GENERATION OF AN INTEGRATED MULTISPATIAL INPUT–OUTPUT MODELOF CITIES (GIMIMoC) II: DYNAMIC SIMULATION

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WORKING PAPER 91/5

SCHOOL OF GEOGRAPHY • UNIVERSITY OF LEEDS

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October 1991

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ABSTRACT

In a previous paper (Wilson and Jin, 1991), a first-stage input-output modelling framework (GIMIMoC) has been developed which describes three suburban systems and associated modules, that is, the MULIO module for the multispatial economic subsystem, the SOCDEM module for the socio-demographic subsystem and the HOSTOC module for the housing stock subsystem. In this paper, the second-stage - dynamics of the GIMIMoC framework - is examined. It is suggested this framework be linked to economic profit level which can be obtained from the MULIO module provided the selling price and purchasing price which consider the unit transport cost are included. Dynamic outcomes of the GIMIMoC framework can then be derived if a set of 'best-fit' adjustable parameters is available. An empirical dynamic GIMIMoC is applied, in an illustrative way, to the Leeds Metropolitan District. The procedures together with some preliminary results are demonstrated.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Christine M Leigh and Dr. Mark Birkin for their early suggestions on data collection.

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GENERATION OF AN INTEGRATED MULTISPATIAL INPUT-OUTPUT MODEL OF CITIES (GIMIMoC) II: DYNAMIC SIMULATION

1. Introduction

It has been argued that many models have been developed for modelling sub-systems, such as input-output and spatial interaction, so the question is raised as to why more progress has not been made with the development of integrated models which can provide a more comprehensive, effective basis for understanding contemporary spatial-economic development? At least three points contribute to the answer. First, in a number of dimensions (multisystem, multispatial, multiple time periods), there is the problem of the sheer scale and complexity involved, exacerbated by an increasing rate of change. Secondly, there is a lack of crucial data which has inhibited certain important kinds of modelling --- for example, involving trade flows between areas across regional boundaries. Lastly, there is, inevitably, a fragmentation of research effort --- and perhaps not enough commitment to multi-disciplinary work.

In a previous paper (Wilson and Jin, 1991) a first stage integrated modelling framework named GIMIMoC (Generation of Integrated Multispatial Input-output Model of Cities) has been constructed to account more thoroughly for contemporary spatio-economic relationships. We suggested that this comprehensive model embody three dimensions of the real world, i.e, multispatial, multisystem and multiple time periods. Three modules at multispatial levels, e.g. urban zone, city, region and even nation, have been integrated: the MULIO (Multispatial Input-output model) for the urban economic subsystem, the SOCDEM for socio-demographic subsystem and the HOSTOC for the urban housing system. An integrated framework described the interactions among the three modules and, in particular, how the multispatial and multisystems elements could be incorporated into the framework, and how the input-output model links with the newly generated models. However, the earlier paper only provided an initial picture, and the dynamics, i.e. the multiple time periods, was not considered. In this paper, we demonstrate the dynamic mechanism of the GIMIMoC framework, and show how such a framework has been empirically applied to the Leeds Metropolitan District (MD). The procedures and some preliminary results will also be illustrated. We begin, in section 2, by defining the associated variables and outlining the dynamic models. We propose (elsewhere c.f. Wilson,1983) that this whole framework is driven by economic profit level, the figure of which can be obtained from operating the MULIO module. In section 3, we show that the dynamic GIMIMoC is not a castle in the air, and that it can be put into operation; demonstrated by its application to Leeds MD. Section 4 makes some concluding comments.

2. The Dynamic Models

2.1. Definition of variables

It has been argued elsewhere (Harris and Wilson, 1978) that an appropriate mechanism for determining an equilibrium is when revenue and cost are equal for each activity and the associated commodity at each location, and this equilibrium may be seen as the steady state in a dynamic mechanism related to economic production levels. Wilson (1990) suggests that the imbalance of the equilibrium can be taken as the driving force of the economic system provided an adjustment parameter (ε) is given. Here, we will show: (a) how the equilibrium can be derived from the MULIO module; (b) how an economic system can be dynamically driven by profitability; (c) the derivation of adjustment parameters; and (d) the dynamics of the GIMIMoC framework. But first, some essential notation needs to be specified. The notations used here are consistent with those in other paper (Wilson and Jin, 1991).

$Q^{nn'}_{jj'cc'rr'}$ (**Q**) is the amount of product produced by industry n in urban zone j in city c in region r that is purchased by industry n' in urban zone j' in city c' in region r' as intermediate cost.

$H^{nn'}_{jj'cc'rr'}$ (**H**) is the coefficient matrix showing the amount of product in industry n in zone j in city c in region r is required when an unit of product of industry n' in zone j' in city c' in region r' id produced.

$T^{mn'}_{jj'cc'rr'}$ (**T**) is the number of employees who are from class m (by income, by skilled class or by sex) living in zone j in city c in region r go to work in industry n' in zone j' in city c' in region r'.

X^{n}_{jcr} (**X**) is the gross product produced in industry n in zone j in city c in region r.

D^{n}_{jcr} (**D**) is the total revenue of industry n in zone j in city c in region r.

$C^{n'}_{j'c'r'}$ (**C**) is the total cost of industry n' in j' in c' in r'.

$A^{n'}_{j'c'r'}$ (**A**) is the fixed asset owned by industry n' in zone j' in city c' in region r'.

$\underline{R}^{n}_{jcr}$ ($\underline{\boldsymbol{R}}$) is the number of employees working in industry n in zone j in city c in region r.

R^{m}_{jcr} (**R**) is work force of social class m residing in urban zone i in city c in region r.

$\hat{R}^{m}_{jcr}$ ($\hat{\boldsymbol{R}}$) is actual employment of social class m residing in urban zone j in city c in region r.

$E^{n}_{j'c'r'}$ (**E**) is labour demand by industry n in urban zone j' in city c' in region r'.

$\underline{p}^{n}_{jcr}$, $\hat{p}^{n'}_{j'c'r'}$ are selling and purchase prices.

p^{my}_{jcr} is price for type y house.

$w^{n'}_{jc'r'}$ is wage rate of industry n' in zone j' in city c' in region r'.

$\gamma^{n'}_{j'c'r'}$ is the depreciation rate for industry n' in zone j' in city c' in region r'.

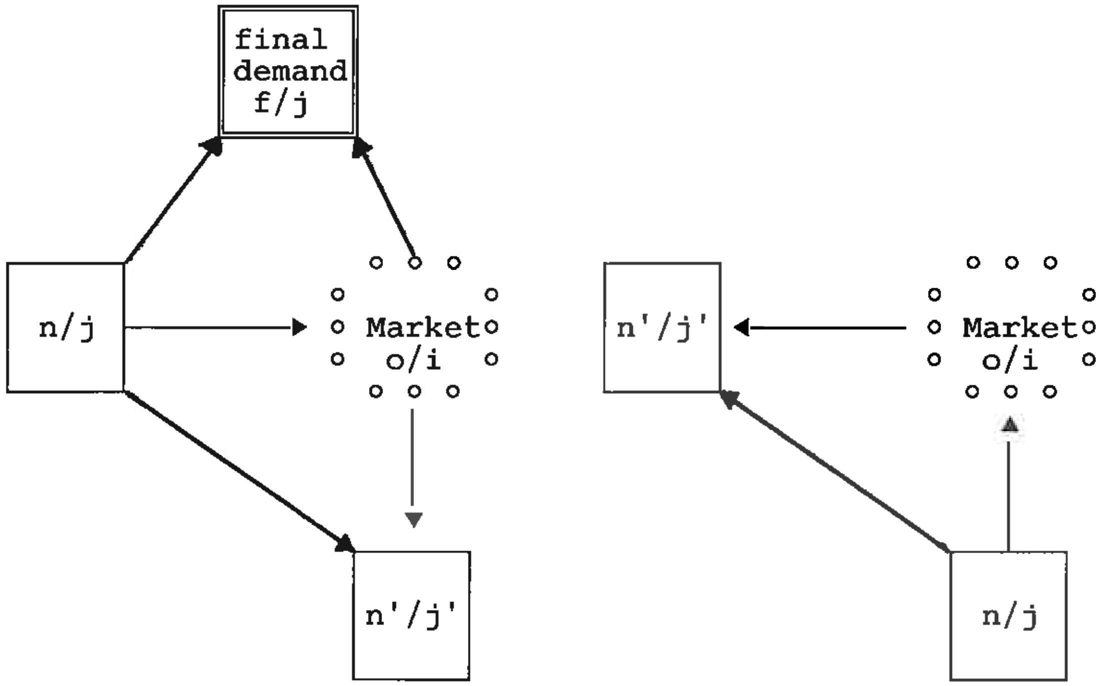
Arrays are denoted by bold capital letters, vectors by bold italic capital letters in the brackets. **Q**, **H** and **T** are (njcr x n'j'c'r') arrays, and ***X***, ***R***, $\underline{\boldsymbol{R}}$, $\hat{\boldsymbol{R}}$, ***A***, ***D***, ***C*** and ***E*** are (njcr x 1) or (1 x n'j'c'r') vectors. Such notation is designed to represent multispatial scales, i.e. the interactions between industries in, zone and zone, city and city, region and region.

2.2. The driving force

If we assume that the total revenue for a particular industry in a urban zone in a city in a region depends on the gross output product level as well as the selling price, then the revenue will be equal to

$$D^{n}_{jcr} = \underline{p}^{n}_{jcr} \, X^{n}_{jcr} \tag{1}$$

such an assumption may be too simple for two reasons. (1) It is impossible to have a uniform price across all the goods in one industry. In Birkin and Wilson's model (1986), a superscript (g) is added to represent a particular commodity produced in an industry, and the problem of over uniformed price is then to some extent remedied. (2) Transportation factors need to be considered, no matter what kind of customers are involved. If we assume that the gross output products are eventually sold to intermediate industries as well as final demand customers through two routes: market and non-market (see Fig.1(a)), then two types of selling prices should be included:



(a) (b)

Key:

f/j — final demand customer f in zone j

n/j — industry n in zone j

o/i — market o in zone i

FIG.1(a): Selling price of industry n in zone j

FIG.1(b): Purchase price of industry n' in zone j'

$$p^n{}_j = \begin{cases} {}^o p^n{}_j & \text{not through market} \\ {}^o p^n{}_j + c^{on}{}_{ij} & \text{through market} \end{cases}$$

where ${}^o p^n{}_j$ is unit product selling price of industry n in zone j (price of factory at gate); c^{on}_{ij} indicates unit transportation cost from industry n in zone j to market o in zone i.

With reference to the total cost for an industry in a region, it may include: purchased input material, transportation, deprecation, and labour cost, which is equal to:

$$C^{n'}_{j'c'r'} = \hat{p}^{n'}_{j'c'r'} \Sigma_n \Sigma_c \Sigma_f Q^{nn'}_{jj'cc'rr'} + w^{n'}_{j'c'r'} \underline{R}^{n'}_{j'c'r} + \gamma^{n'}_{j'c'r'} A^{n'}_{j'c'r'} \qquad (2)$$

or

$$\boldsymbol{C} = \hat{p}\mathbf{Q} + w\underline{\boldsymbol{R}} + \gamma\boldsymbol{A} \qquad (3)$$

The first items of the right-hand side indicates the material cost. It should be noted that the purchasing price also needs to be considered in two situations, i.e. when materials are purchased through market and not through market (see Fig. 1(b)). In the former case, the purchase price are equal to the unit product price plus the unit transportation cost from industry n in zone j to market o in zone i as well as the unit transportation cost from the market o in zone i to industry n' in zone j'. In the latter, since the purchase is from industry n in j directly, the purchase price for industry n' in zone j' is equal to the unit product price plus transportation price from industry n in zone j to industry n' in zone j'. These two types of purchase price can be demonstrated as below:

$$p^n{}_j = \begin{cases} {}^o p^n{}_j + c^{no}{}_{ji} + c^{on'}{}_{ij'} & \text{through market} \\ {}^o p^n{}_j + c^{nn'}{}_{jj'} & \text{not through market} \end{cases}$$

where $c^{no}{}_{ji}$ implies the unit transportation cost from industry n in zone j to market o in zone i; $c^{on'}{}_{ij'}$, the unit transportation cost from market o in zone i to industry n' in zone j'; $c^{nn'}{}_{jj'}$, the unit cost from industry n' in zone j' to industry n' in zone j'.

The second item shows the total labour cost which is derived from multiplying the number of employees by the relevant wage rate. The third item shows the cost that is incurred from fixed assets that are usually used for simple reproduction such as replacing the old facilities.

Let us assume

$$D^n_{jcr} = D^{n'}_{j'c'r'} \tag{4}$$

Then

$$\pi^{n'}_{j'c'r'} = D^{n'}_{j'c'r'} - C^{n'}_{j'c'r'} \qquad \text{or}$$

$$\pi = \boldsymbol{D} - \boldsymbol{C} \tag{5}$$

In which π is the profit for industry n' in zone j' in city c' in region r'. It is obvious that an equilibrium exists when the profit is equal to zero.

It is worth noting that this equilibrium can be obtained from a multispatial input-output table (MULIO) which is described in Wilson and Jin (1991). The total revenue (***D***) can be derived from the gross product in the sale directions, provided the selling price is given. And the total cost (***C***) can be obtained by adding the interregional interindustry transactions (material cost and transport cost) and parts of the primary input such as the labour cost and depreciation. Then the profit can be derived from the following equation:

$$\pi = \underline{p}\boldsymbol{X} - (\hat{p}\underline{\boldsymbol{Q}} + \phi\boldsymbol{P}) \tag{6}$$

in which ***P*** is a vector indicating the primary input in the MULIO module, and ϕ shows the ratio between costs such as labour and depreciation, and the total primary input. The purchase and selling prices are the same as were discussed above.

2.3. The dynamic mechanism

Once the profit is derived, we can see that there are dynamic relationships between the derived profit and the whole economic system, for instance, the multispatial input-output module (MULIO). We start from the assumption that the new increased economic production level (i.e the gross output product) depends on the volume of profit in the previous time period, say one year, and an adjustment parameter (ε),

$$\boldsymbol{X}_{(t+1)} = \boldsymbol{X}_t + \varepsilon_t (\boldsymbol{D}_t - \boldsymbol{C}_t) \tag{7}$$

then the total revenue in year t+1 will be equal to

$$\boldsymbol{D}_{(t+1)} = \underline{p}\boldsymbol{X}_{(t+1)} \tag{8}$$

the material, labour, depreciation and total cost will be

$$\boldsymbol{Q}_{(t+1)} = \boldsymbol{Q}_t + \varepsilon_t(\boldsymbol{D}_t - \boldsymbol{C}_t) \tag{9}$$

$$w\underline{\boldsymbol{R}}_{(t+1)} = w\underline{\boldsymbol{R}}_t + \varepsilon_t(\boldsymbol{D}_t - \boldsymbol{C}_t) \tag{10}$$

$$\gamma\boldsymbol{A}_{(t+1)} = \gamma\boldsymbol{A}_t + \varepsilon_t(\boldsymbol{D}_t - \boldsymbol{C}_t) \tag{11}$$

$$\boldsymbol{C}_{(t+1)} = \hat{p}\boldsymbol{Q}_{(t+1)} + w\boldsymbol{R}_{(t+1)} + \gamma\boldsymbol{A}_{(t+1)} \tag{12}$$

Apparently,

$$\pi_{(t+1)} = \boldsymbol{D}_{(t+1)} - \boldsymbol{C}_{(t+1)} \tag{13}$$

$$\boldsymbol{X}_{(t+2)} = \boldsymbol{X}_{(t+1)} + \varepsilon_{(t+1)}\{\boldsymbol{D}_{(t+1)} - \boldsymbol{C}_{(t+1)}\} \tag{14}$$

$$\boldsymbol{X}_{(t+3)} = \boldsymbol{X}_{(t+2)} + \varepsilon_{(t+2)}\{\boldsymbol{D}_{(t+2)} - \boldsymbol{C}_{(t+2)}\} \tag{15}$$

$$\boldsymbol{X}_{(t+4)} = \cdots\cdots$$

$$\vdots$$

$$\boldsymbol{X}_n = \boldsymbol{X}_{(n-1)} + \varepsilon_{(n-1)}\{\boldsymbol{D}_{(n-1)} - \boldsymbol{C}_{(n-1)}\} \tag{16}$$

Then the dynamic model for each time period is constructed. If the total time periods (N) are assumed, 'N' time iterations will be completed eventually.

2.4. Derivation of adjustment parameters

So far, we have described the procedures for deriving dynamic models, and indicated that the profit, together with an adjustment parameter (ε), is the driving force of the economic systems. One potential mystery arises: where does this adjustment parameter (ε) come from? It results from calibration, which is the process of comparing $\{\underline{\mathbf{X}}^n{}_{jcr}\}$ predicted by the model with a set of observations of the same array, perhaps from a sample survey or available published data, and denoted by $\{\mathbf{X}^n{}_{jcr}\}$, and from a procedure whereby given a series of ε, finding out the ε which gives the best-fit between predicted and observed (c.f. Wilson, 1983). Some measures of goodness-of-fit such as the 'correlation coefficient' denoted by R^2 and 'sum of square' denoted by SS are usually available. For instance, in deriving the parameter ε, the 'sum of square' (SS) is equal to $\Sigma_n\Sigma_j\Sigma_c\Sigma_r\ (\mathbf{X}^n{}_{jcr} - \mathbf{X}^n{}_{jcr})^2$, a zero result from which obviously represents a perfect fit whilst the result is increasingly large for bad fits. The parameter (ε) for the best fit is what we incorporate into our dynamic model to simulate the future economy.

Three adjustment parameters may be assumed to represent three economic situations:

$$\varepsilon \begin{cases} > \blacktriangle X^n{}_{jcr} \,/\, (D^n{}_{jcr} - C^n{}_{jcr}) & \text{High prediction} \\ = \blacktriangle X^n{}_{jcr} \,/\, (D^n{}_{jcr} - C^n{}_{jcr}) & \text{Best-fit simulation} \\ < \blacktriangle X^n{}_{jcr} \,/\, (D^n{}_{jcr} - C^n{}_{jcr}) & \text{Low prediction} \end{cases} \qquad (17)$$

where $\blacktriangle X$ indicates the new increased products.

From equation (17), when ε is equal to $\blacktriangle X^n{}_{jcr} \,/\, (D^n{}_{jcr} - C^n{}_{jcr})$, it can be shown that the parameter (ε) is perfectly fitted, and simulation can be undertaken based on this. The parameter (ε) can be adjusted too, i.e. a larger ε may indicate a potential good economic situation and a smaller ε reflects a gloomy economic scenario.

2.5 The dynamics of the GIMIMoC framework

As the GIMIMoC framework consists of three interrelated submodules, the dynamic GIMIMoC includes three dynamic modules as well, i.e. dynamic MULIO, SOCDEM and HOSTOC modules. Here, we will demonstrate that the profit is not only the driving force of an economic system but also the whole GIMIMoC framework only if dynamic parameters are properly adjusted. The procedures of the profit drives the sub-modules of the GIMIMoC framework, and how parameters are adjusted for socio-demographic, housing systems are discussed in turn.

The dynamic MULIO module is basically the same as the models described before. By deriving the profit for a particular industry in an urban zone in a city in a region, and incorporating the relevant adjustment parameters, the following dynamic models can be derived:

$$\boldsymbol{X}_{(t+1)} = \boldsymbol{X}_t + \varepsilon_t\ \pi_{(t)} \tag{18}$$

$$\boldsymbol{D}_{(t+1)} = \underline{p}\boldsymbol{X}_{(t+1)} \tag{19}$$

$$\boldsymbol{X}_{(t+1)} = \hat{p}\boldsymbol{Q}_{(t+1)} + w\underline{\boldsymbol{R}}_{(t+1)} + \gamma\boldsymbol{A}_{(t+1)} \tag{20}$$

$$\pi_{(t+1)} = \boldsymbol{D}_{(t+1)} - \boldsymbol{C}_{(t+1)} \tag{21}$$

$$\boldsymbol{X}_{(t+2)} = \boldsymbol{X}_{(t+1)} + \varepsilon_{(t+1)}\pi_{(t+1)} \tag{22}$$

$$\vdots$$

The following dynamic results can be obtained from the MULIO module:

* new increased gross product ($\Delta \boldsymbol{X}_{t+1}$)
* profit by industry (π_{t+1})
* Interindustrial transactions (material cost $p\boldsymbol{Q}_{t+1}$)
* Labour cost ($w\boldsymbol{R}_{t+1}$)
* Depreciation cost ($\gamma \boldsymbol{A}_{t+1}$)
* final demand and primary input.

The dynamic SOCDEM module correlates to the dynamic MULIO model, and the dynamic outputs of SOCDEM, such as labour demand, vacancies, unemployment and travel-to-work flow, depend upon the dynamic MULIO module, i.e. the economic product and profit level. The dynamic SOCDEM module also depends on some exogenous factors, such as the birth rate, death rate and migration rate, which need to be given before hand. We begin with the travel-to-work flow which usually varies with the recession or expansion of the economy. It is likely that a region is very attractive if there are many job opportunities, and the region is less attractive if very few job chances are available. It is apparent that the labour movements are determined by the attractiveness forces in industrial zones, which is identical to the assumption of constructing spatial interaction models (c.f. Wilson 1983). The spatial interaction model can then be implemented to derive the travel-to-work flow occurred between the actual workers by social class originated from the residential zones and the actual workers absorbed by different industries in industrial zones. The total number of workers originated from residential zones (supply) are equal to the number of labours absorbed in industrial zones (demand). Suppose, the total number of origins and destinations in year t+1 are given, then the travel-to-work flow in year t+1 can be written as:

$$T^{mn}_{ijcc'rr'(t+1)} = \hat{A}\hat{B}\hat{R}^{m}_{icr(t+1)}\underline{R}^{n}_{jc'r'(t+1)}e^{-\beta t^{mn}_{ijcc'rr'}} \quad (23)$$

where $\hat{A}$ and $\hat{B}$ are balancing factor, $\hat{R}$ and $\underline{R}$ are total number of labours originated in zone i in city c in region r, and the number of labours absorbed by the industry n in zone j in city c' in region r'. t is transportation cost, and ß, a parameter. By operating equation (23), the dynamic interrelationships between the labour supply and demand in year t+1 at each spatial scales can be obtained.

Two dynamic imbalance equations will then be obtained.

(i) $U^{m}_{jcr(t+1)} = R^{m}_{jcr(t+1)} - \Sigma_{n'}\Sigma_{j'}\Sigma_{c'}\Sigma_{r'}T^{mn'}_{jj'cc'rr'(t+1)}$ or

$$\boldsymbol{U}_{(t+1)} = \boldsymbol{R}_{(t+1)} - \hat{\boldsymbol{R}}_{(t+1)} \quad (24)$$

In equation (24), $\boldsymbol{U}$ shows the unemployment existing in social class m in zone j in city c in region r. The volume of the work force depends on exogenous factors such as birth and death rates, and the economic activity rate which has to be predicted or given from the outside of the dynamic model, i.e.

$$\hat{R}^{m}_{jcr(t+1)} = \hat{a}^{m}_{jcr(t+1)} G^{m}_{jcr(t+1)}, \qquad \text{or}$$

$$\hat{\boldsymbol{R}}_{(t+1)} = \hat{a}_{(t+1)} \boldsymbol{G}_{(t+1)} \qquad (25)$$

$\hat{a}$ is the pre-predicted economic activity rate in time period t+1, and $\boldsymbol{G}$ is the total population of social class m in zone j in city c in region r.

$$\text{(ii)}\quad V^{n'}_{j'c'r'(t+1)} = \Sigma_m \Sigma_j \Sigma_c \Sigma_r T^{mn'}_{jj'cc'rr'(t+1)} - \Sigma_m E^{mn'}_{j'c'r'(t+1)}$$

$$\boldsymbol{V}_{(t+1)} = \underline{\boldsymbol{R}}_{(t+1)} - \boldsymbol{E}_{(t+1)} \qquad (26)$$

in which, $\boldsymbol{V}$ indicates the number of vacancies available in industry n' in zone j' in city c' in region r' in t+1; $\underline{\boldsymbol{R}}_{(t+1)}$, the actual employment in industry n in time period t+1, is given in equation (23), and the labour requirement, $\boldsymbol{E}_{(t+1)}$, is derived from the dynamic MULIO module, i.e.

$$E^{n'}_{j'c'r'(t+1)} = \hat{e}_{(t+1)}\, X^{n'}_{j'c'r'(t+1)} \qquad (27)$$

or

$$\boldsymbol{E}_{(t+1)} = \hat{e}_{(t+1)} \left[\, X_t + \varepsilon\pi_t \,\right] \qquad (28)$$

where $\hat{e}_{(t+1)}$ is the predicted productivity rate for industry n' in zone j' in city c' in region r' in year t+1. The output results from the MULIO module are input into the dynamic SOCDEM module, which is indirectly affected by the profit level because it is influenced by the dynamic gross output level, whilst this level is determined by the profit.

The dynamic HOSTOC (Housing stock) module concentrates on two submodels: the housing supply model and the housing demand model. The former, i.e. the number of houses available in time period t+1, is usually determined by housing construction, while housing construction depends in turn upon the construction investment from both public and private sources, and investment is eventually affected by the profitability level. However, this profit is different from the one defined before. It is derived from the comparison between the revenue for type y house (rent, mortgage, government subsidises etc.) and the cost for type y house (maintenances, painting, etc.). More type y houses could be either constructed of improved in year t+1 if more profit are made in previous year t, *vice versa*. So if we suppose ${}^{s}H^{y}_{jcr(t+1)}$ is the number of type y houses available in residential zone j in city c in region r in time period t+1, and s for the housing demand, then

$$ {}^{s}H^{y}_{jcr(t+1)} = {}^{s}H^{y}_{jcr(t)} + \varepsilon'_{t}(D^{y}_{t} - C^{y}_{t}) \qquad \text{or} $$

$$ {}^{s}\boldsymbol{H}_{(t+1)} = {}^{s}\boldsymbol{H}_{t} + \varepsilon'_{t}(\boldsymbol{D}^{y}_{t} - \boldsymbol{C}^{y}_{t}) \qquad (29) $$

where the parameter ε'_{t} is derived by following the procedures described in section 2.4. Apparently, a series of dynamic models can be derived from the initial time period t until the total time period 'N'. i.e.

$$
\begin{aligned}
{}^{s}\boldsymbol{H}_{(t+1)} &= {}^{s}\boldsymbol{H}_{t} + \varepsilon'_{t}\,(D^{y}_{t} - C^{y}_{t}) \\
{}^{s}\boldsymbol{H}_{(t+2)} &= {}^{s}\boldsymbol{H}_{(t+1)} + \varepsilon'_{(t+1)}\{\boldsymbol{D}^{y}_{(t+1)} - \boldsymbol{C}^{y}_{(t+1)}\} \qquad (30)\\
&\vdots \\
{}^{s}\boldsymbol{H}_{(n)} &= {}^{s}\boldsymbol{H}_{(n-1)} + \varepsilon'_{(n-1)}\{\boldsymbol{D}^{y}_{(n-1)} - \boldsymbol{C}^{y}_{(n-1)}\}
\end{aligned}
$$

In the case of the dynamic housing demand model, the number of type y houses demanded ${}^{d}\boldsymbol{H}^{k}{}_{jcr}$ may be specified as

$$
{}^{d}H^{y}_{jcr} = {}^{d}H^{y}_{jcr}\,(P^{m}_{jcr},\ w^{m}_{jcr}, R^{m}_{jcr},\ P^{y}_{jcr},\ C^{mn'y}_{jj'cc'rr'}) \qquad (31)
$$

The spatial interaction equation for the above model has been expressed through multiple regression analysis (Wilson and Jin 1991), and a number of parameters (δ) are allocated to each variable in equation (31). The dynamic housing demand model will then use the derived dynamic results from both the MULIO and SOCDEM module as well as the multiple regression analysis. We have

$$
{}^{d}\boldsymbol{H}_{(t+1)} = \delta + \delta_{1}\underline{\boldsymbol{P}}_{(t+1)} + \delta_{2}w\underline{\boldsymbol{R}}_{(t+1)} \pm \delta_{3}p_{(t+1)} - \delta_{4}c_{(t+1)} \qquad (32)
$$

where δ, δ_1, δ_2, δ_3, δ_4 are regression parameters, and p is housing price; and c is travel cost between the residential location and work place. It seems that both population and income have positive relationships with the housing demand,

and housing price and travel cost likely have the negative relationship with the housing demand. It is important to note that equation (31) and (32) are only crude expressions for deriving housing demand, and more specified models are needed to spell out the housing demand for different social classes in different places demanding different types of houses in different zones.

A dynamic housing stock situation for house type k in residential zone j in city c in region r in time period t+1 can now be obtained:

$$H^{y}_{jcr(t+1)} = {}^{s}H_{jcr(t+1)} - {}^{d}H^{y}_{jcr(t+1)} \tag{33}$$

The dynamic models described above reflect the basic nature of geography, i.e. 'everything depends on everything else'. In the dynamic MULIO model, the production level (expansion or recession) for a particular sector in a particular zone is affected by the profitability of this sector in the previous year, and the volume of the profit depends on sectoral revenue and cost; In the SOCDEM module, the production expansion or recession will influence the supply and demand of labour associated with a particular social group in a residential zone, and the supply of labour is dependent on the size of work force, whilst the workforce depends on the activity rate and population size. The size of the work force and actual employment may lead to an imbalance which can be taken as unemployment for a particular social group. The demand for labour is related to the production level as well as productivity. The imbalance between the labour requirement and the actual employment by industry can be regarded as the vacancy rate for a particular industry in an industrial zone. In the HOSTOC module, the housing supply is influenced by the housing profit level and housing demand can be calculated by using derived dynamic results, such as population size and income from both the MULIO and SOCDEM modules.

The overall dynamics of the GIMIMoC can be shown in Table 1. In this table, it can be seen the production level, labour requirements and housing stock supply in a particular time period, say t+1, are dependent on the profit level in the previous time period, say t, provided appropriate adjustment parameters are given. If a total number of time periods (n) is assumed, then the whole GIMIMoC will be iterated 'n' times and comprehensive information for the MULIO, SOCDEM and HOSTOC modules can thus be provided at each time period.

TABLE 1:
The overall dynamics of the GIMIMoC framework

Module	Models	Time period	
MULIO module in t+1	$\boldsymbol{X}_{(t+1)} = \boldsymbol{X}_t + \varepsilon_t(\boldsymbol{D}_t - \boldsymbol{C}_t)$		(34)
	$\boldsymbol{D}_{(t+1)} = \underline{p}\boldsymbol{X}_{(t+1)}$		(35)
	$\boldsymbol{C}_{(t+1)} = \hat{p}\boldsymbol{Q}_{(t+1)} + w\boldsymbol{R}_{(t+1)} + \gamma\boldsymbol{A}_{(t+1)}$		(36)
SOCDEM module in t+1	$\boldsymbol{T}_{(t+1)} = \hat{A}\hat{B}\hat{\boldsymbol{R}}_{(t+1)}\underline{\boldsymbol{R}}_{(t+1)}e^{-\beta t}$		(37)
	$\boldsymbol{U}_{(t+1)} = \boldsymbol{R}_t - \hat{\boldsymbol{R}}_{(t+1)}$	t+1	(38)
	$\boldsymbol{V}_{(t+1)} = \underline{\boldsymbol{R}}_{(t+1)} - \hat{e}\,\boldsymbol{X}_{(t+1)}$		(39)
HOSTOC module in t+1	${}^{s}\boldsymbol{H}_{(t+1)} = {}^{s}\boldsymbol{H}_t + \varepsilon'_t(\boldsymbol{D}^y{}_t - \boldsymbol{C}^y{}_t)$		(40)
	${}^{d}\boldsymbol{H}_{(t+1)} = f(\underline{\boldsymbol{P}}_{(t+1)}, w\underline{\boldsymbol{R}}_{(t+1)}, p)$		(41)
	$\boldsymbol{H}_{(t+1)} = {}^{s}\boldsymbol{H}_{(t+1)} - {}^{d}\boldsymbol{H}_{(t+1)}$		(42)
MULIO in t+2	$\boldsymbol{X}_{(t+2)} = \boldsymbol{X}_{(t+1)} + \varepsilon_{(t+1)}\pi_{(t+1)}$		(43)
	$\vdots$		
SOCDEM in t+2	$\boldsymbol{T}_{(t+2)} = \hat{A}\hat{B}\hat{\boldsymbol{R}}_{(t+2)}\underline{\boldsymbol{R}}_{(t+2)}e^{-\beta t}$	t+2	(44)
	$\vdots$		
HOSTOC in t+2	${}^{s}\boldsymbol{H}_{(t+2)} = {}^{s}\boldsymbol{H}_{(t+1)} + \varepsilon'_{(t+1)}\pi_{(t+1)}$		(45)
	$\vdots$		
MULIO in n	$\boldsymbol{X}_n = \boldsymbol{X}_{(n-1)} + \varepsilon_{(n-1)}\pi_{(n-1)}$		(46)
	$\vdots$		
SOCDEM in n	$\boldsymbol{T}_n = \hat{A}\hat{B}\hat{\boldsymbol{R}}_{(n)}\underline{\boldsymbol{R}}_{(n)}e^{-\beta t}$	n	(47)
	$\vdots$		
HOSTOC in n	${}^{s}\boldsymbol{H}_n = {}^{s}\boldsymbol{H}_{(n-1)} + \varepsilon'_{(n-1)}\pi_{(n-1)}$		(48)
	$\vdots$		

3. Empirical operation of the dynamic GIMIMoC

This dynamic GIMIMoC model system has been applied to the Leeds Metropolitan District (MD) which is located in the north-east part of the UK, within the region of Yorkshire and Humberside. During the last decades, the economic situation in Leeds MD is in common with other north cities deteriorated and this decline has accelerated in recent years. The main symptoms are: low growth of economic production and profit level; due to the deceleration of growth of profit level, a rise in unemployment figures and inflation rate, and the number of vacancies has gone down and, as a result of the decrease in profit, housing construction has been more or less constrained. It is important to have a comprehensive and good understanding of the interrelationships between economic and demographic changes, between economic and housing changes, between demographic and housing changes, and their impacts upon each other in the city. The application of the modelling system to Leeds MD is an opportunity to respond to the needs of reality and provide a picture (albeit crude) of current and future economic situations for the Leeds MD.

Secondly, by subjecting it to numerical experimentation, empirical application shows that the developed dynamic GIMIMoC can not only be a plausible explanation in theory but also be operated empirically.

Three steps are necessary to derive the dynamic Leeds MD GIMIMoC: firstly identify the initial conditions, secondly derive values for profit and the various parameters, and thirdly specify the dynamics.

The initial conditions are basically accounts of the stocks and steady-state flows for the urban economic system, the demographic system and the housing market. Three empirical account-based modules for Leeds MD have been constructed: the MULIO module, the SOCDEM module and the HOSTOC module. For a detailed account of how these modules have been constructed and how the associated data requirements have been satisfied see Jin, Leigh and Wilson (1991); Jin and Birkin (1991); and Jin, Wilson and Leigh (forthcoming). The key comparative statistics from these accounts take the first and essential step towards the derivation of the adjusted parameter (ε) and the Leeds dynamic GIMIMoC.

From the Leeds MULIO:

*industrial gross production level;
*industrial profit level;
*Labour and capital cost.

From the Leeds SOCDEM:

*travel-to-work flow;
*actual employment by industry or by social class;
*unemployment by social class;
*vacancy by industry.

From the Leeds HOSTOC:

*housing supply by type;
*housing demand by type;
*housing stock between housing supply and demand.

The profit level and parameter (ε) are derived from the procedures outlined in 2.4, i.e. by testing various parameters. In table 2, we present the 'best-fit' parameters obtained for industries in Inner Leeds. Two chosen trial sets of parameters are given, and then two sets of trial gross products ($\underline{\boldsymbol{X}}$) are obtained. It can be seen that the first set of parameters(ε_1) has resulted in relatively high errors. The 'Sum of Square' (SS) across all the trial industries is about 10,145.88, and the 'Root Mean Square' (RMS) is 100.73. As this set of parameters does not satisfy the 'best-fit' standard, another set of parameters (ε_2) is then tested. By comparing the trial gross products ($\underline{\boldsymbol{X}}$) based on the second set of parameters to the 'actual' gross product ($\boldsymbol{X}$) predicted from the available employment structure, the 'SS' and 'RMS' are worked out. The 'Sum of Square' is about 1,528, and the 'Root Mean Square' only 39.09. Further comparing these outcomes from the two sets of parameters, it is obvious that the results from the second set of parameters approach the 'best fit' standard much more closely than the results from first set. The second set of parameter (ε_2) is then incorporated into the Leeds MD dynamic GIMIMoC framework.

TABLE 2:
Comparison between two chosen sets of adjusted parameters

	Actual GOP[a] X	Parameter ε_1	Trial $\underline{X}_1$	Error $\underline{X}_1-X$	Parameter ε_2	Trial $\underline{X}_2$	Error $\underline{X}_2-X$
I[b]	0.53	0.003	0.20	-0.33	0.004	0.20	-0.33
II	52.59	0.026	59.10	6.51	0.024	59.80	7.21
III	2051.01	0.038	2071.80	20.79	0.012	2058.70	7.69
IV	368.13	0.117	299.90	-68.23	0.117	343.80	-23.33
V	525.90	0.149	558.90	33.00	0.148	508.40	-17.50
VI	315.54	0.101	286.20	-29.34	0.102	302.60	-12.94
VII	1985.83	-0.025	2041.20	55.37	0.114	2005.80	19.97
ΣSS[c]				10,145			1528.01
RMS[d]				100.7			39.09

Note:

a: Gross output products from the employment structure

b: Seven industries: agriculture, energy, manufacture, construction, distribution, transportation, service.

c: $SS = \Sigma_j \Sigma_n (\underline{X}^n{}_j - X^n{}_j)^2$

d: $RMS = \surd\ \Sigma_j \Sigma_n (\underline{X}^n{}_j - X^n{}_j)^2$

The Leeds MD dynamic GIMIMoC has four dimensions:

(1) Time. Three time periods are considered, i.e. year 1990, 1995 and 2000;

(2) Space. All the variables have spatial attributes, i.e. from zone to zone, region to region. The spatial scales

considered here are: (i) inner Leeds, outer Leeds and the rest of the world; (ii) the city of Leeds; (iii) the region of Yorkshire and Humberside;

(3) Alternative projections, e.g. low, moderate and high projections. Three alternative projections are derived by adjusting the associated parameters. We assume that the best-fit set of parameters will provide simulation results for the Leeds MD socio-demographic, economic and housing systems. High projection (i.e. when a favourable economy is expected) can be obtained by increasing the best-fit parameter, whilst low projection (i.e. when the worse economy is expected) by decreasing the best-fit parameter (see Fig. 1).

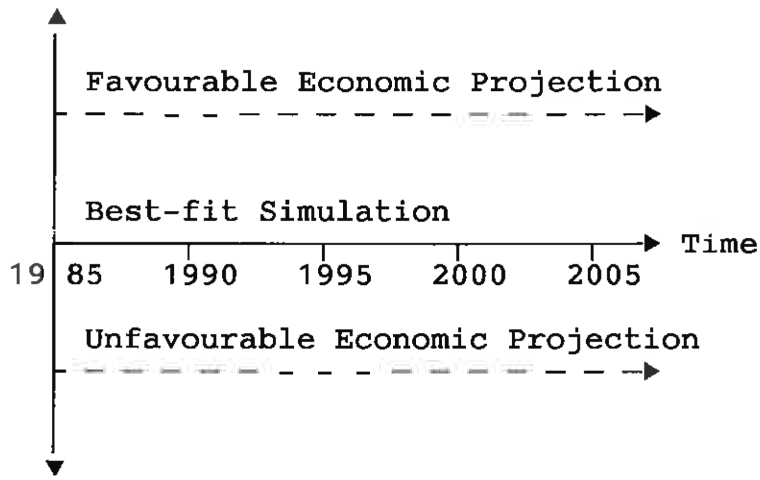


FIGURE 2: Alternative projections from adjusting the best-fit parameters

(4) Multiple systems. As outlined before, the dynamic

GIMIMoC consists of three interacting modules, each of which reflects a defined subsystem, e.g. the MULIO for the urban economic system, the SOCDEM for the urban socio-demographic system and the HOSTOC for the urban housing system.

The Leeds MD dynamic models are expressed in Fortran 77, and run on the Amdhal V7 at Leeds Computer Centre. Parallel to the four dimensions, the derived results also have the same features. A large amount of information is output from the operation of the model, but, within the scale of this paper, only limited results can be presented here. The adjusted parameters based on equation (17) are listed in Table 3. The dynamic profits for industries in both inner and outer Leeds, derived from Equation (6), are illustrated in Appendix 1. Appendix 2 and 3 describe the levels of gross output products and vacancies for different industries in both inner and outer Leeds in a specified time period (from Equation 7 and 26). The housing stock condition by type for both inner and outer Leeds in a time period, which is obtained from Equation (33), is demonstrated in Appendix 4.

TABLE 3:
The adjusted parameters for three projections

ε*	Year&zone	I**	II	III	IV	V	VI	VII
L	1985-1990							
	Inner	0.003	0.022	0.104	0.105	0.135	0.091	0.103
	Outer	0.003	0.021	0.098	0.105	0.114	0.090	0.099
	1990-1995							
	Inner	0.002	0.020	0.091	0.099	0.122	0.099	0.088
	Outer	0.002	0.019	0.088	0.099	0.103	0.090	0.090
	1995-2000							
	Inner	0.001	0.018	0.089	0.090	0.110	0.090	0.080
	Outer	0.001	0.018	0.079	0.090	0.097	0.081	0.081
M	1985-1990							
	Inner	0.004	0.024	0.115	0.117	0.149	0.102	0.114
	Outer	0.004	0.023	0.108	0.115	0.138	0.099	0.110
	1990-1995							
	Inner	0.002	0.019	0.098	0.119	0.149	0.098	0.141
	Outer	0.003	0.021	0.085	0.082	0.130	0.088	0.110
	1995-2000							
	INNER	0.001	0.021	0.119	0.118	0.127	0.101	0.146
	OUTER	0.002	0.021	0.107	0.110	0.100	0.077	0.111
H	1985-1990							
	Inner	0.004	0.024	0.115	0.117	0.149	0.102	0.114
	Outer	0.004	0.023	0.108	0.115	0.138	0.099	0.110
	1990-1995							
	Inner	0.002	0.019	0.127	0.129	0.149	0.108	0.125
	Outer	0.003	0.021	0.119	0.126	0.140	0.108	0.121
	1995-2000							
	Inner	0.001	0.021	0.138	0.128	0.150	0.108	0.137
	Outer	0.002	0.022	0.127	0.126	0.148	0.108	0.132

* ε indicates the adjustments under three sets of assumptions, i.e. low (L), moderate (M) and High (H).

** indicate 7 industries, i.e. agriculture, energy, manufacture, construction, distribution and service.

It can be seen that the levels of profit, gross output product of different industries depend on the given sets of adjusted parameters. When the best-fit set of parameters is raised to a certain level, i.e. the most optimistic projection, the profit and gross product of different industries are all to some extent increased, as are the number of vacancies and houses, for example, under these assumptions, in inner Leeds, the best-fit parameter for manufacturing industry is raised from 0.115 to 0.117 for the time period 1990-1995 (see Table 3), and then the profit is increased from £1373 million to 1391 million (Appendix 1), and the gross output product from £2,058.7m to £2,084.2m (Appendix 2), and the number of vacancies from 7,163 to 8,616 persons (Appendix 3). On the contrary, when the best-fit set of parameters is decreased, the profit, gross output product, and vacancies are all affected. For example, in inner Leeds, the parameter for the manufacturing industry is increased from 0.104 in time period 1985-1990 to 0.091 in time period 1990-1995 (Table 3), then the profit declines from £1,365.6m to £1,363.2m (Appendix 1), and the gross products from £2,044.5m to £2,034.5m (Appendix 2), and 352 (6,477-6,125) employment opportunities are then lost (see Appendix 3). Changes in the housing stocks reflect the same patterns as the profit levels (Appendix 4). It is worth noting that the best-fit set of parameters can be further adjusted to derive alternative plans. However, to what extent it should be adjusted depends upon the objectives of urban planners or any other social analysts.

4. Summary

In this paper, we propose once again that profit is the driving force of an economic subsystem. In addition, procedures to derive the profit of a particular industry and to adjust the relevant dynamic parameters have been described. It is suggested that the profit can be derived from the multispatial input-output table provided the selling and purchasing prices which has considered the unit transportation cost are incorporated. The best-fit set of parameters is the one that has the best simulation results. The dynamic GIMIMoC framework has been applied, in an illustrative way, to the Leeds Metropolitan District (MD), which shows that the GIMIMoC framework can be empirically operated.

It is important to note some models within this framework are expressed only crudely, such as the dynamic housing demand model which is simply expressed as a pretty crude regression equation may need to be explored in detail. A spatial interaction type of model can be applied to model the housing demand flow which may result in more accurate outcomes than the regression equation. The dynamic results from the framework can be input into the MULIO module, by operating which, dynamic multiplier impacts could be generated. This however may need further research in the future.

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APPENDICES

APPENDIX 1
The profit by industry by industrial zone

(£m)

YEAR&ZONE	I*	II	III	IV	V	VI	VII	TOTAL
LOW								
1990								
INNER	0.1	26.8	1365.6	215.7	360.0	165.1	1324.5	3457.8
OUTER	22.8	199.5	731.7	171.3	175.6	32.6	174.6	1508.1
1995								
INNER	0.1	26.8	1363.2	216.1	360.7	165.7	1301.9	3434.5
OUTER	22.8	199.3	731.1	171.8	175.7	32.8	165.6	1499.1
2000								
INNER	0.1	26.8	1361.4	215.1	358.0	165.4	1294.4	3421.2
OUTER	22.8	199.1	726.9	170.7	175.0	32.8	165.7	1493.0
MODERATE								
1990								
INNER	0.1	26.8	1373.0	217.0	362.9	165.5	1333.7	3479.0
OUTER	22.8	199.8	735.9	172.4	178.3	32.6	174.7	1516.5
1995								
INNER	0.1	26.8	1369.1	218.7	367.4	165.7	1341.4	3489.2
OUTER	22.8	199.6	730.1	169.7	179.4	32.8	163.9	1498.3
2000								
INNER	0.1	26.8	1384.6	218.8	362.8	165.8	1346.2	3505.1
OUTER	22.8	199.6	739.8	173.0	175.7	32.7	162.6	1506.2
HIGH								
1990								
INNER	0.1	26.8	1373.0	217.0	362.9	165.5	1333.7	3479.0
OUTER	22.8	199.8	735.9	172.4	178.3	32.6	174.7	1516.5
1995								
INNER	0.1	26.8	1391.1	219.9	367.4	166.1	1329.8	3501.2
OUTER	22.8	199.6	746.1	175.4	180.6	32.9	162.9	1520.3
2000								
INNER	0.1	26.8	1402.0	220.2	368.4	166.2	1338.0	3521.7
OUTER	22.8	199.8	751.2	175.8	182.0	32.9	160.3	1524.8

*See Table 3.

APPENDIX 2

Gross products by industry by zone

(£m)

	I*	II	III	IV	V	VI	VII	TOTAL
LOW								
1990								
INNER	0.2	59.7	2044.5	321.4	503.8	300.9	1990.0	5220.3
OUTER	42.3	249.7	1021.9	216.8	234.2	61.8	464.2	2290.9
1995								
INNER	0.2	59.6	2034.1	321.3	502.8	302.5	1958.4	5178.9
OUTER	42.3	249.3	1018.7	217.1	233.7	62.0	452.8	2276.0
2000								
INNER	0.2	59.6	2031.1	319.4	498.6	301.1	1946.0	5155.9
OUTER	42.3	249.1	1012.1	215.6	232.7	61.7	450.5	2264.0
MODERATE								
1990								
INNER	0.2	59.8	2058.7	323.8	508.4	302.6	2005.8	5259.3
OUTER	42.3	250.1	1028.8	218.4	238.2	62.0	467.2	2307.0
1995								
INNER	0.2	59.6	2044.4	325.8	513.0	302.4	2029.9	5275.1
OUTER	42.3	249.8	1016.9	214.3	238.8	61.9	456.3	2280.3
2000								
INNER	0.2	59.7	2072.7	325.8	505.6	302.9	2037.7	5304.5
OUTER	42.3	249.7	1032.4	218.8	233.6	61.6	455.3	2293.7
HIGH								
1990								
INNER	0.2	59.8	2058.7	323.8	508.4	302.6	2005.8	5259.3
OUTER	42.3	250.1	1028.8	218.4	238.2	62.0	467.2	2307.0
1995								
INNER	0.2	59.6	2084.2	327.9	513.0	304.0	2008.5	5297.4
OUTER	42.3	249.8	1041.9	221.9	240.6	62.6	458.2	2317.2
2000								
INNER	0.2	59.7	2101.8	328.1	514.0	304.1	2024.0	5331.8
OUTER	42.3	249.9	1049.1	222.2	242.4	62.6	458.6	2327.1

*See note to Table 3

APPENDIX 3
Vacancy by industry by industrial zone
(persons)

YEAR	ZONE	I*	II	III	IV	V	VI	VII	TOTAL
LOW									
1990									
	INNER	0	230	6477	1982	8142	2934	27747	47516
	OUTER	46	1179	7670	4126	5130	247	9784	28185
1995									
	INNER	0	208	6125	2084	8267	3278	21436	41399
	OUTER	31	1085	7457	4285	5112	323	4667	22963
2000									
	INNER	0	187	5975	1903	7475	2994	19078	37615
	OUTER	15	1027	6687	3910	4817	297	3854	20610
MODERATE									
1990									
	INNER	0	251	7163	2209	8987	3289	30711	52611
	OUTER	62	1292	8453	4519	6210	272	10871	31681
1995									
	INNER	0	197	6649	2535	10212	3255	34640	57489
	OUTER	46	1201	7259	3580	6579	317	5710	24695
2000									
	INNER	0	218	8040	2552	8859	3360	36125	59157
	OUTER	31	1200	9040	4704	5101	282	5189	25550
HIGH									
1990									
	INNER	0	251	7163	2209	8987	3289	30711	52611
	OUTER	62	1292	8453	4519	6210	272	10871	31681
1995									
	INNER	0	197	8616	2748	10212	3587	30709	56070
	OUTER	46	1201	10163	5501	7085	389	6281	30670
2000									
	INNER	0	218	9540	2798	10464	3604	33535	60162
	OUTER	31	1257	11046	5623	7618	400	6110	32088

* See note to Table 3.

APPENDIX 4

Housing stock condition(room) by type by zone
(rooms)

YEAR	ZONE	A*	B	C	D
LOW					
1990	INNER	-6515.9	-2729.3	406.2	3480.7
	OUTER	-2958.1	5201.1	233.3	-7546.8
1995	INNER	-7093.2	-3787.7	361.9	2974.2
	OUTER	-9628.9	3958.3	131.4	-8113.2
2000	INNER	-4101.4	-1417.7	500.8	3494.8
	OUTER	-5360.1	5543.9	205.5	-7716.1
MODERATE					
1990	INNER	-3578.1	-461.3	545.1	4001.3
	OUTER	-3824.5	6603.3	243.8	-239.9
1995	INNER	-3578.1	-461.3	545.1	4001.3
	OUTER	-3824.5	6603.3	243.8	-239.9
2000	INNER	-3632.1	-461.3	545.1	4001.3
	OUTER	-3824.5	6603.3	243.8	-239.9
HIGH					
1990	INNER	-640.5	2110.5	684.0	4521.9
	OUTER	-4943.4	-234.6	254.4	84.4
1995	INNER	-3023.1	758.8	730.6	4534.1
	OUTER	-3322.6	1011.9	294.7	426.8
2000	INNER	2852.6	5498.9	869.5	5575.3
	OUTER	956.3	2317.4	368.8	823.9

*A, B, C and D indicate four types of houses, i.e. owner occupied, city council, housing association and others.