Backcast Analysis for Realizing Sustainable Urban Form in Nagoya

YASUO TOMITA, DAISUKE TERASHIMA,
AMIN HAMMAD and YOSHITSUGU HAYASHI

Because cities vary greatly from one to another there is no ideal sustainable urban form which can be applied to all. Here the case of Nagoya is considered, and the application of backcast analysis, using an integrated land-use and transport model, to investigate the appropriate policy scenario to realize an ideal urban form under given environmental and financial constraints is described.

1. Introduction

One common phenomenon in developed countries is that many are experiencing declining growth and a shrinking economy. In addition, the population configuration of these cities has changed markedly in recent decades. These changes are posing financial constraints on improving and maintaining the cities' urban infrastructures, and at the same time aggravating global environmental problems. Without adequate urban policies, social and economic activities in some areas of the cities can be expected to decline further, transport energy consumption would continue to increase following current trends, accessibility between urban activities would decrease, and urban infrastructure would be in short supply. Therefore, many researchers propose transferring the sprawled suburban areas in cities to more compact urban forms while maintaining the quality of life and the level of economic activities. However, most existing studies related to such policies have focused on qualitative analyses of ideal urban forms, while those quantitative analyses that do exist, focus mainly on the reduction of transport energy consumption.

In this paper, using a land-use and transport model developed by Hayashi and Tomita (1990), we try to answer the following questions to realize an ideal urban form by applying quantitative analysis:

1. What are the urban policy scenarios that can realize more compact forms in sprawling built-up areas? This process is called *'de-suburbanization'* in this paper. We will use *backcast analysis* to investigate the appropriate policy scenario to obtain an ideal urban form under given environmental and financial constraints.

2. How can the de-suburbanization policies be financed?

The organization of the paper is as follows: first, debates on the concept of 'the compact city' are reviewed in Section 2 to consider what is the ideal urban form. Then, the model developed by Hayashi and Tomita (1990) that will be used for backcast analysis, is described in Section 3. In Section 4, the parameters of the model, which is composed of several sub-models, are estimated based on the data of Nagoya Metropolitan Area, Japan. In Section 5, de-suburbanization policies, combining a housing subsidy to households who locate in the city centre zone and an increase in housing supply in this zone are analysed and used to demonstrate how the savings in infrastructure development could be achieved by de-suburbanization. Finally, Section 6 states the conclusions of this research.

2. Debates on the Compact City

According to Frey (1999), various arguments for and against the compact city came to the fore in about 1990. The supporters, called *centrists*, including the CEC (1990), Jacobs (1961), Newman and Kenworthy (1989), Elkin *et al.* (1991), McLaren (1992), Owens and Rickaby (1992), believe that the compact city has environmental and energy advantages and social benefits. On the other hand, there are some researchers who are against the compact city, the *decentrists*, including Breheny (1992*a*), Green (1996), and Knights (1996), who insist that the need for the compact city is not proven. For example, according to Banister (1992), there is evidence that fuel consumption per capita is highest in more rural areas, but also there are indications that the largest cities (for example, London) are likely to be less efficient than medium-sized and smaller towns, presumably as a result of congestion. In addition to the *centrists* and *decentrists*, there are the *compromisers* who insist that a *decentralized concentrated* urban form would be more suitable for larger cities with populations above 500,000 (Owens and Rickaby, 1992; Breheny, 1996). The ideal urban form is a combination of the best of town and country (Hooper, 1994), which is similar to the idea of Ebenezer Howard's concept of *The Sociable City* (Hall and Ward, 1998).

From these debates, it can be concluded that research focusing on a single aspect, such as the relationship between energy efficiency and transport or energy and urban form, is not likely to generate a reliable basis for the conception of a sustainable city or region (Breheny, 1992*b*). As cities are different in form and structure because of factors such as topography, history, climate, and socio-economic conditions etc., they cannot all fit the same formula when it comes to a question of a sustainable urban form (Frey, 1999). In the next section, in order to consider what is a suitable urban form for the specific city, how to reform that city, and how to finance the policies, the land-use and transport model that will be used in this paper is introduced.

3. Integrated Land-use and Transport Model Framework

Integrated land-use and transport models have been developed for over 40 years since the Lowry Model (1964) and used as analysis tools for making structure plans related to land use and transport. These models have been reviewed in several papers (Webster *et al.*, 1988; Wegener, 1994; Miller *et al.*, 1998; Waddell, 2002). Through the development process, they evolved in various directions: from aggregate models to disaggregate, static to dynamic, empirical to economics-based, using rough zones to detailed or grid zones, using GIS and micro-simulation techniques, and expanding models by adding various sub-models, such as household lifecycle sub-models, migration sub-models, and environmental assessment sub-models, etc.

Following this trend in model development, the land-use and transport model used in this paper evolved to become more disaggregate and to use GIS and micro-simulation. This model consists of five sub-models as shown in figure 1 (Hayashi and Tomita, 1990): (1) business location, (2) residential location, (3) land price, (4) transport, and (5) environment sub-models. The features of each sub-model are explained in the following:

1. *Business Location Sub-model.* This sub-model is a spatial interaction model that has a mechanism of interrelationship in economic activities, both between spaces and between industrial sectors, through a spatial interaction index conceptually similar to the inter-regional input-output table. This sub-model can simultaneously estimate the business activity distribution by sector and trip O-D by purpose except for commuting, by

assuming the spatial index is proportional to the number of trips.

2. *Residential Location Sub-model.* This sub-model simulates individual migration decision processes by using a disaggregate behavioural model considering the changes of attributes and socio-economic conditions. Another feature is that the locational surplus (locational utility minus land price) is the main explanatory variable in modelling household's location choice (Nakamura, Hayashi and Miyamoto, 1983). The output of this sub-model includes population distribution and the commuting O-D trip matrix.

3. *Land Price Sub-model.* This sub-model is formulated by a random bidding model (Lerman and Kern, 1983), which is based on the assumption that the highest random bid is realized as the land price. This sub-model can output the locational surplus in addition to land prices.

4. *Transport Sub-model.* This sub-model consists of two steps: modal split and traffic assignment. The modes in this sub-model are motor vehicle and rail. The modal split is formulated by using an aggregate logit model, and in both vehicle traffic and rail passenger assignments, stochastic equilibrium models are used.

5. *Environment Sub-model.* The link flows, which are estimated by the transport sub-model, are converted into NO_x, CO, CO_2 emissions and energy consumptions of the links. Then these values are converted into the concentrations around the links by using the conventional gas diffusion model. Finally these results are displayed on a GIS system.

In the following section, the residential

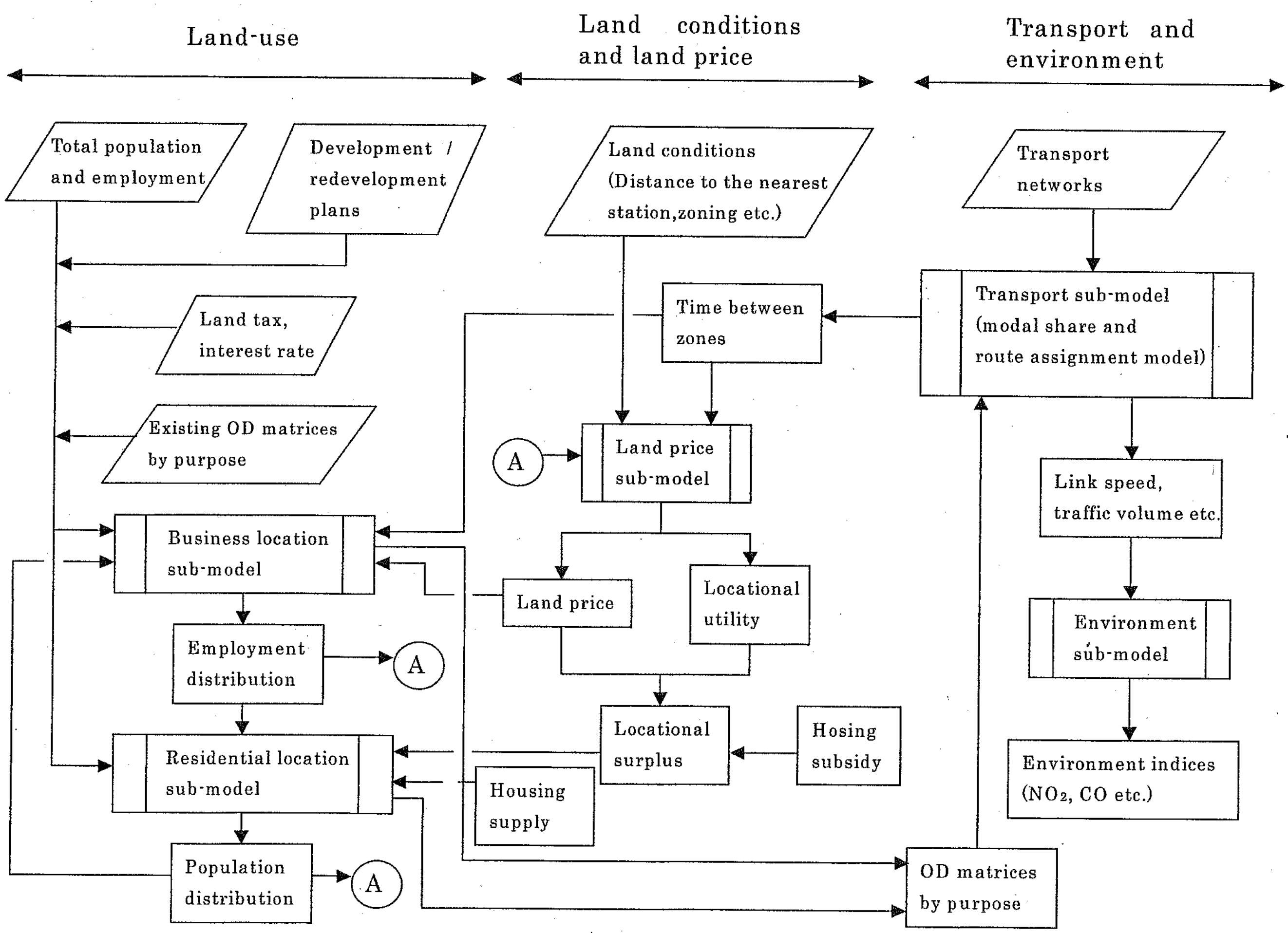

Figure 1. Model framework.

location sub-model and the land price sub-model are described, as they are directly related to policy analysis in section 5.

4. Residential Location Sub-model and Land Price Sub-Model

4.1. Formulations of Sub-models

Residential Location Sub-model. The residential location sub-model consists of 3 equations: (1) equation of potential migration demand; (2) equation of revealed migration demand and dwelling type choice; (3) equation of residential location choice. However, only the third equation is discussed here as it is directly related to the backcast analysis discussed in Section 5. This equation is formulated in equation (1) under the following hypotheses: (*a*) A household chooses a residential zone that has the larger utility and/or the smaller cost, i.e. the larger location surplus (Nakamura, Hayashi, and Miyamoto, 1983); and (*b*) if the locational surpluses are equal in different zones, a zone is chosen in proportion to its housing supply.

$$P_{ji} = (S_i)^{\alpha}\exp(\beta X_{ji}) \,/\, \Sigma_i (S_i)^{\alpha}\exp(\beta X_{ji}) \quad (1)$$

P_{ji} : Probability that a household, whose head commutes to zone j, chooses zone i

X_{ji} : Locational surplus of zone i whose head commutes to zone j

S_i : Amount of supplied dwellings in zone i

α, β: Parameters

The locational surplus (X_{ji}) in the above equation is measured by using the following land price sub-model.

Land Price Sub-model. The land price sub-model is formulated by a random bidding model (Lerman and Kern, 1983), which is based on the assumption that the highest random bid becomes the land price. The land price (P_i) is formulated as follows.

$$P_i = (1/\omega) \ln \Sigma_j \exp(\omega\, b_{ji} + \beta + \ln N_{ji})$$
$$(\text{where } b_{ji} = \Sigma_k \alpha_k Z_{ki}) \quad (2)$$

P_i : Average land price in zone i

b_{ji} : Price that a household whose head commutes to zone j bids for zone i

N_{ji} : Number of commuters between zones i and j

Z_{ki} : The k_{th} land condition of residential zone i

ω, α_k, β: Parameters

By using this land price sub-model, the locational surplus (X_{ji}) in equation (1) is measured by subtracting the land price (P_i) from the bidding price (b_{ji}).

4.2. Parameter Estimations in Nagoya Metropolitan Area

The integrated land-use and transport model was applied in Nagoya Metropolitan Area, in order to examine how de-suburbanization may be realized using backcast analysis. The area is set within about 20 km radius from the city centre of Nagoya and is divided into 33 zones for the analysis as shown in figure 2. The population of the whole subject area is 4.27 million (1990) and employment is 2.43 million (1991). The city centre is located at zone 6 in figure 2. The zone's area is

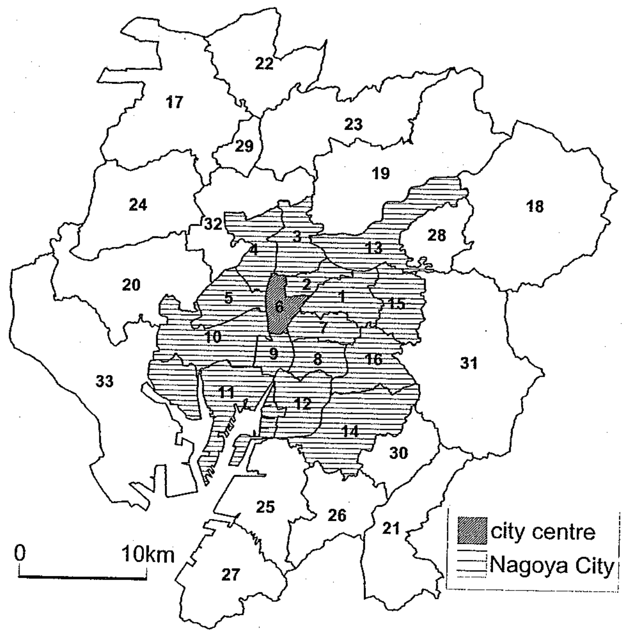

Figure 2. Nagoya Metropolitan Area and zone system

10 km^2, the population is 60,000 (1990), and employment is 200,000 (1991).

Residential Location Sub-model. For the calibration of the sub-model, disaggregate survey data of household migration (1993) were used. Although all equations of the sub-model were calibrated, only the results of the residential location choice equation are shown in table 1. These results mean that a household is likely to choose the zone that has a larger locational surplus and where more dwellings are supplied. The goodness-of-fits are almost good as the likelihood ratios are between 0.16 and 0.25.

Land Price Sub-model. The land price sub-model was estimated by using official land price data (1991). Table 2 shows the estimated parameters. The coefficient of commuting time means that a one-minute increase in commuting time causes a 18,300 yen decrease in bidding price, and a 1 km increase in distance to the nearest underground station causes a 27,500 yen decrease in bidding price. The coefficients of zoning regulation dummy variables mean that the bidding price of commercial and business zones is highest followed by the bidding prices of residential exclusive zones and then residential zones. Although the t-values of the estimated parameters are high, the correlation coefficient is not so high. This should be improved in the future.

5. Backcast Analysis for De-suburbanization

5.1. Policies for De-suburbanization and their Effects

The question of what is a sustainable urban form is not clearly answered. However, de-suburbanization seems to be one of the answers, because this policy can be expected to heighten agglomeration economy in the city centre and result in decreases in total commuting distance, time, and energy con-

Table 1. Estimated results of residential location choice equation (by dwelling type).

Variables	*Model-1 (owner- occupied detached house)*	*Model-2 (owner-occupied flat)*	*Model-3 (rented detached house)*	*Model-4 (rented flat)*
Amount of housing supply (α)	0.988 (7.3)	1.297 (7.3)	1.584 (6.3)	1.597 (17.2)
Locational surplus (β)	0.351 (6.8)	0.392 (7.6)	0.382 (5.0)	0.433 (21.5)
Number of samples	103	95	41	732
Likelihood ratio	0.21	0.16	0.18	0.25

Note: Values in brackets are t-values.

Table 2. Estimated results of land price sub-model.

Variables			*Coefficients*	*(t-value)*
Commuting time (minutes)		(α_1)	-1.83	(31.5)
Distance to nearest underground station (km)		(α_2)	-2.753	(-35.4)
Zoning regulation dummy variables	Residential exclusive zones	(α_3)	2.193	(12.9)
	Residential zones	(α_4)	0.962	(6.0)
	Commercial and business zones	(α_5)	14.55	(880)
	Industrial zones	(α_6)	0.000	
Variance parameter (ω)			1.68	(23.7)
Constant (β)			5.91	(21.2)
Number of samples			273	
Correlation coefficient			0.64	

Note: Unit of land price: 10,000 yen/m^2.

sumption, etc. It is also hoped that this policy would not cause much negative effect due to the higher population density in the city centre providing the concentration is not excessive. In this section, two de-suburbanization policies: (*a*) a housing purchase subsidy to households who migrate into the city centre, and (*b*) an increase in housing supply in the city centre (zone 6 in figure 2) were studied.

Figure 3 shows the population increase rate in the city centre caused by a housing subsidy. The population gradually increases with increases in the housing subsidy. For example, the figure shows that a 10 per cent housing subsidy causes about a 5 per cent increase in population and a 20 per cent subsidy causes about a 20 per cent increase in population.

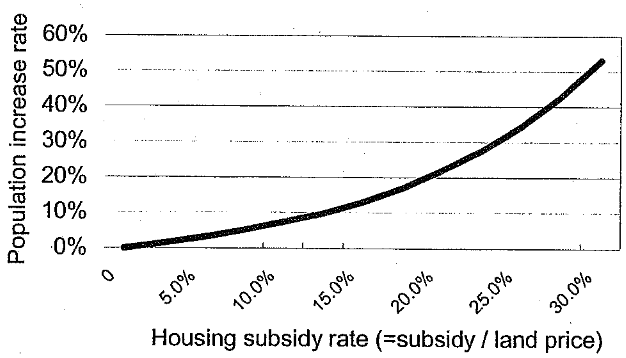

Figure 3. Effect of housing subsidy on population in city centre.

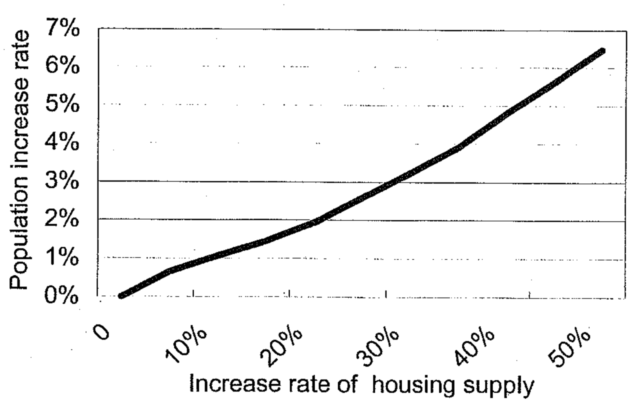

Figure 4. Effect of housing supply on population in city centre.

Figure 4 shows the rate of population increase in the city centre caused by an increase in housing supply in that area. Similar to the case of housing subsidies, the population gradually increases with the increase in housing supply. For example, the figure shows that a 20 per cent increase in housing supply causes about a 2 per cent increase in population and a 40 per cent increase in housing supply causes about a 5 per cent increase in population. This means that a housing supply policy would be less effective than a housing subsidy policy.

Figure 5 shows the effect of a mixed policy of housing subsidy and increase in housing supply. The lines in this figure are the acquired indifferent curves between housing subsidy and supply policies to attain the same population. The indifferent curves being concave indicates a synergetic effect caused by the mixed policy. Moreover, the distance between the different curves becomes gradually narrower, which demonstrates the scale effect of the mixed policy.

5.2. *Cost Saving in Infrastructure Improvement and Maintenance due to De-suburbanization*

(*a*) *Effects of De-suburbanization.* De-suburbanization brings some positive effects as follows:

1. Improving the accessibility between urban

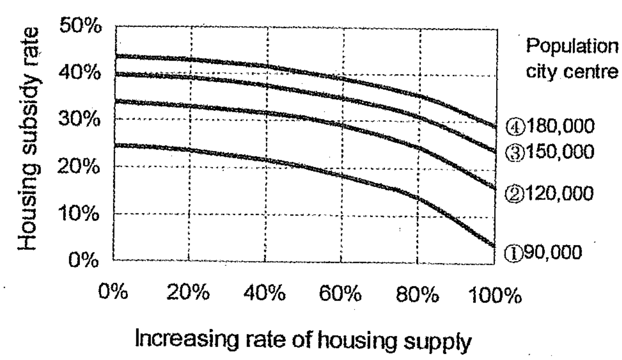

Figure 5. Mixed policy effects on population in city centre. (*Note:* Present population (1990) in the city centre is about 60,000 which is at the origin point of the coordinate axes.)

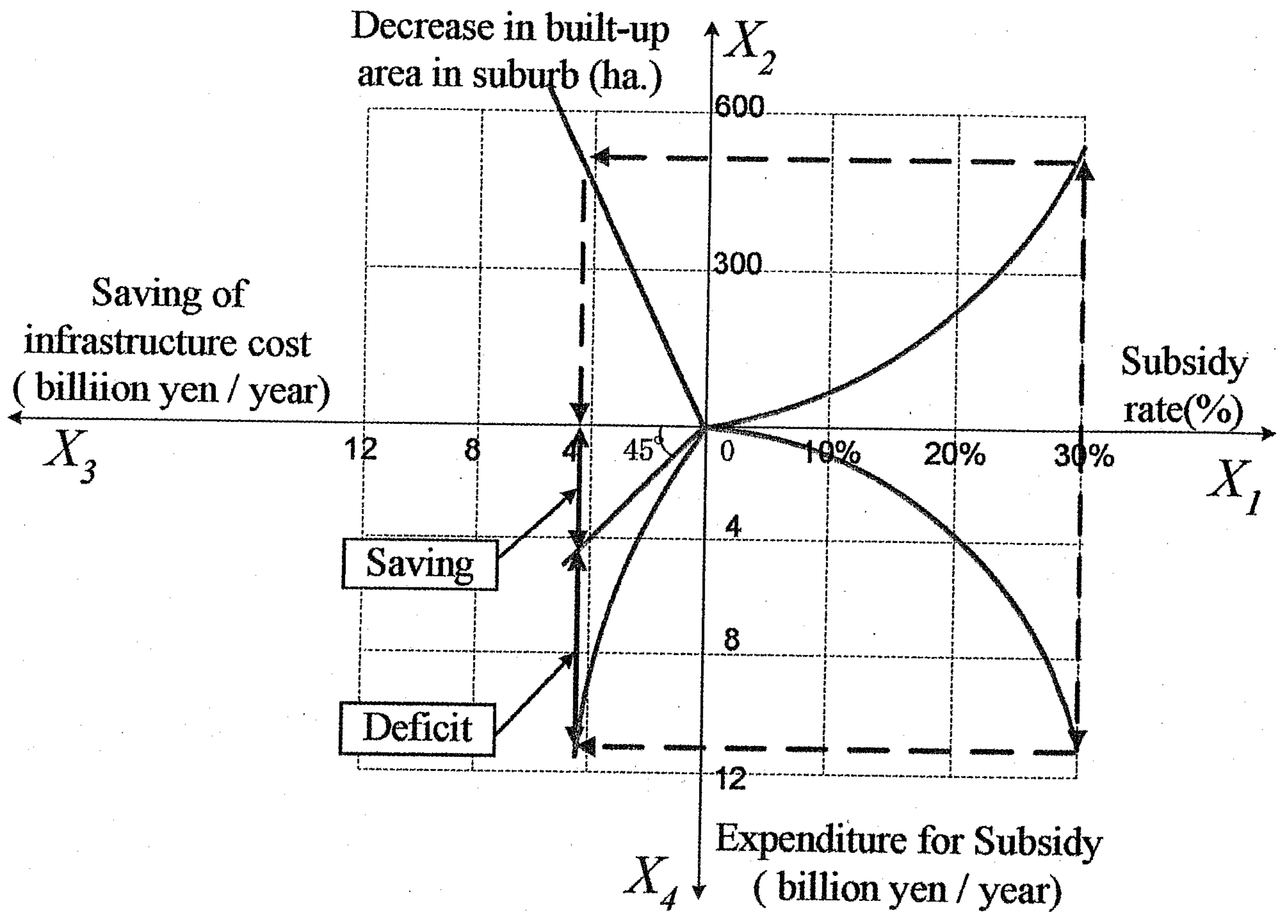

Figure 6. Relationship between housing subsidy, de-suburbanization, and infrastructure saving effect. (*Note:* Subsidy rate (%) = Subsidy/Land Price.).

activities, which causes an agglomeration economy;

2. Lessening the impact on the environment by decreasing transport energy consumption; and

3. Cost saving in infrastructure improvement and maintenance, etc. This saving effect is estimated in the following section.

(b) Estimation of Infrastructure Cost Saving Effect. The cost saving in infrastructure improvement and maintenance caused by the housing subsidy policy was estimated under the following assumptions:

1. Built-up area is proportionate to the population;

2. Infrastructure improvement and maintenance cost is proportionate to the built-up area.

Figure 6 illustrates the relationship between housing subsidy rate (X_1), decrease in the built-up area in the suburb (X_2), saving of infrastructure cost (X_3), and expenditure for housing subsidy (X_4). The relationship between housing subsidy rate (X_1) and the decrease in built-up area (X_2) is given by using the analysis result shown in figure 3, converting population to built-up area. The decrease in the built-up area (X_2) is then converted to the saving of infrastructure cost (X_3), by multiplying X_2 and the infrastructure cost per built-up area in each zone. The expenditure for housing subsidy (X_4) can be calculated by multiplying X_1 and the number of households moving into the city centre.

As shown in figure 6, in case of a 30 per cent subsidy rate, the decrease in the built-up area is 500 hectares and the saving of infrastructure cost is 4 billion yen. At the same time, 11 billion yen is acquired for housing subsidy policy expenses. As a result, the deficit caused by the policy is 7 million yen. In order that the policy becomes effective and feasible, the other benefits of the policy excluding infrastructure savings (e.g., from agglomeration economy and environmental issues) need to be more than the deficit.

6. Conclusions

The debate on the compact city, which came to the fore in about 1990, led to the conclusion that a sustainable urban form could not be described by a single formula fitting all cities because cities are very different one from another. For example, according to some researchers, a decentralized concentrated urban form would be more suitable in larger cities with populations of more than about 500,000. Therefore, a suitable urban form should be considered specifically for each city based on the characteristics of that city. Land-use and transport models can be used to analyse the policies for realizing these urban forms and the methods for financing their implementation.

In this paper, a backcast analysis for de-suburbanization was implemented in Nagoya, using an integrated land-use and transport model developed by Hayashi and Tomita (1990). As a result, the following conclusions can be stated:

1. A housing subsidy policy is more effective than a housing supply policy to realize de-suburbanization. The synergy effect between those policies was demonstrated.

2. The cost saving of infrastructure improvement and maintenance due to de-suburbanization was estimated. The saving effect was large enough to finance about 35 per cent of the housing subsidy expenses in the case of a 30 per cent housing subsidy rate.

3. In order for the de-suburbanization policy to be effective and feasible, the other benefits excluding infrastructure savings (e.g., from agglomeration economy and environmental issues) need to be greater than the deficit.

In our future work, we will examine various urban forms other than the centralized form and will evaluate de-suburbanization effects other than the infrastructure saving effect.

REFERENCES

Banister, D. (1992) Energy use, transport and settlement patterns, in Breheny, M. J. (ed.) *Sustainable Development and Urban Form*. London: Pion.

Breheny, M.J. (1992*a*) Sustainable development and urban form: an introduction, in Breheny, M.J. (ed.) *Sustainable Development and Urban Form*. London: Pion.

Breheny, M.J. (ed.) (1992*b*) *Sustainable Development and Urban Form*. London: Pion.

Breheny, M.J. (1996) Centrists, decentrists and compromisers, in Jenks, M., Burton, E. and Williams, K. (eds.) *The Compact City: A Sustainable Urban Form?* London: E & FN Spon.

Commission of the European Communities (1990) *Green Paper on the Urban Environment*. Brussels: European Commission.

Elkin T., McLaren, D. and Hillman, M. (1991) *Reviving the City: Towards Sustainable Urban Development*. London: Friends of the Earth.

Frey, H. (1999) Compact, decentralized or what? the sustainable city debate, (Chapter 2). In *Designing the City*. London: E & FN Spon, pp. 23–35.

Green, R. (1996) Not compact cities but sustainable regions, in Jenks, M.. Burton, E. and Williams, K. (eds.) *The Compact City: A Sustainable Urban Form?* London: E & FN Spon.

Hall, P. and Ward, C. (1998) *Sociable Cities. The Legacy of Ebenezer Howard*. Chichester: Wiley.

Hayashi, Y. and Tomita, Y. (1990) A Micro-analytic Residential Mobility Model for Assessing the Effects of Transport Improvement. Selected Proceedings of Fifth World Conference on Transport Research.

Hooper, A. (1994) Land availability and the suburban option. *Town and Country Planning*, **63**(9), pp. 239–242.

Jacobs, J. (1961) *The Death and Life of Great American Cities*. New York: Vintage Books/Random House.

Knights, C. (1996) Economic and social issues, in Jenks, M., Burton, E. and Williams, K. (eds.) *The Compact City: A Sustainable Urban Form?* London: E & FN Spon.

Lerman, S.R., and Kern, C.R. (1983) Hedonic theory, bid rents, and willingness to pay: some extensions of Ellickson's results. *Journal of Urban Economics*, **13**, pp. 358–363.

Lowry, I.S. (1964) *A Model of Metropolis*. Santa Monica, CA: The RAND Corporation, RM-4035-RC.

McLaren, D. (1992) Compact or dispersed? Dilution is no solution. *Built Environment*, **18**(4), pp. 268–284.

Miller, E.J., Kringer, D. S. and Hunt J. D. (1998) Integrated urban models for simulation of transit and land-use policies. Transit Co-operative Research Project, National Academy of Sciences.

Nakamura, H., Hayashi, Y., and Miyamoto, K.(1983) Land use - transport analysis system for a metropolitan area, *Papers of Regional Science Association*, **51**, pp. 43–63.

Newman, P.W.G. and Kenworthy, J.R. (1989) *Cities and Automobile Dependency: An International Source Book*. Aldershot: Gower.

Owens, S. and Rickaby, P.A. (1992) Settlements and energy revisited. *Built Environment*, **18**(4), pp. 247–252.

Waddell, P. (2002) UrbanSim: modeling urban development for land-use, transportation and environment planning. *Journal of the American Institute of Planners*, **68**(3), pp. 297–314.

Webster, F.V., Bly, P.H. and Paulley, N.J. (1988) *Urban Land-use and Transport Interaction: Policies and Models. Report of the International Study Group on Land-use/Transport Interaction (ISGLUTI)*. Aldershot: Avebury.

Wegener, M. (1994) Operational urban models: state of the art. *Journal of the American Planning Association*, **60**(1), pp. 17–30.