ON THE COMPLEXITY OF URBAN LAND USE
CHANGE: OR, WHAT THEORETICAL MODELS
LEAVE IN THE DUST

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PREFACE

This paper represents a revision of and extension to Research Paper No. 80, published previously in this series. It undertakes to bring together different empirical approaches to the analysis of the changing spatial structure of urban land use, and at the same time to document the limitations of current theoretical models of urban land use. The paper concludes with suggestions on data needs and on necessary extensions to dynamic land use models.

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ABSTRACT

The essence of theory is simplification. Too often, however, that simplification is myopic, and itself becomes the basis of a new image of reality. Urban land use theories are one example. Their view of a timeless monocentric and featureless city composed of utility-maximizing robots and single commodity firms, whose actions are uninhibited by public values or policy constraints, bears increasingly little resemblance to the modern complex multi-dimensional and highly political urban landscape.

The purpose of this paper is three-fold: to review some of the deficiencies of current theoretical and planning models; to document, empirically, the complexity of urban land use structure and change; and to outline a framework for a continuing research effort at analyzing macro and micro-level processes of land use change.

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INTRODUCTION

The complexity of urban land use structure and change, despite the rapid evolution of a sophisticated body of theory and analytical methods, still confounds both researcher and policy-maker alike. In the face of this complexity theoreticians understandably retreat into increasingly more abstract models. Granted, the real world does interfere with mathematical tractability. But what is the balance between tractability and realism?

At the same time, policy-makers and planners are faced with a lack of precise empirical information on land use change, and a paucity of empirically documented relationships between land use and changes in socio-economic structure, infrastructure and public policy. Moreover, planners are faced with a contradiction. On the one hand are the macro-level concerns of most operational planning models and, on the other hand, the micro-level scale at which the decision-making processes they are attempting to influence are expressed.

These difficulties are due in part to the diversity and multiplicity of processes operating on and through the contemporary urban landscape. Our current family of theoretical land use models are essentially static descriptions of an unreal landscape. They tell us little about the underlying processes themselves. Not only are these processes complex,

but the impact of each varies in space and time. Some processes are contradictory or contravailing pressures. Others are cumulative and mutually reinforcing and still others are essentially independent. Each process also has its own spatial geometry, reflecting different spatial covariances, but evident over only a certain range of spatial aggregations. Each process also involves different kinds of land use conversions which mirror differences in location, demand, the economics of land subdivision and building replacement and the presence or absence of development controls. Such differences tend to be ignored by standard theoretical models and by operational models based on aggregate measures of change, traditional categories of use, and on one level of aggregation.

Objectives

This paper is a response to these concerns. It reports on a program of empirical research designed to investigate underlying regularities in urban land use patterning and change. The intention here is not to review details of the methods employed, or of the statistical results, but to provide an overview of where the research is going and what questions it might eventually help to answer. In so doing it attempts to contribute to an improvement in the empirical base on which theoretical development is so dependent.

These analyses build principally on two rich but very different sets of data for Metropolitan Toronto. The first consists of aggregate statistics on land use by minor planning district (n=413) for 1956,

1963, 1968 and 1971-2. The areas in each of 30 categories (net of roads and railways) have been coded for the first three dates and for 59 categories in 1972, as obtained from comprehensive aerial photographs and field surveys.¹ The second data set is a computerized inventory of individual properties compiled from municipal assessment files for the years 1952, 1962, 1971 and 1976. At the time of writing this inventory was limited to the City of Toronto.²

Although these two data sets are not strictly compatible, we have made several attempts to link them, through some of the analytical procedures recorded below, although this work remains incomplete. In addition, and as needed, we draw on other conventional sources for data on employment, commuting, the housing stock, and census socio-economic structure.

Some Limitations of Existing Research

Empirical analyses, without the guiding hand provided by theory or by precise policy-relevant research questions, can become mindless number crunching. In the former, fortunately, there is now an extensive body of literature which summarizes land use theory, notably recent volumes by Papageorgiou (1976) and Richardson (1977). This literature lifts the burden of review from this paper. The role of perceived policy problems in guiding research will be evident as the discussion is developed. These problems explicitly or implicitly shape the questions we ask of our data and research.

Although there may be no need to review land use theory as such, there is a need to outline in more detail the weaknesses of the research from which this paper takes its initiative. These criticisms essentially reflect a set of premises regarding the shortcomings of much of our existing analytical research. We are for the moment bypassing the specific criticisms of urban models: the myopic assumptions (i.e. monocentric city), the exclusion of all but market forces, and the calibration methods (i.e. static equilibrium) employed in the typical neo-classical model of urban structure. Most are also essentially non-spatial, or are spatial only in the sense of incorporating distance from a central point, and ignore the temporal dimension.

* Four limitations stand out:

1. conceptual simplicity: The argument here is that traditional aggregate models of urban land use structure and change are inadequate descriptions of the complexity of that structure. In fact, they not only ignore but often obscure the important interdependencies which underlay that structure by recognizing only a few categories of occupancy and by oversimplifying the multivariate competitive process through which land is allocated to users.
2. analytical and data limitations: Most existing land use modelling procedures fail with respect to one or more of the following criteria:
  - (1) the land use typologies on which they are based do not reflect the spatial and temporal processes operating in the urban landscape. Most are concerned only with residential uses, or at best with two others: manufacturing and the public sector. They tend to be functional classifications, largely untested in terms of internal homogeneity, and are generally insensitive to policy and planning objectives.
  - (2) such models generally ignore the adjustment process in the building stock, that is the succession process in land occupancy, through which the use of one site or area is converted to another use. Of particular importance is the fact that adjustment occurs, at any given time, only through changes to a subset of available properties.

- (3) the sensitivity of their analytical results to the particular spatial grid employed is seldom evaluated.
- and (4) adequate time series data are seldom available, at least in a compatible and disaggregate form, to permit dynamic as opposed to static analyses.

3. Neglect of the supply side: Most theoretical and programming models are primarily concerned with the demand side of the land use equation. The supply side, and the interaction between demand and supply are frequently assumed away, or are assigned only a peripheral position in the analysis.
4. Policy needs: Urban planning and policy formulation necessitates a real-time information gathering procedure for monitoring land use changes within the city. Any such procedure requires an analytical framework for the collection, classification and collation, as well as the analysis of land use.

There are no doubt other equally (or more) serious concerns than these, such as the distributional effects of particular land use configurations, but these are beyond the scope of the current paper.

Analytical Methods: The Context

The sequence of on-going research from which this paper derives is outlined schematically in Figure 1. Each stage in this sequence serves both as an output, capable of standing on its own merit, and as an input to subsequent analyses. Admittedly the sequence is somewhat arbitrary. It represents the evolution of converging research interests rather than a strictly a priori design.

In the initial step, principal components techniques are employed to identify internally homogeneous land use types, both in cross section and for the analysis of change. These components, after testing for size and scale differences (spatial stability) and internal homogeneity (within-component variance), then serve as input to three other analyses.

Figure 1: Outline of Research Strategy on the Dynamics of Urban Land Use

The first is a regionalization procedure, the purpose of which is to create spatially (contiguous and non-contiguous) homogeneous sets of interdependent uses. These land use "environments" in turn become the spatial grid for the analysis of micro-level land use succession through transition probability matrices.³

The second extension involves the input of these components into a series of multiple regression equations designed to evaluate the determinants of differential rates of land use change between zones within an urban area. Coefficients are estimated for three levels of spatial aggregation each with several different measures of land use change as the dependent variables. These principal component regressions (PCR's) can then be reordered into a set of linked intra-urban spatial growth models. The latter task has yet to be done. Finally, the land use components have been linked with changes in the socio-economic landscape through canonical correlation analyses. These results have been extended in a recent paper (see Briggs and Leonard, 1977).

A parallel level of analysis begins with the micro-scale files on individual property records. These files, with linked identification codes which enable one to trace the evolution of uses of individual properties over time, serve as the basis for constructing matrices of the rates of conversion within and between land use types. They also enable one to trace the specific sources of the net changes which emerge in the aggregate data, and to merge property records with other sources of data on micro-level changes in urban structure. Moreover, it is only at this level that analyses of the behavioral bases of land use change can be appropriately undertaken.

A third aspect of the research involves an attempt to link these changes to modifications in particular policy instruments such as zoning, service and building restrictions and transportation facilities. Specific tests have been carried out for certain critical policy areas such as the central core and inner city.⁴ What still remains to be done is to link these analyses back to the PCA regression models and the regionalization procedures discussed above.

It could be argued that with data on the universe of individual property changes this linking is not necessary. This would only be true if the universe was to be available on a continuing basis. This is unlikely, in the Toronto area or elsewhere. Instead we will likely rely on strategically defined samples which need the context of aggregate surveys to establish the boundaries conditions for estimating future changes. In any case aggregate analyses do have somewhat different information requirements than do the micro-analyses simply because the former internalize many of the relationships important at the micro scale.

TYPOLGY OF CHANGE

The first task was to construct, through principal components and discriminant analysis, a revised typology of land use structure change. In doing so an attempt was made to vary the level of spatial aggregation of the data, to employ alternative measures of change and factoring procedures, and to vary the boundary of the area under study, as suggested below (Table 1). Fortunately the data file is sufficiently

Table 1: Alternative Data and Analytical Designs

	Type of Measurement			Boundary Definition		
	Raw	Percent	Z Transform	Political Unit	Built-up Area	Metro Area
Basic Planning Units (413)						
Census Tracts (297)						
Minor Planning Districts (79)						
Homogeneous Socio-Economic Zones (62)						
Major Planning Districts (24)						

Not undertaken

flexible to allow the aggregation from basic planning units or B.P.U.'s (n=413) into a nested series of units: census tracts (n=297), minor planning units (n=79), socio-economic zones (n=62), and major planning districts (n=24).⁵

The purpose of the alternative data constructs in Table 1 was, as previously noted, to test the stability of the analytical results over a range of different definitional frameworks. It is well known that the results of analyses of spatial structure are influenced to a considerable extent by the size and shape of the spatial units employed and the boundaries selected for the area under study (Cliff, et al., 1975). What is perhaps less well known and documented is that the spatial scale of analysis determines the internal variance structure of the variables used. Each definitional system has its own variance distribution and its own structure of spatial associations, as will be demonstrated later. Thus, generalizations deriving from one level of analysis may be inapplicable at another level.

Although there is not sufficient space here to display the differences in analytical results, it should be noted that they were often substantial. At one extreme there was little similarity in the spatial associations among land uses between the B.P.U. grid and the major planning districts (n=24). At best, a reasonable degree of similarity exists between the census tract and the socio-economic zone analyses, sufficient to allow for generalization over this part of the space scale. Thus, for illustrative purposes, the following discussion concentrates on results from the 1963-72 period, for one measure of change (standardized percentage change), for the 62-zone system.

The initial purpose of the analysis again is to identify clusters of land use whose patterns of change are spatially covariant. It is assumed that these clusters are the outcomes of the same or similar spatial processes. This is a critical assumption, the plausibility of which rests on the stability of the empirical results and on parallel research on micro-level decision-making (Bourne, 1976).

The results of earlier versions of this analysis (with data to 1971) have been published elsewhere (Bourne, 1974). As the present results do not differ substantially, it will suffice here to provide a brief summary and to comment on recent empirical extensions and on the weaknesses of current theory in anticipating these changes. The first and most obvious comment is that the coefficients of correlation among land use changes are, for the most part, low. Regardless of the scale of measurement the coefficients are weak (Figure 2). Although a more parsimonious grouping is clearly possible, the degree of redundancy in the existing data is limited. The increasing size of development schemes, and the imprint of agglomeration economies and exclusionary zoning become evident.

Figure 2: The Structure of Interdependence: Frequency Distributions of the Correlation Coefficients among Land Use Change.

A second point is that these simple typologies constructed subsequently through principal components procedures are stable only over very limited ranges of spatial aggregation. It is possible to accept hypotheses on the similarity of factor structures for the census tracts and the 62-zone aggregation of tracts, but even those tests were marginal.⁶ Thus, any generalizations on land use patterning must be conditional on the spatial grid employed. Moreover, as expected, the total variance enveloped in each set of components increased with each decrease in the number of zones.

Principal Components

Changes in the area occupied by the original 30 categories of land use collapsed, through principal components analysis,⁷ into 11 factors accounting for just under 78 percent of the initial variance (Table 2). The factor scores are mapped in Figures 3 through 7. The dominant factors may be broadly described, as noted above, as representing clusters of uses whose patterns of change across the urban area are covariant. This in turn suggests the hypothesis that changes in these uses represent the outcome of similar spatial processes, specifically of a similar conversion process. This hypothesis will be more discussed at greater length in a subsequent section of this paper.

Factor 1 is clearly a suburbanization process. It combines the decline of previously vacant land with increases in that mix of uses which typically comprise relatively new and internally homogeneous neighbourhood units (single-family housing, schools and churches). This

TABLE 2

PRINCIPAL COMPONENTS FACTOR STRUCTURE:
LAND USE CHANGE 1963-72*

Factor No.**	Factor Loading***	Variable Name/Process Description	<u>Percent Variance Explained</u>	
			Each Factor	Cumulative
1		THE SUBURBANIZATION PROCESS	20.2	-
	0.80	Single-family residential		
	-0.72	Vacant land		
	0.62	Elementary & secondary public schools		
	0.57	Churches and places of worship		
	0.52	Row housing and semi-detached		
	0.48	Other public open space		
2		EXTENSION OF THE URBAN CORE	9.0	29.2
	-0.89	Commercial offices		
	0.88	Government offices and services		
	0.79	Parking lots and structure		
	-0.55	Row housing and semi-detached		
	0.46	Hospitals		
3		OPEN SPACE CONVERSION	8.5	37.7
	-0.87	Drive-ins, private open space		
	0.83	Parks (public)		
	-0.67	Agricultural land		
	-0.49	Other public open space		
4		INFRASTRUCTURE AND UTILITIES CHANGE	7.5	45.2
	0.81	Other public utilities		
	-0.72	Hydro-electricity utilities		
	0.63	Elementary separate schools		
	-0.51	Other storage yards		
5		COMMERCIAL-INDUSTRIAL CHANGE	6.3	51.5
	-0.82	Retail and general commercial		
	-0.81	Service stations and garages		
	-0.64	Industrial (manufacturing)		
	0.57	Vacant land		
	0.51	Warehousing and storage		
6		HIGH DENSITY RESIDENTIAL AND COMMERCIAL CHANGE	5.7	57.2
	0.77	Apartments and flats		
	-0.51	Single-family residential		
	0.68	Hotels and motels		

Table 2 (cont'd)

OTHER LOCALIZED PATTERNS OF CHANGE				
7	-0.78	Golf courses (private)	4.8	62.0
	0.71	Private schools and colleges		
	0.47	Single-family residential		
8	-0.90	Railroads and storage yards	4.6	66.6
	0.46	Parking lots and structures		
9	-0.86	Cemeteries	4.3	70.9
	0.57	Universities and colleges		
	-0.49	Churches and places of worship		
	-0.47	Row housing and semi-detached		
10	0.81	Arenas, places of assembly	3.9	74.8
	-0.48	Industrial		
	0.45	Expressways		
11	0.59	Commercial offices	3.1	77.9
	0.51	Retail and general commercial		

*Defined as $(L_{ij}(1972) - L_{ij}(1963)) / \sum_i L_{ij} \cdot 100$; for each of i categories in j zones; $j=62$; $i=29$.

**Oblique factor rotation, with the degree of obliqueness (δ) set at the modest level of 0. in the objective function

$$\sum_{p < q=1}^{q=m} \left(\sum_{j=1}^{j=n} a_{jp}^2 \cdot \sum_{j=1}^{j=n} a_{jq}^2 - \frac{\delta}{n} \sum_{j=1}^{j=n} a_{jp}^2 \sum_{j=1}^{j=n} a_{jq}^2 \right)$$

where m = number of common factors, n = the number of variables, a_{ij} = the factor loadings, q = a counter for the common factors and p is some common factor.

***Loadings $> |0.45|$

Note: In the factor correlation matrix for the oblique rotation, three coefficients are marginally significant at the .05 level: between factors 1 and 3, and factors 3 and 11.

Factor 3: Suburbanization

Factor 4: Extension of the Urban Core: The Renewal Process

Factor 5: Open Space (Public land) Conversion

Factor 6: Infrastructure and Utilities

Factor 7: Commercial-Industrial Change

cluster of uses arises not simply through their coincident location on the urban margin, but also through their proportionally uniform consumption of vacant land.⁸

Factor 2 is somewhat more complex, in part because of the negative sign on commercial offices, yet it essentially reflects the reuse of urban land. Detailed inspection of the changes in each area indicates that this factor not only picks out redevelopment within the downtown core but emphasizes the extension of the fringe of the core into surrounding zones. In this fringe old and generally low-density office structures, as well as row housing, have been replaced through redevelopment by government office and hospital use and, particularly by parking lots.⁹ This redevelopment process is now the subject of widespread concern in Toronto and many other cities. Ironically, perhaps, most theoretical models either ignore or underplay the importance of the reuse of urban land, through on-going renewal processes, or they assume a totally elastic supply of land and building space.

Factor 3 represents a somewhat unusual result but should not be unexpected given the extensive areas of our cities which are in public uses, particularly open space and recreational uses. This dimension, labelled public land conversion, merges the reduction in agricultural land and land in private open-space use with increases in public parks and open space. In most instances these areas are well removed from the developing urban fringe characterized by vacant land holdings, but there are also numerous examples scattered throughout the built-up urban area.

Subsequent factors represent smaller and more localized clusters of use changes. Factor 4 describes the expansion (or decline) of public utility systems and rather surprisingly, the reuse of some of the extensive land holdings of the powerful electricity commission. This requires further investigation. Factor 5 identifies two polarized patterns of change. The first is the decline of selected commercial and industrial areas in the inner city, and their conversion to storage uses or into the vacant category. The second is the growth of retail, highway-oriented automobile and industrial uses located largely, but not exclusively, in suburban areas. Factor 6 in turn describes a more specialized component of change, grouping high density apartments and hotels, in juxtaposition to single-family uses. The remaining factors are of lesser importance, and their interpretation is increasingly uncertain. They were not used in subsequent analyses.

CORRELATES OF CHANGE

Even this cursory description of an enormous set of descriptive output affirms the obvious complexity of urban land use change. It also raises a number of intriguing research questions. In addition, the factor structure, while intuitively reasonable, is nonetheless somewhat weak and unstable. More critically, there is no way to differentiate between the importance of the components in terms of their relevance to the identification of processes of change.

At this stage one can legitimately ask the question: what factors account for different kinds and rates of land use change across the urban area as reflected in these composite factors? How do these differ from traditional explanations of land use change derived from theoretical models or planning exercises? What are the differences between spatial components? A previous analysis attempted preliminary answers to these questions, with the aid of discriminant and step-wise multiple regression.¹⁰ Initially a set of predictor variables was established to account for spatial variations in land use change within and between census tracts (or zones). Similar equations were replicated for both aggregate land use change and for the factor scores and then each analysis was allowed to select the best-fit variables. This paper employs a modest extension to that comparative evaluation with additional predictor variables and revisions to the procedure of variable selection.¹¹

To reiterate, in the previous study it was hypothesized that inter-zonal variations in the rate of land use change were a function of the following attributes of each area:

- 1) available vacant land for new development (% area vacant)
- 2) the density of existing development in each area
- 3) the relative accessibility of each area or zone with respect to the city centre (CBD) and the geographic centre of population, measured by linear and travel time distances and by immediate proximity to public transit (subway stations) systems and freeway interchanges;
- 4) the geographic distribution and density of employment, by industrial type, by place of work;
- 5) the composition, character, quality and value of the existing building stock;

- 6) the relative prior stability of each area, measured in terms of previous residential turnover rates.

Missing from this list are at least four critical sets of variables: behavioral attributes of developers and other agents of change, land costs, agglomeration benefits, and the imprint of zoning and development controls. Comprehensive data do not exist for any of these though it was possible to obtain some rough approximations for two of the four. Land costs estimates were obtained through industrial and real estate land price surveys. Zoning, it may be argued, is largely irrelevant at this aggregate scale. However, a crude measure of the potential for change is possible through sampling the amount of vacant land zoned for high-density development and industrial uses. A survey of developer behavior is reported elsewhere (Bourne, 1976).

The Predictor Variables

Estimates for the extended set of 41 variables were constructed for both census tracts (n=297) and equal population zones (n=62), as defined earlier, and converted to common logarithms (Table 3). Note that the variables are descriptive of the area (or zones) prior to the period of study (i.e. before 1963) whenever possible. Most therefore derive from the 1956 and 1961 censuses or from special tabulations carried out for 1963 (for land use) or 1964 (travel times, employment), and analyses based on these data (Harper, 1973; MacKinnon and Lau, 1973). More recent data are available in nearly all cases (i.e. from the 1971 Census), but to include such measures in a regression format would be to explain land use changes in terms of itself. At a later date, with the land use file up-dated to 1976 we expect to revise the analysis using 1971 census and related variables. Finally,

TABLE 3

HYPOTHESIZED INDEPENDENT VARIABLES FOR
LAND USE CHANGE ANALYSIS, 62 ZONE ANALYSIS

Variable No.	Code	Variable Description (date)
Land Availability:		
1	% Vac	% of total area vacant (1963)
Size and Existing Density:		
2	Area	Total area of tract (zone)
3	PDens	Population density (1961)
4	ΔPDens	Change in population density (1956-61)
Accessibility:		
5	Dist	Linear distance to C.B.D. (Queen-Yonge)
6	DPC	Linear distance to geographic population centre
7	TCar1	Travel time by car to C.B.D. (1964)
8	TCar2	Travel time by car to population centre (1964)
9	Tpt1	Travel time by public transit to C.B.D. (1964)
10	Tpt2	Travel time by public transit to population centre (1964)
11	TTC	Proximity to public transit line (1 yes; 0 no)
12	Free	Proximity to freeway interchange (1 yes; 0 no)
Employment Potential and Employment Density (1964):		
13	Pemp	Employment density in primary industry
14	Memp	Employment density in manufacturing
15	Cemp	Employment density in construction
16	Temp	Employment density in transportation
17	Wemp	Employment density in wholesaling
18	Remp	Employment density in retail
19	Femp	Employment density in finance, insurance and real estate
20	Psemp	Employment density in personal services
21	Gemp	Employment density in community and government services
22	Tpop	Employment potential
Type and Quality of Building Stock (1961, 1966)		
23	%Crd	% dwellings crowded
24	%00	% dwellings owner-occupied
25	%Ten	% dwellings tenant occupied
26	%B20	% dwellings built before 1920
27	%B45	% dwellings built after 1945
28	%NMR	% dwellings needing major repair
29	%Sdet	% dwellings single-detached
30	%Apts	% dwellings apartments and flats
31	NDW	Total number of dwellings

Table 3 (cont'd)

Neighborhood Turnover (1956-61)

32	Occ<1	% dwellings occupied <1 year
33	Occ1-2	% dwellings occupied 1-2 years
34	Occ3-5	% dwellings occupied 3-5 years
35	Occ6-10	% dwellings occupied 6-10 years
36	Occ 10	% dwellings occupied >10 year

Land and Housing Values

37	LVal	Average asking price (acre zoned industrial land)
38	HVal	Median house value
39	Rent	Average apartment rent

Institutional Constraints

40	ZonP	Acres of available vacant land, zoned high density
41	ZonI	Acres of available vacant land, zoned industrial

Sources: Varied, or estimated by research staff.

Note: Those variables obtained by aggregation of census tract data into the 62 zones are weighted averages or percentages.

there is obviously a considerable degree of redundancy in the list of variables in Table 3 which must be eliminated in preliminary screening techniques and by the step-wise regression procedure itself.

These predictor variables will behave in very different ways depending on which measure of change is introduced as the dependent variable. These hypotheses are set out in Table 4 for three dimensions of change. Further complexity arises because the factor structure incorporates both the conversion of raw land on the urban periphery and the reuse of already developed land within the urban area. These two dominant processes, clearly reflected in the preceding factor structure, are seldom combined in contemporary theoretical models. Yet redevelopment and urban extension are clearly and intimately related.

One obvious implication of incorporating redevelopment into any subsequent model is that the convenient limits on new growth provided by the geographic size of an area and its distance from the CBD are effectively removed. Through reuse and redevelopment, densities for any specific use in each area could be continuously increased over time or land uses could continue to change without a change in density.

With these differences in mind it would make little sense to examine only aggregate rates of change. One would expect, for example, that distance to the C.B.D. would show a positive association with aggregate land use change, a negative association with the renewal process and no association with infrastructure change. Therefore, regression estimates were derived for nine different dependent variables, beginning

TABLE 4

HYPOTHESIZED SIGNS OF PREDICTOR VARIABLES
WITH COMPONENTS OF LAND USE CHANGE

Variables*	Aggregate	Suburbanization	Renewal
	Model A H_o	Model E H_o	Model F H_o
1,2	$b > 0$	$b > 0$	$b < 0$
3	$b < 0$	$b < 0$	$b > 0$
5-12	$b > 0$	$b > 0$	$b < 0$
13-21	$b < 0$	$b < 0$	$b > 0$
22	$b < 0$	$b < 0$	$b < 0$
23,25,26,28,30	$b < 0$	$b < 0$	$b > 0$
24,27,29,31	$b > 0$	$b > 0$	$b < 0$
32-34	$b > 0$	$b > 0$	$b < 0$
35,36	$b < 0$	$b < 0$	$b > 0$
37-39	$b < 0$	$b < 0$	$b > 0$
40,41	$b > 0$	$b > 0$	$b > 0$

*See Table 3 for descriptions

with net total (aggregate) change and then disaggregating for each of the major factor scores. In each case, the set of independent variables selected also varied widely. The different formulations are given in Table 5. The resulting coefficients for the factor score regressions, however, can only be interpreted in broad conceptual terms because they are artificial constructs of the original variables.

Regression Results

As most of the analytical results are presented elsewhere (Bourne and Griffith, 1975; Bourne, 1976), the discussion can concentrate on the implications of the regression results for theories of urban structure and land use and on the prospects for further research.

Generally, the regression results again proved to be intuitively plausible, but highly unstable (Table 6). Nor did they support the predictions of existing theory. The equations showed wide variations between differing measures of land use change and different scales of spatial aggregation. Although levels of variance explained (R^2) and their respective F values were high for many analyses, they shifted dramatically for different sets of independent variables.

As expected, the results improved in terms of explanatory power, moving from census tracts to the analyses based on fewer spatial zones (n=62). This improvement was not consistent however among the disaggregated regressions. Clearly the conversion processes identified above have different spatial resolutions and dissimilar properties of internal homogeneity. Some differences would be expected, since variance reduction

TABLE 5

ALTERNATIVE ANALYSES OF LAND USE CHANGE

Model Code	Dependent Variables	No. of Zones/Tracts	No. of Predictor Variables Entered	No. of Significant Variables
A	Net aggregate change	62	41	6
B	Net aggregate change	297	41	9
C	Net aggregate change	62	8	5
D	Net aggregate change	297	8	4
E	Component 1 factor scores (suburbanization)	62	41	7
F	Component 2 factor scores (core area extension)	62	41	4
G	Component 3 factor scores (public land conversion)	62	38	4
H	Component 5 factor scores (commercial-industrial)	62	38	4
I	Factor 6 scores (high density hotels, apartments)	62	36	4

Notes: Factor 4, titled change in public utilities, is not included here because of its unique spatial geometry and limited spatial extent.

: Models B, C, D are not reported here.

is dependent on the number of observations, but this difference is so large as to suggest that the 62 zone aggregation effectively obscures much of the complexity in land use change evident at the census tract level. The R^2 values were also higher for overall aggregate land use change than for all but one of the regressions based on factor scores, the core area extension (or renewal) factor. In other words the more localized the change the less predictable is the spatial pattern, at least with variables such as those used here which are descriptive of the entire urban area.

The variables selected by the step-wise procedure in both aggregate models are generally similar. They emphasize the importance of variations in available vacant land, in employment densities, previous residential turnover rates, and distance from the C.B.D. The most powerful variable is the % vacant land measure. Distance from the C.B.D. is positively associated with the rate of land use change, but only marginally so. In fact, access to employment (which is widely distributed within the metropolitan area) is a better predictor of change.¹² Moreover, since each of the employment location variables has a very different spatial frequency distribution, we would expect each to behave differently with respect to rates of land use change.

Further, the historical continuity of urban development, which is generally ignored in theoretical models, is emphasized here by the importance attached to variables measuring the imprint of previous patterns of change. Land use conversion rates are negatively correlated with areas of prior stability (% occupancy > 10 years) and positively

correlated with those showing predominantly short-term occupancy patterns (% occupancy 1-2 years). The hypothesized relationships with the geographic size of area and existing development densities also hold: the rate of change is higher in larger zones and decreases as the level of development (population and employment) density increases. Both of these relationships reflect the higher growth rates of suburban areas, with size of area being more important for census tracts than for 62 zones and the reverse holding for development density. Finally, a negative relationship with % tenant occupied housing simply relates new growth on the suburban margin to the relative dominance of owner-occupied housing in those areas during the study period. This situation changed in the latter part of the period, with the shift to rental construction in suburban areas. This shift no doubt reduced the strength of the relationship with the tenancy variable.

The greatest variability, of course, occurs when comparing the step-wise equations for aggregate change and those for each of the disaggregated factor score equations. It may be argued that most theoretical land use models ignore everything that happens in the land market between the city center and the periphery. They are in fact models of the extension of the urban fringe and thus of the density of population only between the center and periphery (Richardson, 1977).

This emphasis is not surprising given the complexity and apparent uniqueness of the variables selected by the disaggregated step-wise regression equations in this study. Only the suburbanization equation in any way resembles the aggregate change equation, and that largely through the dominant position in the two regressions of the %

vacant land variable. The other variable sets are relatively unique. Part of this uniqueness is of course forced by the particular set of input variables employed, but in larger part it reflects the complex nature of the urban landscape and the processes operating on that landscape, and the different spatial frequencies of these processes.

For the suburbanization component (factor 1) the % vacant land variable again dominates, but with a much reduced coefficient. This difference reflects the effect on redevelopment patterns of the availability of vacant parcels scattered throughout the urban area. The implied process of land conversion is essentially the same in both the aggregate and the suburban cases, but in the former it incorporates the renewal process. The environment in which the conversion takes place is different from that on the periphery. Other significant variables include length of occupancy (negative with % 6-10 years and positive with % 1-2 years), the geographic size of the area ($b > 0$), the median value of housing ($b > 0$), and % apartments ($b < 0$). All of the signs are in the expected direction, with only two marginal exceptions.

What is perhaps most interesting here is not what is in the equations but rather what is missing. Distance from the C.B.D., the underlying spatial parameter of classical land use models, does not appear. Nor do the other accessibility measures, or measures of zoning or land cost. The reason for the absence of distance and accessibility measures is that suburbanization, when defined as a process of land use conversion, is discontinuous in space and time. It occurs, over any given interval of

TABLE 6

RESULTS OF REGRESSION ANALYSIS: AGGREGATE LAND USE CHANGE AND FACTOR SCORES, 62 ZONES*

Model	Dependent Variable	Constant Term	Predictor Variables and Coefficients**						R ²	F Value
A	Aggregate Change		% Vac. Land	% Occ. 1-2 Yrs.	Femp Dens.	Distance to CBD	ZonI	% Tenant		
		5.129	.412 (0.34)	.332 (.062)	.212 (.065)	.059 (0.14)	.121 (.052)	-.09853 (.03596)	.869	68.89
E	Suburbanization Factor 1 Scores		% Vac. Land	Area	% Occ. 6-10 Yrs.	Median Value	% Apt.	% Occ. 1-2 Yrs.		
		-0.271	.045 (.010)	.002 (.001)	-.042 (.012)	.005 (.002)	-.019 (.006)	.036 (.014)	.675	20.17
F	Renewal Factor 2 Scores		Femp Dens.	MEMP Dens.	LVAL	% Apts.				
		-0.061	.110 (.006)	.046 (.009)	-.014 (.005)	-.010 (.003)			.875	147.37
G	Conversion Factor 3 Scores		AREA	% Occ. >10 Yrs.	PDens	% Occ. 6-10 Yrs.				
		-0.889	.003 (.001)	-0.25 (.009)	-.008 (.003)	-.019 (.010)			.543	23.11
H	Commercial/Industrial Factor 5 Scores		% Built >1945	% Occ. 3-5 Yrs.	% Occ. 6-10 Yrs.	ZonI				
		1.820	-.009 (.004)	-.031 (.015)	-.028 (.013)	-.011 (.005)			.471	17.22
I	High Density/Apts. Factor 6 Scores		% Occ. <1 Yr.	% Crd. Dwlg.	Median Value	TCAR2 to CPop.				
		1.758	.065 (0.15)	-.063 (0.17)	-.0008 (.0002)	-.034 (.016)			.325	8.53

*Figures in parentheses are standard errors of individual regression coefficients.

**See Table 2 for codes and explanations.

time, of particular locations in a broad ring around the edge of the built-up area, but not in all such areas. For any other period of time the locations of most rapid change would again be different, although perhaps still within the same distance band outward from the city center. In addition, suburbanization is not a simple and continuously increasing function of distance from the center. Richardson (1975), among others, has noted the discontinuous nature of density measures of urban spatial structure.

The other equations are equally complex and divergent, although all but the core area (renewal) factor include one or other of the occupancy variables. Again these variables are designed to act as surrogates for previous rates of land use change. To the extent that this proxy role is appropriate, occupancy change is a powerful predictor.

→ The regression for the renewal factor produces the highest R^2 (0.87) and has the most succinct variable selection, but it is somewhat disappointing. Previous employment concentrations, notably in finance and insurance (Femp) sector, are strongly and positively correlated with subsequent rate of land use development, but this rate in turn is inversely related to existing apartment concentrations (% apt.) and to estimated land values. These results may appear contradictory, but they are not in terms of the measurement units employed here. The Femp variable emphasizes the expansion of the core area, while the land cost variable has a more complex spatial geometry. Apartment development, in contrast to our theoretical expectations is more closely associated with environmental attractiveness than access to employment. On the other hand, in accounting for the renewal component of land use change the prior exist-

ence of office concentrations in the central core, and of vacant land on its fringe, as well as at selected outlying locations, renders the high R^2 result intuitively obvious.

Interpretation of the other equations is at this stage somewhat more tenuous. Variations in the rate of conversion of low-density land uses into public open space use are shown to be positively related to the size of the geographic area, and negatively to measures of residential stability (occupancy 6>10 years and >10 years); areas which presumably have also been built-up for some time, and population density. Interestingly, none of the accessibility variables, nor the zoning or land value variables emerge as significant predictors.

The commercial/industrial (factor) scores show a direct association, despite the signs of the coefficients (the original factor loadings were all negative) with age of the housing stock and residential turnover rates. As many of these changes represent commercial and industrial decline in older built-up central city and inner suburban areas these relationships appear reasonable. Ironically, this decline is also positively associated with variations in available land zoned for industrial use.

The final equation, representing the growth of high-density apartment and hotel development, is the weakest equation of the set ($R^2 = 0.33$). Such developments show the expected positive relationship with previous high occupancy turnover rates and weak but significant negative relationships with the quality of the built environment (% crowded dwellings),

median value of housing and marginally, with travel time to the geographic center of the metropolitan population.

Again these relationships are plausible in light of Toronto's patterns of apartment construction and redevelopment prior to the start of the study period (1963). At that time, apartments, were largely concentrated in the northern sector outward from the central core into the older suburbs. Since then they have become much more widely distributed but with a marked polarization between newer suburban areas (particularly along the freeway by-passes) and areas near the central core or subway stations in the central city. Apartment development, and redevelopment, have tended to concentrate in below average quality (and price) areas but not consistently so. They clearly avoid areas of the lowest quality housing. It is through this polarized spatial pattern that the covariation with hotel construction emerges.

The pattern of apartment construction has a number of other important implications in terms of the empirical validity of land use theory. Although evidence additional to the above is clearly necessary to draw any firm conclusions, the regression results do indicate that apartment development in the 1960's introduced a new and different dimension to the spatial patterning of residential land uses, rents and population densities. High-density apartments in the suburban fringe increased dramatically during the study period. They show no significant correlation with distance from the city center, the existing density of development, or access to employment at least not with these admittedly

crude indices of zoning or land value. Other studies have also indicated that the rent (cash rent) profile for these apartments is surprising uniform across the metropolitan area. Although, when the quality of local services is added in the high-density rent profile becomes somewhat more regular, it is nonetheless a major departure from what theory would lead us to expect.

Many of these relationships, of course, change in direction as well as degree when a more micro level of analysis is employed. Rent levels, zoning restrictions, land costs, and environmental quality do emerge as more significant factors in the land use conversion process when individual sites or small aggregations of sites are the basis of measurement (Bourne, 1976). This is subject of on-going parallel research.

REGIONALIZATION OF CHANGE

What broad form of spatial patterning emerges from this reconstructed typology of urban land use change? Is it possible to construct composite zones showing similar rates and kinds of land conversion? Is the concentric zonation concept inherent in the theory of ecological succession reflected in patterns of land use change?

The simple and direct answer is no. A series of regionalization procedures were undertaken, using Ward's traditional grouping algorithm, applied to varying sets of factor scores from the above analysis. They also produced highly variable and unstable groupings, for both the census tract and 62-zone grid systems. In fact, without a contiguity constraint the grouping procedure produced spatially discontinuous and essentially

isolated regions. There was certainly a less distinctive spatial patterning than might have been expected. With a contiguity constraint the results were more orderly, but not necessarily more plausible.

One illustrative example of the output of the grouping (unconstrained) is given in Figure 8, for the 62-zone level and using the 6 largest factors from the oblique principal components analysis. Six multizone groups emerged, along with 17 single-member groups. From the multi-member groups four stand out: the central core (zones 31, 32); rapidly growing zones on the suburban fringe (1, 6, 7); selected stable inner suburban areas (13, 28, 39, 43); and a broad band of zones characterized by relatively slow but mixed residential-nonresidential land use changes.

This result in one sense is consistent with the flavor of arguments in previous sections. Land use change is far too complex and discontinuous to submit to simple uni-dimensional spatial models. By forcing contiguity the researcher misses the obvious fact that similar land conversion processes may be operating at very different locations within the urban area and that similar and proximate areas do not necessarily share similar histories of land use change at any given point in time.

Summary

What conclusion can be drawn at this stage in the sequence of analyses in Figure 1? Do we have the beginnings of a more solid empirical base for theory and for formulating operational planning models? Or do we have only a plethora of inconsistent facts and statistics whose relationship to theory is at best marginal and at worst inconsequential? It is not sufficient to argue that the spatial scales of interest in theory and in empirical analyses such as the above are simply different. They must be reconcilable at some level of generalization.

Figure 8: Regionalization of Land Use Change (unconstrained).

The answer of course depends on how much further we can extend the data base and the analysis. In the following section of this paper some of the current extensions under review are briefly discussed and future possibilities are suggested.

EXTENSIONS TO MICRO-LEVEL CONVERSION ANALYSES

The highly aggregated data employed in the previous analyses, based on changes in within-zone land use homogeneity, tell us very little about the actual conversion of land uses involved in urban structural change. Although, in any one zone office land use, for example, may expand (or decline) relative to other uses such as industrial, we do not know what activities or uses were actually involved in the change. That is, we can infer but we cannot measure whether one particular use physically replaced another.

One logical extension of this empirical analysis, as outlined in Figure 1, is to link aggregate spatial changes with data on the micro-level conversion process within each area or zone. Initially we can draw on another previously compiled and analyzed data set on land use changes in Toronto. In this case we employ the methodology of transition matrices to describe the conversion process. Since this type of analysis is sufficiently well known the methodology need not be repeated here.¹³

Unfortunately such data are available at present only for the City of Toronto, and on a comprehensive basis from 1952 through 1967 (through 1971 on a sample basis). Nevertheless, this area approximates the pre-

war built-up area (ca 1946), and thus land use change will capture most of what has been called above the renewal process. More recent data are available for the central (or core) area, and these currently are being employed as a case study.

The role of current policy problems shaped the form of this particular empirical enquiry more than the limitations of theory. The preceding aggregate analyses are obviously of little value in attempting to answer questions regarding the impact of different policy options except at the extremely generalized level of long-term equilibrium densities. What, for example, are the land use effects of altering the densities at which urban development may take place? What is the effect of the location of a new transportation facility on land use conversion? What, specifically, are the structural effects of density limits, down-zoning, employment decentralization policies, and of the attempt to encourage a greater mixture of land uses at the local scale? The latter were in fact questions asked by planners with little more than the above described data bases as input.

The Transition Matrices

Parcel-by-parcel transition matrices of land use conversion had previously been developed for each census tract and were reaggregated here for 32 of the 62-zones lying within the central city. The p_{ij} elements in these matrices represent the maximum likelihood estimates that a property of use i will be converted to use j in each of n zones, estimated over three five-year periods. One of these matrices, for the downtown or central core area, is given in Table 7. ¹⁴

TABLE 7

LAND USE CONVERSION PROBABILITIES: CENTRAL CORE AREA,
10 USE CATEGORIES

1962 (Existing) Use	1971 New Use									
	1	2	3	4	5	6	7	8	9	10
1 Low Density Residential	.00	.05	.21	.03	.01	.57	.05	.00	.00	.08
2 High Density Residential	.00	.00	.16	.02	.08	.50	.09	.00	.00	.15
3 Office Commercial	.00	.02	.39	.02	.03	.23	.00	.00	.00	.31
4 General Commercial	.00	.01	.21	.08	.01	.59	.00	.01	.00	.09
5 Automobile Commercial	.00	.00	.35	.00	.11	.17	.06	.00	.10	.21
6 Parking Lots and Structures	.03	.12	.32	.04	.03	.08	.02	.00	.15	.21
7 Warehousing and Storage	.00	.00	.22	.02	.00	.45	.15	.00	.00	.16
8 Industry	.00	.00	.17	.05	.02	.32	.09	.15	.05	.15
9 Transportation & Utilities	.00	.00	.00	.00	.05	.61	.23	.00	.00	.11
10 Vacant	.01	.05	.20	.02	.01	.62	.03	.05	.00	.01

Note: $\sum_{j=1}^{10} P_{ij} = 1.00$

Aside from the peculiarities of the coefficients in Table 7, which in themselves offer a useful device for monitoring change, how can such matrices be used? And how might they be linked to the analyses reported above?

Two different applications of these matrices have been undertaken. One considers the matrices to be unconstrained Markov chain processes, to which specific policy changes are introduced. Under conventional assumptions of stationarity and transformability, the matrices were simulated with a number of stated policy restrictions: such as down-zoning of high-density residential and office development, restrictions on further parking uses, and increases in the land area available for industrial uses. By altering the transition probabilities accordingly, we can estimate, albeit crudely, the effects of policy constraints on the rate and character of land use conversion in the central core.

An alternative approach downplays the between-use conversion basis of the first approach and concentrates strictly on the development "potential" of each property or site in the central core as allowed under current zoning density bylaws. The rows and columns of the matrices represent the proportion of allowable density on each site. The p_{ij} 's in the transition matrices then measure the probability that a site currently built to a density of X-times coverage will be redeveloped to the Z-times coverage allowed under current or future density restrictions. Unless $X < Z$ no development is permitted in the short-term

research model, although in a longer-term model Z itself could become a random variable subject to exogeneously-given probabilities.

⇒ Essentially this approach represents a variation of the space-packing problem; that is, how much development will occur in the central core within the limits provided by current density provisions. These limits act as a ceiling on change while the rate at which, over time, development converges on those ceilings, can be estimated from past rates of change or from an exogeneously given theoretical arguments such as those of capital theory or risk aversion (Clapp, 1977). Such a model has been developed for the City of Toronto by Nowlan (1976) with considerable success.

Although the logistics of such analyses are indeed cumbersome, and the theoretical rationale somewhat confused, there is scope here for useful policy-relevant research. A readily available property-based information file on a real-time basis is a first prerequisite. A second prerequisite involves the further clarification and specification of the relationships between easily observed macro-level indices of urban structure and micro-level processes of change.

How this link between macro and micro land use changes might best be achieved is open to debate. At this stage all that has been attempted is to employ regionalizations of the principal components output as an alternative basis for defining micro-level land use conversion matrices. Conversely, these matrices can be used as tests of the homogeneity of change processes operating within each of the aggregate regions. More

formally, the conversion matrices themselves can be made functions of the aggregate directions of change as reflected in the relative weights attached to each of the principal components. Ideally this relationship should be recursive. That is, not only will the importance of the suburbanization process, relative to renewal within the built-up area alter the nature of the micro-level transition matrices, but the ease (in cost or policy terms) of conversion among individual types of use (i.e. redevelopment, townhousing) will also shape overall patterns of change.

In this study we have abstracted from the context of overall growth rates in the urban area by considering only differential within-zone changes in land use homogeneity and in property conversion. This context could usefully be added. To date, however, no operational and dynamic models of metropolitan Toronto's space economy or demographic profile exist from which estimates of the rate of change could be derived.

CONCLUSIONS

This paper has reviewed a few examples of an empirically-based approach to research in urban land use. The discussion was set within a context of the complexity of urban structure and of the limitations of both theory and current empirical research to encompass that complexity.¹⁵ Although the analyses reported to date do not go far in providing a sounder empirical base for either theory or applied land use models, they do raise a number of important questions and suggestions for further research.

Perhaps the most useful result is simply to emphasize some of the elements which must be built into any extensions to dynamic models of urban land use. These include:

- i) consideration of the importance of differences in the spatial scale of analysis in determining which relationships emerge as significant predictors of change
- ii) the existence of several processes of structural change, each with its own spatial geometry and its own predictor variables
- iii) multiple core areas or nuclei around which patterns of land use change and interaction are organized
- iv) the highly variable spatial frequencies of different land use types
- v) the historical sequencing of land use and structural change, and the effects of very different conditions prevailing during the period of time over which change is measured
- vi) a specific temporal dimension which recognizes that only certain areas (and properties) are available for development (or redevelopment) at any given point in time.
- vii) the differential imprint of public policy controls between aggregate and micro levels of analyses.

Perhaps none of these elements are new, but taken together they seem to offer a promising set of guidelines for subsequent research.

Obviously we cannot expect theoretical models to replicate the real world in all its complexity, or even to come close to doing so. But it is possible to argue that too few of our theories of urban structure have been empirically tested, particularly with recent data. Given the rapidity of change in our cities this deficiency renders many such theories increasingly inappropriate if not misleading. A continuous monitoring of the complex land use systems is clearly in order.

Footnotes

1. These data were made available by the Research Division of the Metropolitan Toronto Planning Board.
2. A similar data set has been constructed for selected areas on the fringe of Toronto, which could be integrated at a later stage (see Martin, 1977).
3. A recent extension of this methodology is outlined in a paper by Robinson (1977).
4. As examples applied to policy initiatives in Toronto see Bourne (1976) and Nowlan (1977).
5. A 59-zone grid of approximately equal area zones was analyzed but is not discussed here.
6. Tests of congruence between the factor scores were undertaken between all of the factor structures but are not reproduced here.
7. For most of the analyses the BMDx72 program was used, with unities in the main diagonal of the correlation matrices, with both orthogonal and oblimin rotations to achieve simple structure. For the oblimin solutions the SPSS statistical package was used (see Bourne and Griffith, 1975).
8. In this data set vacant land is differentiated from agricultural land through aerial photographs, with the latter defined as showing some evidence of active cultivation.
9. To a considerable extent these parking areas represent temporary land uses between demolition and redevelopment. Many of these areas, however, are not redeveloped for some time, if at all, as the transition matrices developed in the following section of the paper demonstrate.
10. The BMD02R multiple regression step-wise program was employed. The variable selected for inclusion at each step is that with the largest F value to enter. In most of the analyses the F values for inclusion were .01, for deletion .005, with a tolerance level of .001.
11. With a large set of predictor variables, many of which are highly collinear, regression results can be highly unstable. Two approaches to counter this instability were attempted. First, the regression analyses were repeated with a much smaller set (8) of predictor variables selected from the initial set. Second, successive discriminant analyses were undertaken using all of the original input variables. Neither added substantially to the results.

12. As an indication of the inaccuracy of the standard assumption of a monocentric city with all employment concentrated at the centre, less than 17 percent of total employment in Metropolitan Toronto is in the downtown core and less than 35 percent is in the entire central area planning district.
13. A thorough review of the methodology is provided in Curry and MacKinnon (1974).
14. Note that Table 7 includes only those properties which underwent change. Thus the main diagonal includes those properties which changed physically through redevelopment but which remained in the same general category of land use. In constructing the transition matrices in this way essentially abstracts out the effects of differential rates of change over time in the urban structure as a whole.
15. This criticism is certainly not valid of large-scale models such as the N.B.E.R. urban simulation model (see Ingram, Kain and Girin, 1972). If anything these models have been so elaborate, in an attempt to deal with the complexity of the urban landscape, that they become almost inoperative.

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