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CHAPTER 19

A SEQUENTIAL LAND USE/TRANSPORTATION MODEL WITH EXTERNALITIES: LINKING THE DYNAMICS OF REGIONAL ECONOMIC GROWTH AND URBAN SPATIAL STRUCTURE

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1. Introduction

1.1 Research Objective

One of the least satisfactory features of regional analysis is the gulf between the studies of regional economic change and the study of regional spatial structure. Recent regional economic analysis concerns empirical and theoretical developments in growth theory, econometric modelling, and input-output techniques; but are rarely concerned with spatial structure. Similarly, studies of spatial structure are generally undertaken in a static context seldom related to the process of regional economic change. We contend the sectoral composition of a region's economy exerts an important influence on the spatial structure of the region.

Interdependence between activities is an important factor in the growth of regions. Interactions between agents makes the location decision of one agent dependent on the location decisions of other agents. Input-output relationships are important determinants of clustering both within and between activities. Interdependency is further influenced by standard

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structural transformations in the composition of demand, trade, production, and factor use in a developing economy.

Neoclassical approaches such as Fisher (1935) and Clark's (1957) development stages theory, Kuznets' (1957, 1966) modern economic growth theory, and Lewis's (1954) dual economy theory suggest that structural change is essentially a byproduct of economic growth. Based on these three underlying theories, Chenery (1960) develops general models of structural change that link changes in the composition of consumer demand to rising per capita income.

We contend that the process of metropolitan economic growth drives transformations in the spatial structure of the activity system. Our study depicts the dynamics of land use patterns, integrating Chenery's regional economic development processes into an activity location model. Structural transformations are revealed by nonproportional growth across sectors. Economic development produces changes in input-output relationships that are translated into updated transhipments between activities.

Our research model is a simulation that accounts for interactions between

(1) *a priori* profitabilities,
(2) transport costs defined by a congestive transportation network,
(3) externalities
(4) relocation costs, and
(5) technological change.

These factors tractably explain the evolution of an urban economy, and the effect of this evolution on urban structure.

1.2 Trends in Regional Spatial Structure

Contemporary metropolitan areas are characterised by decentralised patterns of employment. As a large metropolitan region grows, a point is reached at which economic activity and population begin to relocate from the metropolitan centre to subcentres situated within the metropolitan region. The emergence, growth, decline, and obsolescence of individual urban subcentres is part of a dynamic process resulting from simple economic behaviour. Some authors characterise this evolving form as a counterurbanisation that implies erosion of a single centred metropolis, and as a process of population de concentration characterised by decreasing densities and increasing local homogeneity (Berry 1976). Others describe it as a dispersion of activities producing a random sprawl of tract housing, shopping malls, and industrial parks, each locating without any specific relation to particular focal points (Blumenffeld 1964). Many see this emerging form as a mixed blessing, increasing the consumption of land and other finite resources (Clark1954). Regardless of the perspective taken, the study of how such subcentres develop and their impacts on land values, population distribution, and travel patterns is central to the investigation of land use and transportation interaction.

Empirical studies abound. In 1980, 57 percent of all office space in the US was located in urban centres and 43 percent in suburbs; by 1986, 60 percent was in the suburbs, compared to 40 percent in the centres (Pisarski 1987). Originating in America's sunbelt (Cervero 1986), the suburban office boom has become nationwide, occurring even in older industrial areas. In greater Philadelphia and St. Louis, for example, suburban employment grew by 8 and 17 percent respectively between 1982 and 1986, contrasted by a loss in central city jobs over the same period (Orski 1986; Urban Land Institute 1987). Erickson (1983) describes the evolution of suburban economic activities in the US through 1960 as a process of "dispersal/differentiation," followed by a subsequent phase of "infilling/multinucleation." Hartshorn and Muller (1986) describe the changing of land uses in American suburbs in terms off our stages, including bedroom communities (pre-1960), independence (1960-70), catalytic growth (1970-80), and high rise / high technology (post-1980).

Many expect the trend toward decentralisation to accelerate in the coming years as America's economy continues to shift from a manufacturing base to an emphasis on service and information processing activities. Suburban areas offer cheaper land, reduced externalities, proximity to regional airports, smart buildings laced with fibre optic cables and advanced telecommunications equipment, pools of second wage earners, and country like amenities (Dowall 1987, Urban Land Institute 1986 and 1987).

Relevant specifications of urban space must represent condition sunder which policentrism might emerge, discussing where the centres maybe located (Richardson 1988). Blackley and Follain (1987) argue that accessibility to amenities other than workplaces need to be accounted for in locational equilibria. This implies that spatial externalities should be represented in location decisions.

1.3 Regional Economic Analysis

The relationship between a region's economy and its spatial structure should be viewed in dynamic terms. If sectors of an expanding regional economy are subject to technical change, there may be significant modifications in their locational characteristics. A similar outcome is expected if existing sectors are replaced with new sectors that have substantially different locational requirements.

Neoclassical economic theory treats economic growth as the result of the long term effects of capital formation, labour force expansion, and technological change under conditions of competitive equilibrium. "Shifts in demand and the movement of resources from one sector to another are considered relatively unimportant because the marginal returns in the use of these factors (labour and capital) should in principle be equal in all uses (Chenery, et al 1986)." Hence, there are no incentives for drastic structural change. Structural change is essentially a by product of growth, which in turn is produced by increases in factor supplies and productivity.

However, economic growth may also be treated as a result of transformations in the structure of production. These transformations are required to meet changing demand, and to make more productive use of technology. Conditions of imperfect foresight, incomplete competition, and limits to factor mobility imply that these structural changes are most likely to occur under conditions of disequilibrium (Chenery, et al 1986).

The relationship between growth and structural change can be divided into two parts. These are the effects of growth in per capita income on structure (the demand side); and the effects of changing structure and productivity increase on growth (the supply side). Fisher (1935) and Clark (1957) articulate a sequential path of economic development through which all societies progress. Under this development stages theory of growth, societies are assumed to experience changes in the dominant occupation of the labour forces. This process is explained by changes in comparative costs and changes in income elasticities of demand. Kuznets (1957, 1966) and many others place the study of industrial growth in a broader perspective. Instead of focusing so narrowly on the allocation of resources, Kuznets describes the increasing industrial outputs as part of the general transformation he identifies as "modern economic growth." Starting with the national accounts recorded by a number of countries, Kuznets measures the changes in the composition of consumption, production, trade, and other aggregate measures as income rises; demonstrating similarities between the growth patterns of the 1950s. He measures comparable development patterns both among countries and over time.

Building on these growth process theories, Chenery and others (Chenery 1960; Chenery, Shishido, and Watanabe 1962; Chenery and Taylor 1968; Taylor 1969; and Chenery and Syrquin 1975) develop general models of structural change. These models usually assume similar changes in the composition of consumer demand with rising per capita income. These multisectoral, cross country models address the demand side in terms of three sets of relationships. These are

(1) income elasticities of demand for each commodity,
(2) input-output relations that are a function of per capita income, and
(3) export demands and import proportions that reflect the factor endowments and policies of different groups of countries.

Under these conditions, the basic causes of structural change are technological progress, population growth, rising level of income, consequent changes in trading conditions, and the supply of external capital.

Chenery employs regression equations as reduced form representations of a detailed general equilibrium system. In this simplified model, the level of per capita income and population are the only explanatory variables, implying that all of these factors can be collapsed into income and market size effects. The model yields solutions for levels of consumption, production, and trade by sector as a function of the level of per capita income.

2. A Sequential Urban Land Use Model

The sequential urban land use model developed here consists of two major components,

(1) a discrete programming model of the market for urban land and transportation, and
(2) an interactivity flow system that accounts for structural transformations resulting from economic development.

Contemporary suburbs are interdependent, collectively comprising the metropolitan economy. This metropolitan economy is, in turn, part of a larger system of economies, engaging in trade with its hinterland, other metropolitan economies, and the rest of the world. At the same time, the metropolitan region is an economy with an evolving differentiation between suburbs, each of which exhibits specification in term of its activity characteristics.

Recognising interdependencies is the principal means of integrating the regional economic development process into an activity location model. The model is initialised by an exogenous economic structure and spatial pattern. Given an initial spatial pattern, the characteristics of establishments change. These economic changes result in structural transformation and nonproportional growth across sectors. Given income elasticities for each sector and an existing set of input-output relationships, the structural transformation model endogenises production levels and traffic intensities. Exogenous values in the discrete programming model describing segment revenues, externalities, and relocation costs might also be influenced by production levels. Given these updates, the discrete programming model identifies a new land use pattern. In the next time period, more economic structural changes are realised and the structural transformation model once again produces new traffic intensities.

2.1 The Market for Urban Land and Transportation

Urban spatial structure is the outcome of a process that allocates activities to sites. The process is principally one of transactions between owners of real estate and those who wish to rent or purchase space for their homes and businesses. These transactions are accomplished by the general rule of the market. We assume the urban area is divided into many discrete sites. These sites have different attributes. Each site belongs to an owner who is free to sell or lease his property. At the beginning of each transaction period, every establishment evaluates the merits of every site, and decides what price it would be willing to pay for access to each site.

The passage of time brings changes in the number and types of establishments bidding for access to locations. Existing establishments also change in terms of their characteristics. Households change in size, manufacturers acquire new production methods, and retailers shift product lines. Some sites change hands and some establishments move to new locations. As long as some establishments are moving, the pattern of accessibility and contiguity changes for other establishments. Even if site characteristics are fixed, these various changes accumulate overtime to cause significant shifts in the matrix of site bids.

In most contemporary regional I-O tables, the structural coefficients represent inter industry trade flows. Recent developments in combining input-output and transportation planning models have made it possible to construct comprehensive urban and regional activity models. A metropolitan area industry activity model divides the local economy into identifiable sectors along two dimensions, product (or industry) and geography. Transactions representing interactivity linkages are identified across industries and locations.

Gordon and Moore II (1989) and Moore II and Gordon (1990) formulate a sequential programming model that simulates the spatial evolution of modern cities. Locators are assumed to make decisions from a *ceteris paribus* perspective (Moore II and Gordon 1990). By solving a series of linear assignment problems that track urban land use over time, their model presents a sequence of urban location decisions resulting from locators' efforts to maximise net revenues by mitigating congestion costs and other externalities (Moore II and Gordon 1990). Network congestion and other effects are endogenous in each period, but traffic intensities between all activities i and j are exogenous. In the current study, interactivity flow systems are conditioned on economic development patterns that include changes in the composition of demand, trade, production, and factor use as functions of per capita income.

The arrival, departure, and ongoing bidding of activities constitute the principal mechanisms for spatial rearrangement. Unsuccessful bidders are consigned to a null site, or queue. Activities bid nothing for access to the queue, and there is no constraint on the number of activities that can locate there. To represent this process in a more complete way, Moore II and Gordon also introduce a nonbidding or null activity called "vacancy" that bids nothing for physical sites and can be assigned to any number of sites. When nonvacancy activities offer (sufficiently) positive bids for sites, existing vacancies are displaced.

Index activities from 1 to I and physical sites from 1 to M. Append an I+1st row accounting for vacancies, and an M+1st column corresponding to the null location, or queue. The augmented matrix that results is **A**, an initial $[(I+1)\times(M+1)]$ matrix of seminet revenues. At time 0, $\mathbf{A}(0)=[a_{im}(0)]$ is the profitability of plants i at m, ignoring externalities and transportation. That is, **A**(0) is the value to plant i of the attributes of site m independent of the locations of other plants.

The principal advantage of the solution procedure is that complex information about congestion and other externalities is assumed to flow from recent experience, allowing the sequential use of linear programs to emulate the decisions of locators. A flowchart describing this approach appears in Figure 1.

Step 6 is key, updating each activity's location bid. Given $\mathbf{A}(0)=[a_{im}(0)]$, the $[(I+1)\times(M+1)]$ matrix of seminet revenues (identified in Step 0); $\chi(t)=[\chi_{jn}(t)]$ the $\{[(I+1)\cdot(M+1)]\times 1\}$ vector of optimal location assignments from the previous time period (identified in Step 2); $\mathbf{F}=[f_{ij}]$, an exogenous matrix of traffic intensities between all activities i and j (identified in Step 3); $\mathbf{C}^*(t)=[c^*_{mn}(t)]$, the $(M\times M)$ matrix of user equilibrium link costs (identified in Step 4); and $\mathbf{E}^*(t)=[e^*_{imj}(t)]$, the $[I\times(I\cdot M)]$ matrix of potential spatial externalities imposed by each activity j at (fixed) location n on each activity i at (variable) location m (identified in Step 5); the bid for each locator i prepares for each site m is updated based on each locator's semi net revenues and anticipated experiences at all locations. That is, compute the $[(I+1)\times(M+1)]$ matrix of location bids

$$\begin{aligned}\mathbf{A}(t+1)=[a_{im}(t+1)]=[a_{im}(0)\cdot v_i(t)/v_i(0)]\\ +\Sigma_{j=1->I+1}\{\Sigma_{n=1->M}[c^*_{mn}(t)\cdot f_{ij}\cdot\chi_{jn}(t)+e^*_{imj}(t)]\}\\ (\text{for all } i=1->I+1, \text{ for all } m=1->M+1)\end{aligned} \quad (1)$$

where $v_i(t)$ is the value added by activity i in time period t as identified in the structural transformation model. Given fixed site characteristics, activities will still change their production levels as a result of changes in the cost of primary materials. Consequently, $a_{im}(0)$ is updated in each time period relative changes in the value added levels associated with each activity. The values $a_{im}(0) = 0$ if i is vacancy and/or m is the null site.

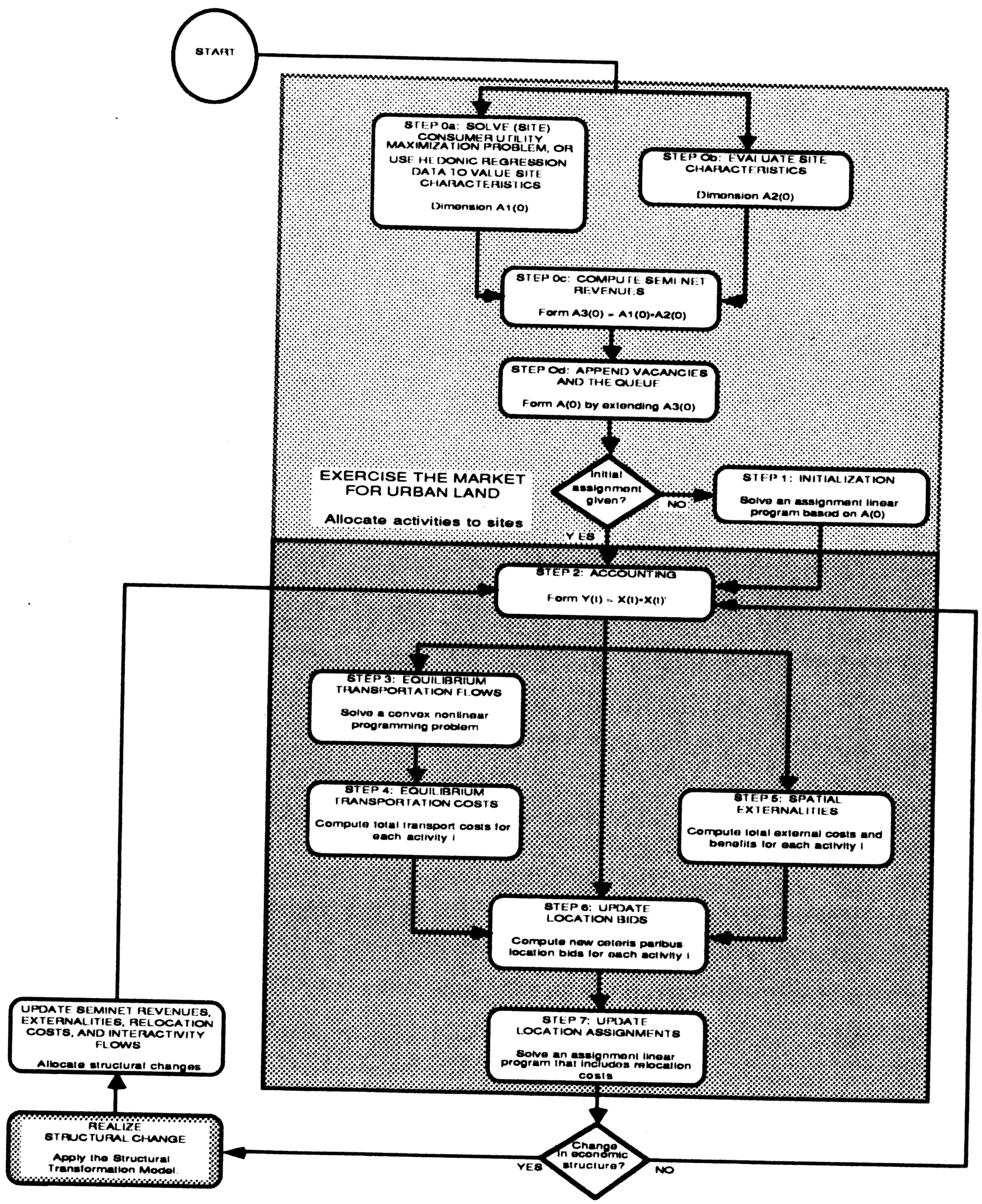


Fig. 1. Algorithmic Representation of the Sequential Urban Land Use Model: An Extended Version of the Moore II and Gordon Model (1990)

Step 7 is a market clearing operation. Given the matrix $A(t+1)=[a_{im}(t+1)]$, and an exogenous $[(I+1)\times 1]$ vector $R=[R_i]$ consisting of activity specific relocation costs; solve the following linear program.

Maximise

$$\Sigma_{i=1->I+1}\Sigma_{m=1->M+1}\{a_{im}(t+1)-R_i\cdot[1-\chi_{im}(t)]\}\cdot\chi_{im}(t+1) \quad (2)$$

subject to

$$\Sigma_{i=1->I+1}\chi_{im}(t+1)=1$$
(for sites $m=1->M$; i.e., for all sites m, except the null site) (3)

$$\Sigma_{m=1->M+1}\chi_{im}(t+1)=1$$
(for activities $i=1->I+1$; i.e., for all activities i in I, except vacancy) (4)

$$\chi_{im}(t+1)\ \geq 0$$
(for all activities $i=1->I+1$, for all sites $m=1->M+1$) (5)

where $\chi_{im}(t)$ is exogenous to time period t+1 (Moore II and Gordon 1990).

Steps 8 and 9 impose structural transformations associated with economic development on the location assignment model.

2.2 Summary of the Structural Transformation Model

There are two dominant approaches to multisectoral analysis in modelling structural transformation. Leontief (1951; Leontief, et al 1953) was the first to use the input-output (I-O) approach to study structural changes in the American economy. Leontief's research analyses the effects of changes in input coefficients between 1919 and 1939 on the structure of production and labour use. External trade and domestic demands are held constant. Chenery, Shishido, and Watanabe (1962) use a similar procedure to trace transformations in the structure of Japanese production between 1914 and 1954 in response to changes in demand, trade, and technology.

Computable general equilibrium (CGE) models are more sophisticated alternative originally derived from the I-O perspective. Johanson (1960) linearised Walras' general equilibrium model for Johanson's empirical application to the Norwegian economy. Johanson employed Leontief's input-output system to describe interindustry relations, but he included demand and production functions that depend on relative prices. Such CGE models are developed further in a number of recent studies (Taylor and Black 1974; Dervis 1975; J. de Melo 1977, M.de Melo 1979; de Melo and Robinson 1980; Celasun 1986) that focus on issues of international trade, growth, economic structure, and income distribution in developing and developed countries. These models are sometimes called price endogenous models because all prices must adjust until the decisions made in the productive sphere of the economy are consistent with the final demand decisions made by households and other autonomous decision makers.

Significant differences between the two approaches arise in cases where relative prices change substantially. In the long term, the most important price is the rising cost of labour, which leads to the substitution of capital for labour and to changes in comparative advantage. CGE approaches can distinguish between capital-labour substitution and technological change. I-O approaches aggregate these effects.

As noted above, the structural transformation of a developing economy may be defined as the set of changes in the composition of demand, trade, production, and factor use that takes place as per capita income increases. Although the CGE approach is clearly preferable inmost contexts on theoretical grounds, the important advantages of the CGE approach are offset by the limited data on prices and capital stocks. Also, the relevant production functions are cumbersome, and must be approximated from observations scattered across both space and time. Lastly, there are problems in proving the existence of an equilibrium solution (Diewert and Wales 1985). Consequently, we use the input-output approach to explain the locational changes resulting from structural transformation. Data permitting, a CGE model can substituted directly.

The research model derives activity growth functions from a general equilibrium model that allows for changes in the composition of demand and in factor proportions. The general equilibrium models of Walras (1954), Leontief (1951), and Dorfman, Samuelson, and Solow (1958) customarily omit elements that would lead to persistent differences in growth rates. These elements include limited natural resources, changing factor supplies, nonhomogeneous consumption functions, economies of scale, and international trade. Accounting for imports, exports and intersectoral requirements defines four determinants of the level of production. These include three components of demand and one alternative source of supply. The accounting identity for this system is

$$X_p = D_p + W_p + E_p - M_p \tag{6}$$

where X_p is domestic production of commodity p, D_p is domestic final use of p, W_p is use of p by other producers, E_p is the export of p, and M_p is the import of p.

Intermediate demand W_p for a commodity p depends on output levels from the sectors using p, on the substitutability of other inputs for p, and on the variation in the relative prices of inputs. Based on previous work involving international comparisons (Houthakker 1957; Chenery and Watanabe 1958; Taylor 1969; Chenery and Syrquin 1980 and 1986), price effects are suppressed on the assumption that per capita income incorporates the effects of all these explanatory variables. Thus the function for intermediate use of commodity p is

$$W_p = \Sigma_k \alpha_{pk} \cdot X_k = \Sigma_k \alpha_{pk} \cdot (Q_k + M_k) \tag{7}$$

where the α_{pk} are input-output coefficients, X_k is the total output of commodity k, and Q_k is the sum to total intermediate purchases and value added in the production of commodity k.

Structural change is often defined by sectoral shifts, which may include changes in any component of demand or value added by production. Alternatively, changes in structure can also be measured as sector specific deviations from proportional growth across sectors. Under the assumption of proportional growth, equation (14) can be expressed for time t

$$X_p\hat{}(t) = X_p\hat{}[Y(t)] = \lambda(t) \cdot X_p[Y(0)] \tag{8}$$

where $X_p\hat{}(t)$ indicates total production of commodity p proportional toper capital income at time t, and

$$\lambda(t) = Y(t) / Y(0) \tag{9}$$

is the proportionate increase in income between periods time 0 and time t.

In general, these proportional benchmarks will not be realised. Deviations from proportional growth can be expressed as follows

$$\Delta X_p(t) = X_p(t) - X_p\hat{}(t) = \Delta W_p + \Delta D_p - \Delta M_p + \Delta E_p \tag{10}$$

Thus, deviation from proportional growth in each sector can be traced back to deviations from proportional growth in intermediate demand, final demand, imports, and exports. Equation (10) implies several alternative decompositions of structural change that depend on import substitution, and the nature of changes in interactivity structure.

The explanatory variables for the determinants of sector growth depend on the degree of openness of the economy, its trade pattern, and its rate of growth. The United Nations (1963) tested eight proxy variables for these factors in estimating growth patterns for individual industrial sectors. This and other studies of economic development patterns has led to the identification and measurement of a number of structural changes associated with rising income. As a result, income level has been used as an overall index of development as well as a measure of output. We employ income per capita as an explanatory variable on the assumption that per capita income incorporates effects of all other explanatory variables.

To investigate structural changes implied by sectoral deviations from proportional growth, we need to measure the income elasticities of domestic production X, domestic final demand D, exports E, and imports M for each sector p. Regression analysis provides a convenient vehicle. Regression has been widely used to compare and explain the uniform patterns of industrial growth measured by Chenery (1960), Kuznets (1966), Chenery and Taylor (1968), and Chenery and Syrquin (1975, 1980).

At the national level, economic development takes place in an environment in which trading opportunities and technology are constantly changing. The growth functions derived from cross sectional analysis describe the adaptation of countries at different levels of income to conditions of technology and trade existing at one point in time. Ideally, these states indicate the path that a typical country would follow if its income increased so rapidly that conditions of trade and technology were relatively constant (Kuznets 1957, Chenery 1960).

Estimated income elasticities depend on the type of function fitted. The double logarithmic function is preferred for most international comparisons (Houthakker 1957; Chenery and Watanabe 1958; Taylor 1969; and Chenery and Syrquin 1980 and 1986). Chenery (1960) and United Nations (1963) show that the logarithmic form fits the available data much better than a linear function for most sectors. Houthakker's (1957) findings support this assumption in the case of household consumption. We use linear logarithmic regression equations in which the value of each determinant of sector growth depends on per capita income. For example, the function for final domestic use per capita is

$$\log(D_p) = \log(\beta_{p0}) + \beta_{p1} \cdot \log(Y) \qquad (11)$$

where β_{p0} is the initial state of final use of commodity p implied by data series, β_{p1} is an income elasticity for the consumption of commodity p, and Y is per capita income.

Consider the hypothetical regional economy summarised in Table 1. Based on updated estimates of domestic production $X[Y(t)]$, domestic final demand D[Y(t)], exports E[Y(t)], and imports M[Y(t)] for each sector p; we will apply equations (6) and (7) to compute intermediate use W(t). The various phenomena associated with economic development can lead to technological changes within any and all sectors, and there are several ways these changes might be represented in the matrix of technical coefficients.

Table 1. A Hypothetical Regional Economic System

	Inputs \ Outputs	Processing								Purchasing			
		Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Households	Total Intermediate Use W_p	W_p / Total Output	Final Demand D_p	Exports E_p	Total Output X_p
Processing	Sector 1	1,000	1,500	100	200	500	600	1,400	5,300	0.838	600	500	6,400
	Sector 2	500	400	700	100	300	800	1,700	4,500	0.763	800	600	5,900
	Sector 3	700	200	800	100	500	300	500	3,100	0.775	600	300	4,000
	Sector 4	1,100	100	200	800	600	400	400	3,600	0.923	300	0	3,900
	Sector 5	400	0	100	1,400	300	200	900	3,300	0.825	500	200	4,000
	Sector 6	200	600	700	600	200	600	800	3,700	0.804	500	400	4,600
	Household	1,600	1,800	700	500	700	900	100	6,300	0.875	900	0	7,200
	L_k Total Intermediate Purchases	5,500	4,600	3,300	3,700	3,100	3,800	5,800	29,800		4,200	2,000	36,000
Payments	L_k / Total Outlays	0.859	0.780	0.825	0.949	0.775	0.826	0.806		0.828			
	v_k Value Added	700	1,200	400	200	600	600	1,200	4,900				
	v_k / Total Outlays	0.109	0.203	0.100	0.051	0.150	0.1340	0.167	0.136				
	Q_k $L_k + v_k$	6,200	5,800	3,700	200	3,700	4,400	7,000	34,700				
	M_k Imports	200	100	300	0	300	200	200	1,300				
	X_k Total Outlays	6,400	5,900	4,000	3,900	4,000	4,600	7,200	36,000				36,000

Viewed from this perspective, the fundamental problem is generic. Given new distributions for the row and column marginals of a matrix, the objective is to make best use of the information content in the original matrix to update the matrix entries in a way that satisfies the conditions imposed by the new marginals. We rely on the biproportional adjustment method (Hewings 1977, 1982) used to update input-output, migration, and trip interchange tables. Biproportional adjustment minimises the I-divergence, i.e., the information gain, of the posterior array relative to the a priori array. Other approaches to the same problem include linear and quadratic programming, and variational inequalities (Nagurney 1993). These approaches differ in terms of how distances between the a priori and posterior matrices are defined, and in terms of the algorithms used to address the constrained optimisation problems that result.

Our use of biproportional adjustment does not provide an endorsement of one penalty function versus another. We do not presume to know if technological changes imply the creation of new technologies, or substitutions between existing technologies. Further, we do not know which adjustment procedure maps best to this mixed process of innovation and choice. We elect biproportional adjustment because the theoretical and computation aspects of the procedure are well understood, because the positivity of the initial array ensures the positivity of the unique solution to the problem, and because it operates directly on technical coefficients rather than on flows.

Ideally, Leontief sectors are aggregations of activities producing a single product by similar techniques. Given the variety of products produced by typical plants, realising a close approximation of this concept is impossible. In empirical inter industry studies, a productive sector corresponds to a grouping of processes and products that may differ in some respects. Still, an aggregate sector of production activities may be satisfactory for a Leontief model even if the activities involved do not have uniform inputs of primary factors.

Table 1 describes flows between sectors, yet the discrete programming model identifies locators at the level of activities. Consequently, sector flows updated by the structural transformation model will have to be disaggregated into activity flows before the land use model can be applied. The rules used to disaggregate a sector into constituent activities can be traced back to the rules for consolidating the sectors of a detailed input-output table. The rules of consolidation involve simple summation of flows in a particular base period. Let X_{ij} denote the flow from activity i to j; let D_i denote the final demand for activity i; and let X_i denote the total output of activity i.

$$X_i = \Sigma_{j=1->J} X_{ij} + D_i . \tag{12}$$

Generalising to any period, let the input coefficient α_{ij} denote the quantity of input from activity i that is needed to produce one unit of output j.

$$\alpha_{ij} = X_{ij} / X_j . \tag{13}$$

The flows between sectors p and k consist of flows between several constituent activities i in sector p and j in sector k. At the sectoral level,

$$\alpha_{pk} = X_{pk} / X_k . \tag{14}$$

Interactivity flows can be estimated from intersectoral flows by reversing the procedures implied by standard consolidation rules. If the activities defining a given sector have similar input-output characteristics, intersectoral flows can be disaggregated into an interactivity flows even if the activities vary with respect to the use of primary inputs. In terms of the abbreviated notation associated with Table 1, compute

$$f_{ij} = f_{pk} \cdot (X_{i\ in\ p} / X_p) \cdot (Q_{j\ in\ k} / Q_k) \tag{15}$$

where

$$X_p = \Sigma_{\text{all activities i in sector p}}\ X_i \text{, and} \tag{16}$$

$$Q_k = \Sigma_{\text{all activities j in sector k}}\ Q_j. \tag{17}$$

More generally,

$$f_{ij}[Y(t)] = f_{pk} Y[(t)] \cdot \{X_{i\ in\ p}[Y(0)] / X_p[Y(0)]\} \cdot \{Q_{j\ in\ k}[Y(0)] / Q_k[Y(0)]\}, \tag{18}$$

where $Y(0)$ denotes per capita income in the base year.

Because urban land use configurations are characterised by capital intensive land uses, input substitutions between land and capital are of special importance in an urban context. In this exercise, activities are classified based on the intensiveness of the land input. High, medium, and low land intensive activities correspond to low, medium, and high density land uses respectively.

2.3 Algorithmic Elements of the Structural Transformation Model

In each time period, interactivity flows are derived from income levels. A flowchart describing this approach appears in Figure 2.

Step 0: Estimation of Income Elasticities for Determinants of Intermediate Purchases

Under the I-O approach, imports are classified by purchasing sector, but our discussion of import substitution classifies imports in terms of output accounts. Thus we require transactions to be tracked insufficient detail to permit one set of import values to be converted to the other. Given cross regional or time series observations on X_p, D_p, E_p, and N_k, estimate income elasticities by specifying logarithmic regression equations in which the explanatory variable is per capita income. That is, estimate

$$\log\{D_p[Y(t)]\} = \log(\beta_{p0}) + \beta_{p1} \cdot \log[Y(t)], \tag{19}$$

$$\log\{X_p[Y(t)]\} = \log(\phi_{p0}) + \phi_{p1} \cdot \log[Y(t)], \tag{20}$$

$$\log\{E_p[Y(t)]\} = \log(\eta_{p0}) + \eta_{p1} \cdot \log[Y(t)], \text{ and} \tag{21}$$

$$\log\{N_K[Y(t)]\} = \log(\gamma_{p0}) + \gamma_{p1} \cdot \log[Y(t)]. \tag{22}$$

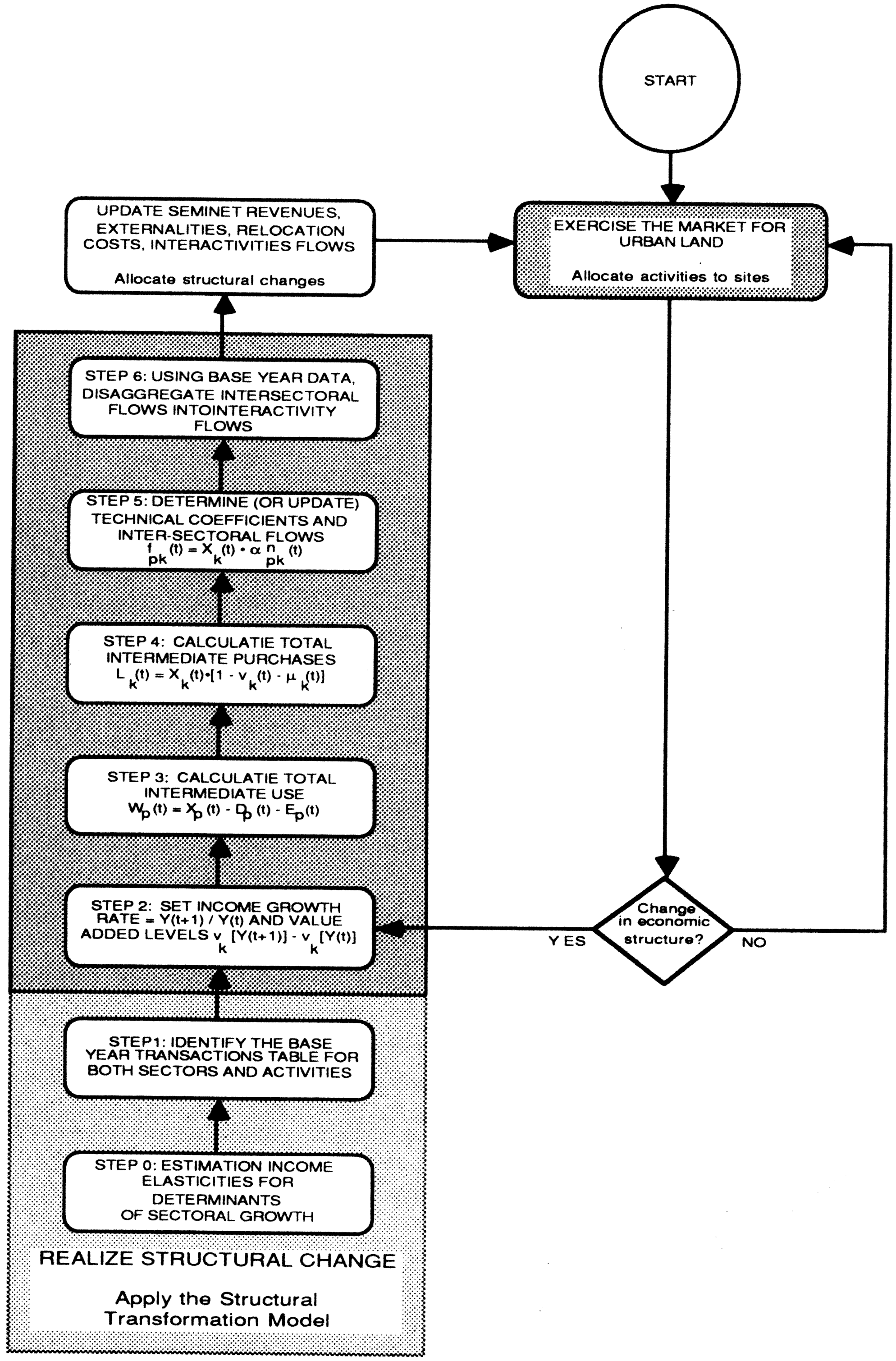


Fig. 2. Algorithmic Representation of Structural Transformation Model

where X_p, D_p and E_p are the domestic production, domestic final use, and exports associated with each sector p, respectively; N_k is the imports associated with each sector k, and Y(t) is the level of per capital income at time t. The subscript 0 denotes each data series' initial state. The coefficients β_{b1}, ϕ_{p1}, γ_{p1}, and η_{p1} are a vector of income elasticities for determinants X_p, D_p, E_p, and N_k, respectively.

Step 1: Identify Base Period Transactions Table for All Sectors and Activities

Establish a transactions table for the region. Let "p" denote a producing sector. Let "k" denote a purchasing sector. Identify base year values for determinants $D_p[Y(0)]$, $X_p[Y(0)]$, $N_k[Y(0)]$, and $E_p[Y(0)]$; technical coefficients $\alpha_{pk}[Y(0)]$, and the sum of intermediate purchases and value added in sector k $Q_k[Y(0)] = \{L_k[Y(0)] + N_k[Y(0)]\}$. Based on each activity's land use characteristics, decompose each sector p's total output $X_p[Y(0)]$ and outlays $Q_k[Y(0)]$ into corresponding activity totals $X_i[Y(0)]$ and $Q_j[Y(0)]$.

Step 2: Define Income Growth Rates and Value Added Ratios for Period t

Given the per capita income levels $Y(t)$ for each time period t and an initial state $Y(0)$, define an exogenous income growth rate $\lambda(t) = Y(t) / Y(0)$. In this exercise, we assume a 10 percent increase in per capita income per period. Define an exogenous value added vector $v_k(t) = v_k[Y(t)]$ for each sector k, and value added ratios $\omega_k(t) = v_k(t) / v_k(0)$.

Step 3: Calculate Intermediate Uses for Period t

Given the income elasticities β_{b1}, ϕ_{p1}, γ_{p1}, and η_{p1} determined in Step 0; the initial values for determinants $D_p[Y(0)]$, $X_p[Y(0)]$, $N_k[Y(0)]$, and $E_p[Y(0)]$ identified in Step 1; and the exogenous income growth rate $\lambda(t)$ and the value added ratios $\omega_k(t)$ defined in Step 2; determine the future values of determinants $X_p(t) = X_p[Y(t)]$, $D_p(t) = D_p[Y(t)]$, $N_k(t) = N_k[Y(t)]$, and $E_p(t) = E_p[Y(t)]$; and the future values of intermediate use $W_p(t) = W_p[Y(t)]$. That is, compute

$$D_p(t) = D_p(0) \cdot \lambda(t)^{\beta_p}, \tag{23}$$

$$X_p(t) = [v_p(0) / v_p(t)] \cdot X_p(0) \cdot \lambda(t)^{\phi_p}, \tag{24}$$

$$N_k(t) = N_k(0) \cdot \lambda(t)^{\gamma_p}, \quad (25)$$

$$E_p(t) = E_p(0) \cdot \lambda(t)^{\eta_p}, \quad (26)$$

$$W_p(t) = X_p(t) - D_p(t) - E_p(t), \text{ and} \quad (27)$$

$$\mu_k(t) = N_k(t) / X_k(t) \quad (28)$$

Step 4: Calculate Intermediate Purchases for Period t

Given the exogenous value added ratio $\omega_k(t)$ identified in Step 2, and the vector of import ratios $\mu_k(t)$ identified in Step 3, determine the values of intermediate purchases $L_k(t)$. That is, compute

$$L_k(t) = X_k(t) \cdot [1 - \omega_k(t) - \mu_k(t)]. \quad (29)$$

$$Q_k(t) = L_k(t) + v_k(t) \quad (30)$$

Step 5: Determine Technical Coefficients and Intersectoral Flows for Period t

Given the technical coefficients $\alpha_{pk}(0)$ identified in Step 1 or the coefficients $\alpha_{pk}(t-1)$ identified for the preceding time period, the intermediate uses $W_p(t)$ identified in Step 3, and the vector of intermediate purchases $L_k(t)$ identified in Step 4, update intersectoral flows $f_{pk}(t)$ via biproportional adjustment.

- **Step 5a:** Compute $\Sigma_{k=1->K} X_k(t) \cdot \alpha_{pk}(t-1) = W_p^1$. (31)
  Update $\alpha_{pk}^1(t) = \alpha_{pk}(t-1) \cdot [W_p(t) / W_p^1]$. (32)
- **Step 5b:** Compute $\Sigma_{p=1->P} X_k(t) \cdot \alpha_{pk}^i(t) = L_k^i$.
  Update $\alpha_{pk}^{i+1}(t) = \alpha_{pk}^i(t) \cdot [L_k(t) / L_k^i]$. (33)
- **Step 5c:** Compute $\Sigma_{k=1->K} X_k(t) \cdot \alpha_{pk}^{i+1}(t) = W_p^{i+1}$.
  Update $\alpha_{pk}^{i+2}(t) = \alpha_{pk}^{i+1}(t) \cdot [W_p(t) / W_p^{i+1}]$. (34)
- **Step 5d:** Repeat steps 5b and 5c until $W_p(t) / W_p^{i+1}$ and $L_k(t) / L_k^i$ approach 1.
  Update $\alpha_{pk}(t) = \alpha_{pk}^n(t)$ where n is the terminal value of i.
- **Step 5e:** Compute intersectoral flows $f_{pk}(t) = X_k(t) \cdot \alpha_{pk}^n(t)$. (35)

Step 6: Disaggregate Intersectoral Flows into Interactivity Flows for Period t

Given total activity outputs $X_i[Y(0)] = X_i(0)$ and activity outlays $Q_j[Y(0)] = Q_j(0)$ identified in Step 1, and intersectoral flows $f_{pk}(t)$ identified in Step 5, determine interactivity flows $f_{ij}(t)$. That is, compute

$$f_{ij}(t) = f_{pk}(t) \cdot [X_{i \text{ in } p}(0) / X_p(0)] \cdot [Q_{j \text{ in } k}(0) / Q_k(0)] \tag{36}$$

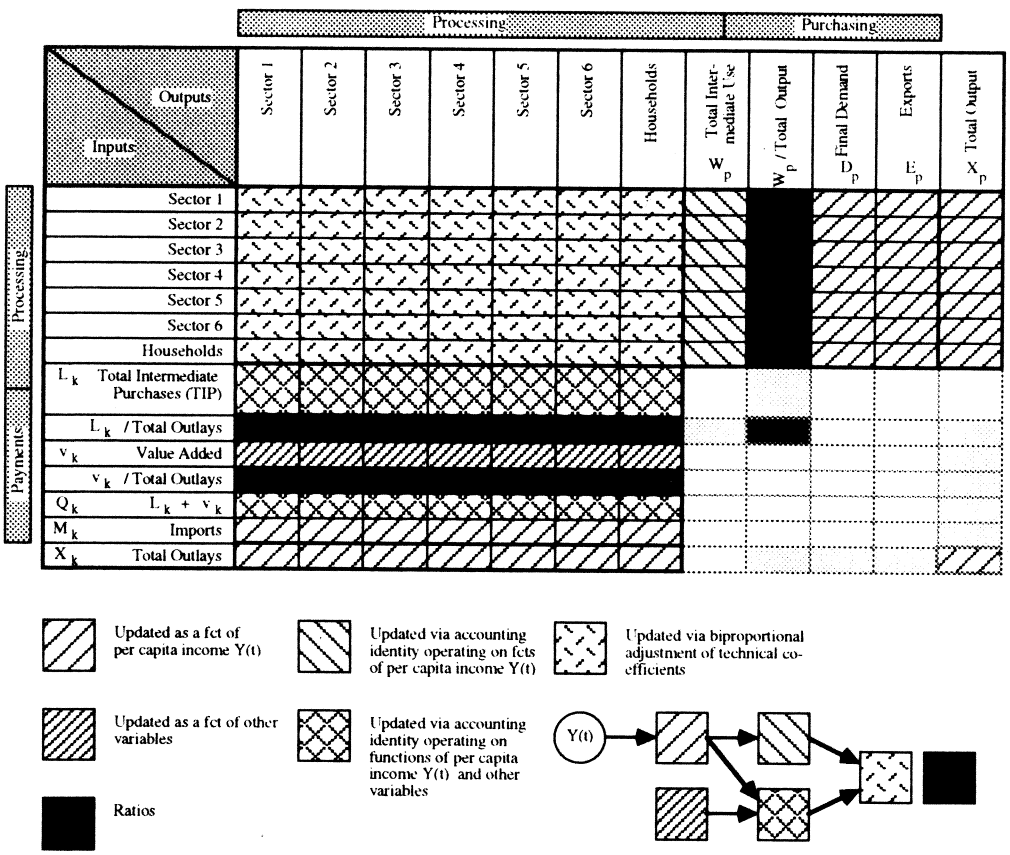
where

$$X_p(0) = \Sigma_{\text{all } i \text{ in } p} X_i(0) \text{ and} \tag{37}$$

$$X_k(0) = \Sigma_{j \text{ in } k} X_j(0)\,. \tag{38}$$

Table 2 summarises the inputs and outputs of the structural transformation algorithm in terms of the numerical data in Table 1.

Table 2. Exercising the Structural Transformation Algorithm on the Entries in Table 1.



3. Numerical Applications

The simulation demonstrates the integrated model by investigating locational changes under conditions of economic growth. The results provide insight into the changes in the regional geography of advancing economies. Moreover, if this evolutionary approach can depict reality reasonably well, then this research may also help us to develop and test some useful empirical hypotheses.

3.1 Spatial Representation of a Hypothetical Metropolitan Region

The hypothetical area is a metropolis based region consisting of an urban area and a periphery. The focus of the study is an urban area consisting 21 hexagonal land use zones (Moore II and Wiggins 1988). The periphery is defined to be a dimensionless null site. Each physical site is initially occupied by an activity. The urban transportation system consists of aggregate links between zones. The network consists of congestive links connecting to nearest neighbours. The system is summarised in Figure 3.

If a located activity is outbid by vacancy and retires to the queue, interactivity shipments involving this activity are assumed to be imported through the null site. Otherwise, the absence of a key production activity would present an infeasibility (Moore II and Gordon1990). The null site is assumed to be a periphery through which imports and import enter and exit the region.

3.2 Data Synthesis

Parameter values describing the economic growth patterns bearing on this research are drawn from the work of Chenery (1960 and 1980), Kuznets (1966), Chenery and Taylor (1968), Chenery and Syrquin (1975 and 1980). These studies provide income elasticities explaining uniform patterns of economic growth.

Exercising the assignment component of the model requires matrices describing seminet revenues, transportation link costs and capacities, external effects, relocation costs, and intersite distances. Precursor exercises rely on synthetic data, and the literature provides little empirical information relevant to the assignment component of this research. A more realistic description of an existing urban configuration is preferred. However, we rely on synthetic data for two reasons. While an empirical exercise would permit us to forecast the trajectory of a real metropolis, it would not further elaborate the function of the model. Also, we want this work to remain as comparable as possible to precursor efforts. Our synthetic data set is available upon request.

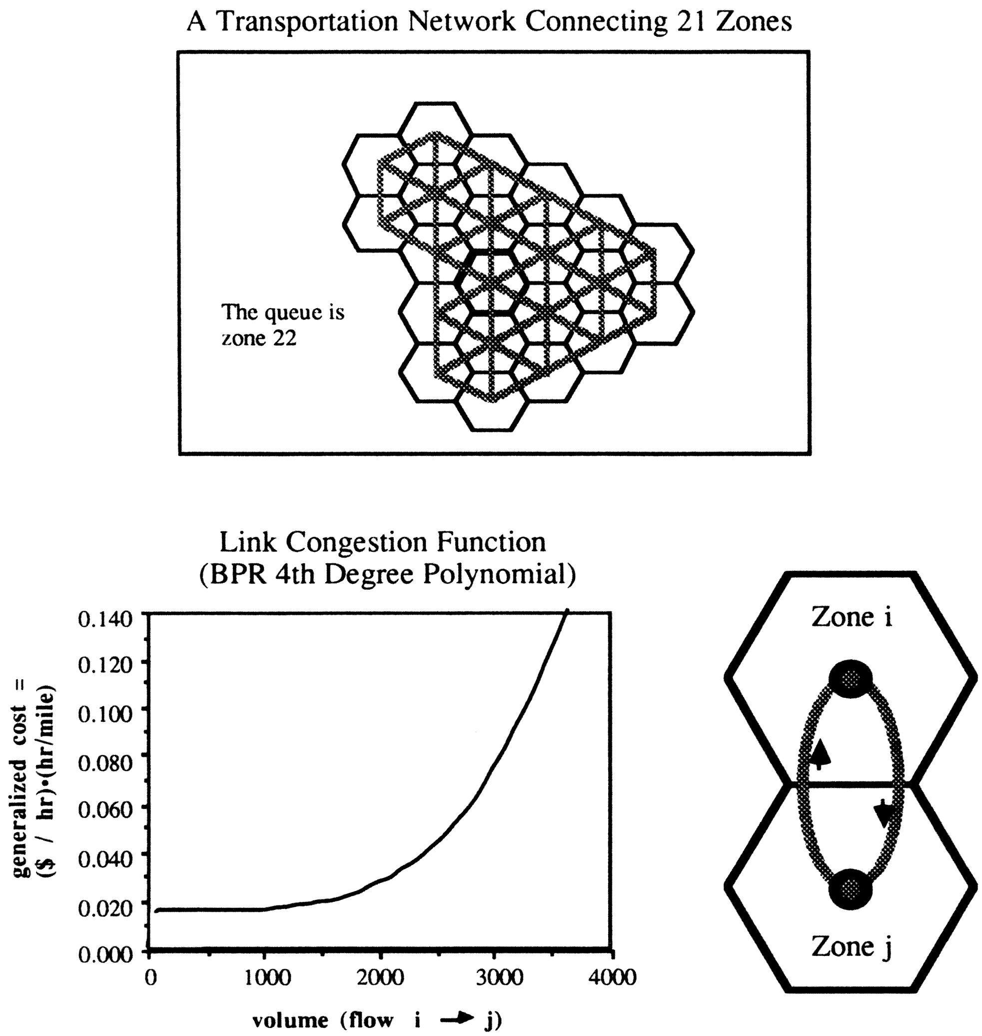


Fig. 3. A 21 Zone System and Associated Transportation Network.

3.3 Results

Development is often characterised by decline in the relative size of the manufacturing sector, almost always accompanied by a rising share of the service sector. Clark (1957) and Fisher (1939) argue that developing economies can be expected to move away from primary production activities toward service production. Because high income elasticities are associated with many service activities, it is argued that this sector only becomes large after the basic necessities are provided by the primary sector, and most demands for manufacturing goods are satisfied.

Such patterns imply nonproportional growth across sectors relative to increases in per capita income. The simulated ratio of production growth rate to income growth rate is summarised in Table 3. The production growth rate of sector p is $\Delta X_p(t) = [X_p(t) - X_p(t-1)] / X_p(0)$. The income growth rate is $\Delta Y(t) = [Y(t) - Y(t-1)] / Y(0)$ = 10 percent. The simulation produces significant differences across sectors in terms of deviations from proportional growth. Sector 2, a final primary production activity such as service, is the fastest growing sector. Sector 5, a primary production activity such as agriculture, is the slowest growing sector. Other sectors, such as manufacturing, fall in between these two extremes.

Table 3. The Ratio of Production Growth Rate to Income Growth Rate: $[\Delta X_p(t) / X_p(0)] / [\Delta Y(t) / Y(0)]$

SECTOR	TIME PERIOD						
	t = 1	t = 2	t = 3	t = 4	t = 5	t = 6	t = 7
Sector 1	1.508	1.542	1.574	1.605	1.636	1.665	1.695
Sector 2	2.128	2.227	2.324	2.421	2.516	2.610	2.703
Sector 3	1.863	1.939	2.016	2.094	2.172	2.251	2.331
Sector 4	1.821	1.889	1.957	2.024	2.092	2.159	2.226
Sector 5	0.716	0.704	0.693	0.682	0.672	0.662	0.652
Sector 6	1.386	1.413	1.440	1.467	1.494	1.520	1.547
Households	1.069	1.073	1.076	1.079	1.081	1.084	1.087

Another phenomenon is the substitution of manufactured goods for primary inputs. The combination of rising purchases by other sectors, together with the substitution of manufactured for primary commodities, produces rapid growth in the intermediate demand for manufactured goods. The corresponding increase in manufacturing output above that implied by proportional growth accounts for the greater part of structural change associated with development. In the simulation, the average shares of intermediate use in total domestic demand increase from 0.828 to 0.846. These increasing average shares of intermediate use imply an increasingly complex economic system. In addition, technological changes are implied by nonproportional growth in domestic demand, final demand, imports, and exports. These technological changes are summarised in Table 4.

A key development phenomenon is increasing use of intermediate industrial products. Lack of interdependence and linkage is perhaps the most typical characteristic of undeveloped economies. Increased use of intermediate inputs is characterises an increasingly complex economic system. As economies develop, their productive structures become more

Table 4. Changes in Technical Coefficients

TIME PERIOD t = 0

	PURCHASING SECTOR						
PRODUCING SECTOR	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	House-holds
Sector 1	0.156	0.254	0.025	0.051	0.125	0.130	0.194
Sector 2	0.078	0.068	0.175	0.026	0.075	0.174	0.236
Sector 3	0.109	0.034	0.200	0.026	0.125	0.065	0.069
Sector 4	0.172	0.017	0.050	0.205	0.150	0.087	0.056
Sector 5	0.063	0.000	0.025	0.359	0.075	0.043	0.125
Sector 6	0.031	0.102	0.175	0.154	0.050	0.130	0.111
Households	0.250	0.305	0.175	0.128	0.175	0.196	0.014

TIME PERIOD t = 1

	PURCHASING SECTOR						
PRODUCING SECTOR	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	House-holds
Sector 1	0.160	0.261	0.025	0.054	0.127	0.133	0.195
Sector 2	0.085	0.074	0.189	0.029	0.081	0.189	0.253
Sector 3	0.115	0.036	0.208	0.028	0.130	0.068	0.072
Sector 4	0.178	0.018	0.051	0.220	0.154	0.090	0.057
Sector 5	0.056	0.000	0.022	0.336	0.067	0.039	0.111
Sector 6	0.031	0.102	0.173	0.158	0.049	0.129	0.109
Households	0.237	0.291	0.165	0.126	0.165	0.185	0.013

TIME PERIOD t = 4

	PURCHASING SECTOR						
PRODUCING SECTOR	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	House-holds
Sector 1	0.165	0.275	0.026	0.062	0.129	0.137	0.194
Sector 2	0.104	0.092	0.226	0.039	0.097	0.229	0.296
Sector 3	0.129	0.041	0.229	0.034	0.144	0.076	0.078
Sector 4	0.192	0.019	0.054	0.260	0.163	0.096	0.059
Sector 5	0.042	0.000	0.016	0.273	0.049	0.029	0.079
Sector 6	0.030	0.100	0.164	0.169	0.047	0.125	0.101
Households	0.205	0.255	0.139	0.120	0.140	0.159	0.011

TIME PERIOD t = 7

	PURCHASING SECTOR						
PRODUCING SECTOR	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	House-holds
Sector 1	0.167	0.281	0.025	0.068	0.129	0.137	0.191
Sector 2	0.119	0.107	0.254	0.048	0.110	0.261	0.330
Sector 3	0.142	0.045	0.247	0.041	0.156	0.083	0.083
Sector 4	0.201	0.021	0.056	0.296	0.169	0.100	0.060
Sector 5	0.031	0.000	0.012	0.216	0.035	0.021	0.056
Sector 6	0.029	0.098	0.155	0.177	0.045	0.120	0.095
Households	0.181	0.228	0.120	0.114	0.122	0.139	0.009

roundabout in the sense that a higher proportion of output is sold to other producers than to final users. As with final demand, this phenomenon means a shift in output mix toward manufacturing and other sectors that use more intermediate inputs.

The simulation is initialised by an exogenous match between site sand activities. The subsequent sequence of patterns is summarised in Figure 4. Initially, six low density activities are outbid by vacancy. In each period, seminet revenues, externalities, and activity specific relocation costs are modified in light of value added levels. Locators update their bids in response to the environmental externalities and congestion costs experienced in their current locations. Based on these updated bids, the assignment linear program generates new location patterns. Activities are displaced to the queue when they cannot generate a positive bid that is highest for any site. Not all locators relocate simultaneously. Some activities do not change their locations, whereas some relocate and persist for only a few time periods. Some activities exchange their locations. Vacancies are created frequently. After period 7, the simulation results stabilise. Relocations are still possible, but occur much less frequently. This result presumes no special site improvements or new investments in infrastructure.

3.4 Sensitivity Analysis: Transportation Costs

The research model provides an integrated treatment of regional economic change and spatial structure. Seminet revenues, externalities, and relocation costs are defined by production / location decisions. Input-output relationships change as a result of economic development processes, and these changes are translated into transshipments between activities. Transportation costs, including congestion externalities, play an important role relative to other system elements. If the unit transportation costs are too high, then changes in economic structure will dominate the activities' location decisions because each activity's total transportation costs are rendered very sensitive to the changes in traffic intensities. Thus, it is important to determine whether unit transportation costs dominate other location factors.

We investigate four new scenarios in which free flow link costs are increased by 5, 10, 20, and 30 percent, respectively. The 5 and 10 percent increases in link costs induce no changes in the trajectory of location patterns. A 20 percent increase induces a few changes, the most conspicuous of which is a decrease in the number of vacancies. A 30 percent increase in link costs produces significant differences in locational patterns, and a more rapid convergence to stability.

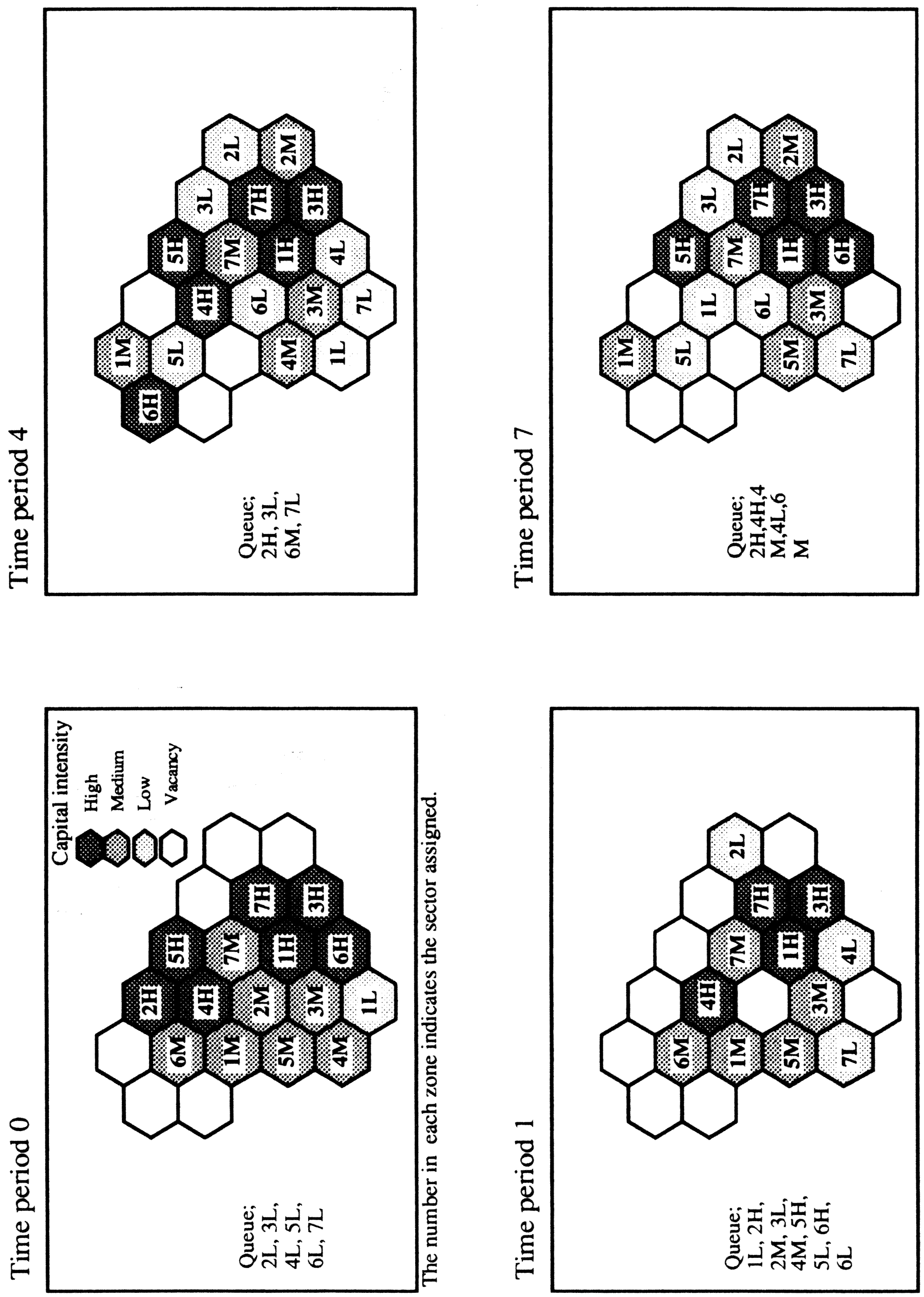


Fig. 4. Simulation Results for Periods 0, 1, 4, and 7

3.5 Conclusions

In contemporary metropolitan areas, decentralisation of activities is a dynamic process resulting from the interplay of simple economic behaviours. The model explained here demonstrates the locational behaviour of activities in a system subject to economic growth. Changes in the spatial structure appear to be related to the locational characteristics of the economic activity; the characteristics of the economic environment; external economies and diseconomies, including the congestability of the transportation system; and relocation costs.

The collective results of these simulations and sensitivity tests demonstrate the utility of decentralisation as a coping mechanism. Economic activities progressively relocate to decentralised locations to maintain access to each other. Gordon, Kumar, and Richardson (1988) contend that the relocation of activities within cities is guided by the desire to avoid congestion. Location of activities, intensity of land uses, means of production, origins, and destinations are all affected by the provision and pricing of transportation facilities, but an increase in transportation costs does not necessarily translate into centralisation. Indeed, the simulation suggests that decentralisation offers more advantage.

4. Policy Implications

The evolution of a policentric spatial structure, either planned or spontaneous, is a reasonable response to the externalises associated with monocentricity (Gordon and Richardson 1993a). The subcentre location of jobs and populations alleviates the external diseconomies of urban scale without sacrificing the benefits of area wide agglomeration economies. However, government intervention often slows these spatial and political shifts toward policentric patterns. Instead of pursuing ambitious decentralisation strategies, metropolitan planners tend to respond to local increases in urban growth, pollution, and traffic congestion. Consequently, resources are invested in infrastructure that exceeds prospective demand. Planners should promote the more efficient policentric structures critical to successful metropolitan growth, and avoid expensive interventions that might inhibit spatial restructuring (Gordon and Richardson 1993a).

The key issues are how, when, and where to intervene. Gordon and Richardson suggest an appropriate scope for planning and regulatory approaches. The first step is to identify when public intervention is justified. The second step is to evaluate the conditions under which market based strategies are less practical than regulation. In most circumstances, planners should draw policy guidance from market approaches. Market based measures use economic principles to alter consumption or production decisions. These include the institution of market exchange mechanisms, or the establishment of prices that reflect true costs. For example, congestion pricing is a pricing system that corrects the market failure inherent in the passenger transport system. Tradeable emissions rights perform similarly in the case of production. Firms that must pay a market price for the right to pollute will not pollute unless the revenues available from production exceed the social cost of emissions.

Because of (perceived) uncertainty concerning the benefits associated with market based approaches, public authorities favour regulation. This reflects a lack of information. As information brokers, planners have a role in forecasting future phenomena. Multiperiod forecasts describing the benefits and optimal budgets of pricing strategies and investments are particularly important. Integrated models of the sort proposed here organise, process, and improve information concerning the anticipated impacts of policies and public investment decisions. By keeping the economic role of externalities explicit, regulatory strategies can be compared to other approaches aimed at internalising externalities.

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