempted to evaluate the long-term impact of urban policies in reducing CO_2 emissions and on the indices of sustainability.

We found that these two policies reduce CO_2 emissions from road transport because they change the location and travel behavior of households and firms. As a result of changing the location and travel behavior, the policies are estimated to reduce the benefit of households. It can be interpreted that the CO_2 reduction and decline in benefit caused by these policies have a trade-off relationship in this analysis. Case studies have demonstrated the applicability of the LUT model to the integrated and quantitative impact assessment of urban policies on CO_2 emissions reduction and sustainability, which have been analyzed partially or qualitatively in past policy studies.

However, we focused only on policy measures like charging and regulations, which increase costs of urban activities including travel and location choice. In addition, in the analysis of charging, the revenue was evaluated separately from the calculation of benefit. These assumptions naturally induce negative benefits. For the discussion to balance emissions reduction and social welfare, we should consider a mix of charging or regulative policies and subsidizing or development policies that enhance urban functions, such as investment in public transport.

REFERENCES

Alonso, W. A. (1964) *Location and Land Use: Toward a General Theory of Land Rent*, Harvard University Press, Cambridge.

Anas, A., and R. Xu (1999) Congestion, Land Use, and Job Dispersion: A General Equilibrium Model, *Journal of Urban Economics*, Vol.45 No.3, pp. 451-473.

Ben-Akiva, M., and S. Lerman (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*, MIT press.

Bureau of Public Roads (BPR) (1946), Traffic Assignment Manual, U.S. Dept. of Commerce, Urban Planning Division, Washington D.C.

Frank, M., and P. Wolf (1956) An Algorithm for Quadratic Programming, *Naval Research Logistics Quarterly*, Vol. 3, pp. 95-110.

Hanaki, K. (2009) Teitanso toshi no jitsugen he mukete no kaiseki (in Japanese), available from: http://2050.nies.go.jp/report/file/lcs_japan/2050_LCS_urbanleaflet_20090208.pdf

Hosoi, K.(1998) Driving Cycles and Emission Factors Necessary for Calculation Total CO_2, *Journal of Japan Automobile Research Institute*, Vol. 20, No. 9, pp. 395-399, (in Japanese).

IPCC (2007), *Climate Change 2007, Mitigation of Climate Change*, Cambridge University Press.

Kobayashi, T., and A. Taguchi (2001) A Model for Urban Space Allocation to Transportation Area and Residential Area, *Journal of the Operations Research Society of Japan*, Vol. 44, No. 3, pp. 281-296, (in Japanese).

Land and Water Bureau, Basic Survey on Land, Ministry of Land, Infrastructure and Transport, 2003.

Miyamoto, K., V. Vichiensan, N. Sugiki, and K. Kitazume (2006) Applications of operational urban models in the world with emphasis on land-use models, *Proceedings of Infrastructure Planning*, Vol. 33 (CD-ROM) (in Japanese).

National Institute for Environmental Studies (NIES) (2006) LCS Research Booklet No.3: Development of Japan Low-Carbon Society Scenarios, available from: http://2050.nies.go.jp/report/file/lcs_booklet/LCS_BOOKLET_No3.pdf

Pigou, A.C.(1920) *The Economics of Welfare*. Macmillan, London.

Prime minister of Japan and his cabinet (2009) Eco-model city for the low carbon society, available from: http://www.kantei.go.jp/jp/singi/tiiki/kankyo/

Research Institute of Economy, Trade and Industry (RIETI) (2008) IAA, Japan Industrial Productivity Database, Ministry of Economy, Trade and Industry.

Safirova, E. A., S. Houde, D. A. Lipman, W. Harrington and A. D. Bagliano (2006) Congestion Pricing: Long-term Economic and Land-Use Effects, Discussion Papers dp-06-37, Resources for the Future.

Statistics Bureau (2003), Housing and Land Survey, Ministry of Internal Affairs and Communication.

Statistics Bureau (2006) Survey on Time Use and Leisure Activities, Ministry of Internal Affairs and Communication.

Statistics Bureau (2007), Family Income and Expenditure Survey, Ministry of Internal

Affairs and Communication.

Urban Transport Planning Office, City Planning Division, City and Regional Development Bureau, Ministry of Land, Infrastructure and Transport, T. Oka, and N. Torisu (2002) Effects on Energy Load by Compact Urban Structure, *Traffic Engineering*, Vol. 37, pp. 35-42 (in Japanese).

Wardrop, J. G. (1952) Some theoretical aspects of road traffic research, Proceedings of the Institute of Civil Engineers Part II, pp. 325-378.

Wegener, M. (2003) Overview of land-use transportation models, *Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management*, pp. 20-40.