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To the Memory of Lu Shaoxiang

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

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Chapter One Introduction

1.1 Rationale

Land use pattern and its change lie at the heart of modern theories of urban spatial structure, as land use deals essentially with the spatial aspects of all human activities on land and the way in which the earth's surface is adapted, or could be adapted, to serve human needs (Best 1981:20). People's print on land is most evident in metropolitan regions, which, in the US case, now house 75% of the whole population with only 1.5% of the country's land[1]. In terms of land use, these are certainly the most complicated areas on earth, as the surface of this small but critical part of the earth is almost completely formed by human activities. As physical expression of human relationships with land, the spatial juxtaposition of different land uses also tells much about the relationships between people. The inquiry into the characteristics of the internal organization of metropolitan land use, however, is not merely an academic matter, observed more than half a decade ago by Homer Hoyt (1939). In the current context of metropolitan growth, the intense policy debates over zoning, growth management, infrastructure investment, environmental preservation, social justice, and life quality improvement all depend upon the forces governing the spatial interrelationship of different types of areas and the past and prospective movements of different types of uses.

While seemingly chaotic to casual observers as to the arrangements of the various human activities on urban land, there are nevertheless plenty detectable regularities to

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[1] The concept of land use should be distinguished from land cover. The two certainly overlap, but the latter often refers to ecological features of the land, while the former emphasizes human activities.

keen readers of the human built environment. Inductive approaches of urban internal spatial structure, as exemplified by the familiar concentric, sectoral and multi-nucleus models, sought to generalize spatial patterns by sorting out the common features of the structures of different cities and abstracting them to a few diagrammatic orders. On the other hand, deductive approaches, pioneered by von Thunen to explain the structure of agricultural land and extended by Alonso in the urban context, attempted to derive simplified but still realistic spatial patterns based on a number of rather simple hypotheses. Inasmuch both approaches offered invaluable insights into the underlying forces of urban structure, realities, as it always turns out, are far more complicated than any models are able to comprehend.

One obvious way to enhance our knowledge on the issue is through the marriage of the two approaches, but this is rarely realized, as evidenced by the scarcity of empirical studies of land use and land use change that link analytical models to observed patterns. This is partly a consequence of the difficulty in dealing with data availability. Despite the fact that the most important job for urban planners is land use planning, they generally have not had a land use map to work with. While there are national census for population, housing, employment, and more recently, transportation behaviors, there have been no consistent national census on land for most countries. Empirical studies of land use are thus made so much harder, and major energy had to be invested in acquiring descriptive features rather than exploring their implications. But the lack of linkage between inductive and deductive approaches is also a result of the methodological difficulty of how to represent space in analytical models of land use. Deductive models commonly represent space by one or more continuous variables, such as travel time to central cities. In reality, many of the spatial factors critical to urban transformation are discrete in nature, divided by sites' physical and topographical delineation, clustering of different neighborhoods, as well as jurisdictional boundaries. Incorporating such discrete factors into analytical models, as required by an empirical study of land use change, presents a considerable difficulty, the solution of which, as suggested in this thesis, requires both technical innovation with regard to spatial representation (GIS in this case) and a modeling framework that link both discrete and continuous spatial factors to analytical models of land use.

1.2 Research Questions and Hypotheses

This dissertation seeks to contribute to our understanding of urban spatial structure by empirically investigating the change of land use in one U.S. metropolitan region, the Boston Metropolitan Region, for selected periods after World War II. The key research question is: *what factors have determined the spatial pattern of land use change in this major US metropolitan region after World War II?* When comparing the models over two time spans in this period, the study tries to answer: *Have these factors changed over time?* In light of policy, *have government policies, in terms of infrastructure/capital investment and land use regulations, had significant impacts on observed land use change?* Finally, with regard to methodology, the study tries to answer: *is the empirical modeling approach used in this inquiry suitable for representing metropolitan land use change process and projecting future urban growth?* Thus the dissertation also focuses on developing a consistent, theory-based modeling framework for land use change.

Land use change in this thesis refers to the transformation of land use *type* from one to another. The reason I choose land use as the object of study is that it offers a spatial representation of human activities, and in this way, it enables us to explore the *competition processes* for land by these different activities. The majority of theoretical and empirical studies of land use, on the other hand, use population (or housing units) and/or employment as indicators of spatial structure. Often they focus on only one type of land use activity -- for example, the use of land by different groups of people for housing. When non-residential land use activity enters, it is generally represented by employment. While this type of analysis offers important insights into the quantitative differentiation of space, qualitative difference is at the same time blurred. The simple fact that land use categories differentiate urban space into discrete units is thereby ignored. The discrete patterns observed in reality are usually difficult -- at least intuitively -- to be represented with smooth, quantitative gradients. The discrete nature of land use dictates that, for each location, generally only one land use type can occupy the site. Therefore, the analysis of the determination of land use types is in essence to understand the competition by different human activities for land.

I focus on land use *change* in a U.S. metropolitan region instead of the pattern of current land stock because the capital for land development is rigid and durable, and urban land development is inherently an evolutionary process. Static theory of economic equilibrium in the tradition of Alonso-Muth-Mills delineates a complete spatial equilibrium between the supply and demand for urban land. But later studies incorporating the facts of durable capital have derived spatial patterns that deviate drastically from the static theories (Miyao 1987). There is important difference in the basic assumptions of durable capital theories of land uses: myopic vs. perfect foresight developer; open city vs. close city; replaceable stock vs. non-replaceable, etc. But all the analyses point out that the temporal dimension is critical in the analysis of spatial structure. In particular, land development is a cumulative process, and the current stock may well be the result of a historical equilibrium rather than a current one. In consequence, to understand the current forces of land use determination, we must look at land use change instead of the existing land use stock. Only for a relatively short period of time may land market be approximated as in equilibrium.

Factors influencing land use change are myriad. This study focuses on the internal structure of metropolitan space and chooses to explore only factors that are spatially differentiated. There are certainly important non-spatial factors that are instrumental in the spatial differentiation of urban process. The transformation of regional industrial structure, for instance, is often the driving force of post-war change of spatial structure for many metropolitan regions. Yet the spatial effect of industrial restructuring is expressed indirectly through spatial means: the change of the relative values of variables such as transportation access, size of educated labor force, local amenities and agglomerative resources, all of which are likely results of the change in industrial structure at the regional level. But it is through these spatial factors that structural forces at a regional level are translated geographically into localities. Important as it is, this study chooses to sidestep the issue of the spatial consequence of region-level forces because this essentially requires cross-regional study. Therefore only factors that are spatially differentiated within a metropolitan region are chosen for hypothesis testing.

Theoretical consideration and data availability prompt this study to include six types of factors, all of which are spatially differentiated, to be tested for their contributions to post-war land use change: initial land use type, transportation accessibility, site-specific characteristics, neighborhood characteristics, spatial relationships between land use categories, and government policies. The following hypotheses, developed after reviewing past theoretical and empirical studies (elaborated in Chapter 2), will be tested with the proposed modeling framework:

- Locational preferences by different land use types are multidimensional, and they differ from each other. Most analyses of land use have stressed the varying preference for access to the central location (CBD) by different land use types, as non-residential urban land often outbid residential use closer to CBD. While this hypothesis is still likely to be valid, there are other dimensions that preferences by different land uses differ, such as site specific characteristics and neighborhood characteristics.
- Non-transportation characteristics, such as neighborhood quality, agglomeration economies and local public goods provisions, are important determinants of land use change. Their relative impact on land use is likely to have increased over time since transportation has been of less importance as a result of the improvement of overall accessibility in a metropolitan region during the post-war period. However, the influence of non-transportation factors does not necessarily obliterate the role of transportation in land use change. Rather, the combination of multiple factors can better explain observed land use change.

- In the context of extensive suburbanization and polycentric metropolitan spatial forms, transportation influences land use in a more sophisticated way. Distance or travel time/cost to CBD, traditionally the quintessential measurement of transportation accessibility of a location, is less important to land use change than other accessibility measures, such as the overall accessibility of the site to all the population and all the employment. Moreover, the importance of such overall accessibility increased over time, while the impact of access to CBD decreased.
- Spatial relationships between different land categories matter in land use change process. Past empirical studies pointed out some aspects of such relationships -- the importance of vacant land availability, for instance. There has, however, never been a systematic exploration of such relationships and they are largely ignored. This study hypothesizes that they are important determinants because of the positive and negative spatial externalities between different land use activities.
- Government also plays a role in land use change process through its activities in land use regulation, taxation and capital investment. Land use regulations influence the direction of land use change for particular sites. Infrastructure investment stimulates land conversion to urban use, but its contribution has decreased.

1.3 Organization of the Dissertation

The thesis is organized in response to the theoretical and empirical inquiries necessary to address the research questions and test the above hypotheses. In Chapter Two, I selectively review the knowledge accumulated thus far about land use and land use change. This includes both theoretical and empirical treatment of the subject, and perspectives from both economic and non-economic theories. The chapter tries to highlight some of the difficulties of the existing approaches and the sources from which this research derived its methodology and developed its hypotheses. Based on the review, in Chapter Three, I theoretically derive the modeling framework used for empirical study, the multinomial logit model for land use change. It emphasizes on how the proposed model structure can be linked to bid-rent theories of land use. It also justifies the explanatory variables to be used in empirical testing and explores the directions of their contributions. Chapter Four presents a detailed descriptive analysis of land use pattern and its change in the study area. It shows how the region looked like with regard to land use patterns, what kind of land use change occurred during the period, where such change took place, as well as anecdotal facts on the forces of the change. The calibration results of the land use change models will be discussed in detail in Chapter Five, which focuses on interpreting the resulting and the change of the factors over time. Chapter Six discusses the implications of these results, the limitations of the current approach, and possible applications of the model in evaluating government policies and simulating future urban development.

Chapter Two Theoretical and Empirical Studies of Land Use Change: A Review of Literature

Since the subject of land use touches the very heart of the built environment and our quality of life, it is no surprise that studies on land use make up a substantial list of literature and, more importantly, they originate from very distinctive perspectives -- sociological, political, economic, geographical, mathematical, ecological, historical, planning, and so on. It is therefore inevitable that any review of the literature on land use and its change has to be eclectic, processing only a subset of the vast volume of scholastic work. This thesis approaches the problem mainly from an economic perspective, thus economic models will be the focus of the review, but some non-economic models, including urban morphology, spatial interaction models, and cellular automata models will also be reviewed since they provide critical theoretical and methodological sources for this study.

2.1 Non-Economic Models

2.1.1 Urban Morphology

Burgess, Hoyt, and Harris and Ullman are perhaps the best-known among earlier inquirers of urban structure and land use pattern. Although their approaches are in many ways unique themselves, they most closely belong to the school of urban morphology, whose studies of urban forms place great emphasis on historical and social factors and cycles of growth and decline. In 1925, Burgess suggested a *concentric zone* model of urban structure. This model, or simplified, idealized representation of reality, was based on Chicago, and was intended to describe the structures of contemporary, rapidly growing industrial cities in North America. The theory has been summarized as follows:

> At the center of these zones lies the *financial and office district*; immediately surrounding this and interpenetrating it is the central retail district where the *large department stores* and *high-grade specialty shops* are found. Clinging close to the skirts of the retail district lies the *wholesale and light manufacturing zone*. Scattered through this zone and surrounding it, *old dilapidated dwellings* form the homes of the lower working classes, hobos, and disreputable characters. Here the *slums* are harbored. Cheap second-hand stores are numerous, and low-priced "men-only" moving-picture and burlesque shows flourish.
>
> In the next zone *heavy manufacturing* may be found, although naturally this use breaks up the uniformity of the pattern to hover along routes of transport. The use characteristic of this district is that of *homes of the respectable working classes*. Apartment houses and tenements of the better grade are common.
>
> Beyond the workingmen's homes lies the "residential" district, a zone in which the *better grade of apartment houses and single-family residences* predominate, and beyond this the commuter's zone of finer houses and larger lots.

The model certainly reminds its reader of Alonso's results, which were derived much later. But Burgess's conclusion is not arrived through the sort of rigorous structural models as Alonso did. Indeed, while transportation is the single most important factor that leads to Alonso's conclusion, Burgess hardly mentioned the importance of transportation at all. Bourne ( ) pointed out that the operating mechanism of the concentric circle model was the growth and radial expansion of the city, with each zone having a tendency to expand outward into the next. Burgess assumed a city with a single center, a heterogeneous population, a mixed commercial and industrial base, as well as economic competition for the highly-valued, severely-limited central space. He explicitly recognized "distorting factors," such as site, situation, natural and artificial barriers, the survival of the earlier use of the district, and so on. But he argued that to the extent of which the spatial structure of a city is determined by radial expansion, the concentric zones of his model will appear. Given the limited data available, the Burgess model was a remarkably astute description of the American city of the time. In general, Burgess was more concerned with portraying the processes of urban expansion in terms of extension, succession, and concentration. He was a sociologist and his model was derived from empirical observations of the way in which the city of Chicago had developed. As such it is a hybrid of idealized land use patterns and urban social structure with a strong emphasis upon residential areas (Kivell 1993).

A second model of the growth and spatial structure of American cities was formulated by Homer Hoyt in 1939 and known as the wedge or *sector theory*. While Burgess's theory deals with both residential and non-residential location patterns, Hoyt's sector theory is primarily concerned with land use patterns resulting from residential development. Hoyt analyzed the distribution of residential neighborhoods of various qualities, as defined by rent levels, and found that they were neither distributed randomly nor in the form of concentric circles. High rental areas, for example, tended to be located in one or more pie-shaped sectors, and did not form a complete circle around the city. Intermediate rental areas normally were sectors adjacent to a high rent area. Furthermore, different types of residential areas usually grew outward along distinct radii, and new growth on the arc of a given sector tended to take on the character of the initial growth in that sector. In summary, Hoyt argued that if one sector of the city first develops as a high, medium, or low rental residential area, it will tend to retain that character for long distances as the sector is extended outward through the process of the city's growth.

Although no geometric pattern can be superimposed upon a city, Hoyt tries to explain the observed sectoral land use change. He suggests that "the movement of the high rent area is in a certain sense the most important because it tends to pull the growth of the entire city in the same direction." With regard to the determination of the position of high and low rent sectors, some generalizations can be made about their location. The area occupied by the highest income families tends to be on high ground, or on a lake, river, or ocean shore, along the fastest existing transportation lines, and close to the country clubs or parks on the periphery. The low income families tend to live in sectors situated farthest from the high rent areas, and are normally located on the least desirable land alongside railroad, industrial, or commercial areas. Rental areas are not static. Occupants of houses in the low rent categories tend to move out in bands from the center of the city, mainly by filtering into the houses left behind by the higher income groups, or in newly constructed shacks on the fringe of the city, usually in the extension of the low rent section. " (Hoyt p117-118).

Hoyt's analysis is also notable for his technique. His basic data are taken from numerous real property surveys, which was disaggregated and can be aggregated according to needs so that "almost any sized area may be selected as a standard unit of measurement." Hoyt's spatial unit of analysis in deriving his residential structure is city block, which is regarded as "a relatively homogeneous and unchanging entity." (p4) The main instrument is the "block data map", which indicates for each block in a city the characteristics as represented by eight data items from real property surveys. Hoyt mapped each of a number of housing characteristics on separate maps. In a way not so much different from the overlay functions in modern GIS, he conducted a manual *overlay* using a series of special transparent maps. By superimposition of maps of such selected and limited factors, the area in which the characteristics overlap can be delineated. The centers of the worst housing conditions are indicated at the points of coincidence of all factors used. Moreover, Hoyt also attempted to find one factor that represents and stands for a whole congeries of other housing factors so that a quick and fairly accurate analysis can be allowed for cities where basic data are lacking. Accordingly, the average rent of homes in a block is selected as an index of those housing factors. The reliability of rents serving in this capacity is established on the basis of relationships between rent and other factors. When addressing the issue of the form of growth of the entire city, Hoyt used *a series of maps* showing the built up (settled) areas of each city so that "the direction of growth and the topography on the shape of the settled area are clearly brought out." Hoyt's technique is therefore pioneering and followed by students of morphological studies of urban form. Their basic tool is the *detailed map* often to the level of site. They emphasized on the *historical evolution* of the urban form, and tried to reach conclusions about the general pattern of urban growth and land use, through synthesis, generalizing on one or numerous cases, and from an integrated, ecological perspective that takes into account both social and economic factors.

A third model, formulated by Harris and Ullman (1945), was less simple and elegant than those of Burgess and Hoyt, but perhaps closer to reality. The *multiple nuclei* *model* recognizes that many cities do not grow outwards only from a single center, but rather absorb other, previously separate nuclei in the course of their growth. Moreover, these nuclei need not be "business" centers. As the city grows, specialized land use develops on separate tracts of land, which are square, rectangular or irregular in shape, nor in the rings and wedges of Burgess and Hoyt. In identifying factors affecting development, the authors paid special tribute to the *interaction between different land use activities*. The factors they considered important include (1) the interdependency of certain types of activities, requiring physical proximity to specialized facilities such as transportation networks or services; (2) the natural clustering tendency of certain types of activities which enhances profitability; (3) the clustering of activities having no particular affinity for each other, but which are nuisances to other uses; (4) the inability of certain activities to afford the high rents or land costs in certain areas of the city. The model is much less specific than the other models, and implicit in it is the view that a simple generalization of urban land use patterns is not possible.

These three models have become so well established in the literature on urban structure that they are normally referred to as "the classical models". Naturally, models which have been around for such a long time will have attracted a wide measure of criticism (Carter 1976; Hallett 1978; Hudson and Rhind 1980), and the evolution of urban land use in the past three decades highlights some of their deficiencies. Some attempt to deal with criticisms of the earlier models can be seen in the development of the later ones, notably the attempt to move away from the assumption of a single, overwhelmingly dominant central area. For all of their shortcomings, however, the models have an enduring quality and they have undoubtedly been fruitful in shaping our understanding of patterns of urban land use and structure.

The three models also have had great impact on British urban geography, and became one of the sources of the school of urban morphology, with Michael Conzen as its most influential member. Conzen's major work and arguably still the most important single contribution to urban morphology in the English language was *Alnwick, Northumberland: a Study in Town-Plan Analysis*, first published in 1960. In this study, Conzen outlined a framework which has become the principles for urban morphology. For the first time, he adopted a thoroughgoing *evolutionary approach* and recognized of individual plots as being the fundamental units of analysis. His study is based on extensively detailed cartographic analysis, using large-scale plans in conjunction with field survey and documentary evidence. In discussing his approach in the Alnwick study Conzen wrote: "An evolutionary approach, tracing existing forms back to the underlying formative processes and interpreting them accordingly, would seem to provide the rational method of analysis." The so-called evolutionary patterns were assembled by utilizing such historical sources as rentals, building plans submitted in connection with applications to build, and large-scale printed and manuscript plans, in association with detailed plot-by-plot and building-by-building field surveys that included the recording of detailed topographical information on large-scale Ordinance Survey Plans (Whiteland). In the end, Conzen's morphology (*townscape*) of a city is a combination of three elements: town plan, pattern of building forms, and pattern of urban land use.

In summary, morphological studies of urban land use patterns relied heavily on cartographic maps of representative cities or towns. This emphasis on maps was strengthened later by detailed examination of plot/parcel level data for the study areas. Thus the authors were particularly space-conscious and they provide detailed insights into the spatial process of urban change. Their approach is also historical, as they try to assemble maps for a sequence of periods for the study region, pay special attention to the change in the built environment, and draw inference about the dynamics of urban spatial structure from the observed historical evolution of the cities. Their reasoning is usually comprehensive, incorporating social, economic, historical, institutional as well as technical factors. Their method is neither quantitative nor deductive. Instead, they rely on generalization from detailed case studies. Such generalization is achieved theoretically by proposing concepts such as concentric, sectoral, urban fallow (Conzen), which are often useful beyond the cases being studied. For many, their analyses are seen as principally descriptive and offer no systematic models of causal relationships and thus cannot be used to determine the effects of system changes on land use patterns. Yet these models have enjoyed lasting impact for the richness of their geographic and historical accounting of the cases, for the insightful, and still largely valid general patterns they articulated, and for the understandings of the dynamics of urban spatial structure they provided through detailed observation.

2.1.2 Spatial Interaction Models

Spatial interaction models offer another perspective to the locational decision for residents and business. Central to spatial interaction models is the concept of *flows* from one location to another. Such flows may include commuting trips, shopping expenditure, industrial inputs and outputs, communications and population migration. By explaining spatial flows according to the characteristics of the origins, the destinations, as well as the "spatial impedance" between two places, spatial interaction models provide a framework in which different forces can be empirically incorporated into explaining residential and business locations. This is accomplished by specifying different attractiveness variables measured for each zone. The flexibility of the model structures allows their wide application for practical planning problems.

The origins of spatial interaction models are the gravity models, which are drawn chiefly from the analogy between Newton's law of planetary motion and human spatial process (Reilly 1931). Gravity models became widely used and abused in the fifties and sixties, and it was not until 1967 that Wilson provided the first theoretically valid derivation of the gravity model from statistical information-minimizing (or entropy-maximizing) principles.

With Wilson's (1967) *entropy-maximization* approach, these models are derived from information-theoretic principles which seek to find the most random predictions of individual choices consistent with observations on the aggregate (macro) or average (mean) states of the entire population of choosers. The derivation is realized by finding the most probable distribution of trips between zones, with some given linear constraints. Using such a framework, Wilson (1970) was able to derive the now familiar "family" of spatial interaction models: unconstrained, production-constrained, attraction-constrained, and doubly constrained. (Alonso (1973) presented a more general formulation of the models). Wilson also derived the *intervening opportunities model* using the same entropy maximizing approach, thus providing a common base for interaction models and intervening opportunities models. Later the general principle of entropy maximization is used for building models for a wide variety of spatial activities (Wilson 1970, Batten and Roy 1982, Erlander and Stewart 1990).

A somewhat different formulation of the problem of travel mode and location decisions is McFadden (1973) and others' work on micro-economic consumer choice among discrete alternatives. This research area stresses the importance of stochastic utility maximization and the use of disaggregate small-sample data in the estimation of choice models via maximum likelihood. Utility has a randomly distributed component. If the distribution is assumed to take one particular form (Genbell Distribution), McFadden shows that the probability function takes the form of a multinomial logit model. Later theoretical development of discrete choice tries to provide alternative interpretation, give more sophisticated treatment of error term, extend the framework to dynamic settings, and present more accurate explanation of choices (see Arcangeli et al 1985, Fisher and Nijkamp 1985, 1987, Horowitz 1991).

There are striking similarities in the mathematical forms of the multinomial logit model and the spatial interaction model. Anas (1983) provides a unifying treatment of the two types of models and proves that the minimum-information and the behavioral discrete choice modeling approaches are identical. "The two paradigms imply mutually consistent and fully equivalent model search and model specification strategies: one is rooted in micro-behavioral postulates, the other in macro-statistical information theory." In spite of this, there are important differences in the way models are specified under these two different paradigms, as model-specification criteria employed differ. The behavioral approach insists on specifying a model consistent with utility theories, and accordingly will leave out variables considered to be irrelevant or without sound theoretical support. On the other hand, information theory *per se* does not have an explicit theory as to what *should* go into a model. But such theory is often implied in their selecting of the explanatory variables, and in their discussion of whether a particular parameter has the correct sign. Historically, there is also difference in the use of data within the two paradigms. While spatial interaction models usually use aggregate data based on some zones, discrete choice models rely on disaggregate data about individual behaviors. But Anas's experiment with Chicago transportation data (Anas 1981) suggested that differences in model specification are much more important than differences in aggregation, at least in their effects on coefficients, elasticities, and marginal rates of substitution.

The wide-spread application of spatial interaction models in transportation studies has also influenced urban modeling, as one of the first urban models, the Lowry model built for Pittsburgh, was built upon a series of spatial interaction models used for the allocation of different types of employment and population within a city. This tradition was certainly well retained, as currently, most of the so-called large scale urban models are formulated based on some types of spatial interaction models (Wegener 1994).

In these large scale models of land use, spatial interaction models by themselves produce estimates of population, households, and employment rather than land use pattern. Land use is derived by translating such population and employment increase into land consumption. This can be done simply by assuming a fixed ratio of land consumption for each type of economic activity -- thus a certain amount of increase in manufacturing jobs will result in a corresponding increase in manufacturing land use.

This approach can be made more sophisticated if the conversion-ratios are empirically calibrated according to current land use and economic situations in the zone -- this approach is used in the land use module (*LANCON*) of the ITLUP model (Putman 1991). Alternatively, in the MEPLAN model (Williams 1994), some pricing mechanisms are built into the land consumption submodule in which prices are adjustable according the imbalance between demand and supply of land. Note that all these models are zone-based: they simulate how much land will be allocated for certain uses within each zone, usually Traffic Analysis Zones (TAZs) or census transts. They are not spatially disaggregated as the particular locations of each land allocation within the zone is not explicitly modeled.

The spatial interaction models have also been formulated to simulate the dynamic process of land use change. The structure is first introduced by Harris and Wilson (1978) for retail floorspace. While in the traditional production-constrained interaction models, retail facilities are only treated as an attractiveness factor, Harris and Wilson considered how such variables will adjust (expand or shrink) according to the scale of patronage, that is, according to the conditions of the flows which are partially determined by the intitial stock. Numerically, they also demonstrated how such non-linear mechanisms will result in very different equilibrium or disequilibrium situations. This "stock approach" under a spatial interaction framework was later extended to other sectors such as agriculture, industry, residence and school (Clarke and Wilson 1985, Bertuglia et al 1990). One interesting aspect of such models is that bifurcation and catastrophe process can be generated through different critical values.

2.1.3 Cellular Automata Models of Land Use Change

In an effort to simulate the dynamic spatial process of land use and urban structure, recently a number of researchers have explored the application of cellular automata framework originally developed in physics into the field of urban modeling. A cellular automaton can be thought of as an array of cells whose states depend on the states of the neighboring cells. More specifically, a cellular automaton consists of three components: the rectangular cell, its neighbors (either right adjacent cells or cells within a certain distance), and a set of transition rules which describe how the state of one cell is stochastically determined by its original state and its neighbors. This framework has become appealing since it is intrinsically spatial and can generate very complex forms by means of very simple rules (Tobler 1979, Couclelis 1985).

While Batty and others (Batty and Longley 1987, Batty and Xie 1994) applied cellular models with two cell states (vacant and occupied) to simulate the growth of built-up areas, White and Engelen (1993) formulated another demonstrative cellular model to generate spatial patterns of land with multiple use types. In particular, their model allows the existence of four states for each cell: vacant, housing, industrial, and commercial. A set of transition rules determine the probability of each cell to change land use type with regard to its neighbors. For example, a vacant cell with commercial cells in immediate vicinity will have a high probability to change to commercial, but if there are commercial cells in more distant cells, the probability decreases. The model developed "is intended to be used to investigate basic questions of urban form rather than to provide realistic simulations of the development of particular cities." (p. 1178). Numerical simulations result in different land use patterns for a hypothesized city with different initial conditions (seeds). Even with the same initial conditions and rules, different patterns will emerge as the transition is a stochastic process with random numbers generated by the computer[2].

Cellular model has been able to capture some of the micro process of land use change and neighborhood effects, in particular the impact of neighboring land uses in the determination of a site's future state. These are notably absent in other land use models. Cellular model is also able to have a finer spatial resolution since, unlike spatial interaction models, it does not depend on an aggregate zonal system. However, at the current stage, the behavioral base of fractal specification is usually weak, with rules of automaton transformation adopted rather discretionarily. It seems a more powerful framework would emerge with some combination of the theoretical strength of economic location theory and the spatial consciousness of the cellular models.

2.2 Economic Location Theories

Economic approaches to land use determination treat land use as a result of rational behaviors of various decision-makers: households, businesses, industry, and public institutions. The theories are built upon basic behavioral assumptions of these players, and the results are derived from conditions of equilibrium.

The concept of location is of central importance in economic study of land. It is a concept that distinguishes urban economics from the "aspatial" body of economics. Land is intimately related to the concept of location because "space" is the most important aspect of the physical characteristics of land (Goldberg and Chinloy 1984). There exist

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[2] Krieger (1991) developed a somewhat similar experimental model in which urban phenomena are accounted for solely through filtering and segmentation processes. Filtering, in Kreiger's model, causes

two long established paradigms to attack the location and spatial problem from an economic perspective. Weberian location theories (Weber 1928) focus on the spatial choice of a *single firm* with reference to predetermined locations of markets for output and input. Locations in Weber's theory differ in their access to input and output resources, and a location decision mainly involves assessing the trade-offs of various transportation costs among input and output elements. Such concern with site choice of individual producers was followed and developed by researches of spatial demand and supply, spatial pricing and output and network location choice models for firms (Beckmann and Thisse 1986).

2.2.1 The Monocentric Model and Bid-Rent Framework

On the other hand, von Thunen (1966, original 1826) and Ricardo (1821) started another theoretical tradition that explicitly treat land as an important input of production, the use of which is determined in part by its location. Richardo is among the earliest to point out rent differentiation of land for agricultural use, but the primary source of such differentiation, according to him, is fertility differentials, or the difference in agricultural land productivity. Von Thunen is the first to develop a land use model based on a *featureless plain*--his isolated state--on which, even without fertility differentials, both land use types and land use intensities vary spatially. He introduced the concept of bidding into land use study, and assumed that the various agricultural land uses around a market place bid for the use of land, and land is assigned to the highest bidder in each case. The rent each crop can bid at each location will be the savings in the transportation

neighboring sites to become more similar over time, segmentation causes them to become dissimilar; both of its product that site affords in contrast with a more distant site. His rigorous economic model explains the existence of concentric agricultural rings around an urban center, with inner rings occupied by crops that can enjoy more cost savings being closer to the center.

Alonso's work (1964), largely regarded as the starting point of modern urban economics (Mills 1987), extended von Thunen's analysis of the agricultural sector into both residential and business location. But perhaps more importantly, Alonso's *method* of studying market equilibrium in a spatial context has since become the standard approach to economic location problems, followed by most later analyses. The critical concept in this approach is *bid-rent curve*, representing the willingness-to-pay by each land user. Although not the first to propose the concept of bid-rent, Alonso injected new analytical power into the notion. Bid-rent curves, in Alonso's framework, served as a unifying measure against which the demand by different activities for land can be compared. This unifying measure is important because the equilibrium conditions for agricultural, residential and business land uses involve very tradeoffs in their objective functions. For agricultural activity, in the simplified case, the tradeoff is solely between land price and the savings in transportation cost; For households, whose objective is assumed to be maximal utility, the tradeoffs involve land cost, commuting cost, as well as individual preference for central location. For business firms, whose objective is to maximize profits, the tradeoffs involve land cost, direct transportation cost, indirect revenue consequences and cost savings consequences. For each of these three agencies, Alonso derived its bid-rent curve. This essentially translates a multidimensional problem

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filtering and segmentation are modeled stochastically.

for each activity (for example, five dimensions in the case of residential use -- utility, land, distance, the composite good, and money) into two dimensions: distance and the cost of land. The presumed bidding process for land dictates that each site goes to the users offering the highest bid. In particular, activities with steeper bid rent curve occupy more central locations. Thus the development of a bid-rent theory of land uses transformed what had previously been regarded as a *discrete* phenomenon of land use to one that could be viewed and modeled as a *continuous* function in space. Alonso's original model is also a monocentric one, as the reference point for all location decisions is a single site, the central business district (CBD). The CBD serves as the sole export point for all metropolitan industrial output, and as the single workplace destination for all intra-regional commuters. The bid-rent curve and related attributes consequently become functions of distance to CBD.

While Alonso worked in a framework where all different agents consume land directly, Muth (1969) and Mills (1967) analyzed a more specific model for *residential* location choice, where land is an intermediate input in the production of housing, which is the final consumption good. Concerned only with residential location patterns, their models deal more with the quantitative aspect of spatial differentiation rather than the discrete nature of land use. By analyzing the utility maximization conditions for households and profit maximization conditions for housing producers, their equilibrium models explain how important spatial characteristics -- housing price, housing consumption, land rent, and population density -- vary over the space (as a function of the distance to CBD). Later development of residential location within the monocentric framework attempts to relax some assumptions by incorporating the factors of income

(Wheaton 1974, 1977, Hartwick et al 1976, Anas and Kim 1992 and Pasha 1992), taste heterogeneity (Anas 1990), decentralized employment around the CBD (Brueckner 1979, White 1988), street configurations (Yinger 1993) and uncertainty (Capozza and Helsley 1990). Most of these works still hold the monocentric assumption, and the resulting patterns vary only with regards to CBD, but more complexities have been added and the strict regularity in the original Alonso-Muth-Mills models often would not hold.

Similar methods of equilibrium analysis are extended to the *business* sectors. Earlier models conclude that farther away from the center, output is produced less capital and labor intensively (Mills 1969). Therefore, if multiple employment sectors exist in a city, the industry with a higher ratio of marginal transport costs to land per unit of output will occupy the inner ring (Miyao 1981: Chapter 1). More realistic assumptions were added to such a model by taking into account an additional suburban export point (White 1976). The result is a "partially segregated" pattern in which production and residence are still located in separate rings, but residential land use can be found in rings between the two export points. The pattern for business and residence becomes more complicated when Mills later discovered that a completely integrated pattern -- one in which production actually intermingles with residences throughout the city -- can emerge under certain assumptions of transport costs (Mills 1970, 1972: Chapter 5). According to the result worked out by Schweizer and Varaiya (1976, 1977), if production techniques are substitutable, the ordering of rings by techniques and commodities produced changes with required output, and techniques employed in inner rings may reappear in distant outer ones. This *"reswitching" property* defies commonly accepted stylized facts such as the decline with distance of capital/land, or output/land ratios.

Although more complicated business and residential land use patterns have been derived with the introduction of more factors into the models, most of the above analyses have the common feature that, following Thunen's and Alonso's tradition, they maintain only one single reference point as a definition of space. The space they analyze is in essence one dimensional.

2.2.2 Dynamic Location Theory

The above models of residential and business land uses are static as they only consider the equilibrium state at which every component achieves its optimal position. Yet in reality disequilibrium may be more often observed than equilibrium. Introducing temporal elements into analytical land use models undoubtedly further complicates model structure, as temporal interdependence has to be imposed on already complex spatial interdependence. One body of researches focuses on the spatial adjustment process in a dynamic setting. Extending Alonso's framework, Wheaton (1979) examines how land use change could occur when competitive bid-rent curves shift in response to changes in transportation costs, wage rates, household incomes, preferences for travel versus housing, and production technologies and productivity levels. Decreases in transportation costs or increases in household incomes will, for example, cause the bid-rent function to be shifted outward, causing discrete changes in the allocation of particular land users to particular sites. Analytical models formulated by Miyao (1975, 1979) confirmed such intuition in the case of residential location.

Theoretical formulation of this fashion treats land use change as a series of successive equilibrium instantaneously determined. The fact that the capital stock is both durable and largely immobile was ignored. Past land use patterns, therefore, play no role in determining present or future patterns. Land use models which do account for capital durability--particularly residential capital--yield significantly different land use outcomes than those generated by the basic Alonso model (Miyao 1987). While housing durability is regarded by Harrison and Kain (1974) as the main factor which can explain much of the cumulative growth process of American cities in the last several decades, Anas (1976, 1978) is among the first to formulate an analytical model of durable residential capital. With the assumptions of myopic expectation (actors expect current variables to remain unchanged in the future) and perfect durable housing (no replacement of existing housing can take place), he derived a sequence of urban residential expansion with use densities *increasing* with distance, a property which contrasts sharply with that of the Alonso-Muth-Mills model. Brueckner's vintage model (1980), on the other hand, assumes that demolition is costless while keeping the assumption of myopic expectations. He concludes that redevelopment takes place if the present value of the expected revenue from continuing to utilize an old building falls below the price of the original land. His numerical simulation suggests a strong tendency toward redevelopment in the inner segment of the city, leading to *discontinuous* decreases in structural and population densities with distance. Wheaton's (1982, 1983) analysis, also assuming myopic expectation, shows that redevelopment tends to yield substantially higher structural and population densities than those in the old surrounding areas. His simulation results indicate generally declining, but often discontinuous density functions with distance.

A second class of urban growth models assume perfect (rather than myopic) foresight, so all decision are made in an inter-temporally optimal manner at the initial time period. Brueckner and Rabenau (1981) investigates a closed city model where an exogenous population change is fully anticipated by developers, and generates a variety of possible land use patterns such as *leap-frog sprawl* and discontinuous density gradients. Wheaton (1982, 1983) proves the possibility of a "reversed" development pattern with urban land development taking place from the urban fringe toward the center. Mills (1981) is one of the very few researchers who examine durable capital for more than one land use type. He shows that the assumption of uncertainty and heterogeneous expectations can yield a spatial intermixing of various kinds of land use and possibly non-use in addition to leap-frog development. All these results deviate significantly from Alonso's original model of urban land use. Taken together, they illustrate the difficulty and complexity of modeling actual land use changes.

2.2.3 Toward Complex Urban Forms

Even under the formulation with durable capital, important aspects of land use determination are still missing. A significant spatial phenomenon in the post war period is the formation of numerous suburban centers (McDonald 1987, Giuliano and Small 1991). Numerous studies have verified that important quantitative characteristics -- rent, housing value, density -- are not only a function of distance to CBD, but also dependent on the accessibility to the subcenters (Griffith 1981, Gordon et al 1986, Heikkila et al 1989, McDonald and McMillen 1990, Dowall and Treffeisen 1991). Theoretical explanation of centers (CBD and subcenters), however, have been rare and inconclusive. According to Helsley and Sullivan (1991), subcenters arise from the tradeoff between external scale economies in production and diseconomies in transportation. Clapp's

(1984) work on endogenous centers provides a potential framework for anticipating where subcenters will be located. Yet due to mathematical complexities, he was only able to demonstrate how the monocentric case can be derived from this general model. Two studies (Ogawa and Fujita 1980, Fujita and Ogawa 1982) analyzed a somewhat simplified model where space is represented with only one dimension by a lone narrow line. They considered the interactions between production and consumption, as well as the agglomerative effects among firms. They pointed out that a rich set of possible equilibrium configurations may result with the model specifications. Of interest are less standard patterns. For example, business and residential activities are integrated at the center, and next to this are pure business districts, followed by pure residential districts. Moreover, the equilibrium conditions are very sensitive: marginal changes in the parameters may result in dramatic (long run) changes of the land use pattern.

Also in question is the assumption that transportation is the sole factor in shaping land use patterns. Skepticism over the central role of transportation in land use determination is highlighted by the debate over "wasteful commuting", a term first provoked by Hamilton to refer to the fact that almost eighty percent of observed commute of a sample of U.S. cities is "wasteful" in the sense that all of this commuting could be eliminated by inducing people to swap either jobs or houses until all commute-reducing swaps have been carried out. He thus concludes that the monocentric model is fundamentally flawed. With a more realistic method for calculating optimal commute according to existing available employment and residential choices, Hamilton (1989), Small and Song (1992), Giuliano and Small (1993) not only confirmed the existence of large amount of wasteful (or excess) commuting, but also rejected *any* model that allocates workers to residences so as to minimize aggregate commuting cost (Small and Song 1992).

It is interesting to note the important improvements made on the original monocentric model during the wasteful commuting debate. Not only is monocentricity abandoned in favor of actual decentralized employment through the calculation method proposed by White, but factors such as actual transportation network, neighborhood and housing characters (Cropper and Gordon 1991), heterogeneous employment and household types (Thurston and Yezer 1991) and two-worker households (Kim 1994) also enter the picture. The inclusion of all these factors *did* succeed in reducing the amount of wasteful commute as a larger proportion of it becomes "rational". However, significant amount of commuting still remains unaccountable even after the inclusion of these factors. These results certainly call for alternative theoretical frameworks that can provide more realistic explanation of residential location process.

The debate over wasteful commuting contributes to the more broad conclusion that transport cost is no longer a key factor in locational decision-making (Giuliano 1989). Empirical analysis by Clark and Burt (1980), for example, implicates that households are indifferent to commute costs until these costs become significantly large: below some commute distance (about three miles) there appears to be no relationship between housing and job locations. Therefore transportation cost may be but one of multiple factors that households consider when choosing residential locations. Moreover, with overall accessibility greatly increased in U.S. metropolitan areas, relative differences in accessibility have declined, and its importance may be decreasing. The failure of neoclassical bid-rent theories to explain commuting patterns prompt researchers to search those factors that de-link transportation and location decisions. Such factors may include: rapid job turnover and high relocation costs, the existence of two-worker households, the increasing significance of non-work trips, the possible overshadowing importance of housing and neighborhood characteristics, racial discrimination, and local public policy such as property tax and zoning controls (Giuliano and Small 1993). The importance of these considerations in residential location choice suggests that, rather than weighing only the tradeoff between transportation cost and housing savings, the model should allow the entrance of much more factors to the tradeoff scheme. In particular, location-specific items are not only housing price and commuting cost. Many other goods, services, and characteristics that were represented in the analytical models as the "composite good" in reality may vary with locations, and must enter the equations representing locational equilibrium.

Similar arguments hold true for non-residential land uses. As suggested by Erickson and Wasylenko (1980), agglomeration economies, labor-force availability, and site availability are all significant variables that affect land use patterns (Erickson and Wasylenko, 1980). In fact, when Alonso was presenting his bid-rent model for the firm, he was aware of the importance of other locational factors, as he cited Isard and Chamberlin on the factors that determine the rent of urban site: (1) effective distance from the core; (2) accessibility of the site to potential customers; (3) number of competitors, their locations, and the intensity with which they view for sales; (4) proximity of land devoted to an individual use or set of uses which are complementary in terms of both attracting potential customers and cutting costs; and (5) the prices that can be charged and the type of business which can best be conducted on the location." (Alonso p 44).

Efforts to incorporate non-transportation factors into the monocentric model have proven no easy task. One approach is to extend the idea of transportation accessibility to the more general concept of location-dependent *amenity*, including, in addition to transport access, all socioeconomic characteristics associated with each site (Diamond and Tolley 1982). Extending the bid-rent approach under this amenity concept, however, confronts the problem that, unlike savings in transportation costs, these amenities of socioeconomic characteristics are *not* explicitly valued in a competitive market: while one can calculate the savings in transportation costs and gains in utilities resulting from moving closer to CBD, no direct method exists that one can find the market value for the improved public services, better environmental quality, or more attractive appearance that is associated with the specific neighborhoods the site is located. In fact, the market value for accessibility itself is difficult to measure if jobs, shopping and entertainment are located in different places instead of all at one central place.

One technique to analyze amenities is through their indirect effects on other markets, or the implicit markets (Rosen 1974). *Hedonic price equations*, which relate observed housing prices with structure or neighborhood characteristics, can be calibrated to estimate the prices of each component of housing, including structural features, transport accessibility and neighborhood conditions. These prices offer an indirect measure of the contribution of these factors to land uses. Variables most often used for hedonic price functions include housing physical conditions, school quality, crime, racial composition, neighborhood socio-economic status, air quality, and accessibility (Bartik and Smith 1987). The interpretation of hedonic pricing results, however, can often be confusing as it reflects neither the demand nor the supply side of housing market, but is rather a reduced form equation (Rosen 1974, Quigley 1979). Moreover, although numerous hedonic price models have been tested for residential and business land and housing price, the linkage between such models and land use determination is not made clear.

Empirical hedonic price models have generally concluded that there is strong relationship between neighborhood ethnic composition and residential land use. In particular, almost all studies found that land/housing prices are positively correlated with the proportion of white population in the neighborhood, suggesting a general preference for "whiter" community even after controlling other neighborhood effects such as income. These results have to be interpreted carefully because they do not distinguish the submarkets for minorities and whites (Yinger 1979). Various authors have explored the residential location pattern for different racial groups under assumptions of the racial prejudice. While some authors see racial segregation in US metropolitan areas as a natural, rational outcome (Clark 1986, 1988), many others contend that the current observed pattern of segregation can only be explained by the existence of discriminatory actions (Yinger 1979, Galster 1988, 1989).

This kind of sorting according to ethnic identities into different neighborhoods should not be confused with another type of sorting: the sorting of residents into different jurisdictions according to their preference for public goods and services[3]. This Tiebout

[3] These two types of sorting will only be similar if preferences for public goods are divided along the racial line (which seems very unlikely).

Hypothesis -- that consumer mobility and competition among local jurisdictions will result in an efficient allocation of resources to the local public sector -- has been the theoretical base of numerous later researches on the effect of government, especially local government, on locational choice. Introduction of property tax and capitalization effects further stratifies the sorting process (Hamilton 1976, Wheaton 1993). Empirical researches, on the other hand, have generally adopted hedonic type models to evaluate the effect of property tax or local government service to residential location choice (Yinger et al 1983).

2.3 Difficulties

There is often apparent incompatibility between these approaches and the spatial general equilibrium models of the Alonso type. In fact, while spatial equilibrium theories tend to ignore or assume away non-transportation factors, works using the hedonic or Tiebout framework are also prone to ignore the spatial component. Efforts have been made to incorporate non-transport attributes into analytical general equilibrium models. The problem is that, unlike transport accessibility, the spatial differentiation in government services or neighborhood qualities cannot be captured in one or several distance measures. Cremer (1990) developed an analytical model in which both transportation accessibility and school quality influence residential location choice. However, while he holds that transportation cost increases with distance to CBD, he also assumes that school quality decreases with distance to CBD, which may have some element of truth, but nevertheless too simplistic to be realistic. As a result, although as an analytical model it provides some insights into the interplay of the two factors in determining locational choice, such a model cannot be expected to explain the actual spatial differentiation in land use, which does not appear to have any single reference point. Wheaton summarized the discomforting relations between these two approaches in the following statement:

> The apparent incompatibility of these approaches is largely a result of the different mathematical requirements inherent in their perspectives. The monocentric models rely on a continuous representation of space, where the concept of travel cost can be easily determined. Theories that emphasize externalities and public goods, however, destroy this simplicity. The very concept of a political jurisdiction divides space into discrete parcels, and the external cost arising between such parcels is not simply linear. (Wheaton 1979: 126)

The problem of mathematical tractability also arises as analytical economic models try to incorporate more factors to be more realistic. One case in point is the work by Yinger (1993) which derives spatial patterns (urban boundaries) according to different street layout. When the discussion of the street grid reaches to a configuration with several diagonal arteries, mathematical analysis of the spatial form becomes extremely complex. Yet in reality, street patterns in metropolitan regions can be far more complicated than the most sophisticated scenarios analyzed by Yinger, plus that there are also a growing number of suburban centers. The neo-classic analytical framework in the fashion of general equilibrium seems inadequate to study the relationships between such a complex road pattern and land use distribution. This problem was also noted by Wheaton who stated that "with multiple centers, workplaces, or trip purposes, transportation cost bears a discontinuous and highly complicated relationship to Euclidean space." (Wheaton

1979). He went on to suggest that the only recourse is to develop models in which space is approximated by discrete parcels or cells.

Chapter Three Modeling Land Use Change: Theory, Method, and Specification

Causes of land use change are myriad. In order to empirically test the importance of individual factors, we need a theoretical model that not only allows us to quantitatively link land use change and a number of measurable explanatory factors, but also represents the underlying process of land use change. This chapter tries to present such a model: the multinomial logit model for land use change based on probabilistic bid-rent theory. The derived model framework will be used in the next two chapters for analyzing the land use change process in the Boston Metropolitan Region.

3.1 Bid Rent and the Determination of Land Use

William Alonso's "Location and Land Use" first presented a monocentric urban economic model based on basic economic principles of utility and profit maximization. The urban form he derived from this strict economic approach is the classical monocentric city, where the nature of a city only varies with regard to distance to CBD. The reason that spatial variation exists only along this dimension is that, in his basic model, locations differ only in their commuting time to CBD, which is assumed to be a linear function of straight line distance. In addition, the most critical tradeoff taken into account in this model is between commuting cost and land cost. Therefore, land price, and consequently land use, vary only along the radial axis.

Methodologically, however, Alonso's work proposed the concept of "bid rent" which forms the crux of modern urban economic analysis and underlies most formal microeconomic models of urban spatial structure (Anas, 1982, p17). Bid rent is the concept that captures the essence of the bidding model of land market. It is a tool used to establish spatial equilibrium, in which firms and households are indifferent to locational difference, and therefore have no incentive to move. In terms of land use, bid rent enables the comparison between very different land use types in their relative preference for land and is therefore a forceful tool to explain why land is used differently.

There are limits and difficulties with the bid rent approach as presented by Alonso. Strong assumptions are needed for the model to work. This includes the assumption of "a featureless plain, on which all land is of equal quality, ready for use without further improvements." (p15) It also assumes a single urban center, which serves both as employment center and export point for industrial products. Space differs only in reference to CBD, as transportation costs and commuting time varies along this axis. These assumptions are needed to make the mathematics tractable so that analytical forms of bid rent and land use patterns can be derived. However, they seriously restrict the spatial contents of the model. The various aspects of spatial variation are exactly the focus of this study, therefore it certainly cannot afford to use these assumptions.

While these restrictive assumptions about space are needed for an elegant analytical model, they are not necessary for the bid-rent framework to work. In the following paragraphs I try to present how the concept of bid-rent can be used to derive a *reduced form model* for land use change determination, which, while sacrificing analytical elegance, retains the spatial richness of land use phenomena, and allows testing of the contributions of various potential factors. In particular, the estimation model I will use is the multinomial logit model, and I will establish how this model structure is linked to the bid-rent theory of land use[4].

As with Alonso, I assume that land is allocated in a bidding process. Each site is used by the bidder willing to pay the highest possible price, or bid rent. Land use change takes place through the functioning of the land market. Home owners and renters weight the tradeoffs between land/housing prices and locational amenities at each site, decide the prices they are willing to pay for the land, and will offer bids for land that vary across different parts of the city according to their amenities. Similarly, commercial and business land users maximize their profit by weighing locational advantages against land prices, and offer bids for each site that also varies across the city because of the additional revenues the site will draw or the cost savings it will bring. Land owners compare the bid rents offered by different residential users and business users, and sell the sites to the highest bidder.

In order to illustrate the concept of bid rent, consider, for example, the case of industrial land use. Assume that all firms in the industrial sector operate under the Cobb-Douglas production function given by

$$Q = \alpha I_L^{\beta_1} I_X^{\beta_2} I_{S_i}^{\beta_3}$$

where Q is the output of a firm, I_L *is* land input, I_X is other inputs, I_{S_i} is level of public goods or service provided locally at i. If the prices of the firm's product, the land and the

[4] There are a number of land use modeling studies that use the multinomial logit model. Their models are generally not based on urban economic theories of land use. The interpretation of MNL presented here is not necessarily relevant for these models, especially in case where the modeling objects are non-urban land. However, in the urban case, such a theoretical interpretation of MNL enables us to theoretically think about how explanatory factors affect land use change in the market.

input are P_Q, P_L, and P_X respectively, the profit equation for a firm locating at location i is then:

$$\pi_i = P_{Q_i} Q - P_{L_i} I_L - P_{X_i} I_X$$

Maximizing the profit, and substituting the resulting levels back into the profit equation yield an expression for the maximum profit a firm in the industrial sector can make at location i, as a function of input prices, output prices, and the community i's public services:

$$\pi_i^* = \beta_s [\alpha P_{Q_i} (\frac{\beta_1}{P_{L_i}})^{\beta_1} (\frac{\beta_2}{P_{X_i}})^{\beta_2} I_{S_i}^{\beta_3}]^{1/\beta_s}$$

where $\beta_S = 1 - (\beta_1 + \beta_2)$.

Let $\bar{\pi}$ be the common level of profit, and solving the above profit function for P_{L_i} yields the bid-rent for land as a function of the *effective* prices of all inputs and output at location i, public services at location i, and the common level of profit:

$$P_{L_i} = \beta_1 [\alpha P_{Q_i} (\frac{\beta_s}{\bar{\pi}})^{\beta_s} (\frac{\beta_2}{P_{X_i}})^{\beta_2} I_{S_i}^{\beta_3}]^{1/\beta_1}$$

The bid rent P_L is important for equilibrium because, if at every location in the city, land price is fixed according to the above equation, the firms will be indifferent to location: the profit each location will bring about is the same, therefore they will have no incentive to move to another location.

Note that the above equation is not a solution to the problem of the relationship between bid rent and location: spatial indicators do not explicitly appear in the equation; rather, they are implied in the variables on the right hand side of the equation. Under this specification, the bid-rent industrial land uses can offer is positively correlated to the effective output prices and the local services offered, and negatively correlated with the effective input prices. All three variables, however, vary with locations: output price is lower for places faraway from export facilities (highway, railway, or airport) because transportation cost in effect lowers the actual price the firm gets; wage as an input price can be lower at places closer to labor for employees' savings on commuting cost. Therefore locational properties affect the bid-rent of industrial land use by exerting influence on these effective prices and the local public services. If we know the effective input and output prices, the local public services for each location, and all the relevant parameters, we can analytically derive the bid-rent for the industrial land use. If, as in the usual case, these parameters are unknown, we can indirectly infer the bid-rent as a function of the locational properties that affect effective input and output prices, and the local public services. The model thus becomes a reduced form model, but the inferential testing can be conducted through empirical econometric models.

In general, the production functions may take much more complicated forms, and the bid-rent function in most cases cannot be analytically derived. However, from the above derivation for a simple case, we see that the bid-rent is determined by the demand and supply conditions for an agent at each location: assuming a common level of profit, the bid-rent one land use activity can offer will be higher if the effective revenue for its output at this location is high, and will be lower if the effective cost of its inputs at the location is high. The same basic principle applies to residential and commercial land uses since residential and commercial development both have the revenue and cost structure. As in the case of industrial land use, the bid-rents for these two types of land uses can be empirically related to a number of locational properties that influence effective revenues and costs.

If the bid rent by each land use is known, then the site will simply go to the highest bidder. In the classic Alonso model, the bid rent for each land use is strictly a function of the distance to CBD. The difference in the slopes of the bid-rent function at each site results in a classic concentric ring land use model in which, generally, commercial and industrial uses take the central place, residential uses occupy the outer ring, which is in turn surrounded by agricultural use. With the more complicated assumptions of space as used here, the picture is not that neat, as bid rent functions for each land use may vary along many different dimensions and are not necessarily continuous. But the basic principle of land use determination is clear: the land will go to the use able to offer the highest bid rent. Put in notation, let i (i = 1, 2, ..., N) denote location, let l = 1, 2, ..., L denote land use types (for example, l = 1 represents non-urban use, l = 2 represents residential use, l = 3 represents commercial use, etc.), and R_i^l denote the bid-rent offered by use type l for location i. Then, the land use type l^* will be chosen for location i if

$$R_i^{l^*} > R_i^{l'} \qquad \text{for all } l' \neq l^*.$$

3.2 Probabilistic Bid Rent and Multinomial Logit Model for Land Use Change

For each user type, the bid rent each location can offer is determined by the various characteristics of the location such as accessibility, physical features, and tax rates. Mathematically, bid rent for each land use is a function of these characteristics.

Let X_i denote a vector of K variables describing the characteristics of location i. Then for land use l at location i, the bid rent it can offer can generally be written as:

$$R_i^l = f_l(X_i, \varepsilon_i^l)$$

Adding the error term ε_i^l into the function form converts bid-rent into a random variable. The error term can represent numerous types of theoretical or econometric uncertainties in microeconomic decision making. One interpretation of the random bid-rent is that it denotes variations of utility or profits within the same type of land use. It arises because some of the attributes X are unobservable, or are imperfectly measured by the observer, or because there are significant idiosyncrasies that make the bid-rents of the same land use type to be different from each other. The random term can also represent inherent stochastic instability in the utility function of a specific household, or the profit function of a specific business in face of uncertainty. To the observer of land use patterns, the above and other sources of stochastic behavior are *indistinguishable* from each other (Anas 1982). The implication is that the dispersion in bid-rent for the same land use type can only be explained by assuming the existence of random terms and by attempting to statistically measure their distribution over the population.

As a result of the stochasticity of the bid-rent function, land use choice is also probabilistic. Since the bid rent offered by one use is higher than another use with certain probability, instead of certainty, which use will take place at the site is also probabilistic. Let $p(l/i)$ denote the probability that land use type l is chosen for location i, then, to maximize bid-rent, we have:

$$p(l/i) = \text{Prob}\ [\ R_i^l > R_i^{l'} \ \text{ for all } l' \neq l].$$

That is, the probability that land at location *i* will be used as type *l* is equivalent to the probability that type *l* will offer higher bid-rent than any other land use types.

The probability $p(l/i)$ is a function of locational properties X_i. The probabilistic function can be derived if we know the stochastic distribution of the error terms. If the item is assumed to be distributed as multivariate normal distribution, a multinomial probit can be formulated as the choice model. While possessing most of the nice properties of normal distributions, such a model becomes intractable when the number of alternatives is large. The most tractable class of probabilistic choice models are the multinomial logit models (MNL). They are derived by assuming that the random terms for each alternative are independently and identically distributed according to the extreme value (Weibull) distribution (for a mathematical proof of the derivation see McFadden 1974). Such a model takes the relatively simple form of:

$$p(l/i) = \frac{\exp[f(X_i, \beta^l)]}{\sum_{l'=1}^{L} \exp[f(X_i, \beta^{l'})]}$$

where β^l are parameters associated with the bid for use type *l*. In particular, if we assume the bid-rent function *f* is a linear combination of some locational attributes *X*, then the model takes the form:

$$p(l/i) = \frac{\exp[X_i * \beta^l]}{\sum_{l'=1}^{L} \exp[X_i * \beta^{l'}]} \quad (1)$$

The chief advantage of MNL is that it is much more tractable econometrically compared to multinomial probit and other non-linear probabilistic choice models while being a very close approximation to independently and identically distributed multinomial probit. This stems from the fact the extreme value distribution is very similar but slightly skewed compared to the normal distribution with the same mean and variance. The parameters in the MNL are usually calibrated using the maximum likelihood estimation technique.

Note that the explanatory variables in Equation (1) are location-specific, not alternative-specific. That is, the X_i on the right hand side of the equation have only subscripts for location i, while usually in a discrete choice model, the explanatory variables are also alternative specific, and thus also have subscripts for the choice l. The reason for doing this is that the data set contains no information about developers, land users, and the specific activities involved with each instance of land use change. Consider the case of commuters comparing alternative work trip modes, or of households trying to decide where to live. In the commuter case, each traveler faces a series of mode choices (e.g. driving, walking, or taking the bus), all of which have attributes that can be compared with each other (e.g., travel time, wait time, travel cost associated with each mode). In the household location case, each household faces a series of residential choices, all of which can be decomposed into comparable attributes (house size, neighborhood, distance to work, school quality, etc.). Each traveler chooses the commuting mode, which, based on its attributes, maximizes his or her utility. Similarly, each household chooses a house and location, which, based on their attributes, maximizes its utility. In both examples, an identifiable agent confronts and makes real choices.

In the case of site level land use change, the agent should be the site owners and/or land users. Each owner is confronted with the decision of whether or not to initiate a land use change. The factors influencing that decision will include, among others, the attributes of the site. Following the logic identified above, each owner should make the land use change decision (including the possibility of no change) which maximizes their profits.

Yet as we note below, the unit of analysis (or observation) in this research is the site, not the developer or landowner. And while we have reasonably complete information on the characteristics of sites, we lack information regarding the characteristics or motivations of land owners and developers. As a result, our explanatory variables have only subscripts about locations, but not about agents or choices.

There are some schools of thoughts that indeed regard ownership as unimportant compared with locational properties in land development process. One rationale invokes the idea of competition. One can argue that given a highly competitive market and few barriers to entry, the owner doesn't matter. Whether a particular developer is well-capitalized or poorly-capitalized, whether they specialize in residential development or retail development, whether their experience is local or national, in a competitive market, these factors are likely to be of far less importance than the demand for urban development and the availability of appropriate sites. However, there are other schools who regard land ownership as a more important factor in the development process. While this has been a decades-long debate, the truth probably lies in between. This is actually a testable hypothesis with the MNL framework. The omission of agent information in this thesis is a result of data limitation rather than intentional omission.

The other limitation of the above specification lies with MNL itself. The MNL model has the Independence from Irrelevant Alternatives (IIA) property. That is, the odds of a site being chosen for use *i* over *j* is independent of the availability or attributes of alternatives other than *i* and *j*. In the case of land development, it involves the assumption that land developers act independently of each other--that is, each developer or landowner independently appraises the profit potential for every site, and bids accordingly. This assumption rules out the possibility of oligopolistic (whereas groups of landowners or developers act in concert) or strategic behavior (whereas one developer acts primarily to preempt or manipulate another). In reality, of course, landowners and developers *do* engage in oligopolistic and strategic, but the question is whether that behavior is likely to succeed. To the extent that land development has been shown to be no more profitable over the long-run than other businesses, the answer is probably no. Competition, we may assume, levèls the playing field and makes the expected return (or profitability) associated with strategic behavior close to zero. In general, as observed by McFadden (1984), although the IIA property is theoretically implausible in many applications, empirical experience is that the MNL model is relatively robust, as measured by goodness of fit or prediction accuracy, in many cases where the IIA property is theoretically implausible.

3.3 Unit of Analysis and Organization of Spatial Data Layers

Econometric estimation of Equation (1) requires an appropriate unit of "location" based on which samples are collected. For studying land use change, the land parcel is the near-ideal unit of analysis. Parcels are the fundamental unit for which land use is categorized, and the basis of all land transactions. Moreover, parcels are always associated with land owners, renters, or developers. As noted above, these are important agents, in addition to location factors, that determine the land use change process. Regrettably, complete (digital) parcel maps are not yet available for any major metropolitan regions in the country.

What *is* usually available is region-wide databases of dominant land uses. In this research, the database for the Boston Metropolitan Region compiled by MassGIS is used. To make the modeling process more manageable, I collapsed the dozens of land use categories contained in each database into seven: (i) undeveloped; (ii) single-family residential; (iii) multi-family residential; (iv) commercial; (v) industrial; (vi) transportation; (vii) institutional; and (viii) others.

The MassGIS data set was originally in vector format, with polygons delineating the spatial boundaries of different land use categories. This vector database was rasterized into grids with cell resolution of 50 meters by 50 meters. For each cell, the database designates the dominant land use type.

Grid-cells have both advantages and disadvantages as units of analysis. They are small enough to capture the detailed fabric of land use but large enough to avoid problems of data "noise[5]". And, since they are fixed, changes and trends across time can be easily identified. In comparison to vector-based land use polygons, rasterizing sacrifices some accuracy as it arbitrarily divides "natural" land use polygons with square blocks. However, with careful selection of resolution, such sacrifice could be made minimal, while unimportant information about the exact shape of the land use polygon can be (rightly) ignored. Since vector based geographic database also has a resolution,

[5] The presence of many different and distinct land uses in a small area may make it difficult to discern broader land use patterns. This is the problem of "noise".

grid-cells make this resolution issue more explicit. On the negative side, they lack physical or legal reality. Unlike parcels, they are not transacted. Nor are they directly regulated. Thus, they are not themselves the subject of development or redevelopment decisions.

3.4 Model Specification

The general multinomial logit model specified above includes eight sets of independent variables. They are:

1. The initial site use,
2. Neighborhood demographic and housing characteristics,
3. Accessibility and distance measures,
4. Physical, cost and policy constraints,
5. The characteristics of land use in the neighborhood,
6. The existence of any positive and/or negative influences exerted by adjacent sites,
7. Spatial autocorrelation factors.

The following sections describe each of the independent variable sets:

3.4.1 Initial Site Use

The models that follow differentiate between land use change that occurred to previously vacant sites, and land use change that occurred to previously developed sites. The initial land use in the former set of models is all the same. In the latter set of models, sites may be initially developed in residential use (single-family or multi-family), commercial use, or industrial use.

Conventional urban economics holds that commercial and industrial uses are generally of a "higher order" than residential uses. That is, they are capable of generating higher land rents. To the extent that this generalization holds true, previously-developed residential sites should, all else being equal, be more likely to be redeveloped into commercial or industrial uses. Conversely, previously-developed commercial or industrial sites should be less likely to be redeveloped into residential use.

3.4.2 Neighborhood Demographic Characteristics

Numerous hedonic price models have confirmed the significance of neighborhood characteristics in determining land and housing prices. As such they are contributors to land use change as well, since land use is in turn influenced by land prices. In addition, in absence of reliable data source of land price, conditions of housing stock at the neighborhood level indicates how attractive the site would be for residential development, as well as the price that developers need to pay for land for industrial or commercial development in this neighborhood. In this study, for each site, I identified the census tract it was located in at the beginning period, and extracted housing and demographic characteristics for the census tracts from the census. The variables I included are: density of housing units, proportion of white population, percentage of one-unit structure, percentage of owner occupied housing, median rent for renter-occupied housing, median value for owner-occupied housing, percentage of housing stock built in the last ten years, and percentage of housing stock built more than 30 years ago.

* *Proportion of white population*: racial composition has always proved to be an important factor in residential location choice. Surveys of housing preference seemed to indicate that, regardless of their race, would prefer to live in a White-majority neighborhood (Yinger 1979). If this is true, housing built in white-majority

neighborhood can demand high price or rent and, therefore, such sites will be able to offer high bid for residential use. Note, however, a positive parameter for this variable for residential development can not only indicate racial prejudice, but also discrimination in practice (Yinger 1979). On the other hand, there is no *a priori* reason that racial composition should be a factor in commercial or industrial development.

* *Percentage of one-unit structure* and *percentage of owner-occupied housing*: Both variables are positively correlated with the composition of single family housing in the neighborhood housing stock. I expect they will contribute positively to single family residential development and, possibly, negatively to multifamily development. Their impact on the two business land development can go both ways. To the extent that commercial and industrial development skip high priced single family neighborhood to avoid nuisance and seek cheaper land price, the signs may well be negative. However, under-developed areas at urban edge are usually dominated by single family residence, even though the densities of such residence are very low. These areas can be attractive for business land development, for their availability of land and possibly cheaper land price.

* *Median rent* (for renter-occupied housing) *and median house value* (for owner-occupied housing): If housing price bears strong positive relationship with land price, these two variables are indicators of the bid rent or bid price offered by multifamily and single family residential uses. Thus, it is more likely for apartment development to occur where median rent is high, and for single family development to occur where median house value is high.

* *Percentage of housing stock built in the past ten years*: This variable indicates the demand for residential development before the modeling period. If there exists positive correlation between demand for development in the past and present, it approximates demand for residential development. Land development can also be a sequential process in that commercial development will follow new residential development to serve the additional population. If this is true, this variable will also be positive for commercial development.

* *Percentage of housing stock built more than 30 years ago*: This variable indicates whether the neighborhood is an old one. There can exist preference for the age of neighborhood in land development, although the direction of such preference for each use is not certain. Moreover, since land redevelopment is more likely to occur on old capital stock, we expect that this variable will positively contribute to redevelopment.

3.4.3 Accessibility and Distance Effects

As discussed extensively in Chapter 2, urban economists have argued that the demand for sites (as measured by land prices and densities) should be greatest near major city centers, primarily for reasons of minimized work trip transportation costs. To capture any potential regional accessibility affects, I used measured the travel time from every site to downtown Boston. To the extent development really does favor *closer-in* locations, we would expect the estimated coefficients of these two measures to be consistently negative.

Accessibility can be also be measured more generally. Regardless of trip destination of purpose, activities located near major freeways have a higher level of generalized accessibility than activities located father away. Because of this, we would expect such sites to be in greater demand, and thus, to face greater development and redevelopment pressures. This might be particularly important, for instance, for industrial land development/redevelopment -- if import and export are conducted chiefly through trucking to other regions, access to freeway itself is of great value. To test the above hypothesis, I measured the aerial distance from every site to the closest freeway. To the extent that proximity to regional transportation facilities encourages land use change, we would expect the coefficients of these two measures to be negative. Aerial distance is also measured for access to the closest railway. Evidently, with the vastly improved highway network, the importance of railway in land development has been significantly decreased. The only possible impact in the current context is on industrial land development.

In the classical urban economic treatment of land use, jobs, export facilities and shopping opportunities are all assumed to be located in the same place: the CBD of the central city. This assumption makes it valid to measure access only to CBD. In the current context of metropolitan spatial structure where not only are there suburban subcenters, but there also exist functional differentiation among the subcenters with clusters of shopping centers, job centers and entertainment facilities separated from each other, distance as measures of accessibility to these opportunities, has to be represented in a more sophisticated way. In absence of detailed information about the exact locations of jobs and shopping areas, I approximate such access by measuring the aerial distance of each site to the closest business land uses: commercial, industrial, and institutional. All three distance measures are associated with access to job opportunities, so we expect the signs to be positive -- closer to jobs will increase the chance of development. In addition, short distance to the closest commercial land is also an indication of easy access to shopping, and short distance to institutional land can be indication of closeness to recreational facilities like urban parks and golf course. Therefore we expect these too distance measures to be especially positive for residential development.

3.4.4 Physical, Cost and Policy Constraints

The physical characteristics of a site may present absolute or relative constraints to its development. Sites which include permanent wetlands are absolutely constrained from development. Sloped sites face relative constraints: they can be developed or redeveloped but typically at a higher cost than flat sites. To develop sites far from existing urban services (e.g., roads, sewer and water service, and electrical and telephone service) requires either that those services be newly provided, or that they be extended from existing service areas. Either way, the necessity of providing services substantially raises the cost of developing vacant land at the urban fringe.

Site slopes were originally estimated from U.S.G.S. DEM (Digital Elevation Model) data files. Because of the higher costs associated with hillside development, we generally expect to observe a negative relationship between slope and the probability of site development.

The costs of providing infrastructure and essential urban services varies by use and jurisdiction as well as with distance. Some jurisdictions impose more costly and extensive infrastructure standards than others. Similarly, some jurisdictions impose more onerous standards on certain types of development. Finally, most jurisdictions assess impact fees on new development. Because state law governing the setting of impact fees requires only that there be a "rational nexus" between the fee amount and the impact, fee amounts can vary widely between jurisdictions, between different uses, and even according to the location within a particular jurisdictions. Unable to assemble a complete and reliable schedule of impact fees for different uses in all communities, I did not include impact fees (or exaction) in the model.

For undeveloped sites in the Boston Region, I identified those designated as open space, and created dummy variables according whether the open space was protected or not protected, and at what level of government was it protected (federal, state, or local). Assuming that government protection of open space was effective, everything else being equal, we would expect unprotected land to be more likely to be developed than protected open space, and open space protected at a higher level of government less likely to be developed than that at a lower level of government.

3.4.5 Neighborhood Land Use Effects

As a spatial process, land use change at one site is affected by the use activities occurring at neighboring or adjacent sites. This fact, while completely ignored in traditional urban economic studies of land use determination, can be especially important for land use activities *at micro level*, and it is the focus of cellular automaton theories of land use change. In this study, I incorporate such processes into the econometric model of land use change by introducing neighboring or adjacent land use effects as independent variables. I try to distinguish two types of spatial effects related to spatial proximity among sites of similar or different uses. Variables on *neighborhood land use effects* try to capture the land use characteristics of the neighborhood where the grid-cell is located, with *neighborhood* meaning all the grid-cells within a certain distance of the site. On the other hand, variables on *adjacent land use effects* try to capture the land use characteristics of the grid-cells *right next* to the sample grid-cell[6].

Neighborhood land use characteristics affect whether a site will be developed or redeveloped because different land uses generate both *positive and negative externalities*. A grid-cell located in a predominantly undeveloped neighborhood is less likely to get developed, probably because there is lack of infrastructure provision in the neighborhood, or because there is not sufficient agglomerative economies for development. In the same logic, development or redevelopment to commercial use is more likely to occur for grid-cells in neighborhoods with a higher proportion of land already devoted to commercial use, because of the positive externalities that existing commercial use will generate for later commercial development. This argument also holds for industrial and residential development: development or redevelopment to any urban use is more likely to occur if the neighborhood has higher proportions of land in this use.

In addition to the benefits brought out by same land uses, there may also exist positive externalities between different land use types. The shopping center located near a large subdivision or apartment building is the beneficiary of a positive spillover--in this case, a large potential market. Similarly, the current attention being given to mixed-use

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[6] In the terminology of econometrics, this is similar to the issue of spatial auto-correlation, although the dependent variable, as well as the auto-correlated variable here is discrete rather than continuous. The distinguish made here between neighborhood and adjacency effects is in effect the differing degrees of "spatial lags" that can be used to define spatial auto-correlation. Adjacency is first-order spatial lag, while neighborhood is *n*th order spatial lag.

development is based on the presumption that for certain (right) mixtures of uses, positive externalities exceed negative externalities.

Negative externalities, however, do exist with the spatial juxtaposition of different land uses. Indeed, the desire to mitigate negative externalities is the classic argument behind zoning. Industrial uses are typically separated from residential uses to minimize aesthetic, safety, and property value spillovers. Likewise, high-density residential development is often separated from lower-density single-family development to minimize the potential for noise, traffic, and other potential spillovers.

In this study, neighborhood is defined as the 120 grid cells immediately surrounding the site (11 by 11, and exclude the site grid-cell itself). Five variables denoting the share of neighboring sites in each major land use (single-family, multi-family, commercial, industrial, and transportation) were included in each model. These shares vary between 1 and 0: a value of 1 indicates that the neighborhood the site is located in is completely for a particular land use type; a value of 0 indicates no site in the neighborhood is of the particular use.

We have some general hypotheses about the effects of these variables according to the above discussion about positive and negative externalities. First, high proportion of vacant land in the neighborhood will reduce the likelihood of all kinds of development and redevelopment; Second, high proportion of one developed land use in the neighborhood will increase the chance of development or redevelopment to the same land use; Finally, inter-use spillover effects vary by uses: (i) Traditionally, single family land use tends to avoid all kinds of business land uses, as well as apartment use; (ii) Multi family residential development is likely to avoid industrial neighborhoods to mitigate negative externalities, but is likely to favor neighborhoods with high proportion of commercial use for easy shopping opportunities. The chance of apartment development in a neighborhood with high proportion of single family use is uncertain: to the extent that single family neighborhoods already have the necessary infrastructure and services for residential development (such as schools), they draw apartment development; but zoning restrictions and NIMY resistance may exclude apartment development in the single family districts. (iii) Commercial development certainly seeks area having easy access to households. Yet, just as it does for multifamily development, with neighborhood opposition and zoning restrictions, commercial development is less likely to happen in single family neighborhoods. It may be possible, on the other hand, for commercial development to happen in neighborhoods with more apartments, as zoning for such neighborhoods is likely to be less restrictive, and demand for commercial development by high-density residential areas is higher. The effect of industrial land on commercial development seems uncertain. There is a chance that commercial activities such as food and services be attracted to industrial neighborhoods. (iv) Although access to labor force is one important factor affecting industrial location, at a micro scale, industrial land development is likely to avoid residential neighborhoods (single family as well as apartment) for cheaper land and avoidance of negative externalities. Such development, especially small firms, may be drawn to commercial neighborhoods for the readily-available services they provide.

3.4.6 Adjacent Land Use Effects

The five variables used to represent adjacent land use effects are calculated in similar way for neighborhood land use effects: for each site, I summarized the number of grid cells in the surrounding eight (instead of the 120 for neighborhood effects) grid-cells according to use type, and calculated the proportion of each use right adjacent to the sample site. These variables are similar to the neighborhood land use effects variables discussed above as they also try to represent effects brought by spatial proximity. Their interpretations, however, are different because "proximity" here is defined in a much narrower sense, and the set of variables only represent the land use situations right adjacent to the site. This difference in spatial scale can be significant. For instance, high proportions of undeveloped land in a neighborhood of 1 square kilometer can be an indication of lack of infrastructure and agglomerative economies, but high proportions of vacant land right adjacent to the site can be an indication of the availability of large vacant lot so that development can occur at a larger, more efficient scale. Being right adjacent to commercial or residential use is not necessarily beneficial for either type of development, since such uses may require some open space in the close neighborhood. In other words, there can exist numerous idiosyncrasies with the adjacency relationship, and the behavior of this set of variables may differ significantly from that of neighborhood land use effects.

3.4.7 Spatial Auto-correlation Effects

Spatial auto-correlation clearly exists and needs to be dealt with in the land use change model proposed here. There are two sources of spatial auto-correlation. It first comes from the actual land use change process, from the fact that development activities at one site is affected by what has happened, or will happen at adjacent or nearby sites. But spatial autocorrelation also comes from the way data was assembled in this study: the use of grid-cells as the basic unit of analysis inevitably divided most integrated land use units into multiple pieces in an arbitrary way. Thus a five-hectare industrial development will be reported as five or six instances of such land use change, if the grid-cells are based on hectares[7].

There now exist standard methods to deal with spatial-autocorrelation for econometric models with continuous dependent variables (Anselin 1988). There, however, appear no econometric study aimed at addressing spatial autocorrelation in a multinomial logit model, where the dependent variable is discrete. Without definitive theoretical and technical guide, I try to attack the spatial-autocorrelation problem in three ways. First, instead of using the full set of grid-cells, I randomly samples approximately one percent of the grid-cells to be used for model calibration. This sparse sampling hopefully will at least partially offset the artificial spatial autocorrelation caused by the gridding. Second, I introduced neighborhood and adjacent land use effects as explanatory variables. As discussed above, these variables are intended to capture the cross-use externalities brought by spatial proximity, and they will account for some of the observed spatial autocorrelation.

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[7] Note that use of polygons to delineate land use boundaries is not very helpful in improving the situation. The problem with polygon representation of land use is in some way the opposite: while grids arbitrarily divide "natural" land use unit, polygons arbitrarily lumps together "natural" land use units if they are all in the same broad land use category. Therefore, in a vector-based land use database, there are usually some massive polygons representing residential use which span many different jurisdictions and contain parcels and neighborhoods of vast difference. From these polygons, there is not way to tell the spatial units based

Finally, I also introduce the x, y coordinates and their products as explanatory variables. This kridging will account for some spatial patterns that can be captured by the coordinates. We have no hypothesis about the behavior of these variables, their direction and magnitude to the extent that their existence in the equation will help filter out some of the spatial autocorrelation effects. Strictly speaking, these three approaches to spatial autocorrelation are not completely satisfactory, but in the absence of rigorous method to deal with spatial autocorrelation in a multinomial logit framework, they will at least mitigate the problem to some extent.

All the above variables are listed in Table 3.1.

on which actual land use change takes place. The "natural" land use change unit is parcels, and parcel will be the ideal spatial unit for spatial land use modeling.

Table 3.1 List of Explanatory Variables

VARIABLE	EXPLANATION
Initial Land Use Type	
INIT_APT	Initially used for apartment
INIT_COM	Initially used for commercial
INIT_IND	Initially used for industrial
INIT_PUB	Initially used for institutional
INIT_TRA	Initially used for transportation
Census Tract Housing and Demographic Characteristics	
HUDEN	Housing unit density
MDRENT	Median rent
UNIT1P	Percentage of 1-unit housing
WHITEP	Percentage of white
BLT10_P	Percentage of housing units built last 10 years
Accessibility and Distance Measures	
TM_BOS2	Travel time to Boston squared
TIME_BOS	Travel time to Boston
DIST_HWY	Distance to Highway
DIST_RAL	Distance to Railway
DIST_LU4	Distance to commercial use
DIST_LU5	Distance to industrial land
DIST_LU6	Distance to institutional land
Site Physical, Cost and Policy Constraints	
SLOPE	Slope
GEO6	Geologically formed by fine-grained deposits
GEO7	Geologically formed by floodplain alluvium
WETLAND	Wetland
OS_FED	Open space federally protected
OS_STATE	Open space state protected
OS_LOCAL	Open space locally protected
OS_PRTED	Open space permanently protected
OS_PRTMP	Open space temporarily protected
Neighborhood Land Use Characteristics	
NBH_VAC	Proportion of vacant land in neighborhood
NBH_APT	Proportion of apartment land in neighborhood
NBH_SIN	Proportion of single family housing land in neighborhood
NBH_COM	Proportion of commercial land in neighborhood
NBH_IND	Proportion of industrial land in neighborhood
Adjacent Land Use Characteristics	
ADJ_VAC	Proportion of vacant land in adjacent areas
ADJ_APT	Proportion of apartment land in adjacent areas
ADJ_SIN	Proportion of single family housing land in adjacent areas
ADJ_COM	Proportion of commercial land in adjacent areas
ADJ_IND	Proportion of industrial land in adjacent areas
Surface Trends	
XX	X coordinate standardized
XX2	Square of XX
XX3	Cubic of XX
XY	Product of XX and YY
YY	Y coordinate standardized
YY2	Square of YY
YY3	Cubic of YY

Chapter Four Land Use Change in the Boston Region: A Descriptive Analysis

This chapter provides a descriptive analysis of the land use data set for the Boston Metropolitan Region. The data set includes the distribution of land for 153 towns or cities for the years of 1971, 1985, and 1991. The chapter will begin with a description of the original situations of 1971, followed by descriptives of the changes, both aggregately and spatially. It will also empirically correlate the observed land use change with some important locational variables such as access to CBD. The analysis in this chapter provides a base for the more rigorous statistical analysis in the next chapter.

4.1 Initial Land Use Distribution in 1971

The initial 1971 land use distribution provides the physical context within which land use change occurred. To understand patterns of land use change since that time, we need the initial distribution to serve as a reference, based on which we compare how additional urban lands follow or deviate from existing patterns.

Total land in the study region is 650,555 hectares. Among them, 229,138 hectares, or 32%, were developed in 1971, used for residential, commercial, industrial, public, transportation and other urban functions. Another 3% is counted as "other uses" for a number of hard-to-group functions: landfills, water-based-recreation, power lines, new ocean, and cemeteries (Table 4.1). The majority of the developed land (nearly 70%) was used for single family housing. 13% of the developed land was occupied for public use, while transportation, commercial, industrial and apartment uses each took between 3% to 6% of the urban land (Table 4.2).

Table 4.1 Boston Region Land Use Composition, 1971

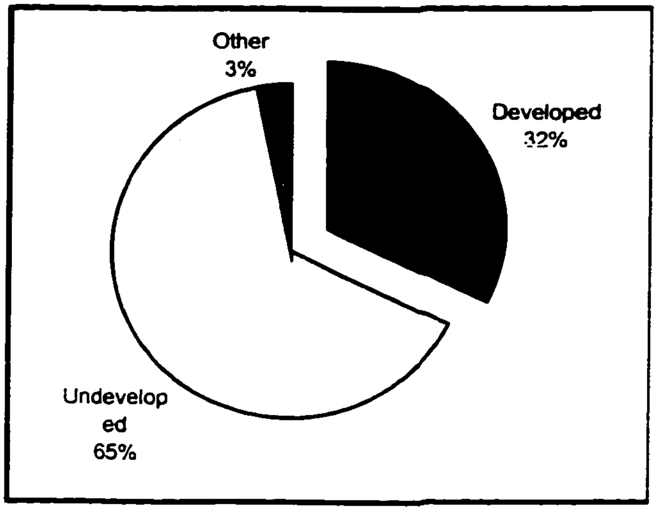
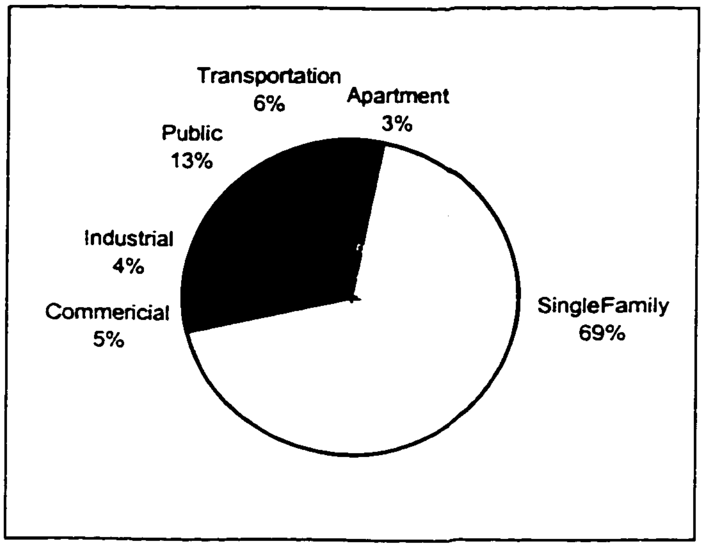


Table 4.2 Boston Region Urban Land Use in 1971

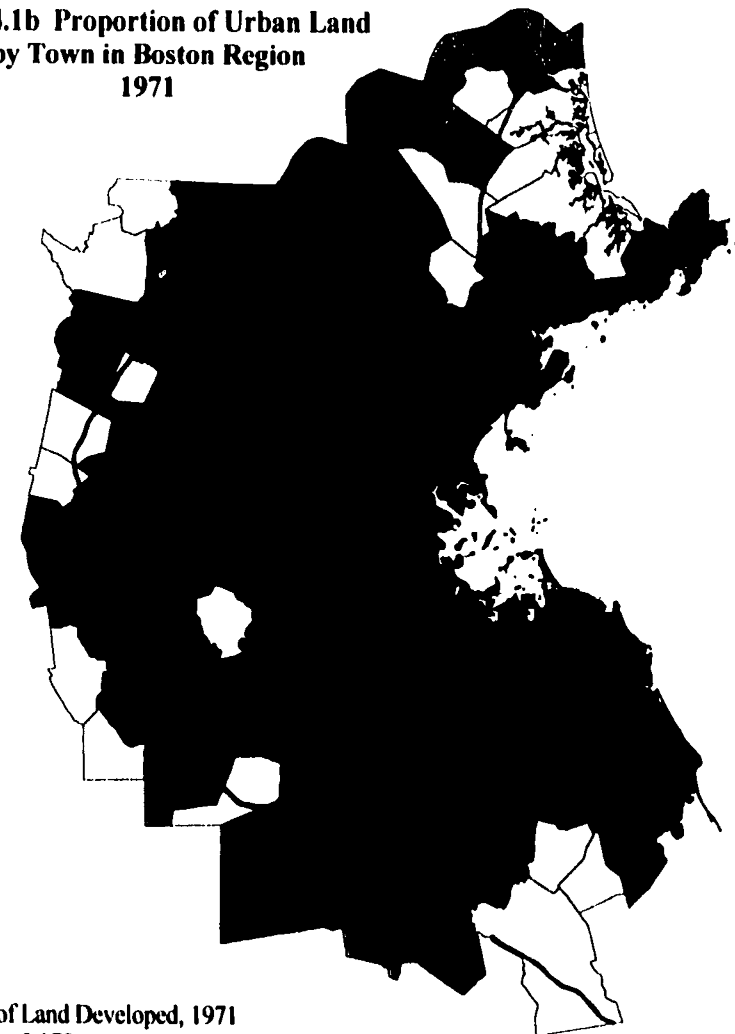


Overall Spread of Urban Land. Map 4.1-a presents the actual extent of urban land in 1971, whereas Map 4.1-b summarizes the percentage of urban land by towns. Both maps reveal the importance of distance to Boston downtown: the level of urbanization clearly decreases as one goes away from Boston. This impression can be further confirmed by Figure 4.1, which shows the percentage of land developed as a function of travel time to Boston downtown. The curve almost perfectly fits a negative exponential curve[8] up to 70 minutes from downtown. The segment for the last 10 minutes show an increase in the proportion of urban land, largely as a result of increased amount of public land at metropolitan fringe, as there were several recreational parks in the periphery. If we exclude institutional land from urban land, the proportion decreases monotonously as travel time to Boston downtown.

[8] with equation $\hat{y} = 1.3239 \exp(-0.3236x)$, and $R^2 = 0.9873$

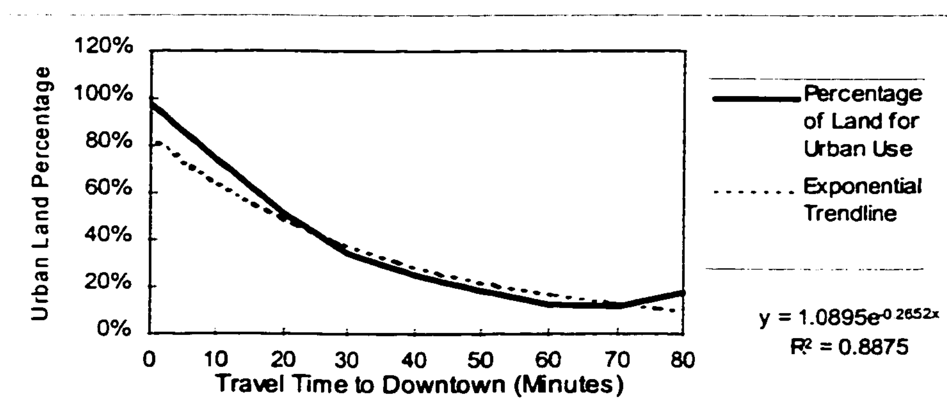
Map 4.1a Spread of Urban Land
In Boston Region
1971

Map 4.1b Proportion of Urban Land
by Town in Boston Region
1971



While the curve in Figure 4.1 may have confirmed the classic monocentric model which predicts a monotonously decreasing land use intensity function, the reality is more complicated. Map 4.1-a shows that urban land is actually very dispersed throughout the metropolitan area. There were numerous small patches of urban land distributed all over the region that were disjoined with other urban land. Many independent cities and towns existed in the hinterland. Everyone of the 153 towns had its share of urban land, although the percentages ranged widely from 5.6% to 99.6%. The area centered around Boston and surrounded by Route 128 was certainly the primary urban center of the region, but there were also secondary urban centers such as Lowell, Lawrence and Haverhill in the north and Brokton in the south, and dozens of other, smaller urban concentrations dating back in some cases to pre-Revolutionary days. An interesting result of the "satellite" pattern of urban development that characterizes the Boston region is the continued presence of sizable areas of open land in the interstices of dispersed pattern of urban centers.

Figure 4.1 Proportion of Urban Land by Travel Time to Boston Downtown, 1971

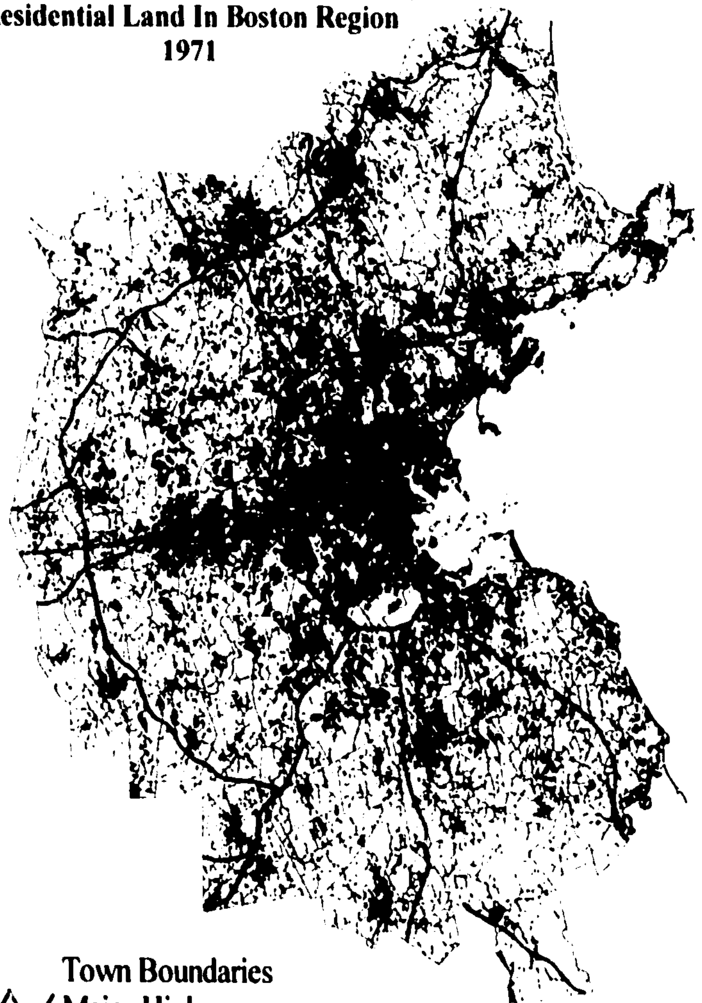


The expansion of urban land outward was neither uniformly concentric. Up to 1971 the regional development pattern resembles a series of passageways, some broader than others, reaching out to merge with older independent settlements or flowing into the open country. The urban extensions to the west and northwest are exceptionally broad. Narrower bands of settlement are apparent to southwest, northwest, and southeast. However, some communities, and in fact some entire subareas, have been partially bypassed by the urban tide. This is particularly true of much of the area to the southwest of Boston as well as of individual communities close to the core urban area. The key to continued low density development seems to be either isolation or difficult terrain, but equally important may be local decisions including large lot zoning and inadequate or non-existent public water or other municipal services.

In summary, while the overall extent of urban land in 1971 conformed well to the a concentric land use model, there were at the same time obvious sectoral patterns, exhibited along major radiating freeways. Under the context of these two big patterns, the actual extent of urban land is actually very dispersed throughout the region, with secondary urban centers located at important transport nodes. This indicates that the history of urban development up to 1971 is much more complex than simple extension of urban land from one center outward, as often assumed in land use change models.

Distribution of Individual Land Use Categories. Maps 4.2 to 4.6 plot the spatial distribution of land for each urban use category, and the proportion of land used for each use by town in the Boston region. The composition of urban land uses as functions of travel time to Boston is plotted in Figure 4.2.

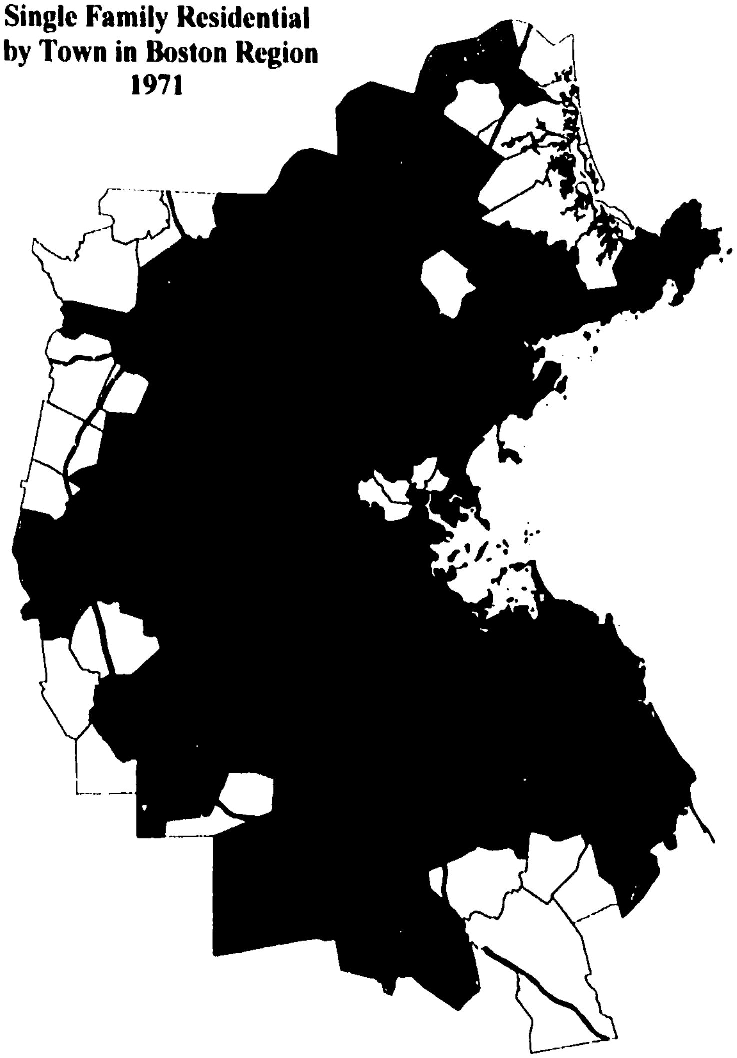
Map 4.2a Distribution of Single Family Residential Land In Boston Region 1971



Town Boundaries
Major Highways
Distribution of Single Family Residential Land, 1971
Single Family Residential

Other Urban Land 1971
Urban Land

Map 4.2b Proportion of Land Used for Single Family Residential by Town in Boston Region 1971

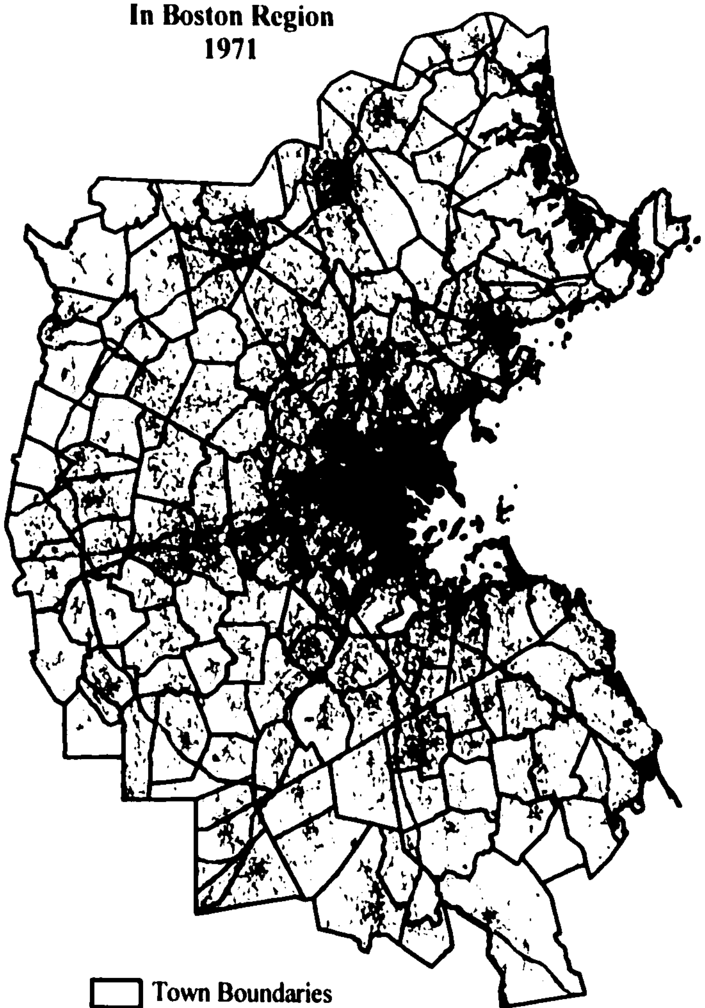


Proportion of Land Used for Single Family Residential by Town, 1971
0 - 0.117
0.117 - 0.188
0.188 - 0.288
0.288 - 0.469
0.469 - 0.686

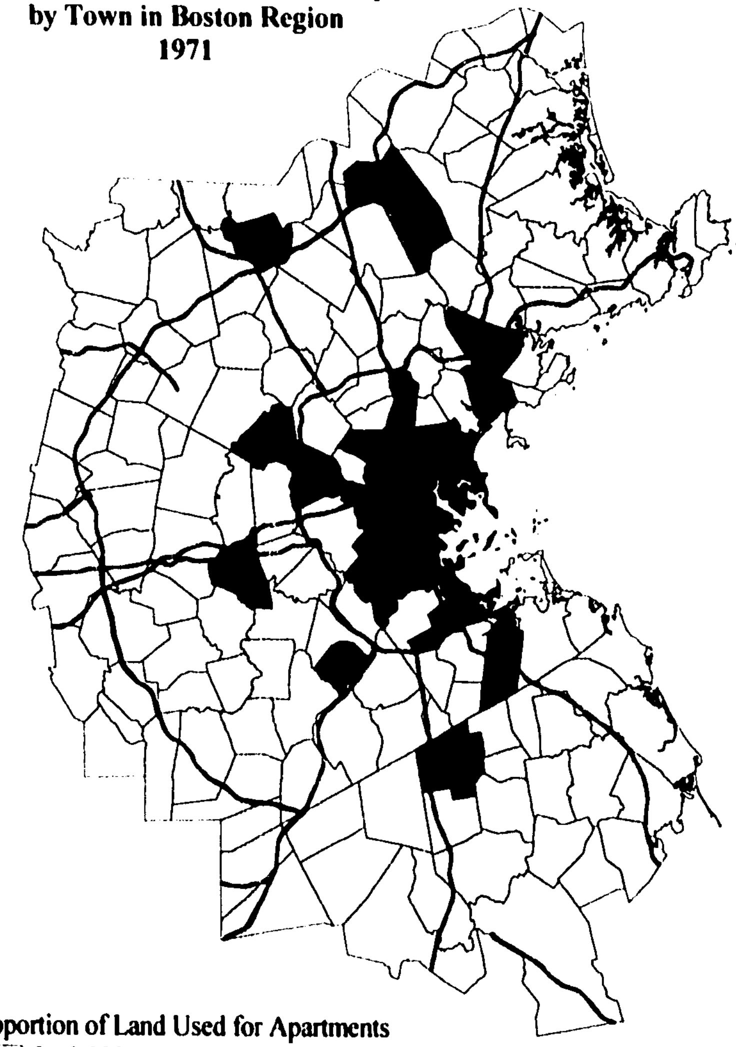
Single Family Land. Maps 4.2-a and 4.2-b reveal that the highest concentration of single family land use is actually not at the central cities of the region. Instead, the most dense single family towns are those right outside the central areas, such as Arlington, Marbehead, Newton, Belmont, Wellesley, Nahant, Melrose, Winchester, Malden and Brookline. In fact, Newton had more single family land area than Boston. This is also true, at a smaller scale, for the secondary centers such as Lowell and Lawrence, as a close examination of Map 4.2-a can tell that there were "holes" at the centers of these towns. This certainly indicates that other urban uses generally outbid single family use for the central locations. Other than this, the distribution of single family land is not that different from that of urban land as a whole. This is not surprising, since almost 70% of urban land is used for single family houses.

Apartments. Apartments were almost the most concentrated urban land use type, as can be observed from Maps 4.3-a and 4.3-b. Out of the 154 towns in the region, one-third had no apartment land at all, another third had only less than 10 hectares of multi-family land. Seven towns -- Boston, Somerville, Cambridge, Everett, Lynn, Medford, and Chelsea -- had nearly 3/4 of the total regional apartment land. All these towns are central cities of the region. A comparison of Maps 3-a and 2-a also reveals that apartments mostly filled into those "holes" left by single family uses in the urban centers.

Map 4.3a Distribution of Apartment Land In Boston Region 1971

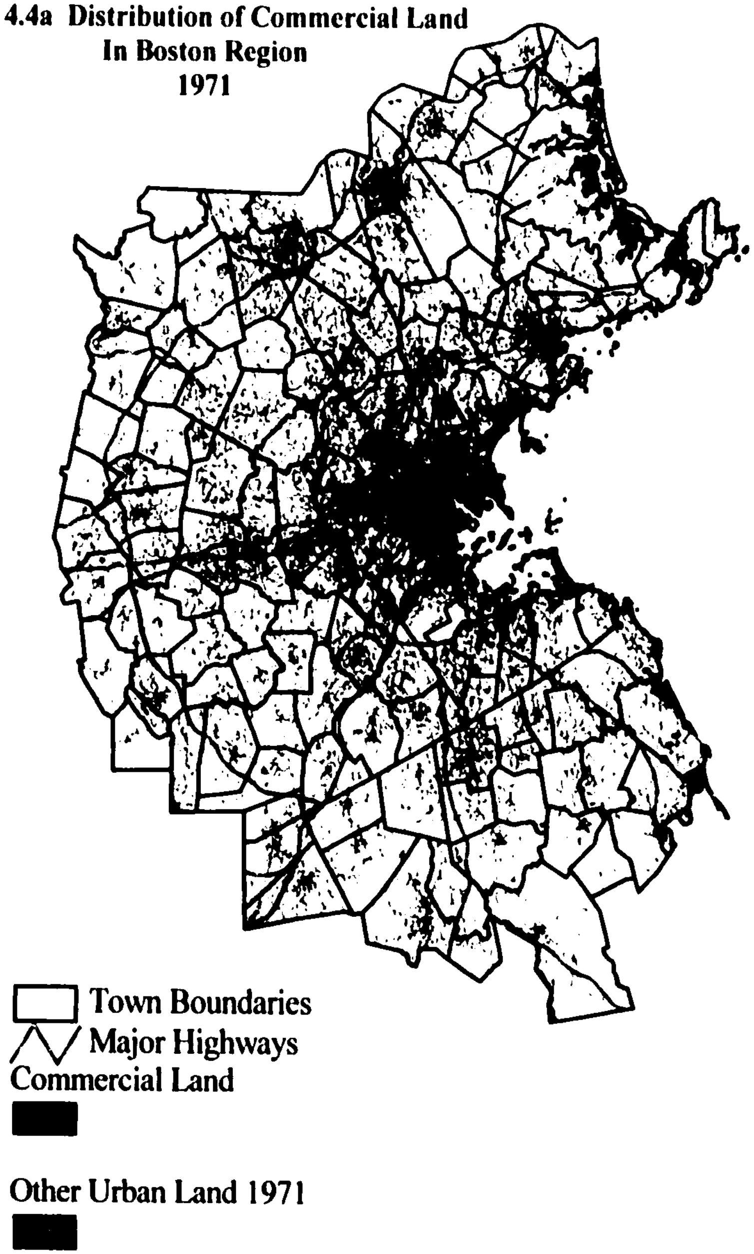


Map 4.3b Proportion of Land Used for Apartments by Town in Boston Region 1971

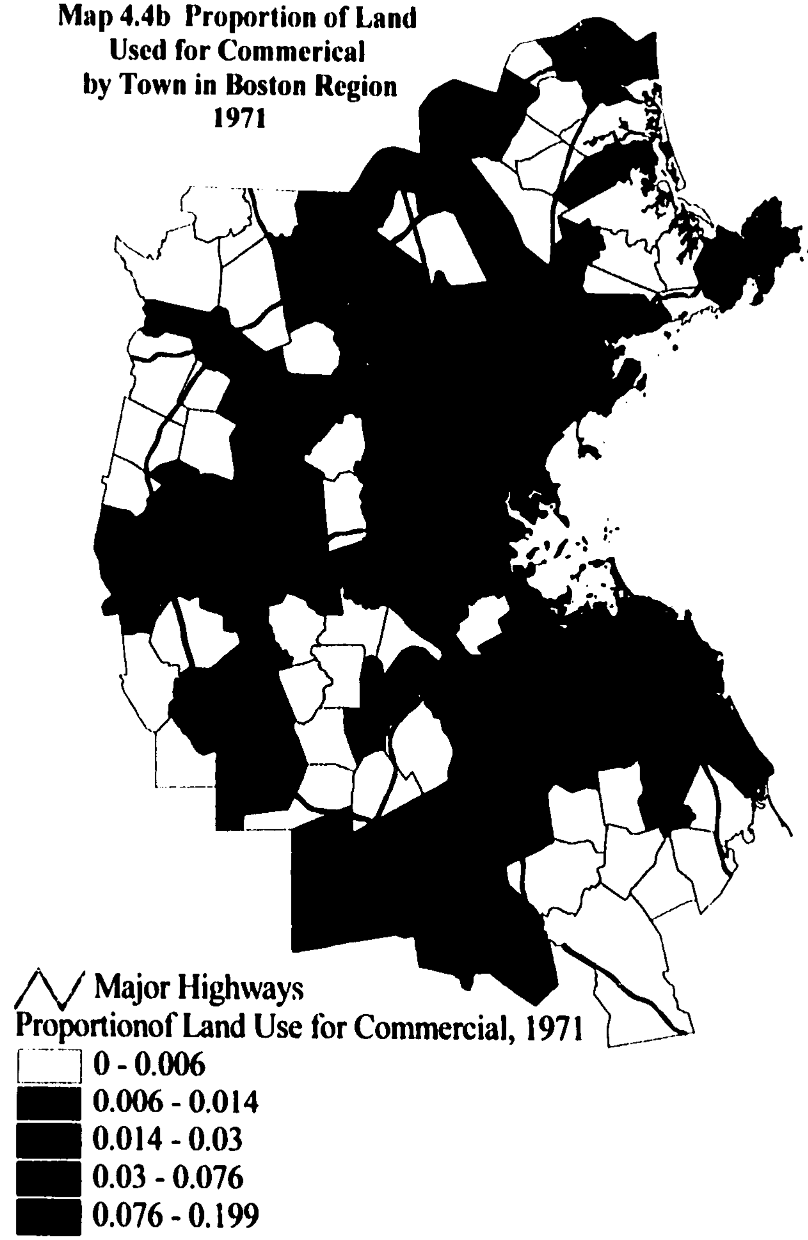


Commercial. Compared to apartment land, commercial land distribution was at the same time more concentrated *and* more dispersed. It was more concentrated in the centers, because large patches of commercial land could be found in major central cities of the region, occupying more central locations than apartments. It was also much more dispersed than apartments, as the sub-regions of the metropolitan area had their own shopping centers, and all the towns retained even smaller commercial districts. In addition to the central commercial area, as shown by Map 4.4-b, major commercial districts can also be found in Waltham, Lawrence, Lowell, Burlington, Brockton, and along the Turnpike. One unique feature of commercial land is that it is often distributed in strips, arranged along major commercial streets by a thin line. This linear distribution feature is apparent in Map 4.4-a.

Map 4.4a Distribution of Commercial Land In Boston Region 1971

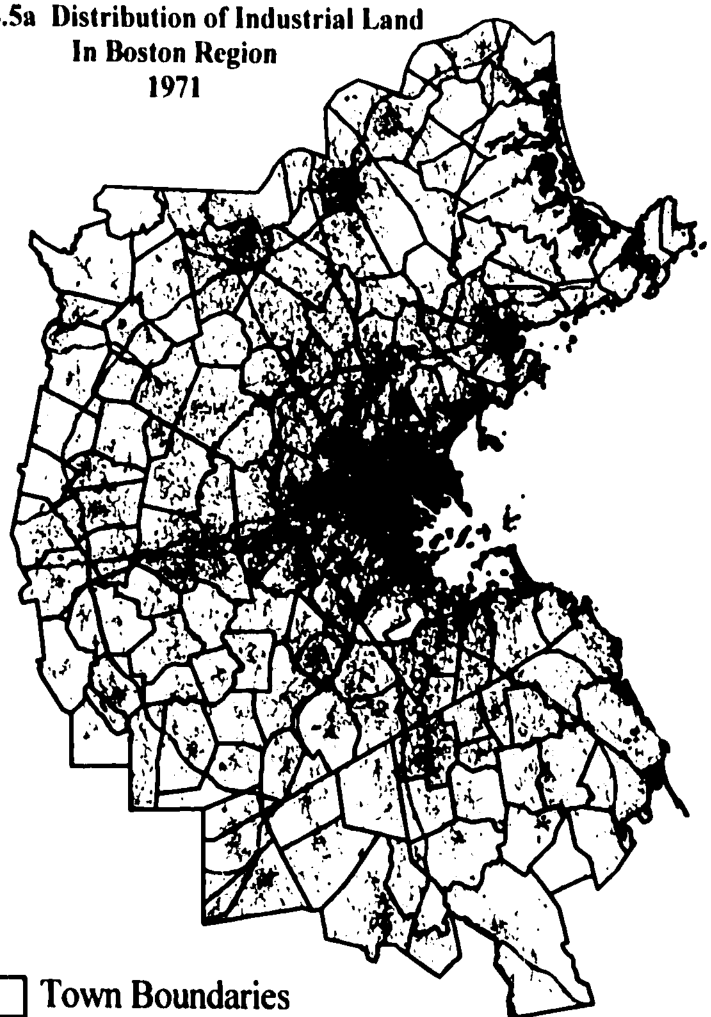


Map 4.4b Proportion of Land Used for Commerical by Town in Boston Region 1971

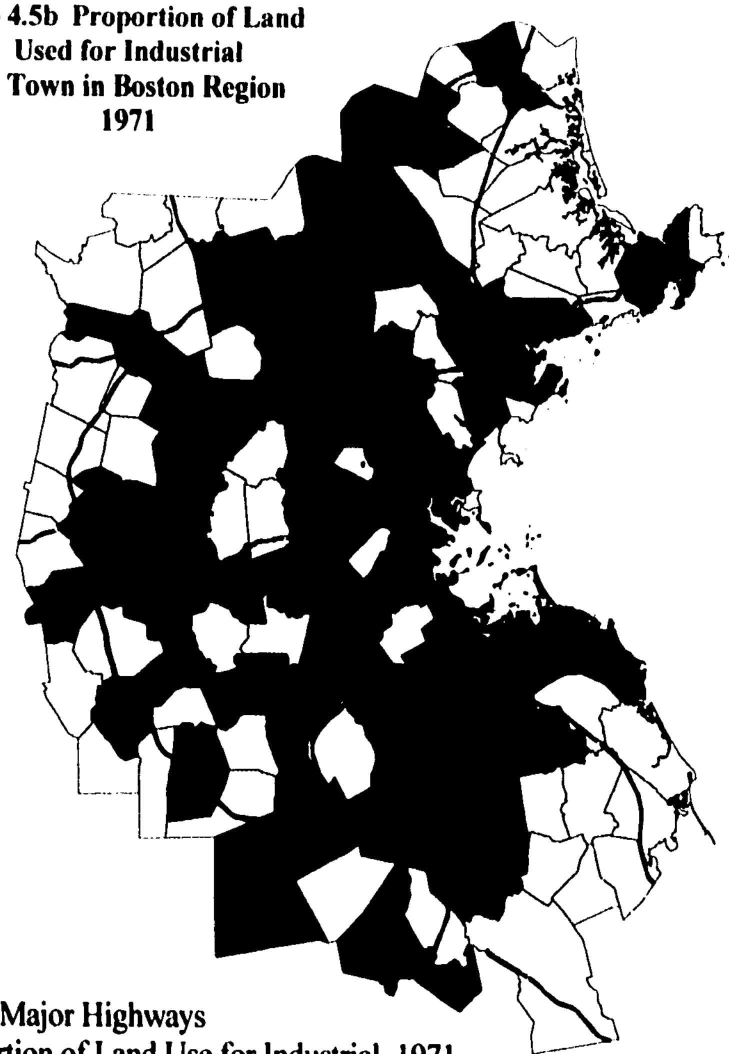


Industrial. Industrial land is mostly distributed in several central cities -- Chelsea, Sommerville, Everett, and Watertown, as well as the suburban center of Lawrence. Map 4.5-a also shows that industrial land was attracted to the freeways, as numerous industrial land patches were found at the major intersections of Route 128, as well as along the Turnpike in the west (especially Framingham), and along Highway 3 and Highway 93 in the north.

Map 4.5a Distribution of Industrial Land
In Boston Region
1971

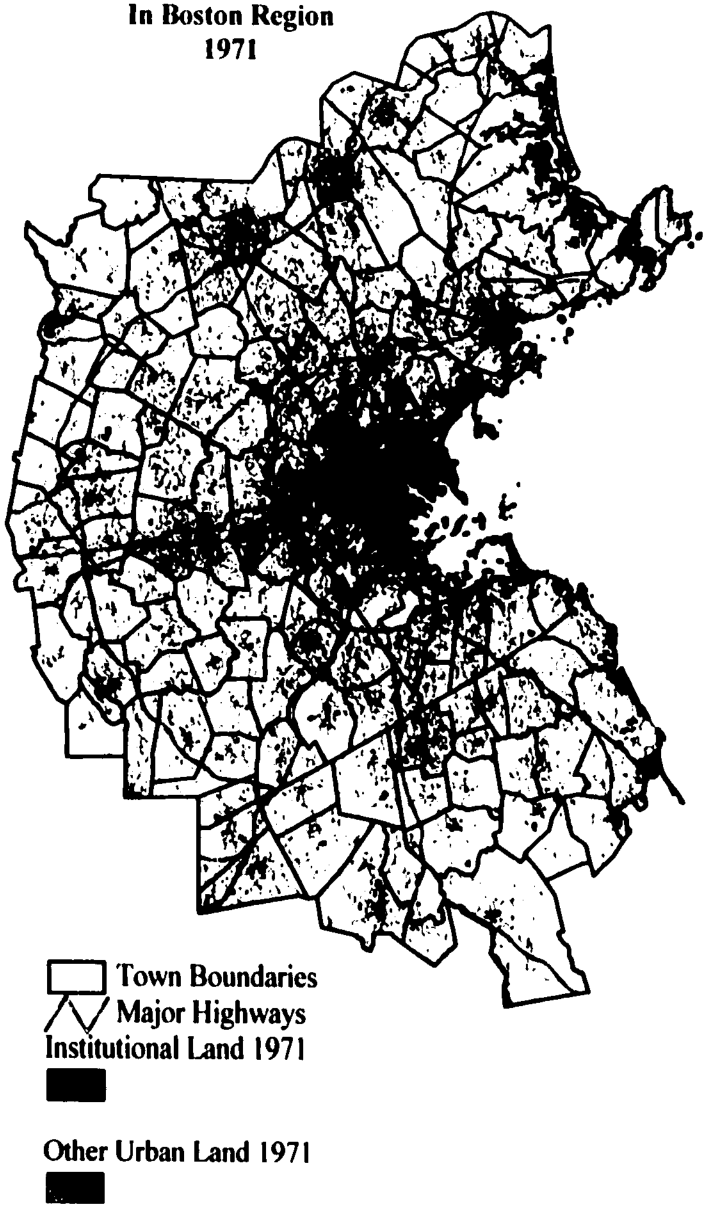


Map 4.5b Proportion of Land
Used for Industrial
by Town in Boston Region
1971



Institutional. Institutional land accommodates a number of social and economic activities: urban public uses, parks, recreation and participation use (golf course, ski resorts, tennis courts, playgrounds), spectator recreation such as stadiums, and water based recreation (beaches, swimming pools). Urban open space, such as parks, cemeteries, and other public green space made up more than 50% of institutional land. To some extent, institutional use is similar to commercial use, as the land is generally used for activities serving local and regional population. Therefore, the overall pattern of institutional land distribution, as shown in Map 4.6-b for distribution by town, is very similar to the one for commercial land use. In fact, institutional and commercial land proportions had a very high correlation coefficient of 0.9 for the 154 towns in the region. In general, like commercial land, institutional land seemed to also follow a negative exponential curve, with the core area within Route 128 having the most area for such use, and declining outward. At the fringe of the region, however, there was an increase of institutional land, especially at the town of Harvard. This is probably a result of the availability of resources for open space. The pattern of institutional land was also different from commercial land in that it did not follow the linear distribution pattern as observed from commercial land.

Map 4.6a Distribution of Insitutional Land
In Boston Region
1971



Map 4.6b Proportion of Land
Used for Industrial
by Town in Boston Region
1971

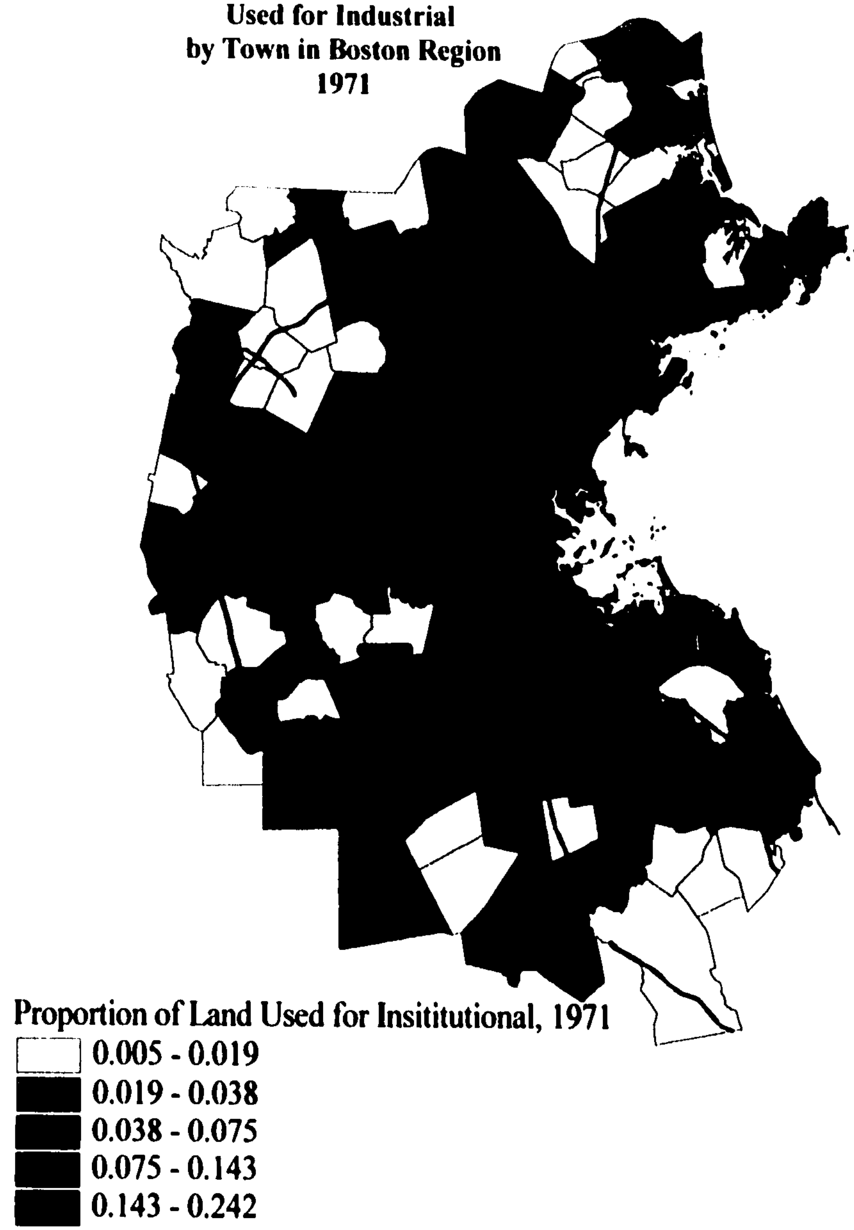
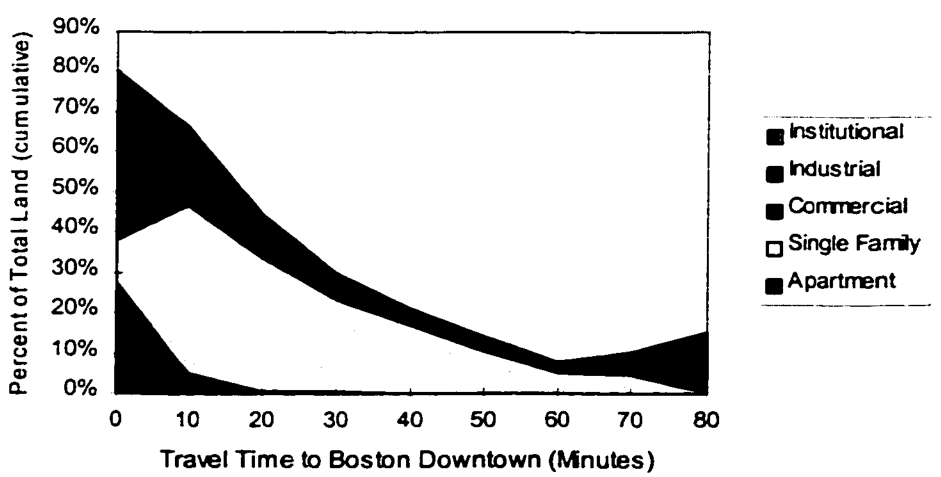


Figure 4.2 summarizes the proportion of five urban land use types as a function of accessibility to the core of the region: Boston downtown. The graph highlights some of the general pattern discussed above. Overall, we saw a gradual decreasing proportion outward for commercial, industrial and apartment land uses. Apartment land in particular, is the most concentrated type of use, as the area within 20 minutes of Boston downtown held 75% of all apartment land. The proportion of land devoted to single family residential use, on the other hand, peaked at the second, instead of the innermost core area, and gradually decreased outward. The innermost zone, while having 38% of all urban land in the region, accommodated only 0.68% of the single family residential land. The proportion of single family land in this zone was only higher than the rings more than 60 minutes away from downtown. Finally, institutional land assumed a generally decreasing proportion, but had a slight increase at the last ring of the region.

Figure 4.2 Composition of Urban Land Uses by Travel Time to Boston, 1971



4.2 Overall Characteristics of Land Use Change Between 1971 and 1991

4.2.1 Land Use Composition

Between 1971 and 1985, the share of developed land increased from 32% to 36%. This represents a total increase of 13% of developed land, or roughly 0.9% annual growth during the 14 year period (Table 4.3).

Table 4.3 Change in Land Use Composition: 1971 to 1985

Land UseType	Proportion in 1971	Proportion in 1985	Percent Change in Acreage	Annual Change in Acreage
Undeveloped	64.8%	59.5%	-8.1%	-0.60%
Developed	32.2%	36.4%	32.5%	2.03%
Other Uses	3.1%	4.1%	13.3%	0.89%

* *Total Area: 650,555 hectares*

The 1991 land use data does not cover the whole study region, but only 541,762 hectares, or 83% of the region. As shown in Table 4.4, this sample area was slightly less developed than the whole region in 1971: 30% of the land is developed, compared to 32% for the whole region. But the area also saw more development in the 1970s and 1980s, as urban land increased annually at a rate of 1.0% and, by 1985, the proportion of developed land increased by almost five percentage points to 35%. Between 1985 and 1991, vacant land conversion accelerated to an annual rate of 1.4%, and the proportion of developed land reaches nearly 38% by 1991. Overall, during the 20 year period between 1971 and 1991, the data shows that developed land in the Boston region expanded by approximately 25%.

Table 4.4 Change in Land Use Composition: Common Areas of 1971, 1985 and 1991

Land Use Type	Proportion in 1971	Proportion in 1985	Proportion in 1991	Percent Change in Acreage 1971-85	Percent Change in Acreage 1985-91	Annual Change 1971-85	Annual Change 1985-91
Undeveloped	66.7%	61.0%	57.8%	-8.5%	-5.2%	-0.6%	-0.9%
Developed	30.1%	34.7%	37.8%	15.0%	9.0%	1.0%	1.4%
Other Uses	3.2%	4.3%	4.4%	37.1%	0.9%	2.3%	0.2%

* *Total Area: 541,762 hectares, where 1991 land use data is available*

A breakdown of the developed land shows that growth rates are uneven for different types (Table 4.5). From 1971 to 1991, all urban land uses expanded except institutional land, whose area decreased by nearly 4% in 20 years. Land for transportation use expanded at an annual rate of only 0.46%, much slower than the average rate 1.14% for developed land as a whole. Consequently, its share of developed land also dropped. All other urban uses saw their shares in the composition of developed land area increased. At an annual rate of 3.1%, industrial land enjoyed the fastest growth. Its share of developed land also increased from about 4% in 1971 to 6% in 1991. However, the overall composition of developed land in 1991 remains similar to that of 1971. Single family use stayed as by far the dominant urban land use in metropolitan Boston, and occupies approximately two-thirds of the total urban land. Despite its declining share, institutional use was still the second most important urban use type in the metropolitan region. The four other urban uses -- apartment, commercial, industrial and transportation -- take comparable shares of the urban land, varying between 4% and 6%.

Table 4.5 **Change of Developed Land Composition, Common Areas of 1971, 1985 and 1991**

Type of Urban Uses	Share in 1971	Share in 1985	Share in 1991	Percent Change in Acreage 1971-85	Percent Change in Acreage 1985-91	Percent Change in Acreage 1971-91	Annual Change 1971-85	Annual Change 1985-91	Annual Change 1971-91
Single Family	66.9%	67.5%	68.1%	16.0%	10.0%	27.6%	1.066%	1.597%	1.225%
Apartment	3.6%	4.1%	4.3%	28.3%	16.3%	49.2%	1.797%	2.543%	2.021%
Commericial	5.6%	5.9%	5.9%	19.5%	9.6%	31.0%	1.279%	1.545%	1.359%
Industrial	3.9%	5.2%	5.8%	51.9%	20.5%	83.1%	3.030%	3.162%	3.070%
Public	13.7%	11.5%	10.5%	-3.1%	-0.7%	-3.8%	-0.225%	-0.112%	-0.191%
Transportation	6.3%	5.9%	5.5%	8.3%	1.1%	9.6%	0.572%	0.190%	0.457%
Total Developed Area (ha)	**163,325**	**187,783**	**204,708**	**15.0%**	**9.0%**	**25.3%**	**1.002%**	**1.449%**	**1.136%**

4.2.2 Land Use Change

Table 4.6 shows more details of the land use change process using the transition matrix, which tabulates the proportion of change between each possible pair of uses. Each cell of the matrix represents the proportion of one use in 1971 (showed in rows) that changed to another use in 1991 (showed in columns). Each cell can also be interpreted as the probability that a land use change occurred between the corresponding use categories. Not unexpectedly, only a rather small percentage of land actually changed use. In fact, probabilities along the diagonal can be interpreted as an index of land use stability (Wilder p64). These probabilities indicate the degree to which land remain in a given use category. From the table it is clear that urban land uses are much more resistant to change: for every urban use except institutional land, only less than 2% of its area changed use in the 20 year period. This certainly confirms the durability of urban capital stock, and indicates the high cost of redevelopment. Institutional land underwent much more change than other urban land uses probably because this category is only partially urban; it includes functions, such as urban open space and beaches, that in certain circumstances are more similar to undeveloped land than to developed land. Moreover, nearly half of the institutional land that changed use (10% of total) went for some special uses labeled in the "others" category.

Table 4.6 Land Use Transition Matrix: 1971-1991

Change From	To Land Use in 1991							
Land Use in 1971	1	2	3	4	5	6	7	8
1. Vacant	0.8652	0.0068	0.0825	0.0061	0.0132	0.0114	0.0024	0.0122
2. Apartment	0	0.9956	0.0001	0.0039	0	0.0004	0	0
3. Single Family	0.0002	0.0009	0.9953	0.0021	0.0007	0.0003	0.0003	0.0001
4. Commercial	0.0002	0.0020	0.0024	0.9915	0.0005	0.0027	0.0005	0.0001
5. Industrial	0.0031	0.0061	0.0007	0.0013	0.9838	0.0040	0.0011	0
6. Institutional	0.0249	0.0145	0.0336	0.0189	0.0252	0.7721	0.0018	0.1092
7. Transport	0.0006	0.0006	0.0002	0.0030	0.0004	0.0003	0.9949	0.0000
8. Others	0.0075	0.0002	0.0015	0.0007	0.0023	0.0019	0.0037	0.9820

* *Lead diagonal indicates percentage of each land use category that remained the same use.*

New Development. Of the 54,822 hectare of land that changed use during these 20 years, 48,661 hectares, or 89% occurred to lands undeveloped in 1971. Table 4.7 lists the hectares and proportion of each type of new development. New development is clearly dominated by construction of single family houses. However, the proportion of vacant land allocated to single family use (61%), is almost equivalent to the use's share of urban land at that time. Comparing Columns 3 and 4 of Table 4.7, one notices that compared to the original situations in 1971, new development was unproportionally devoted to industrial use, and the shares allocated to institutional and transportation uses were significantly less than the existing proportions.

Table 4.7 Vacant Land New Development: 1971-1991

	Area Developed (ha)	Proportion of Area Developed	Compare: Proportion of Urban Land in 1971
Apartment	2,455	5.0%	3.3%
Single Family	29,808	61.3%	60.5%
Commercial	2,210	4.5%	5.1%
Industrial	4,762	9.8%	3.6%
Institutional	4,123	8.5%	12.4%
Transport	883	1.8%	5.7%
Others	4,419	9.1%	9.5%
Total New Development	48,661	100.0%	

Redevelopment. Of the rest 6,161 hectare of land use change that occurred to already developed land, more than 80% represents change from institutional land to some other use. Table 4.8 summarizes land use change for non-institutional urban uses. The rows of the table show the number of hectares in a particular land use category in 1971 that experienced a shift to the corresponding 1991 land use activity. Each column indicates the number of 1971 hectares which shifted to a specific 1991 land use category. The table shows that only 771 hectares were transformed from non-institutional urban land to some other uses. Most of them were originally used for single family houses. Change from single-family to commercial uses is the most important form of redevelopment on non-institutional land; it made up nearly 30% of the total hectares. Single-family-to-apartment, and single-family-to-industrial also, respectively, constitute 13% and 10% of redevelopment area. These facts seem to indicate that single-family land is somewhat more amenable to change than other urban land (except institutional use), and the cost of redevelopment on single-family land may be lower than other types of redevelopment. On the other hand, single family use is also by far the dominant urban land use type in a metropolitan region. As the transition matrix (Table 4.6) shows, the overall probability (frequency) that single family land will change use is still very small (0.47%). In comparison, the chance of industrial land changing to some other use is more than three times higher. More than 1/3 of industrial land use change is to apartment use, but nearly half becomes either vacant land or institutional land. Thus it seems that during this period, industrial land is much more likely than other uses to become vacant or non-use.

Table 4.8 Urban Land Redevelopment: 1971-1991

Land Use Types	1	2	3	4	5	6	7	8	Total Changed from
1. Apartment	-		1	23	0	2	-	-	26
2. Single Family	27	103		225	76	32	31	16	510
3. Commercial	2	18	22		5	25	5	1	78
4. Industrial	20	39	4	8		25	7	0	104
5. Transport	6	6	2	30	4	3		-	52
Total Changed to	55	167	29	287	85	88	43	17	771

Unit: hectare

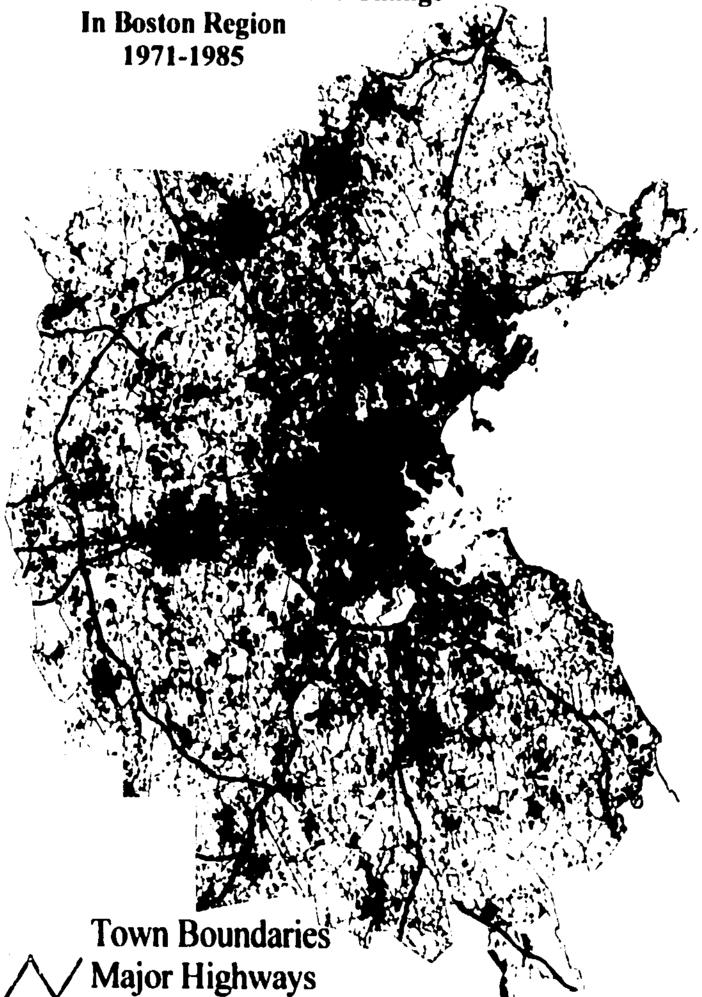
4.3 Spatial Distribution of Land Use Change between 1971 and 1991

This section presents facts as to where land use change took place, and what could be possible reasons that the changes took place in these places. This analysis will provide at least anecdotal insights into the causal relationships of land use change, and prepare for the modeling analysis to be discussed in the next two chapters.

4.3.1 Overall Pattern of Land Use Change

Map 4.7-a shows the actual locations of land use change incidence in the region, for the period 1971-1985. The initial spread of urban land in 1971 was depicted in the map by light gray color. Map 4.7-b summarizes such change at the town/city level by plotting the proportion of land area experienced change of use for each town. Together they give a general picture as to where land use change took place in this period.

Map 4.7a Distribution of Land Use Change
In Boston Region
1971-1985



Map 4.7b Proportion of Land Use Change
by Town in Boston Region
1971-1985

The incidence of land use change, as depicted in Map 4.7-a, was extremely fragmented in the Boston Region. As a result of the fragmentation, the patch sizes for land use changes are generally quite small. The average size of the polygons that have land use change is 3.6 hectares. It also spread all over the region, and every town/city had its share of land use change. The shares, however, varied widely, as Andover and Billerica had more than 2% of regional land use change, and Nahant had only about 0.02% of the change. The ubiquity and fragmentation of land use change in the region is not totally surprising in the context of the initial distribution of urban land described in the previous section. The region had a long history of satellite development patterns with dozens of small and median sized communities dispersed all over the area. Thus it is fairly natural that new land use change took place more as infills into the open interstices than expansion of existing urban cores.

However, the dispersed distribution of land use change should not overshadow the fact that the changes were still unevenly distributed over the region, and one still could detect the concentration of development in certain places, especially with the town level summary as depicted in Map 4.7-b. There appeared to be three large clusters where most land use change took place. The largest cluster was in the northwest of the region surrounding the two suburban towns of Lowell and Lawrence[9], extending from the outer Beltway to the inner Beltway flanked by Freeways 93 and 3. This cluster of land use change included 13 towns. A second cluster with intensive land use change involved seven towns at the southwest of the region, surrounded by four freeways: the inner and outer beltways, Interstate 95 and state route 24. Three western towns -- Westborough, Northborough and Marlborough -- formed a third cluster with intensive development at the intersection of Interstate 495 (the outer Beltway) and the Massachusetts Turnpike. All three clusters were obviously closely related to intersections of major freeways. In addition to these three clusters, towns along the outer Beltway also saw more land use change. In comparison, relatively little change occurred along the west part of Route 128 and along the segment of the Turnpike to the west of the 495 intersection. Also saw little development is the northeast part of the region.

Figure 4.3 summarizes the relationships between total amount of observed land use change (normalized by land area) and travel time to Boston, an indicator of accessibility to central city. The graph presented the changes for both study periods, and decompose the change into two types: new development and redevelopment. For vacant land development during the first study period, proportion of land use change followed a slightly decreasing curve away from the downtown, showing some indication of preference for central location. However, unlike the usual negative exponential decreasing curve, this downward sloping curve for vacant land use change 1971-85 is convex rather than concave. This indicates that the propensity of use change to occur toward the center, if it exists at all, is rather weak.

In comparison to this curve, the curve representing vacant land change during the second study period stays lower at every distance mark from downtown. This is not unexpected, as the second study period has only 6 years, less than half the duration of the first period, and fewer land use change incidences could be expected for this shortened

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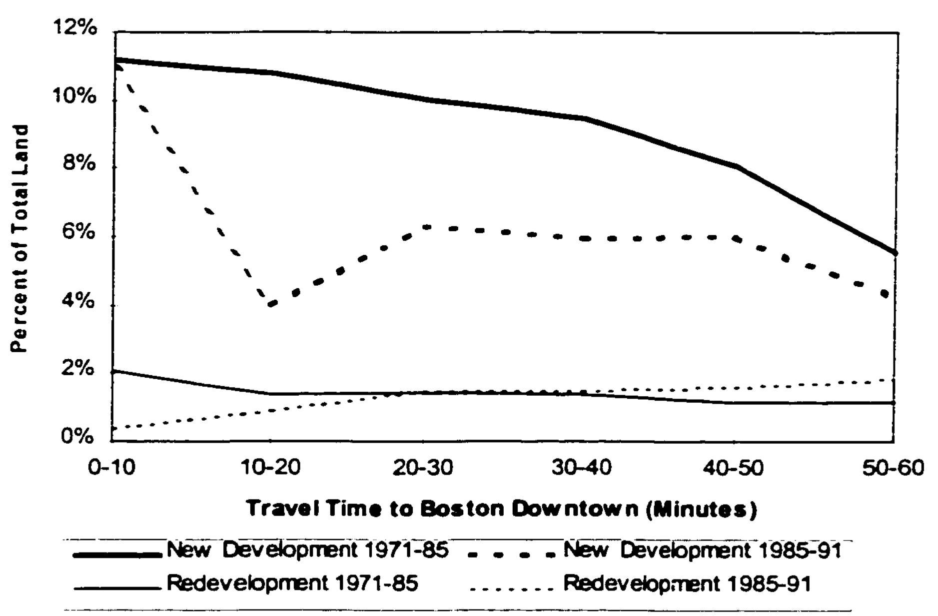
[9] Note that the two towns themselves did not experience as much change.

period. The curve shows a lack of new development in the ring between 10 to 20 minutes away from the downtown. This ring roughly corresponds to the towns right outside Boston City but inside Route 128. The proportions of land changed use also remained approximately the same at 6% for the three rings between 20 to 50 minutes away from downtown. Therefore, if these is some indication that access to central city was a factor for land use change from 1971 to 1985, this factor seemed to play no role in the land use change process from 1985 to 1991.

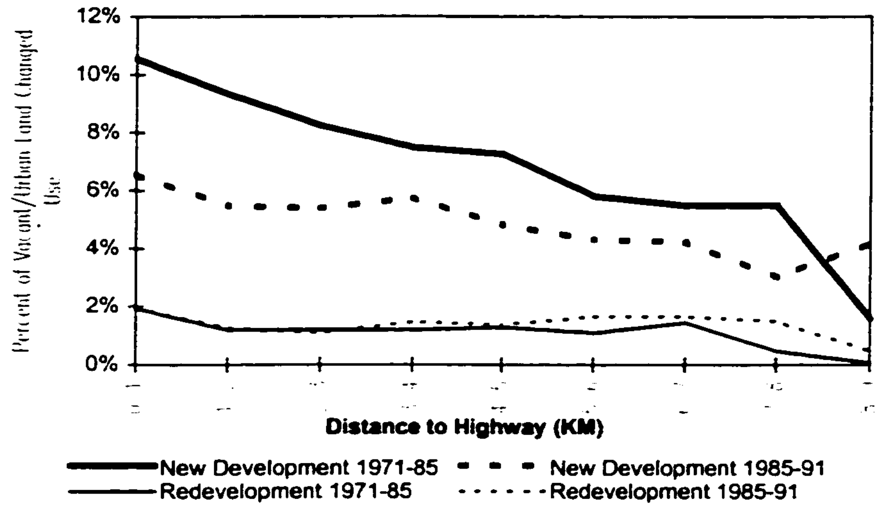
Figure 4.3 Proportion of Land Use Change by Travel Time to Boston, 1971-1991



Conventional emphasis on access to CBD also seemed to be invalid for urban redevelopment. Overall, there were very few instances of urban redevelopment during both periods, and the variation of land use change by travel time to Boston was not big. During the first period, proportions of urban land changed use was about same for all the rings with varying travel time to Boston, except that the closest ring was slightly higher than the rest. For the second period, the curve actually tilted slightly upward, showing some propensity for redevelopment to be away from the center, although this trend may not be statistically significant. Comparing all the four curves regarding the preference for access to central city, we probably could conclude that, first, vacant land development appeared to value centrality more than redevelopment, and second, the importance of centrality decreased (or may even be reversed) during the later period. This result, of course, is subject to more rigorous test in the following chapters.

Figure 4.4 plot the change of land use against Euclidean distance to the nearest freeways in a similar fashion. There also appeared to be similar, if not exactly the same, relationships as discussed for travel time to Boston. For vacant land during both periods, proportion of land having use changed generally declines farther away from the closest freeways. This trend, however, was considerably weaker during the second study period, and may not be statistically significant. For urban land, there appeared to be no significant relationship between redevelopment and access to freeways. For both vacant land development and urban land redevelopment, the value of access to freeways decreased during the later period, a phenomenon that seemed to also hold for travel time to Boston.

Figure 4.4 Proportion of Land Use Change by Distance to the Closest Freeway, 1971-1991



4.3.2 Patterns of Land Use Change for Individual Use Types

The locations of land use change for each individual type of use category may well be very different from the general pattern described above for overall occurrence of use change, since the importance of various locational factors, such as transportation accessibility, physical typography, and community characteristics may play different roles in the process of urban change for different use categories. In this section I discuss the pattern of land use change as observed for the Boston region.

Change of Land to Single Family Residential Use. Map 4.8-a shows the actual incidences of land use change to single family residential use, while Map 4.8-b summarizes, for each town, the percentage of land that changed to this urban use.

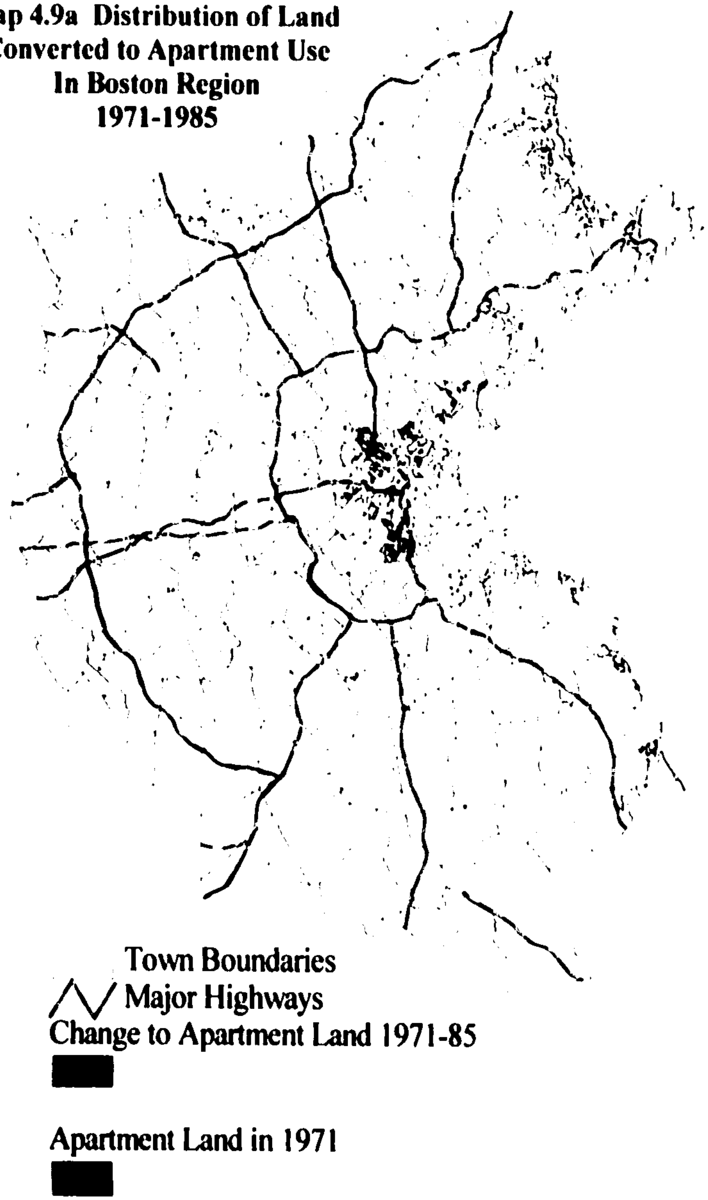
Map 4.8a Distribution of Land Converted to Single Family Residential Use In Boston Region 1971-1985

Map 4.8b Proportion of Land Converted to Single Family Residential Use by Town in Boston Region 1971-1985

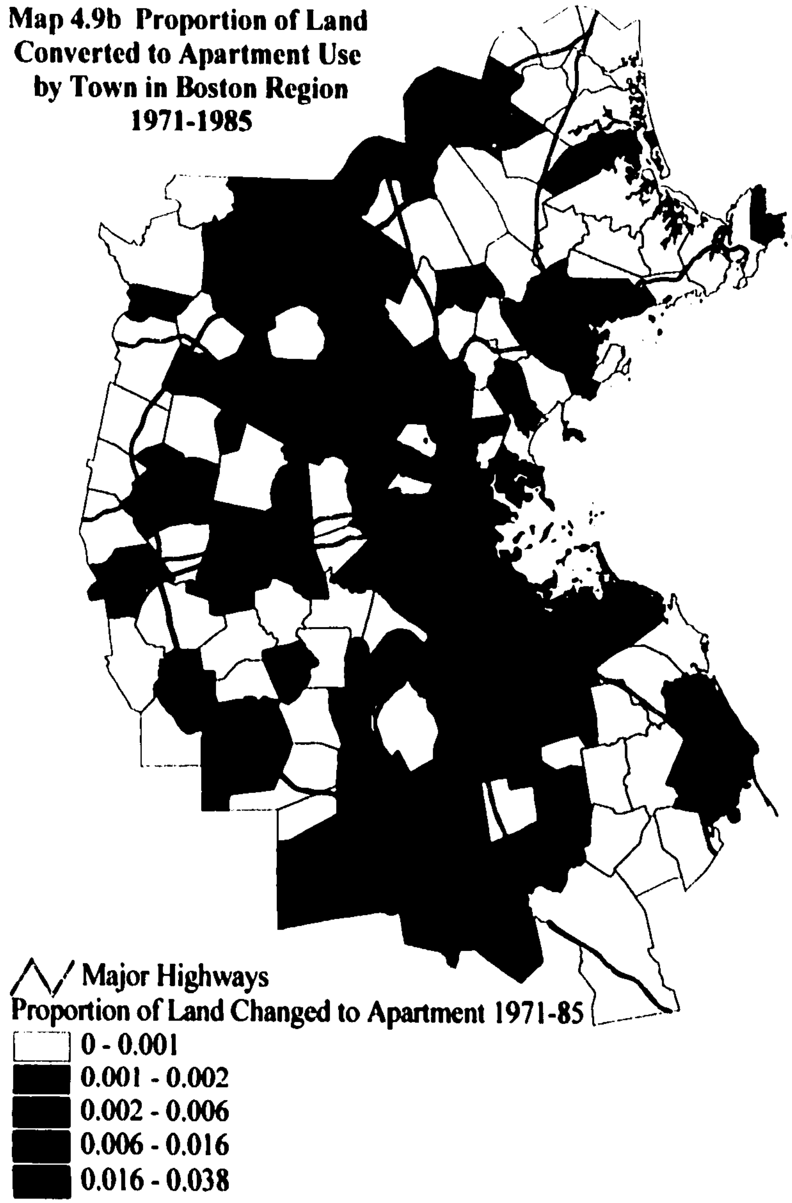
The maps reveal that single family residential development during the 1971-1985 period occurred mostly by filling into the open spaces left by numerous satellite towns. As a result, the spread of single family residential change is very dispersed into the interstices of open space in the region. The average patch size of such change is approximately the same as the average size for all types of land use change during this period. The infill nature of single family residential change is further revealed by the comparison between Map 4.8-b and 4.2-b, the initial distribution of single family residential use. In general, the towns having experienced more single family development are those whose initial proportion of single family land was low. For instance, the towns inside Route 128 but outside the core cities (Boston, Cambridge, Somerville, Everett, and Chelsea) had the highest percentage of land allocated for single family residential use in 1971. However, from 1971 to 1985, except several ones in the north around the intersection of Highway 93, these towns experienced almost no such development. Town level summary indicates that there was relative concentration of residential development along the outer Beltway. Two sub-areas enjoyed some clustering of development. First is the area outside Lowell and Lawrence, fairly close to the two major freeway intersections in the north. Development in the area seemed to be the result of both the extension of the two suburban centers and the outward expansion of the regional core along the two radiating freeways. Another sub-area that saw relatively more development is in the southwest surrounded by the Turnpike, Interstate 95, and the two Beltways. Note that this is the area that, up to 1971, had been somewhat bypassed by urbanization in comparison with its surrounding areas. There seemed to be some reversed development by which the lots along Highway 495 was developed first, and then, between 1971 and 1985, significant infill took place back toward the regional center. In addition to these two major sub-areas, residential development was also relatively concentrated to the west of the interchange of the Turnpike and the outer Beltway, the interchange of the outer Beltway and State Route 3, as well as the part inside the outer Beltway franked by State Route 3 and 24.

Change of Land to Apartments. There were relatively few instances of apartment land development between 1971 and 1985, as revealed by Map 4.9-a. There was also no clear locational logic, at least at the regional level, that can be detected by inspecting the spatial distribution of apartment development in Map 4.9-a and 4.9-b, Patches of new development were generally small, and very dispersed over the region. The distribution did not seem to assume any relationship with the initial distribution of apartment land, which was clearly concentrated in the regional core. Map 4.9-b shows that such development tended to occur more frequently a) inside the inner Beltway, b) along the radiating freeways, and c) at the intersections of the radiating freeways and the outer Beltway. A closer inspection of Map 4.9-a reveals that, at a more micro scale, apartment development tended to occur as expansion of the existing urban areas centered around median or small sized satellite towns in the region. This pattern is particularly obvious for the developments at the periphery of the urban property centered around Lowell and Lawrence.

Map 4.9a Distribution of Land Converted to Apartment Use In Boston Region 1971-1985

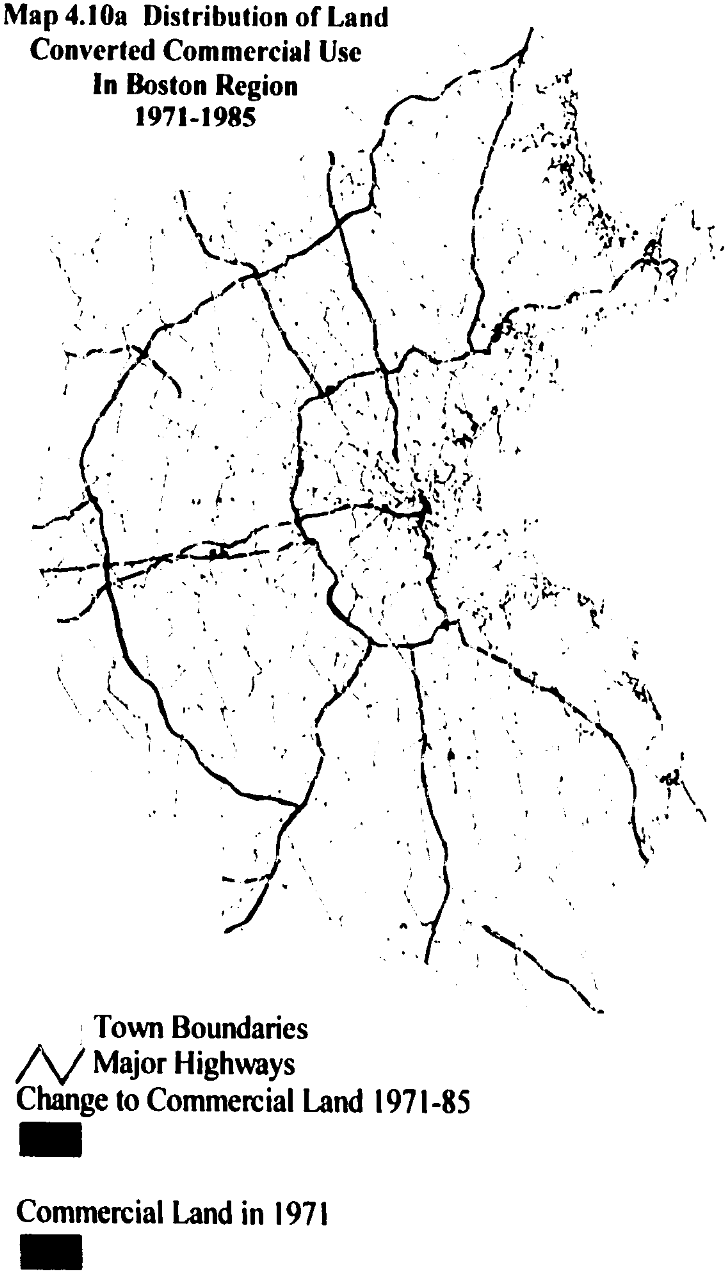


Map 4.9b Proportion of Land Converted to Apartment Use by Town in Boston Region 1971-1985

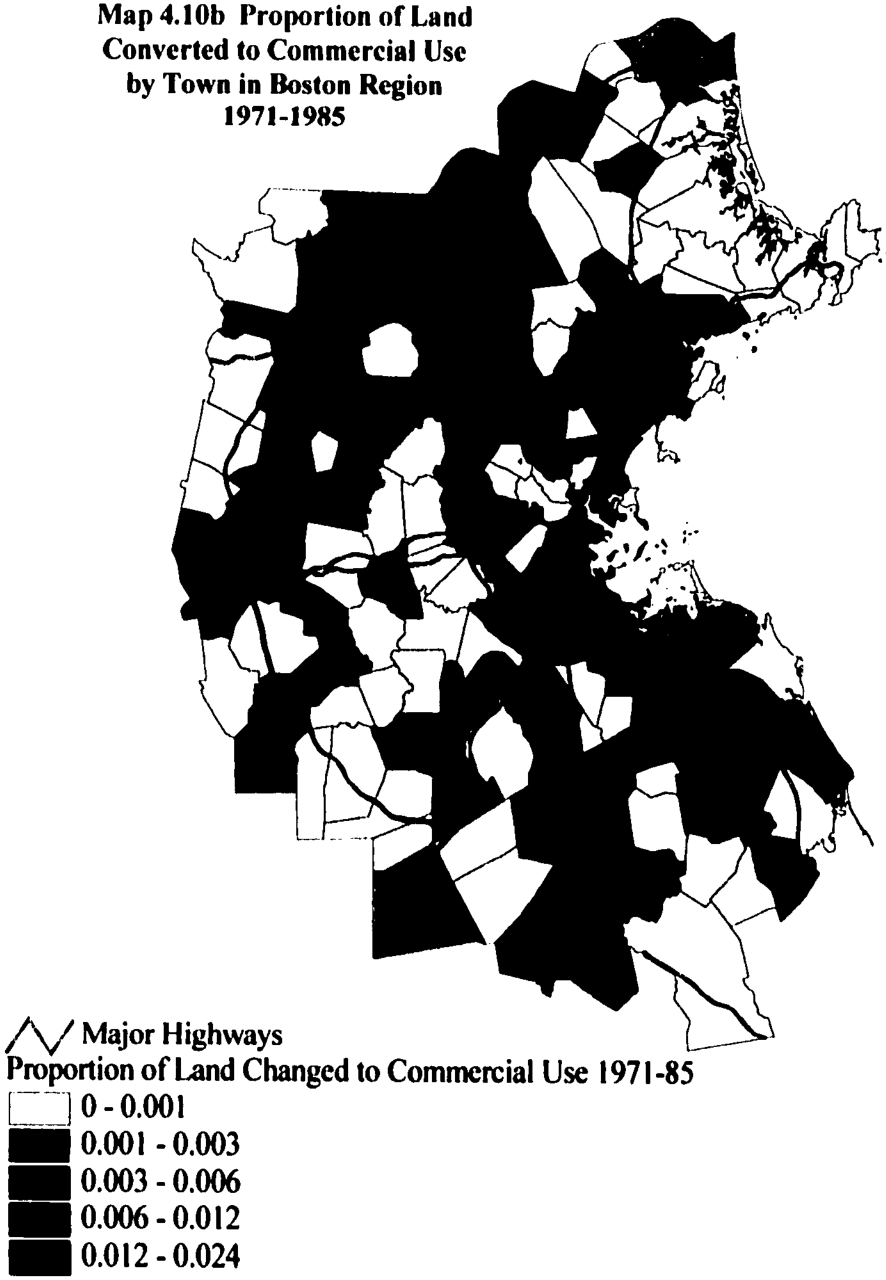


Change of Land to Commercial Use. While the initial distribution of commercial land in 1971 was notably linear, obviously along the major commercial streets in the region, the influence of the freeway network on the distribution was only tentative and at the beginning stage. Commercial land development after then, however, was particularly oriented toward the freeway systems in the region. The buffer corridors within 1 kilometer of major freeways takes only 16% of the total land in the region, but approximately half of the regional commercial land development between 1971 and 1991 occurred within this area. This closeness of commercial development to the freeway network is clearly related to the increasing importance of automobile use in commercial activities, and the trend of construction of large discount stores and suburban shopping malls at places with easy access to freeways. Out of the freeway network, commercial development was more concentrated in (a) the northern segment of Route 128, especially at the intersections of Highway 3, 93 and 95, (b) the southern segment of Interstate 95, north of Boston downtown, especially around the intersection with Route 128, and extending south up to the periphery of the regional core, (c) the western segment of the Turnpike, outside the outer Beltway, and extending along the Beltway north up to the intersection with Interstate 290; (d) the north segment of the outer Beltway, at the intersections with Highway 3 and 93, and also outside the core of the three suburban centers of Lowell, Lawrence and Haverick; (e) the north end of Highway 3, to the south of Route 128; and (f) the segment of Interstate 95 to the south of Route 128. Summary of commercial land development, as depicted in Map 4.10-b, also reveals that the towns enjoying the most development are the ones with each access to the freeway network, especially the six segments discussed above.

Map 4.10a Distribution of Land Converted Commercial Use In Boston Region 1971-1985



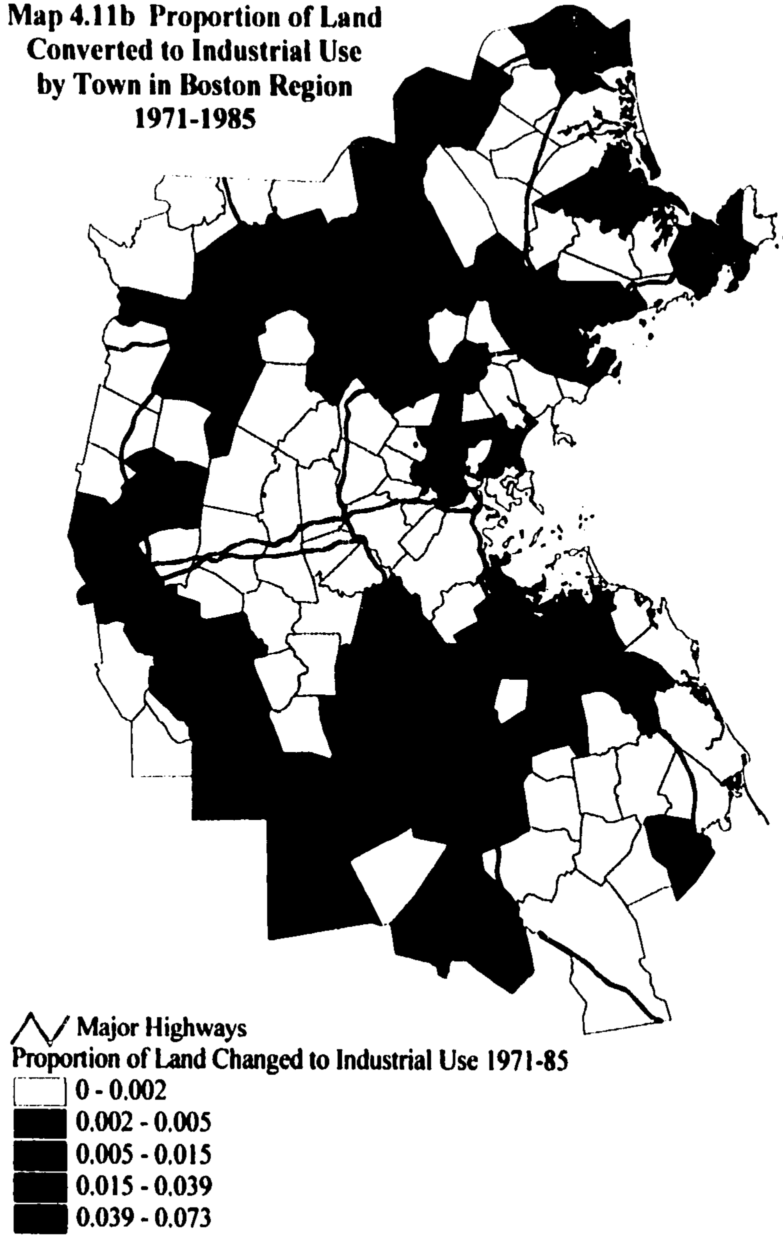
Map 4.10b Proportion of Land Converted to Commercial Use by Town in Boston Region 1971-1985



Change of Land to Industrial Use. The distribution of industrial land development, shown in Map 4.11-a and 4.11-b, is similar to that of commercial development in that it was also obviously related to the regional freeway network. 46% of new development occurred within 1 kilometer of major freeways. There is, however, important difference in the spatial pattern of development between commercial and industrial land. Incidences of industrial development appeared to have larger patch sizes, either because the average lot size of new development was larger, or because different projects of industrial development tended to locate close to each other to take advantage of agglomerative economies. The average patch size of new industrial development was 5 hectare, compared to the average of 3.6 hectare for all land use change incidences. Industrial land development was also more concentrated than any other urban land development, possibly to take advantage of agglomerative economies. A comparison of Map 4.11b and Map 4.5b shows that, unlike other urban land development, industrial land development bore fairly close relationships to the initial locations of industrial land in 1971. Towns undergoing more development are the towns with relatively high proportions industrial land. They include: (1) within the inner Beltway, the area to the north of Boston city; (2) the area in the northwest surrounded by the two beltways, Highway 93 and 3; (3) the intersection of Interstate 95 and 495 in the north; (4) the intersection of the Turnpike and the outer Beltway; (4) along Interstate 95 in the south between the two beltways. It is also interesting to notice, by comparing Maps 4.11-a and 4.10-a, that the general pattern of industrial development is very similar to that of commercial development, only that it took place in a more compact fashion.

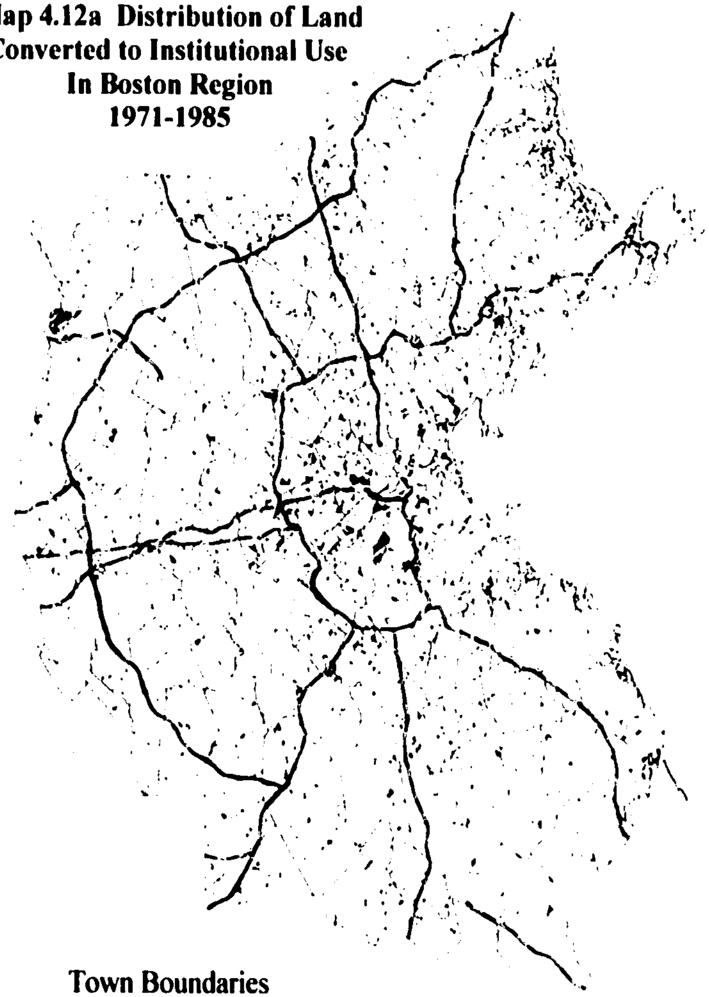
Map 4.11a Distribution of Land Converted to Industrial Use In Boston Region 1971-1985

Map 4.11b Proportion of Land Converted to Industrial Use by Town in Boston Region 1971-1985

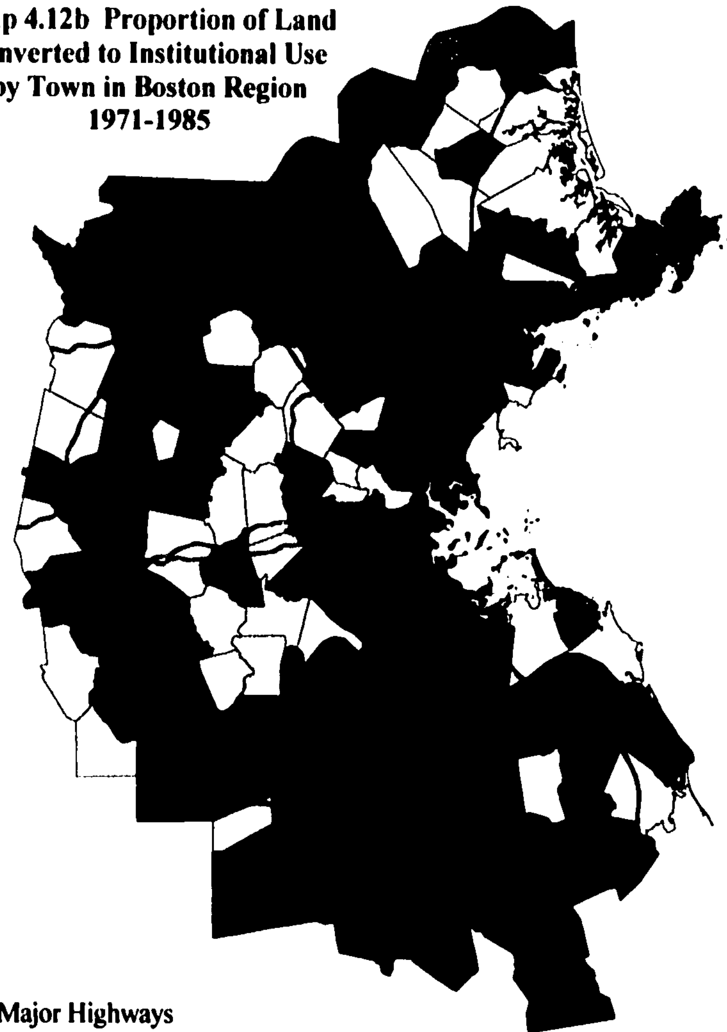


Land Use Change to Institutional Use. Places where land changed use to institutional activities are presented in Map 4.12-a and 4.12-b. There was not significant amount of land changed into institutional use from 1971 to 1985, and the distribution of the event was rather scattered. There appeared to be a couple of areas, both lying between the two beltways, that were bypassed by land conversion to institutional activities. The first is between State Route 3 in the north and Interstate 95 in the south, the second is between Highway 93 and Highway 1 in the north. Other than these two areas, institutional land use change was quite dispersed and there did not appear to be obvious pattern from mere visual inspection of distribution maps.

Map 4.12a Distribution of Land Converted to Institutional Use In Boston Region 1971-1985



Map 4.12b Proportion of Land Converted to Institutional Use by Town in Boston Region 1971-1985



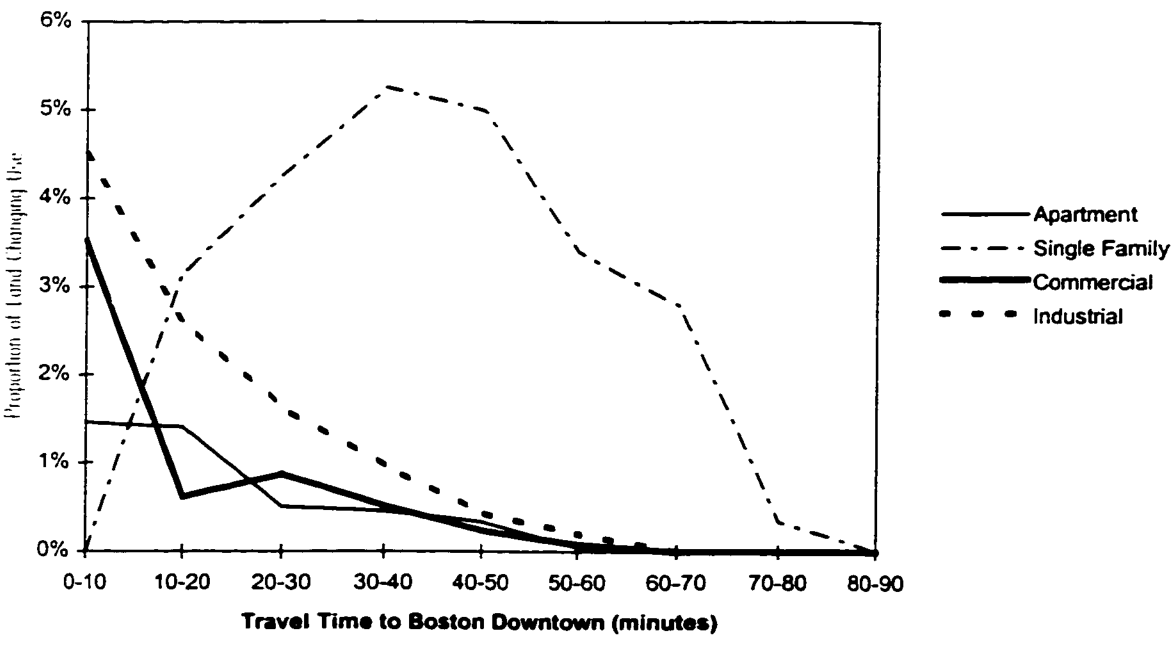
4.4 Land Use Change and Distance/Travel-Time Factors

The above discussion of land use change distribution relies highly on factors such as how far away were the sites away from the center of the region (Boston downtown), and how easy was the sites' access to the regional freeway network. In this section, I summarize in a more systematic way the relationship between observed land use change and central city access and highway access. As I did for summary of overall land use change, I distinguish here between new development on vacant land and redevelopment on initial urban land. I also summarize and compare the changes for both study periods.

4.4.1 Land Use Change and Proximity to Central City

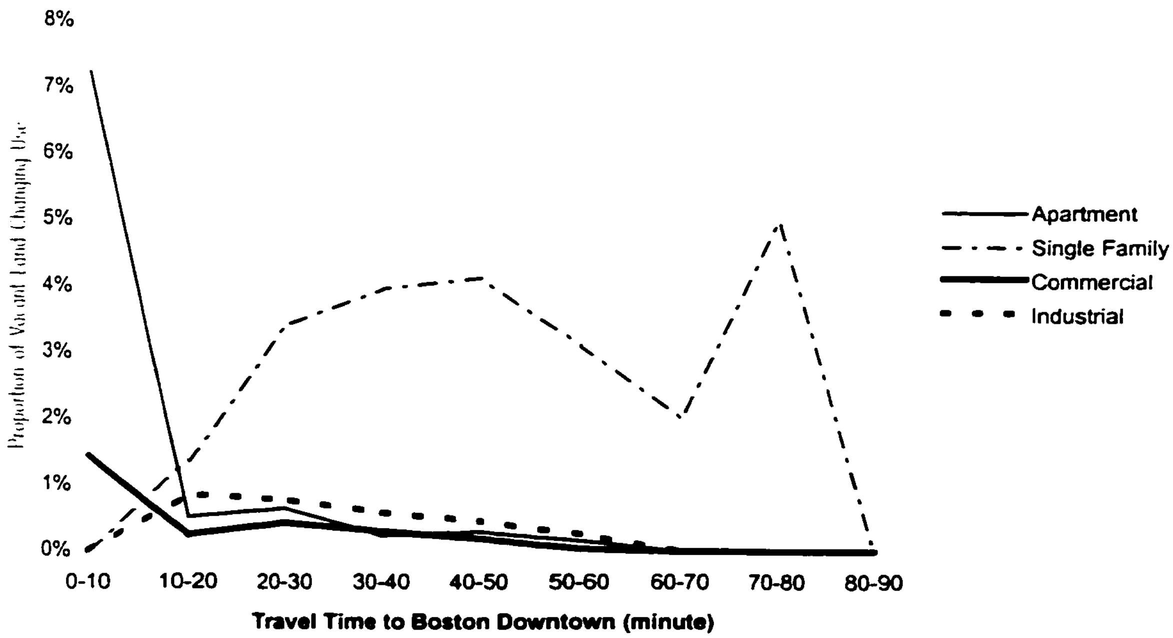
Figure 4.5, which shows the intensity of vacant land use change as a function of travel time to Boston downtown, tells that the preference for central location differs by the types of land development between 1971 and 1985. Industrial and commercial land development on vacant land clearly was attracted toward the central city during this period. In particular, the curve for industrial development almost fits a perfect negative exponential curve. For commercial land, the drive toward center was very strong, but there was a rather sharp drop right outside the central core which resulted in small valley about 10-20 minutes away from downtown. This may be a result of the hierarchical locational nature of commercial land use: the ring between 10 to 20 minutes away from downtown may have been well served by new development very close to downtown, therefore, demand for commercial development locally was relatively lower. Note, however, that vacant land was extremely rare in the rings close to downtown. The first two rings (less than 10 minutes from downtown, and between 10 and 20 minutes from downtown, respectively), has only 0.005% and 3% of the vacant land in region. Therefore, even though percentage of this vacant land stock changing to industrial and commercial use was high, the change actually represented only a very small proportion of the total vacant land development that took place for these two types of use activities. There was also evidence that apartment development on vacant land favored central location, too, although the appeal of the very central location (within 1 kilometer) was almost no more stronger than the next ring. In contrast to these three types of development, vacant land change to single family residential use followed a Bell shape. There was almost no single family development in the first ring. Development pressure peaked about 30 to 50 minutes away from downtown, and then faded away further into the periphery.

Figure 4.5 Proportion of Vacant Land Changed to Each Use Category by Travel Time to Boston, 1971-1985



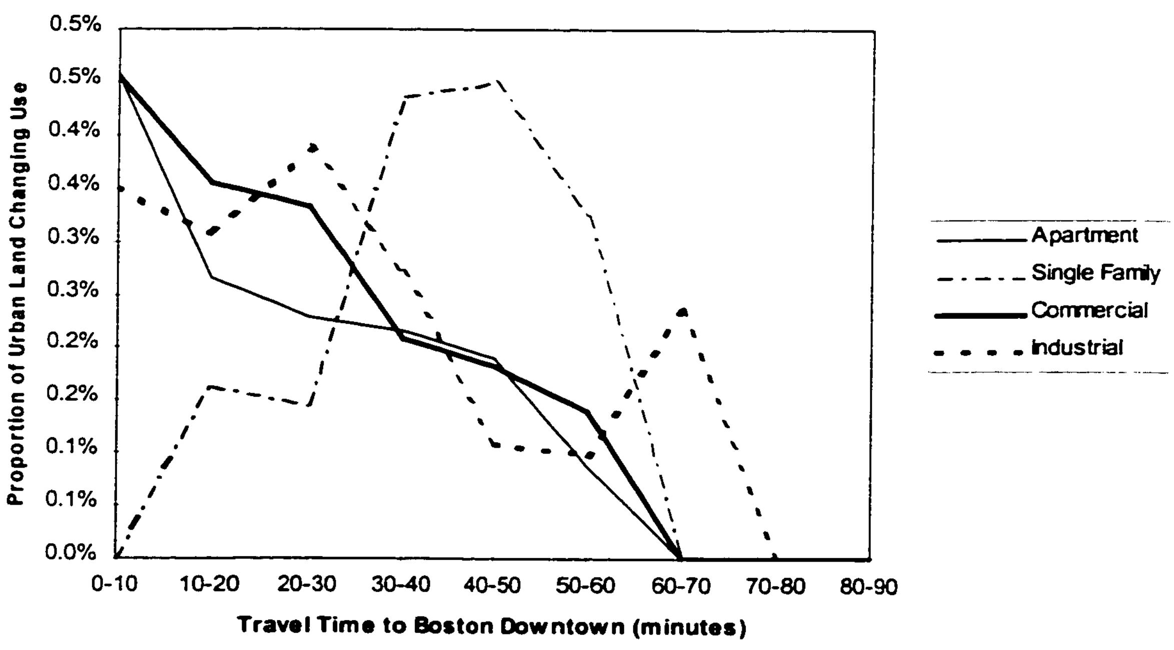
For the second study period from 1985 to 1991 (Figure 4.6), the importance of central location seemed to have decreased for all development types except apartment. While only 1.5% of vacant land in the most central zone changed to apartment use during the 14 years from 1971 to 1985, the proportion changing to apartment use in the 6 years between 1985 and 1991 was 7.2%. This percentage, however, dropped sharply to about 0.5% in the second and third ring. Commercial development approximately followed the pattern observed for the previous period, although attractiveness of central locations was significantly weakened. New industrial land, on the other hand, completely bypassed downtown in this period, and development was peaked between 20 to 30 minutes away from downtown, and gradually decreased toward the outskirts. For single family residential development, there was an idiosyncratic peak 70-80 minutes away from downtown. Otherwise it is Bell shaped, with the peak moving slightly away from downtown.

Figure 4.6 Proportion of Vacant Land Changed to Each Use by Travel Time to Boston, 1985-1991



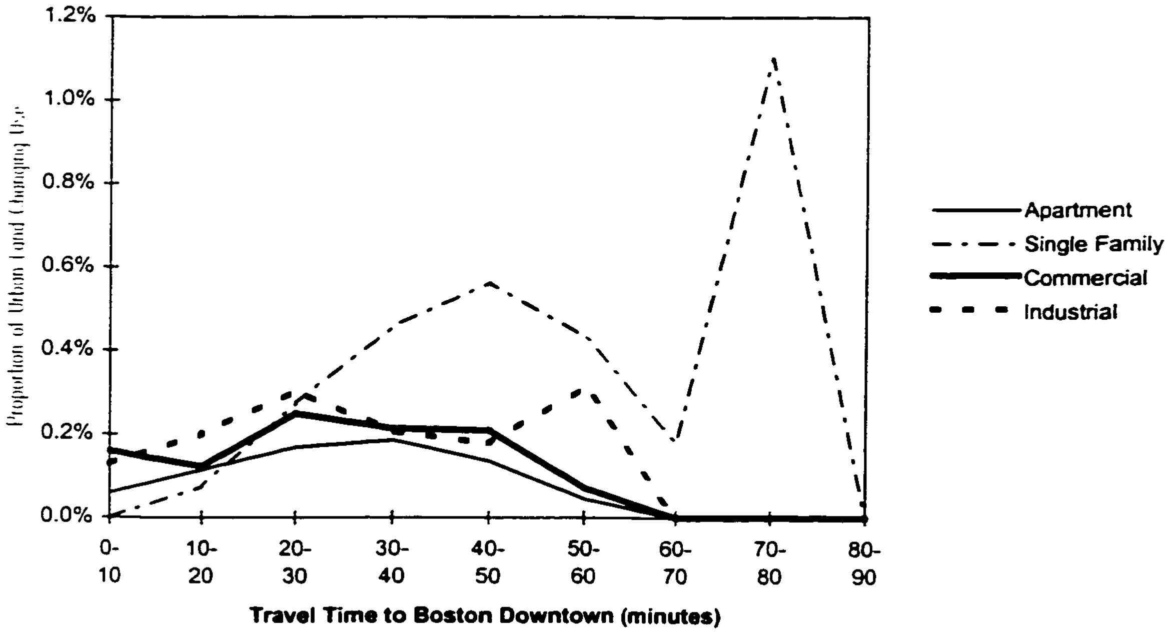
Redevelopment activities from 1971 to 1985, shown in Figure 4.7, presented some interesting resemblance to the pattern observed for vacant land development. Proportion of *urban land* that was redeveloped to commercial and apartment use all declined farther away from downtown, just as they did for vacant land development but at a much smaller scale (percentage of urban land redeveloped was very small compared to percentage of vacant land developed). Redevelopment to industrial land was much less regular. There was an idiosyncratic peak 60 to 70 minutes away from downtown. Apart from this, there was a slight upward slope up to 20-30 minutes away from downtown, and downward slope farther away.

Figure 4.7 Proportion of Urban Land Changed to Each Use Category by Travel Time to Boston, 1971-1985



Redevelopment during the later period, however, assumed a very different pattern. As shown in Figure 4.8, apart from an unusual peak for single family residential development 70-80 minutes away from downtown, as it did for vacant residential development, all the redevelopment types generally followed a Bell curve, with the peaks varying between 20 to 50 minutes away from downtown. It seems that during this period, for urban land redevelopment at least, proximity to central city was of no importance at all.

Figure 4.8 Proportion of Urban Land Changed to Each Use Category by Travel Time to Boston, 1985-1991



4.4.2 Land Use Change and Proximity to Highway

The relationship between land use change and access to highway is plotted in Figures 4.9 to 4.12. In general, the figures appear to show that the relationship between land use change and access to freeway is much stronger for business land use (commercial and industrial) than for residential use (either single family or multi-family). This seems to hold for both new development and redevelopment, but is particularly apparent for new development. Figure 4.9 and 4.10, which are for new development for the two different study periods, are very similar. In both, industrial land use change seemed the most attached to freeway access. For commercial land development, the emphasis seemed to be adjacency to freeway rather than access to freeway -- commercial development was much more likely to be within one kilometer of freeway. Farther than that, distance to freeway seemed to play rather insignificant roles for commercial development. On the other hand, for both types of new residential development, the curves are quite flat or irregular, indicating no significant relationships with access to freeway.

Figure 4.9 Proportion of Vacant Land Changed to Each Use Category by Distance to the Closest Freeway, 1971-1985

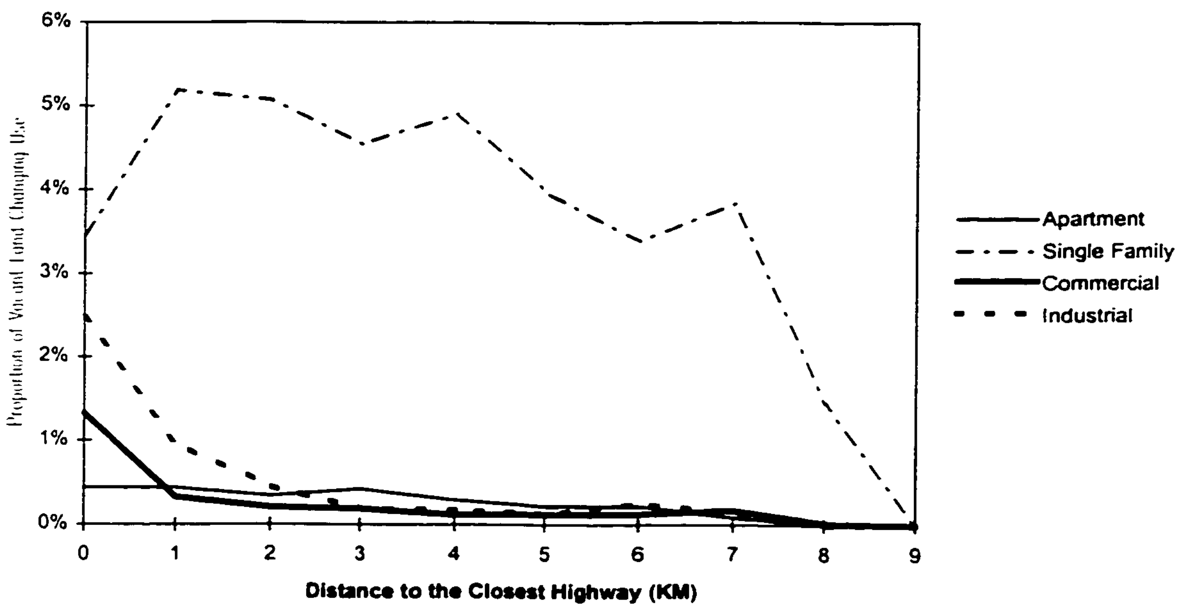
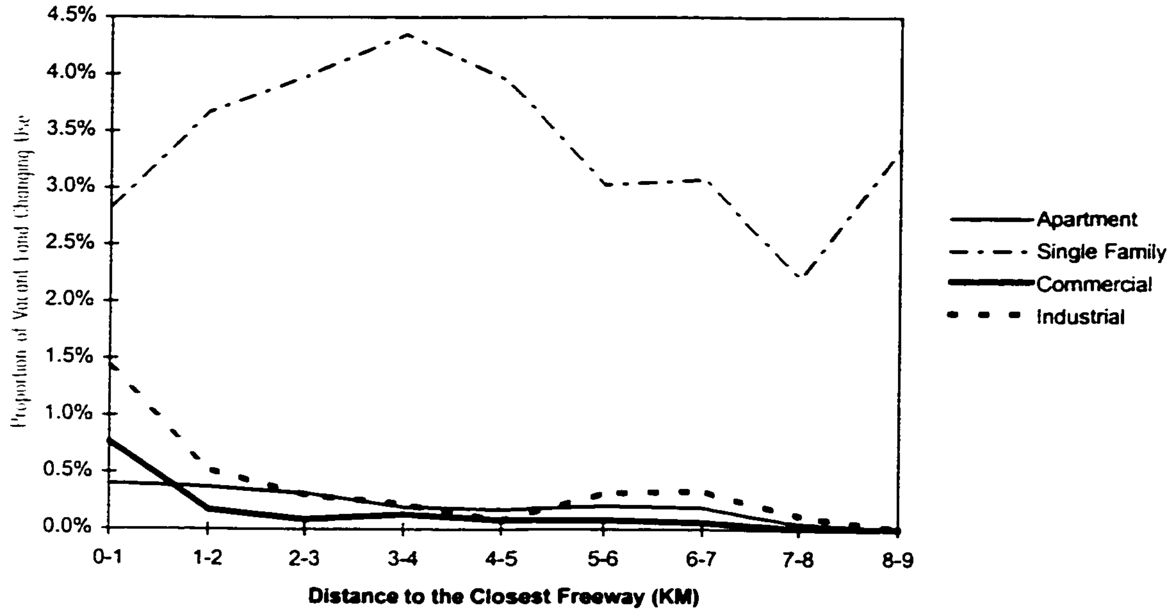


Figure 4.10 Proportion of Vacant Land Changed to Each Use Category by Distance to the Closest Freeway, 1985-1991



The relationship between land redevelopment and freeway access is much less clear in comparison. The curves, as plotted in Figures 4.11 and 4.12, have multi-peaks for all types of redevelopment. For business land redevelopment, there is a peak within one kilometer of highway, and another one 4 to 7 kilometers away from highway. Both residential redevelopment types also have double-peaked curves, and neither peak is the closest distance segment to freeway. However, there seems to exist strong consistency in the pattern observed for the two periods, as it did for land new development.

Figure 4.11 Proportion of Urban Land Changed to Each Use Category by Distance to the Closest Freeway, 1971-1985

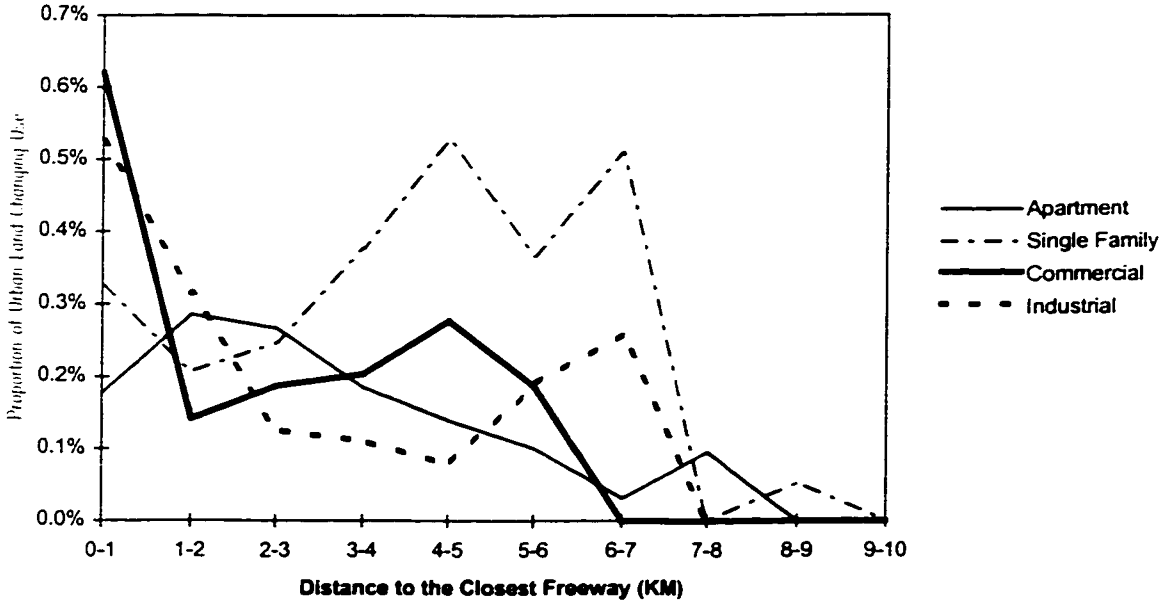
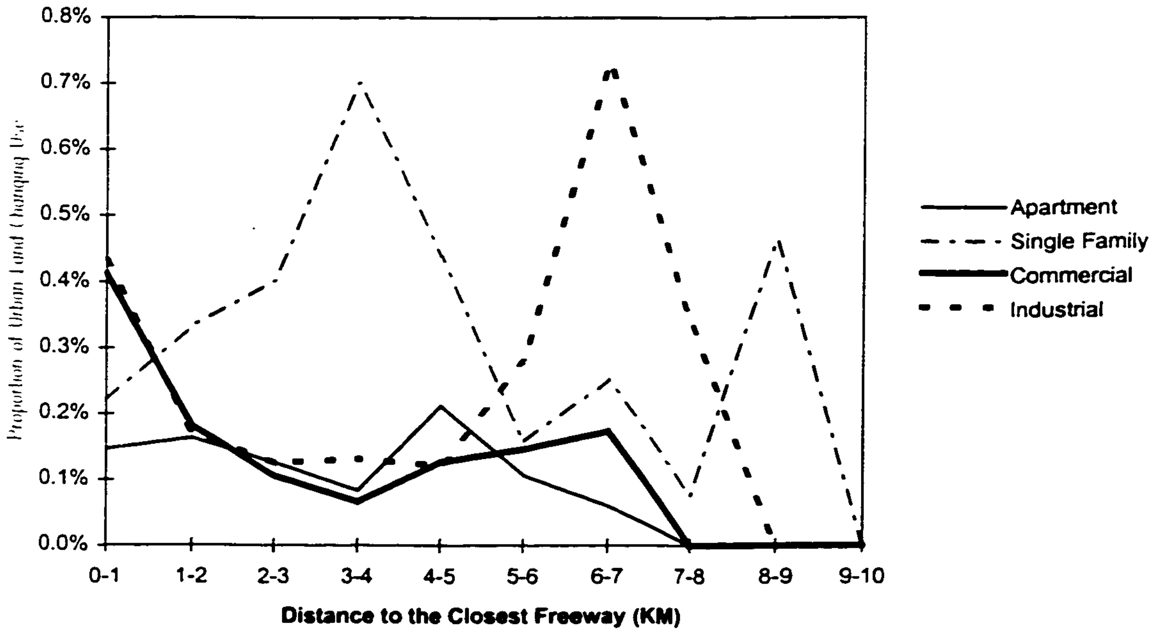


Figure 4.12 Proportion of Urban Land Changed to Each Use Category by Distance to the Closest Freeway, 1985-1991



Chapter Five Land Use Change Model Results: Estimates and Significance

This chapter presents the results of the maximum likelihood estimates of the multinomial logit models. Four models were calibrated: two vacant land development models for 1971-1985 and 1985-1991, and two land redevelopment models for the same periods. In the presentation, "the first period" refers to 1971-1985, whereas "the second period" refers to 1985-1991. For both new development and redevelopment models, I will first explain in detail the results for the first period, and then compare the difference of the second period model from the first period.

Variables used in the calibration were explained in Chapter 3. Table 3.1 is reproduced in the next page for easier reference.

Table 3.1 List of Explanatory Variables

VARIABLE	EXPLANATION
Initial Land Use Type	
INIT_APT	Initially used for apartment
INIT_COM	Initially used for commercial
INIT_IND	Initially used for industrial
INIT_PUB	Initially used for institutional
INIT_TRA	Initially used for transportation
Census Tract Housing and Demographic Characteristics	
HUDEN	Housing unit density
MDRENT	Median rent
UNIT1P	Percentage of 1-unit housing
WHITEP	Percentage of white
BLT10_P	Percentage of housing units built last 10 years
Accessibility and Distance Measures	
TM_BOS2	Travel time to Boston squared
TIME_BOS	Travel time to Boston
DIST_HWY	Distance to Highway
DIST_RAL	Distance to Railway
DIST_LU4	Distance to commercial use
DIST_LU5	Distance to industrial land
DIST_LU6	Distance to institutional land
Site Physical, Cost and Policy Constraints	
SLOPE	Slope
GEO6	Geologically formed by fine-grained deposits
GEO7	Geologically formed by floodplain alluvium
WETLAND	Wetland
OS_FED	Open space federally protected
OS_STATE	Open space state protected
OS_LOCAL	Open space locally protected
OS_PRTED	Open space permanently protected
OS_PRTMP	Open space temporarily protected
Neighborhood Land Use Characteristics	
NBH_VAC	Proportion of vacant land in neighborhood
NBH_APT	Proportion of apartment land in neighborhood
NBH_SIN	Proportion of single family housing land in neighborhood
NBH_COM	Proportion of commercial land in neighborhood
NBH_IND	Proportion of industrial land in neighborhood
Adjacent Land Use Characteristics	
ADJ_VAC	Proportion of vacant land in adjacent areas
ADJ_APT	Proportion of apartment land in adjacent areas
ADJ_SIN	Proportion of single family housing land in adjacent areas
ADJ_COM	Proportion of commercial land in adjacent areas
ADJ_IND	Proportion of industrial land in adjacent areas
Surface Trends	
XX	X coordinate standardized
XX2	Square of XX
XX3	Cubic of XX
XY	Product of XX and YY
YY	Y coordinate standardized
YY2	Square of YY
YY3	Cubic of YY

5.1 Vacant Land Change 1971-1985

Table 5.1a-b presents the parameter estimates and their significance for vacant land change from 1971 to 1985. This is the most important model among the four presented in this chapter for three reasons. First, most of the land use changes in the region are vacant land development. Second, compared to the second period (1985-1991), the first period covers a longer time horizon and has the most cases of actual changes. Third, unlike the second period where the data covers only part of the region, data for this period is sampled from the entire region. Therefore the results of this model are most important and reliable in this study.

Table 5.1a Parameter Estimates of MNL of Vacant Land Development: 1971-1985

Variable	Commercial	Industrial	Apartment	Single Family
HUDEN	-0.0327	0.000532	**0.000306**	-0.00097
MDRENT	**-0.00383**	**-0.00355**	**-0.00345**	**0.00126**
UNIT1P	-0.3343	**-0.4987**	**-1.6906**	-0.0987
WHITEP	-0.6634	**26.6739**	7.5728	**-2.5664**
BLT10_P	0.4408	**2.6664**	-0.267	**0.4845**
TM_BOS2	**-0.00251**	0.000032	**-0.00211**	**-0.00097**
TIME_BOS	**0.0789**	**-0.0854**	**0.1153**	**0.0778**
DIST_HWY	**-0.00397**	**-0.00916**	0.00106	-0.00019
DIST_RAL	**-0.00508**	**-0.00583**	**-0.00574**	**0.00178**
DIST_LU4	**0.0098**	**0.00812**	0.00614	**0.0113**
DIST_LU5	**-0.00475**	**-0.0125**	**-0.00849**	**-0.00365**
DIST_LU6	**-0.0587**	**-0.045**	**-0.0303**	**-0.0181**
SLOPE	**-0.1083**	**-0.1548**	-0.0624	**-0.0349**
GEO6	0.1291	**0.503**	-0.3214	**-0.6923**
GEO7	**-1.5168**	**-0.577**	**-0.4564**	**-1.4751**
WETLAND	-0.6817	**-1.3433**	-8.5427	-0.1466
OS_FED	-6.3953	-8.5655	-8.8408	**-2.644**
OS_STATE	**-1.5884**	**-1.3499**	**-2.1348**	**-1.208**
OS_LOCAL	**-0.9608**	**-1.7951**	**-2.3583**	**-1.4548**
OS_PRTED	**-1.8122**	**-2.4477**	**-0.9711**	**-1.4503**
OS_PRTMP	**-0.9608**	-10.8462	-10.2594	**-1.6199**
NBH_VAC	**-2.7836**	0.4483	**-5.0181**	0.2426
NBH_APT	3.6317	5.0603	**10.1164**	**3.3143**
NBH_SIN	**-2.0487**	**-2.3445**	**-2.2466**	**2.2636**
NBH_COM	**4.843**	1.107	**5.5947**	**-6.9707**
NBH_IND	**8.0616**	**8.6185**	**-6.0929**	**-6.7403**
ADJ_VAC	**1.3589**	**1.528**	**2.3854**	**1.3907**
ADJ_APT	-0.6531	-10.3617	-2.1541	1.6205
ADJ_SIN	-0.4778	-0.0269	0.5462	**0.5622**
ADJ_COM	**4.6472**	**2.8298**	-2.1202	**-2.4314**
ADJ_IND	**-7.3019**	-0.3631	**4.6583**	0.8325
XX	**-15.5651**	**4.4485**	**10.0419**	**2.4148**
XX2	**27.7542**	**-11.5186**	-13.8325	-0.6131
XX3	**-13.8774**	7.3136	6.4659	-1.3665
XY	**-3.356**	-1.1216	**-3.4851**	**-2.2275**
YY	-3.9405	**12.3738**	7.3003	**5.2928**
YY2	6.5914	**-30.852**	-10.626	**-4.6063**
YY3	0.4251	**22.5989**	6.4693	0.8953
INTERCEPT	2.2924	**-28.6502**	**-12.1523**	**-5.0413**

* *Shaded parameters show statistical significance at 0.05 level.*

** $l_0 = 62094$, $l_{est} = 38446$, McFadden's $R^2 = 0.3808$.

Table 5.1b Elasticity Estimates of MNL of Vacant Land Development: 1971-1985

Variable	Commercial	Industrial	Apartment	Single Family	Variable Mean
MDRENT	**-0.52401**	**-0.48596**	**-0.47237**	**0.16763**	135.8825
UNIT1P	-0.26322	**-0.39436**	**-1.34517**	-0.07527	0.7977
WHITEP	-0.61397	**26.51196**	7.55854	**-2.50226**	0.9923
BLT10_P	0.11545	**0.71891**	-0.07647	**0.12730**	0.2711
TM_BOS2	**-4.35253**	0.10693	**-3.65080**	**-1.65089**	1754.3100
TIME_BOS	**3.11236**	**-3.55000**	**4.58838**	**3.06776**	40.5500
DIST_HWY	**-0.50692**	**-1.17190**	0.13756	-0.02260	128.1277
DIST_RAL	**-0.41459**	**-0.47537**	**-0.46808**	**0.14130**	81.0346
DIST_LU4	**0.17773**	**0.14624**	0.10912	**0.20585**	18.7451
DIST_LU5	**-0.26727**	**-0.71420**	**-0.48295**	**-0.20383**	57.6685
DIST_LU6	**-0.94907**	**-0.72537**	**-0.48535**	**-0.28615**	16.3281
SLOPE	**-0.11291**	**-0.16192**	-0.06454	**-0.03556**	1.0539
GEO6	0.00440	**0.01556**	-0.00905	**-0.02012**	0.0299
GEO7	**-0.13585**	**-0.04933**	**-0.03823**	**-0.13201**	0.0921
WETLAND	-0.01268	**-0.02519**	-0.16133	-0.00256	0.0189
OS_FED	-0.09591	-0.12890	-0.13309	**-0.03888**	0.0152
OS_STATE	**-0.10464**	**-0.08857**	**-0.14147**	**-0.07901**	0.0674
OS_LOCAL	**-0.09132**	**-0.17428**	**-0.23029**	**-0.14045**	0.0994
OS_PRTED	**-0.27140**	**-0.36885**	**-0.14241**	**-0.21590**	0.1533
OS_PRTMP	**-0.03579**	-0.42790	-0.40462	**-0.06193**	0.0397
NBH_VAC	**-2.25946**	0.36230	**-4.07212**	0.19544	0.8723
NBH_APT	0.00359	0.00504	**0.01017**	**0.00326**	0.0008
NBH_SIN	**-0.25533**	**-0.29122**	**-0.27934**	**0.26781**	0.0831
NBH_COM	**0.02728**	0.00699	**0.03137**	**-0.03690**	0.0035
NBH_IND	**0.04250**	**0.04537**	**-0.03055**	**-0.03390**	0.0033
ADJ_VAC	**1.14974**	**1.29724**	**2.04511**	**1.17748**	0.8112
ADJ_APT	-0.00057	-0.00863	-0.00182	0.00132	0.0010
ADJ_SIN	-0.04096	-0.00349	0.04414	**0.04547**	0.1213
ADJ_COM	**0.01626**	**0.00999**	-0.00711	**-0.00819**	0.0054
ADJ_IND	**-0.02444**	-0.00128	**0.01548**	0.00271	0.0052
XX	**-7.47064**	**2.09558**	**4.76914**	**1.12350**	0.4780
XX2	**7.86921**	**-3.25954**	-3.91523	-0.16925	0.2834
XX3	**-2.59866**	1.37985	1.22070	-0.24980	0.1877
XY	**-0.74599**	-0.23952	**-0.77525**	**-0.49019**	0.2267
YY	-1.97547	**5.89792**	3.44942	**2.48058**	0.4826
YY2	2.00623	**-9.13951**	-3.11886	**-1.32698**	0.2977
YY3	0.07899	**4.68629**	1.33486	0.17669	0.2078
INTERCEPT	2.45464	**-28.48796**	**-11.99006**	**-4.87906**	1.0000

Below I discuss in detail the calibration results broken down into six groups of variables: (i) neighborhood demographic factors, (ii) accessibility measures, (iii) physical, cost and policy constraints, (iv) neighborhood land use effects, (v) adjacent land use effects, (vi) spatial autocorrelation effects.

5.1.1 Neighborhood Demographic Factors

The group of variables indicating housing and demographic characteristics of the census tracts have mixed performance in the logit model for 1971 to 1985: Each variable is significant for at least one type of land development, but the signs of the estimates are not always consistent with our hypothesis.

Median rent (*MDRENT*) in the census tract, representing general housing price levels in the neighborhood is significant for all four types of land use changes from 1971 to 1985. All vacant land development except single family housing sought to be located in neighborhoods with *low* housing prices. The elasticities of these development probabilities to neighborhood rent levels were also very similar, varying around -0.5. New single family housing development is the only type of new development that responded positively to neighborhood housing price levels, that is, single family housing development was more likely in neighborhoods with *higher* housing prices. The magnitude of elasticity, 0.17, is significantly less than that of the other new development types. Simulations show that if we hold all other variables at the mean and increase the rent level from the mean to 50 percent higher, then the probability of new single family development between 1971 and 1985 will increase from 2.67 percent to 2.91 percent.

Thus, overall, housing price seems to be an important determinant of new land development during the first period.

For the building structure variable (*UNIT1P*), the model shows that the more one-unit housing structure in a census tract, the *less likely* new development will occur. This indicates that all types of new development were somewhat attracted to areas with more multi-unit housing stock. The effect is significant for new industrial and apartment development, and is the weakest for single family housing development. The elasticity is –1.3 for apartment, -0.4 for industrial, and only –0.08 for new single family housing land. This weak effect on new single family housing is not unexpected: if housing structure has an effect on single family land use, it should be attracted to areas with more one-unit-structure neighborhood rather than the contrary. The model results instead show that this was not a factor in either direction during the period.

Racial composition, indicated by percentage of white population in a census tract (*WHITEP*), is also only significant for new industrial land development, which appeared to favor white neighborhoods. The magnitude of this impact is quite big: according to the model results, on average, the probability of industrial land use change is 0.5%; if we leave every other variable at average, but reduce the percentage of white by 6 percentage points from the average, then the chance of this change is almost zero.

Past housing demand, indicated by the percentage of housing stock in a census tract built during the past ten years (*BLT10_P*), has positive effects on all types of new development except multifamily housing, but it is significant only for new industrial and single family housing development. The elasticities show that one percent increase in the proportion of housing units built during the past ten years would lead to 0.7 percent increase in the probability of industrial development and 0.12 percent increase in the probability of single family housing. Therefore, single family housing exhibited some tendency to follow areas with strong development during the previous period, while industrial (and, to a lesser extent, commercial) development followed new housing construction. As most of the new housing were located in the suburbs of the metropolitan region, this "job following housing" phenomenon implied suburbanization of jobs during the period.

5.1.2 Accessibility and Distance Effects

The model measures accessibility of each site by a number of travel-time and distance indicators. Traditionally, following the concentric urban morphologic model and the monocentric economic model, the literature have regarded access to central city as the most important factor. In this study, this access indicator is measured by estimated travel time (by auto) to the central city (Boston downtown), which takes into account the network of freeways and major highways. Local streets and highways are assumed to have different speed but no congestion effects are considered in the measurement. The descriptive plotting of land use change against travel time (Figure 4.5-4.8) in Chapter 4 reveals that the probability of land use change was not only non-linear, but also *non-monotonous* with regard to travel time. The peak probability often occurred away from the center. Under such circumstances, forcing a linear fitting of the travel time is not appropriate[10]. Instead, I used both travel time (*TIME_BOS*) and squared travel time

[10] The estimated parameters of the vacant land use change model which forced a linear fitting of travel time to Boston are (chi-square in parenthesis): -0.0841(21.25) for commercial, -0.0869 (41.3) for industrial, -0.021 (1.36) for multifamily, and 0.0063 (1.68) for single family. This suggests significant downward curves for commercial and industrial use change (the two curves are almost identical), a very slightly

(*TM_BOS2*) in the right hand side of the equation. The square term will allow the model to be non-monotonous with regard to travel time, and will reveal the peak outside CBD if there is one.

Note first that for new industrial development, the squared time is not significant, and the linear term is significantly negative. This indicates that *the probability of industrial development was monotonously decreasing with travel time to CBD*[11]. For other types of new land development, however, both variables are significant, and all have the same signs: positive for travel time, but negative for squared time. These results indicate that for these development types, there was a non-monotonous relationship between travel time and probability of land use change. *For sites very close to CBD*, the linear term is more important, and the positive signs indicate that *probability of development increased farther away from CBD. For sites quite far away from the CBD*, the squared term becomes more important, and the negative signs show that *probability of development would decrease farther away from CBD*. Therefore there was a peak probability some distance away from CBD. The exact position of the peak depends on the relative magnitude of the coefficients.

Figure 5.1 depicts such relationships as revealed by the model. It holds all variables at the mean level and lets only travel time change. As indicated above, there is a strong negative relationship for industrial development, but the relationships for other development types are non- monotonous. The peak probabilities are about 15 minutes

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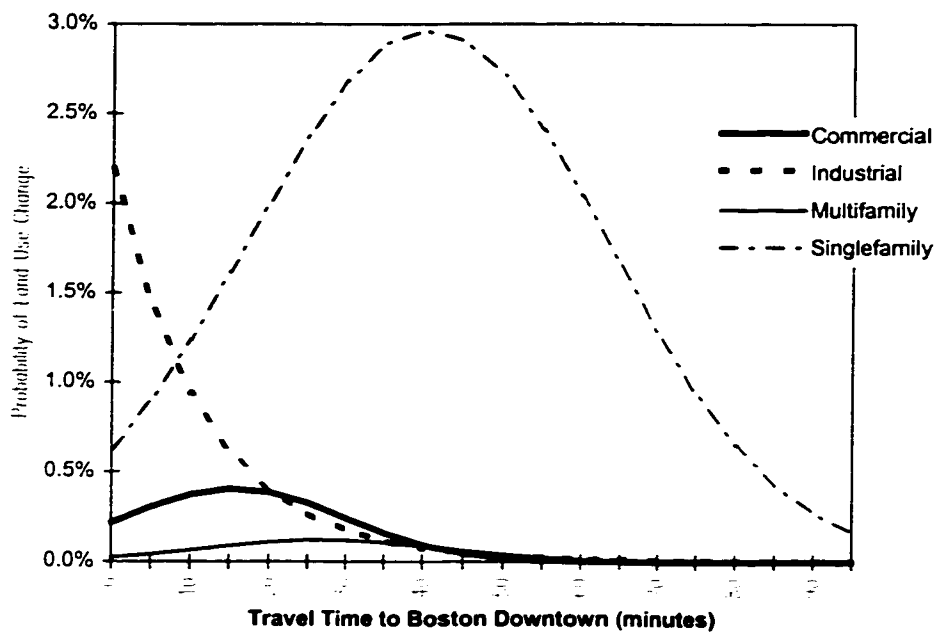
downward curve for multifamily use change, and a slightly upward curve for single family use change. These curves bear little resemblance to the ones in Figure 4.5 except for industrial land development.

[11] Note that for industrial development, the coefficient of the linear term is almost identical to the coefficient estimated without including the squared time.

away from downtown for commercial development, 25 minutes away for apartment development, and 40 minutes away for single family development. The non-monotonic feature is quite significant in these curves, especially for single family development, whose variation with regard to travel time to Boston is quite large. This underlies the importance of introducing the squared term. Otherwise, the linear fitting will cancel out the upward sloping and downward sloping sections and result in a flat distance curve.

Figure 5.1 Vacant Land Development and Travel Time to Boston Downtown, Relationships according to the MNL (1971-1985)



While travel time to Boston downtown measures accessibility with regard to CBD, two other distance measures try to capture accessibility to transportation facilities. *Distance to freeway (DIST_HWY) is significant for the two types of business land development.* Being 1 mile closer to freeway increases the probability of commercial development by 0.004%, and the probability of industrial development by 0.011%. Residential land development on vacant site, on the other hand, did not seem to be either drawn to or expelled away from freeways. Somewhat surprisingly, *distance to railroads (DIST_RAL) was a significant factor for all types of development*. For commercial and industrial development, the marginal effects of railroad distance are very similar to those of freeway distance. For residential development, while new apartment development was attracted to railways, new single family residential development clearly was avoiding railway: being 1 mile farther away from the railway increased the probability of single family development by nearly 0.1%. Altogether, it seemed that *access to transportation facilities was more important to new business development than to new residential development during this period*.

Distances measured for each site to other land uses are intended as approximations of accessibility to jobs and shopping opportunities. All of the three distance measures are statistically significant for almost all types of new land development, but the signs are not always as expected. In particular, distance to commercial land (*DIST_LU4*), which represents access to both jobs and shopping opportunities, is *positively* significant for all new land development except apartment. This is rather unexpected, as we would assume that development would prefer sites closer to other commercial opportunities. On the other hand, the other two distance measures -- distances to the nearest industrial land (*DIST_LU5*) and institutional land (*DIST_LU6*) -- are consistently significant and negative for all types of new development. This suggests that new development was drawn close to areas with industrial and institutional land, probably for the jobs and/or recreational opportunities they represent. Note that institutional land turned out to be a more attractive factor: the marginal effects of institutional land distance are between 3 to 15 times higher than those of industrial land distance.

In summary, the MNL model suggests that *all the accessibility and distance measures are significant for both new commercial and industrial land development from 1971 to 1985*, and both land use change types responded to these variables in a similar way: they tended to occur closer to transportation facilities such as freeways and railroads; They were also more likely to be found closer to existing industrial or institutional land, but tended to locate farther away from existing commercial land. The only important difference between commercial development and industrial development is their preference for central location: while industrial is drawn monotonically to central location, commercial development was slightly upward sloping from 0 to 15 minutes away from downtown. The negative slope of commercial land development (with regard to travel time) becomes steeper than that of industrial development only after about 20 minutes away from downtown.

New residential land development was similar to new business land development in that it was also drawn closer to existing industrial and institutional land, and away from existing commercial land. However, unlike business land development, *residential development was not responsive to accessibility to freeways*. As for access to railways, while apartments tended to locate closer to railways, single family housing development tended to occur farther away from them. Similar to business land development, residential development was closely linked to access to the central city, but both residential development types seemed to seek sites much farther away from downtown than commercial and industrial development, with single family housing development more so than apartment development. It seems that the commonly held belief about the ordering of land use types with regard to distance to CBD is largely validated by the model for vacant land development from 1971 to 1985, although the model also revealed that difference in locational preference among different land use types is more than one-dimensional.

*5.1.3 **Physical, Cost, and Policy Constraints***

Steeply sloped sites were less likely to have any types of new development, as the parameter (*SLOPE*) estimates are all negative and mostly significant (the chi-square for apartment development misses the threshold by a very small margin). Geologically, sites formed by floodplain alluvium (*GEO7*) were less likely to be developed. The other geological variable, which represents sites formed by fine-grained deposits (*GEO6*), had mixed effects on different types of development. Sites designated as wetland (*WETLAND*) were generally less likely to have development, although the estimates did not reach the threshold of significance for commercial and single family housing development. Note that there were almost no case of new apartment development on wetland and, as a result, the chi-square and significance cannot be estimated.

Protection of open space is the only group of policy variables included in the models for Boston Region. Consistently, these estimates are significantly negative for all kinds of development, except for the several parameters where there were not enough observations to accurately estimate the level of significance. There *does not* seem to exist significant difference between the protections by various levels of government: the marginal effects of state-protection (*OS_STATE*) and local-protection (*OS_LOCAL*) are very similar if not identical. For development types that accurate estimates are available, there is neither significant difference between open space labeled as temporary protected (*OS_PRTMP*) and that labeled as permanently protected (*OS_PRTED*).

Most of the variables representing site, cost and policy constraints are dummy variables. Table 5.2 presents the quantitative impact of these dummy variables on land use change. It holds all other variables at the mean level, calculate the probabilities of each type of development when the dummy variable is zero and when it is one, and compare the difference.

Table 5.2 Effects of Site Physical and Policy Constraints Dummy Variables

Variable	Commercial			Industrial		
	Value = 0	Value = 1	%Difference	Value = 0	Value = 1	%Difference
GEO6	0.065%	0.075%	15%	0.072%	0.120%	68%
GEO7	0.075%	0.017%	-78%	0.076%	0.044%	-42%
WETLAND	0.066%	0.034%	-49%	0.075%	0.020%	-74%
OS_FED	0.072%	0.000%	-100%	0.083%	0.000%	-100%
OS_STATE	0.072%	0.015%	-79%	0.080%	0.021%	-73%
OS_LOCAL	0.071%	0.028%	-61%	0.087%	0.015%	-83%
OS_PRTED	0.085%	0.014%	-83%	0.105%	0.009%	-91%
OS_PRTMP	0.068%	0.027%	-61%	0.112%	0.000%	-100%
Variable	**Multi Family Residential**			**Single Family Residential**		
	Value = 0	Value = 1	%Difference	Value = 0	Value = 1	%Difference
GEO6	0.067%	0.049%	-27%	2.729%	1.384%	-49%
GEO7	0.069%	0.045%	-35%	3.051%	0.716%	-77%
WETLAND	0.078%	0.000%	-100%	2.681%	2.328%	-13%
OS_FED	0.076%	0.000%	-100%	2.781%	0.203%	-93%
OS_STATE	0.076%	0.009%	-88%	2.894%	0.884%	-69%
OS_LOCAL	0.083%	0.008%	-90%	3.077%	0.737%	-76%
OS_PRTED	0.076%	0.030%	-61%	3.317%	0.800%	-76%
OS_PRTMP	0.099%	0.000%	-100%	2.845%	0.578%	-80%

For each type of new land development, the effect of a dummy variable is presented as the percentage difference between two probabilities: the probability of the development when the dummy variable is 0, and the probability when the variable is 1. The probabilities are calculated by holding all other explanatory variables at the mean level.

The table shows that the differences that the dummy variables make in terms of *absolute probabilities* are quite small, but measured as *change in percentage*, they are quite substantial. Since the average probabilities of land use change are also very small, the effects of the dummy variables are thus generally quite significant[12]. This is especially true for those variables indicating open space protections. The average probability of development when protected was at least 60% smaller than that when not protected.

5.1.4 Neighborhood Land Use Effects

The model results show that neighborhood land use characteristics -- the compositions of land use categories within the closest 120 grid cells (30 hectares) -- had very important influence on different types of new development. To illustrate the effects of neighborhood land use composition more clearly, in Table 5.3 I changed one particular neighborhood land use percentage from 0 to 10%, while holding the other variables at the mean levels, and calculated the difference in average probability of development. This difference can indicate the magnitude of the effects of neighborhood land use composition for each development type.

[12] The effectiveness ratios (the difference divided by mean probability of change) vary between 0.1 to 0.8.

Table 5.3 Sensitivity Analysis of Effects of Neighborhood Land Use Compositions

Variable	Explanation	Commercial			Industrial		
		(1)	(2)	(3)	(1)	(2)	(3)
NBH_VAC	% vacant	0.600%	0.462%	*-23%*	0.049%	0.052%	*6%*
NBH_APT	% apartment	0.065%	0.092%	*42%*	0.072%	0.119%	*64%*
NBH_SIN	% single-fam.	0.084%	0.068%	*-19%*	0.097%	0.077%	*-21%*
NBH_COM	% commercial	0.063%	0.104%	*64%*	0.072%	0.082%	*13%*
NBH_IND	% industrial	0.062%	0.142%	*127%*	0.070%	0.167%	*140%*
Variable	**Explanation**	**Multi Family**			**Single Family**		
		(1)	(2)	(3)	(1)	(2)	(3)
NBH_VAC	% vacant	3.731%	2.295%	*-38%*	2.115%	2.201%	*4%*
NBH_APT	% apartment	0.065%	0.178%	*172%*	2.666%	3.668%	*38%*
NBH_SIN	% single-fam.	0.087%	0.069%	*-20%*	2.044%	2.552%	*25%*
NBH_COM	% commercial	0.064%	0.114%	*77%*	2.775%	1.400%	*-50%*
NBH_IND	% industrial	0.068%	0.038%	*-45%*	2.767%	1.427%	*-48%*

(1) Average probability when the variable is 0
(2) Average probability when the variable is 0.1
(3) Percentage difference between (1) and (2)

Several observations can be made from the significance of the variables and Table 5.3. First, both new commercial and new apartment development sought to avoid areas with high proportions of undeveloped land, while new industrial or single family residential development would not be affected by whether the neighborhood was predominantly undeveloped. Second, the model shows that a particular type of development was more likely to occur in areas where this type of land made up a high proportion of the total stock. That is, commercial development was more likely in neighborhoods with high proportion of existing commercial land, new apartment was more often found in neighborhoods already having abundant apartments, and so on. As shown in Table 5.3, increasing the proportion of commercial land from 0 to 10 percent will result in an increase of the probability of commercial development by 64 percent. The effect is 25 percent for single family development, 140 percent for industrial development, and 1728 percent for multifamily development. All these four coefficients are statistically significant.

The model also shows that there are positive or negative externalities between different types of land use categories. There was obvious *negative externalities between business land use and single family residential use.* Industrial and commercial development tended to avoid single family residential neighborhood, while single family residential development also tended to avoid industrial or commercial neighborhood. Being located in a neighborhood with 10 percent single family residential land instead of one with no such land reduced the chance of new commercial or industrial development by approximately 20 percent. Similarly, keeping all other factors the same, moving from a neighborhood with no commercial or industrial land to one with 10 percent of such land would reduce the probability of new single family residential development by nearly 50 percent. On the other hand, apartment development, while also avoiding areas with high proportions of industrial land, preferred areas with plenty of commercial land. Holding all other factors at the mean, moving a vacant site from an area with no commercial land to one with 10 percent commercial use would increase the probability of apartment development by 77 percent. For new commercial and industrial development, the insignificance of the coefficients show that they neither preferred nor apartment areas.

Between the two residential land uses, the model shows an asymmetric relationship: while new single family housing were attracted to neighborhoods with relatively high proportions of apartments, new apartment housing tended to avoid areas with high proportions of single family housing. *Between the two business land uses*, industrial land use seemed to have significant positive externalities to commercial development, while commercial land did not have either positive or negative externalities to industrial development.

Most of the results regarding neighborhood land use effects conform to my hypotheses about them discussed in Chapter 3. A cautionary note is needed here as we cannot tell from the model whether these effects were the result of market response of land development to the positive or negative externalities between different land use types, or they were the consequence of local planning efforts which often explicitly promote positive externalities and mitigate negative ones. It can be the results of both causes.

5.1.5 Adjacent Land Use Effects

According to the parameter estimate results of the MNL, *the effects of adjacent land use composition could be quite different from those of neighborhood land use composition*. This is most apparent in the effects of adjacent vacant land. While high proportions of neighborhood vacant land generally reduced the chance of development, *availability of vacant land right next to the site, on the contrary, increased the probability of development*. Although very similar methods are used to acquire the two groups of variables, the difference showed that *spatial scale matters*. Whereas the proportion of vacant land within the closest 30 hectares of land indicates the "undevelopedness" of the site's neighborhood, the same proportion measure for the closest 2 hectares of land indicates the availability of vacant land that could generate economies of scale in development. To the extent that development sought areas already having some urban land use, and thus could save on infrastructure and basic costs, it preferred sites where neighborhood vacant land proportion was low; to the extent that development sought large vacant lots to realize economies of scale in development, it preferred sites where there were vacant land right adjacent to them. Table 5.4 shows that changing the percentage of vacant land adjacent to a vacant site from zero to ten percent would increase the chance of commercial, industrial and single family residential development by approximately 15 percent, and increase the chance of apartment development by 27 percent.

Table 5.4 Sensitivity Analysis of Effects of Adjacent Land Uses

Variable	Explanation	Commercial			Industrial		
		(1)	(2)	(3)	(1)	(2)	(3)
ADJ_VAC	% vacant	0.020%	0.023%	*14%*	0.020%	0.023%	*16%*
ADJ_APT	% apartment	0.065%	0.061%	*-7%*	0.073%	0.026%	*-65%*
ADJ_SIN	% single-fam.	0.068%	0.065%	*-5%*	0.073%	0.073%	*0%*
ADJ_COM	% commercial	0.064%	0.103%	*60%*	0.072%	0.096%	*33%*
ADJ_IND	% industrial	0.067%	0.032%	*-52%*	0.073%	0.070%	*-4%*
Variable	**Explanation**	**Apartment**			**Single Family**		
		(1)	(2)	(3)	(1)	(2)	(3)
ADJ_VAC	% vacant	0.008%	0.011%	*27%*	0.812%	0.932%	*15%*
ADJ_APT	% apartment	0.066%	0.053%	*-20%*	2.671%	3.128%	*17%*
ADJ_SIN	% single-fam.	0.063%	0.067%	*5%*	2.556%	2.699%	*6%*
ADJ_COM	% commercial	0.067%	0.054%	*-19%*	2.697%	2.126%	*-21%*
ADJ_IND	% industrial	0.065%	0.104%	*59%*	2.667%	2.892%	*8%*

(1) Average probability when the variable is 0
(2) Average probability when the variable is 0.1
(3) Percentage difference between (1) and (2)

The adjacency externalities between the same land use types also turned out to be somewhat different from those of the neighborhood externalities discussed in the previous section. A vacant site adjacent to single family residential land was more likely to be developed to single family residential use; a vacant site adjacent to commercial land would have a much higher probability of changing to commercial use. These results are similar to those of the neighborhood land uses, though the scales of the impacts are smaller. However, the adjacency externalities between the same land use types are negative and insignificant for apartment and industrial land. That is, vacant land right adjacent to apartment or industrial uses was actually slightly less likely to be developed to such uses. These results are different those derived from the neighborhood land use variables.

Between business land use and residential land use, single family development seemed to avoid sites right next to commercial land but the impact of being next to industrial land was insignificant. Similarly, apartment development was more likely to be next to industrial land but the impact of being next to commercial land was insignificant. On the other hand, both commercial and industrial developments were less likely to occur adjacent to the resident lands, though the effects are insignificant.

Finally, there appeared to be no significant adjacency relationship between the two residential land use types, whereas between the two business land use types, industrial development preferred being next to existing commercial land, but commercial development appeared to avoid adjacency to industrial land.

Therefore, in comparison with the externalities between land uses brought by neighborhood land use, the effects of immediate spatial adjacency proved to be quite different from those of spatial adjacency in the larger scale. Comparison of Tables 5.3 and 5.4 shows that the signs of half of the parameters are different. In general, the effects of adjacent land uses are smaller than those of neighborhood land uses, and more adjacency variables are insignificant in the model.

5.1.6 Spatial Autocorrelation Effects

As stated in Chapter 3, inclusion of the x, y coordinates and their polynomials in the list of explanatory variables is intended to alleviate some of the spatial autocorrelation effects. This in essence is to extract a *surface trend* of land use change probability for each use. Such surface trend extraction is often used as a descriptive tool to summarize the spatial variation of the variable in interest. In this study, the usual surface trend extraction is extended to the discrete dependent variable case by adopting a logit format. Since we have a number of explanatory variables to account for the observed spatial variations in land use change, this group of variables serves the purpose of *summarizing the spatial variation of the residuals of regression*. That is, they *capture some of the spatial patterns that cannot be attributed to the other explanatory variables*. As such, their significance levels, unlike those of the other variables, are less important. In order to examine their effects, we need to visually present the spatial patterns implied in the coefficients. These spatial patterns are presented in Figure 5.2a to Figure 5.2d for each type of new development for the period of 1971-1985. For each pair of x, y coordinates, I used the estimated parameters from the model to calculate the mean probability at this position, while holding all other variables at the means. The resulting variation of probability according to the coordinates is drawn as 3D surface for each land development. These surfaces show how, even after accounting for the other variables, the probabilities vary across space. As a summary of the regression residuals, they give us hint as to where the models fit better and where they fit worse. Such information, in turn, points to possible ways to improve the model specifications.

Figure 5.2 Surface Trends of Vacant Land Development Model, 1971-1985

Figure 5.2a Surface Trend of Vacant Land Development to Commercial Use, 1971-1985

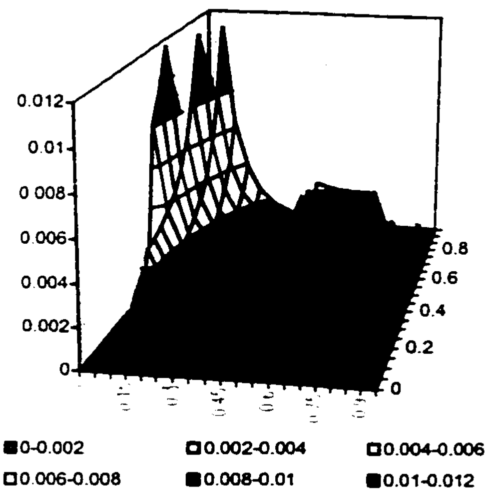


Figure 5.2b Surface Trend of Vacant Land Development to Industrial Use, 1971-1985

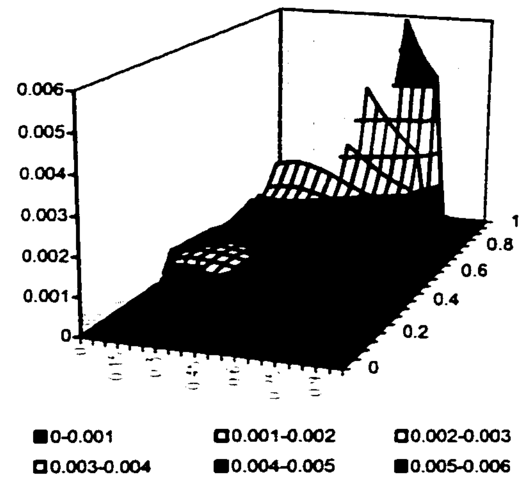


Figure 5.2c Surface Trend of Vacant Land Development to Apartment Use, 1971-1985

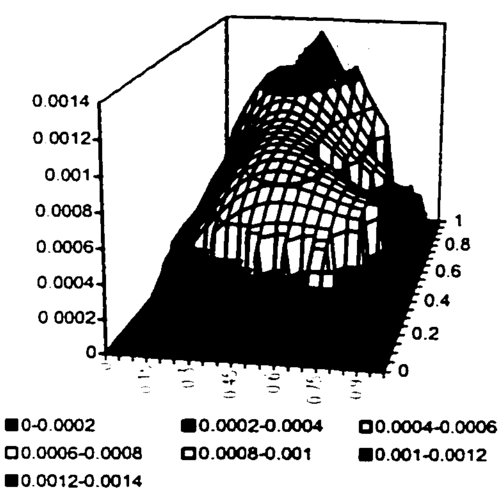
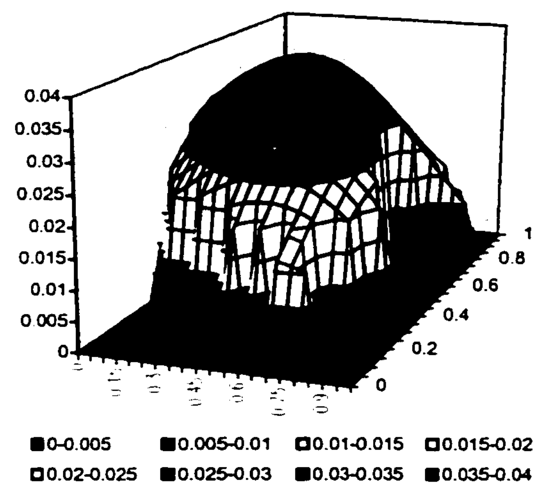


Figure 5.2d Surface Trend of Vacant Land Development to Single Family Use, 1971-1985



* *Vertical axis shows residual probabilities.*

Figure 5.2a shows the surface trend of vacant land development to commercial use. Notice that the surface indeed has very little variation within the scope of the study area: most of the large increase in the northwest region is a result of extrapolation outside the study region. Nevertheless, inside the study area, there is still a tilt upward in the northwest fringe, although the degree of upward sloping is much less dramatic. This indicates that there were some cases of land use change in this area that were not explained by the other variables. The trend surface for development to industrial use (Figure 5.2b) is a bit more complicated. A slight rise of probability in the southwest forms a very small peak, roughly corresponding to the strip along the Outer Beltway between the Turnpike and Interstate 95. A much larger upward rise lies in the north, including the northern towns like Haverick and Newburyport, whose new industrial development seemed significantly underestimated by the explanatory variables included in the model. The surface for apartment development (Figure 5.2c) has an overall upward sloping from southwest to north. A ridge, extending from right outside Boston downtown to the northernmost part of the region, shows the area where the combination of other variables underestimated the probabilities of apartment development. Finally, for single family residential development (Figure 5.2d), the polynomials of the x, y coordinates capture a pattern of variation peaked roughly at the intersection of the Turnpike and Route 128. The equi-probability contours of the trend surface followed eclipse patterns, with the long axis tilting from northwest to southeast.

5.1.7 Model Goodness of Fit

MNL regression does not have an overall goodness-of-fit measure like the R^2 in the least square regression. Since the estimation method for the regression is maximum-likelihood, one way to measure the goodness-of-fit is to calculate the increase in likelihood ratio accompanying the inclusion of the explanatory variables. More often, the equivalent method of calculating the reduction in the -2Loglikelihood ratio is used. For the first period vacant land development model, the inclusion of the variables reduces the −2Loglikelihood from 62,094 to 38,446.

The ultimate test of the model, however, is to see how its prediction corresponds to the actual results. Therefore for each grid cell, I calculated its probability for each possible type of change, and chose the type with the highest probability as the prediction from the model. The prediction results are compared to the actual results, as shown in Table 5.5, which cross-tabulates predicted results with actual results. For example, the first row shows that altogether, there are 599 actual cases of change to commercial use in the sample. 214 of the cases were predicted correctly by the model. On the other hand, the model predicted 26 of the cases as change to industrial use, 81 cases as change to single family use, 20 cases as change to apartment use, and 258 cases as no-change. Bold numbers on the lead diagonal indicate the number of correct predictions.

Out of the 15561 samples (vacant cells), the model is able to predict 64% of them correctly. The major source of wrong prediction is that the model tends to predict a land use change as no-change. This is partly because the predominance of no-change in the sample, which has probably biased the estimation. Examination of the results on the map shows that the model quite often predicts changes quite close to the real site, even though not exactly on spot.

When the model does give a prediction of change, it will most likely give the correct prediction for all development types except for apartment development, which the model is more likely to predict as single family residential development. Overall, the model seems to have quite strong predictive power for new commercial and single family residential development, but relatively weak for new industrial and apartment development.

Table 5.5 Comparison of Actual and Predicted Results from MNL Vacant Land Development 1971-1986

Change from Vacant Land		Predicted Results from Model					
		Commercial	Industrial	Single Family	Apartment	No-Change	Total
Actual Results	Commercial	**214**	26	81	20	258	599
	Industrial	56	**76**	42	15	124	313
	Single Family	62	30	**1474**	56	2055	3677
	Apartment	10	29	61	**50**	141	291
	No-Change	258	153	2020	151	**8099**	10681
	Total	600	314	3678	292	10677	15561

5.2 Vacant Land Change 1985-1991

5.2.1 Neighborhood Demographic Factors[13]

Table 5.6a Parameter Estimates of MNL of Vacant Land Development: 1985-1991

Variable	Commercial	Industrial	Apartment	Single Family
HUDEN	0.000024	**-0.00004**	-0.00003	**0.000027**
MDRENT	-0.00105	**-0.00265**	**0.00238**	**-0.00043**
UNIT1P	0.4775	-0.1388	**-0.8817**	**-1.0098**
WHITEP	1.1703	2.1562	2.2171	**4.074**
BLT10_P	**-3.6776**	**2.952**	**-2.4006**	0.2716
TM_BOS2	**-0.00669**	-0.00069	0.000375	**-0.00125**
TIME_BOS	**0.4252**	0.0391	-0.0462	**0.1011**
DIST_HWY	-0.0022	**-0.00348**	-0.00155	-0.00017
DIST_RAL	-0.00215	**-0.00979**	**-0.00358**	**0.000649**
DIST_LU4	0.00626	**0.00772**	0.00338	**0.00885**
DIST_LU5	**-0.00817**	**-0.00528**	-0.00054	0.00002
DIST_LU6	**-0.0326**	**-0.0713**	**-0.0235**	**-0.0119**
SLOPE	-0.00907	**-0.1214**	**0.1255**	-0.00424
GEO6	-0.6459	-0.0196	0.0117	**-0.5497**
GEO7	**-2.1028**	**-0.7626**	**-1.3184**	**-1.5947**
WETLAND	-0.5575	-0.3423	0.1736	**-1.4481**
OS_FED	-5.3952	-8.2323	-6.7089	-10.6507
OS_STATE	-7.6922	-9.5873	-8.6597	**-1.5661**
OS_LOCAL	-10.3928	**-1.6506**	-10.9788	**-1.6391**
OS_PRTED	-8.9046	-11.2784	**-2.3475**	**-1.396**
OS_PRTMP	-9.6926	**-2.4119**	-10.2053	**-1.5891**
NBH_VAC	**-4.3228**	**-2.9353**	-0.7232	**1.3876**
NBH_APT	-1.5934	**-8.1563**	**9.9358**	0.618
NBH_SIN	**-7.369**	**-6.9017**	1.247	**3.0396**
NBH_COM	**8.3111**	1.1479	**8.5164**	**-3.1266**
NBH_IND	-2.5616	**3.2187**	2.4301	**-5.6527**
ADJ_VAC	**2.77**	**2.2001**	0.255	0.2474
ADJ_APT	-0.0589	-2.9889	0.2658	-1.1381
ADJ_SIN	**4.1965**	**2.0078**	**-2.0322**	0.0691
ADJ_COM	1.8813	1.1592	**-3.012**	-0.0952
ADJ_IND	**3.5471**	**1.7908**	-3.0159	-0.6488
XX	-5.5025	-3.2865	**18.1442**	**3.4244**
XX2	0.6384	5.7747	**-35.4863**	**-4.3474**
XX3	6.91	-4.9806	**20.2053**	1.4542
XY	-2.3126	0.8912	-0.9574	**-1.4515**
YY	**-15.4271**	**13.8637**	-3.6939	**3.9976**
YY2	**20.6906**	**-34.3726**	2.4874	**-5.418**
YY3	-5.4475	**23.2113**	1.2217	1.9434
INTERCEPT	-6.1903	-4.6423	**-7.2672**	**-10.8148**

* *Shaded parameters show statistical significance at 0.05 level.*
** $l_0 = 37149$, $l_{est} = 25827$, McFadden's $R^2 = 0.3048$.

Table 5.6b Elasticity Estimates of MNL of Vacant Land Development: 1985-1991

Variable	Commercial	Industrial	Apartment	Single Family	Variable Mean
MDRENT	-0.30814	**-0.78117**	**0.70594**	**-0.12483**	295.6493
UNIT1P	0.36255	-0.08807	**-0.63127**	**-0.72493**	0.7312
WHITEP	1.07321	2.03842	2.09804	**3.91598**	0.9790
BLT10_P	**-0.37023**	**0.29631**	**-0.24184**	0.02682	0.1005
TM_BOS2	**-12.35937**	-1.23693	0.73730	**-2.27502**	1853.7400
TIME_BOS	**17.70213**	1.55827	-2.00835	**4.15065**	41.8127
DIST_HWY	-0.27750	**-0.43923**	-0.19537	-0.02101	126.3510
DIST_RAL	-0.18235	**-0.82732**	**-0.30307**	**0.05395**	84.4211
DIST_LU4	0.11717	**0.14522**	0.06184	**0.16693**	19.2120
DIST_LU5	**-0.46722**	**-0.30194**	-0.03085	0.00117	57.1915
DIST_LU6	**-0.53791**	**-1.18095**	**-0.38670**	**-0.19396**	16.6161
SLOPE	-0.00943	**-0.12717**	**0.13162**	-0.00437	1.0482
GEO6	-0.02107	-0.00032	0.00072	**-0.01788**	0.0331
GEO7	**-0.20691**	**-0.07319**	**-0.12865**	**-0.15621**	0.0998
WETLAND	-0.01187	-0.00706	0.00446	**-0.03175**	0.0223
OS_FED	-0.08299	-0.12825	-0.10395	-0.16684	0.0160
OS_STATE	-0.54865	-0.68436	-0.61794	**-0.10995**	0.0716
OS_LOCAL	-1.00080	**-0.15639**	-1.05740	**-0.15527**	0.0966
OS_PRTED	-1.40031	-1.77474	**-0.36602**	**-0.21593**	0.1577
OS_PRTMP	-0.42253	**-0.10414**	-0.44495	**-0.06815**	0.0437
NBH_VAC	**-3.36705**	**-2.29240**	-0.57909	**1.05576**	0.8446
NBH_APT	-0.00448	**-0.02278**	**0.02768**	0.00169	0.0022
NBH_SIN	**-1.03193**	**-0.96696**	0.16585	**0.41505**	0.0953
NBH_COM	**0.05993**	0.00862	**0.06140**	**-0.02200**	0.0050
NBH_IND	-0.02008	**0.02709**	0.02066	**-0.04531**	0.0049
ADJ_VAC	**2.33538**	**1.85406**	0.21129	0.20487	0.7745
ADJ_APT	-0.00009	-0.00665	0.00064	-0.00250	0.0028
ADJ_SIN	**0.39995**	**0.19129**	**-0.19386**	0.00646	0.1390
ADJ_COM	0.00932	0.00575	**-0.01490**	-0.00046	0.0072
ADJ_IND	**0.01742**	**0.00882**	-0.01470	-0.00312	0.0082
XX	-2.63657	-1.58692	**8.56409**	**1.59181**	0.4737
XX2	0.20327	1.65120	**-9.98027**	**-1.20222**	0.2819
XX3	1.29425	-0.94214	**3.79485**	0.26812	0.1881
XY	-0.51701	0.20747	-0.21056	**-0.32229**	0.2261
YY	**-7.54497**	**6.71299**	-1.83357	**1.91044**	0.4868
YY2	**6.39195**	**-10.53609**	0.79575	**-1.63460**	0.3074
YY3	-1.20232	**5.07928**	0.25948	0.41766	0.2192
INTERCEPT	-5.99348	-4.44548	**-7.07038**	**-10.61798**	1

The effects of neighborhood demographic factors for the 1985-91 period appear to have a number of differences from those for the 1971-85 period. These effects are summarized below:

[13] Ideally we want to use demographic data for 1985. But here I used 1980 data since census data is not available for the years between 1980 and 1990.

- Median rent for rental housing (*MDRENT*): In the Period 2 model, median rent becomes significant for new commercial development, whereas it is not in the Period 1 model. *From 1985 to 1991, both commercial and industrial development preferred low rent area*. The variable remains significant for the two residential development, although the direction of impact has changed. It shows that *apartment development in the period sought high rent area, while single family housing development sought low rent area*.
- Percentage of one-unit housing (*UNIT1P*): New industrial development, while responding negatively to the share of one-unit housing in the census tract the Period 1 model, was not responsive to the variable in the Period 2 model. Apartment development, as in the Period 1 model, still sought census tracts with high proportions of multi-unit housing units instead of those with single-unit ones. The elasticity of this effect, however, is reduced from 1.7 to 0.6. Unlike the previous model, the Period 2 model shows that new single family development also responded statistically negatively to the share of census tract one-unit housing units. The elasticity is similar to that of apartment development.
- Percentage of white population (*WHITEP*): Single family housing development favored census tracts with higher percentage of white population during this period, whereas the effect was the opposite in the model for the previous period. The parameter estimates for other development types are all positive, but not significant.

- Percentage of buildings between 5 to 10 years old[14] (*BLT10_P*): The variable is significantly positive for industrial development, as it is for the Period 1 model, but unlike the previous model, it becomes insignificant for single family residential development. In addition, both commercial and apartment land development responded negatively to the variable: these two development types , in the 1985-91 period, would seek areas which had not experienced much residential development in the recent period.

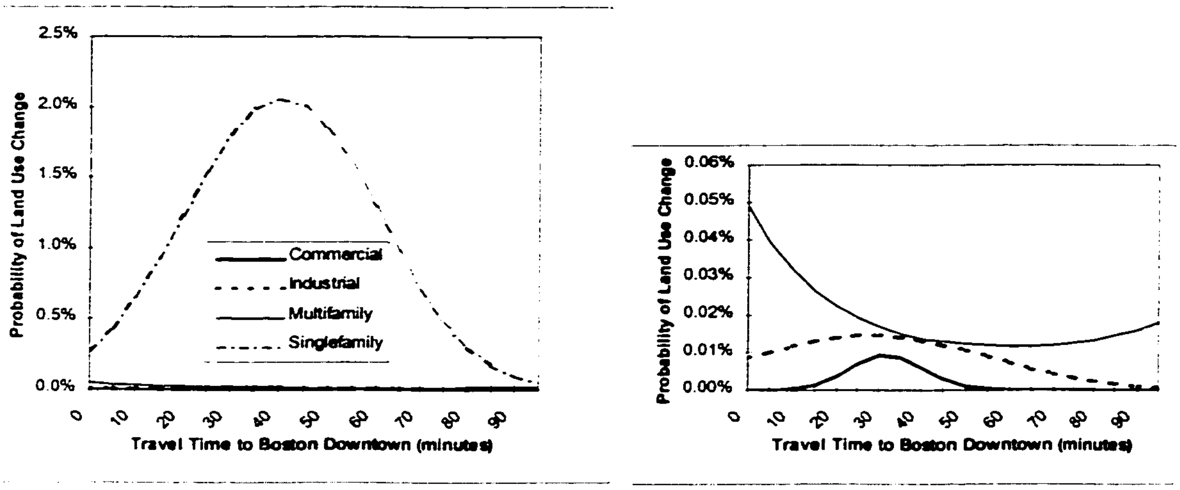
Overall, there is some similarity but also a lot of difference between the 1985-1991 model and the 1971-1985 model. New commercial development in both periods was generally irresponsive to neighborhood demographic features, whereas the factors affecting new industrial development were similar in many ways. The demographic variables, however, had quite different impacts on the two residential types of new development between these two periods. In the second period, single family residential development was more likely in areas of lower housing rent, fewer one-unit structures, and more while population, while new apartment development was more likely in areas with higher housing rent, fewer one-unit structures, and less recent development. The change in the response of housing development to neighborhood demographic features is quite apparent in the model, but the source of the change can also be misspecification of the model, as the demographic data used for the second period is five years earlier.

[14] The ages are for between 5 and 15 instead of the latest 10 years because I have census housing information only up to 1980.

5.2.2 Distance and Accessibility Characteristics

- Travel time to Boston downtown (*TIME_BOS, TM_BOS2*): The relationship between new land development and travel time to the central city in the second study period is plotted in Figure 5.3. The development type most similar to the pattern seen in Period 1 model (see Figure 5.1) is single family residential. The peak of single family development moved from 40 minutes away from downtown in the Period 1 model to approximately 35 minutes away. The vertical variation of the probability along the travel time axis has decreased, indicating a less significant relationship. In fact the variations in the probabilities for the other development types are so small that the vertical axis has to be re-scaled for their patterns to be visible. Both industrial and apartment development demonstrate a monotonically decreasing relationship, although statistically the two variables are significant for neither development types. Travel time is significant for commercial development, and the diagram showed a non-monotonic relationship, similar to the one in Period 1 model. The peak probability location, however, has moved farther away from downtown (15 minutes away in Period 1, 30 minutes away in Period 2). Comparing Figure 5.3 and 5.1, as well the significance of travel time in the two models, we can see *an overall decreased preference for access to central location in vacant land development.*

Figure 5.3 Vacant Land Development and Travel Time to Boston Downtown, Relationships according to the MNL (1985-1991)



- Distance to freeway (*DIST_HWY*): Distance to freeway is a significant variable for both commercial and industrial development in the Period 1 model, as both development types seemed to offer higher bid for places closer to the highways. For the second period, highway ceased to be significant consideration in commercial land location choice. Industrial development continued to favor being closer to freeways, although the marginal effect decreased. Neither of the two types of residential development appeared to be responsive to freeways access in either Period 1 or Period 2. Compared to the parameter estimates of the Period 1 model, the importance of access to highway in general was reduced in the vacant land change process over time.

- Distance to railways (*DIST_RAL*): Distance to railways is significantly negative for all types of land development, as it does for the Period 1 model. During both period, all types of new land development regarded access to railways as favorable locational characteristics, although the marginal effects are much weaker during the second period.

- Distance to the closest commercial (*DIST_LU4*), industrial (*DIST_LU5*) and institutional land (*DIST_LU6*): The parameter estimates of these three distance measures in Period 2 model all have the same signs as those in Period 1 model. All types of development were driven away from commercial land but drawn to industrial and institutional land. The magnitudes of the parameters, however, have generally decreased. All the 12 parameter estimates for these three variables are significant in the Period 1 model, while 4 of them are no longer significant in the Period 2 model.

Summarizing the results for the group of variables indicating accessibility and distance characteristics in the model for the 1985-1991 period, we find that the basic relationships stayed the same as for the earlier period, but the magnitude of the impacts have decreased in the later period.

5.2.3 Site Physical, Cost and Policy Constraints

During the second study period, steep slope was not as restrictive a factor for development as it had been during the first study period. It is no longer a significant variable for new commercial and single family residential development, and apartment development actually preferred steep slope areas in the region. For geological characteristics, similar to Period 1 model results, sites formed by flood plain alluvium (*GEO7*) were less likely to be developed. The other geological factor -- sites with fine-grained deposits (*GEO6*) -- also had negative effect, although it is only significant for single family residential development. Finally, wetland is significant only for single family development during the second period.

The results of the group of open space protection variables reveal that open space protection was a very significant deterrent to all kinds of development. The parameter estimates for all types of protection are uniformly negative. The significance of many estimates cannot be calculated because there were too few observations of the development type occurring to the protection level. This fact is itself an indication of the effect of the protection measures. Wherever accurate estimates of significance are available, they are all significantly negative.

5.2.4 Neighborhood Land Use Effects

- Vacant neighborhood (*NBH_VAC*): Between 1985 and 1991, both new commercial and industrial development were less likely to occur in predominantly vacant neighborhoods. Apartment development also disliked vacant neighborhoods, although the parameter is not significant. On the other hand, the probability of new single family residential development is higher in vacant neighborhoods. These results differ from those of the Period 1 model, but not too much. Industrial development seemed to avoid vacant neighborhoods to a much stronger degree, while apartment became less sensitive to land vacancy in the immediate neighborhood. Single family residential development already showed some weak and insignificant tendency toward undeveloped neighborhoods during the first study period, and this tendency was strengthened in the second period.

- Interactions between the same land use types: Similar to the results of the Period 1 model, the parameter estimates show that the presence of one urban use in the neighborhood would increase the chance of vacant land change to the same use. The marginal effectiveness ratios have been strengthened for the two residential development. For the two business land use changes, it appeared that the presence of commercial land in the neighborhoods became a stronger push for new commercial development, while the impact of existing neighborhood industrial land to industrial development diminished. Overall, the "synergy" effects between land uses of the same types are consistent with the previous period, and became somewhat more significant.

- Externalities between business and residential uses: both commercial and industrial development appeared to avoid residential neighborhoods -- either single family or multifamily -- between 1985 and 1991. Single family residential development avoided neighborhoods with high business land proportion, but apartment development cared less about business land in the neighborhoods. These results are not too different from those of the first period.

- Interactions between business uses and between residential uses: There existed no significant neighborhood externalities either between the two business land use types, or between the two residential land use types. This is unlike the previous period when commercial land development favored industrial areas, single family development favored multifamily neighborhoods, and multifamily development avoided single family areas.

Overall, the neighborhood effects to new land development were consistent with the previous period, and there was also some strengthening of the agglomeration effects for new urban land development to be in neighborhoods of similar types.

5.2.5 Adjacent Land Use Effects

- Vacant land adjacency: Being next to an undeveloped grid cell increased the chance of land use change between 1985 and 1991. This result is similar to the that of the Period 1 model, although the significance levels for the two residential development types have been reduced. This indicates again the importance of vacant land availability in the adjacent areas, especially for commercial and industrial land development.

- Adjacency interactions between the same land use types: The parameter estimates for the adjacency variables between the same land use types are all positive, but the variable is significant only for new industrial development. Compared to the previous period, this adjacent "synergy" effect between similar land use types was weakened.

- Adjacency externalities between business and residential uses: Both types of residential land development avoided being right next to either type of business use. The two business land development types were less likely right next to apartment uses, but were found *more likely* in neighborhoods with more single family housing.

- Adjacency interactions between business land uses and between uses: There are positive adjacency interactions between the two business land uses. In particular, new commercial development preferred more strongly to locations right next to industrial land. The interactions between the two residential uses, on the other hand, are negative, and apartment development particularly avoided being adjacent to single family residential use. These results are somewhat different from the previous period, when there were positive though insignificant interactions between the two residential uses, and the effect of being right next to industrial land is negative for commercial development.

Overall, unlike the effects of neighborhood land uses, adjacent land uses demonstrated quite a lot of change in their impact between the two periods.

5.2.6 Spatial Surface Trend

The surface trend component of the MNL model is plotted in Figures 5.4a-d for each new development. There is an upward sloping for commercial development in the southeast corner of the region, whereas in Figure 5.2a, the corresponding trend for the previous period, the upward sloping is to the northwest corner. The spatial variation of industrial development is very similar to the one for the previous period: there is a general upward sloping toward the north region. The surface trend for multifamily residential development is more complicated than the others. Three elements can be observed from Figure 5.4c: a significant upward sloping to the south of the region, a slight upward sloping to the northern region, and a slight east-west valley roughly following the Turnpike between these two peak. This pattern indicates a substantial under-prediction of apartment development in the south and north by the other variables. Finally, for multifamily residential development, there is a center in the southeast part of the region sloping downward in all direction, as well as an upward sloping to the northwest corner of the region. These figures are comparatively more complicated than the ones drawn for the previous period, which probably tells that there are more unexplained variations of the later period than the previous one.

Figure 5.4 Surface Trend of Vacant Land Development, 1985-1991

Figure 5.4a Surface Trend of Vacant Land Development to Commercial Use, 1985-1991

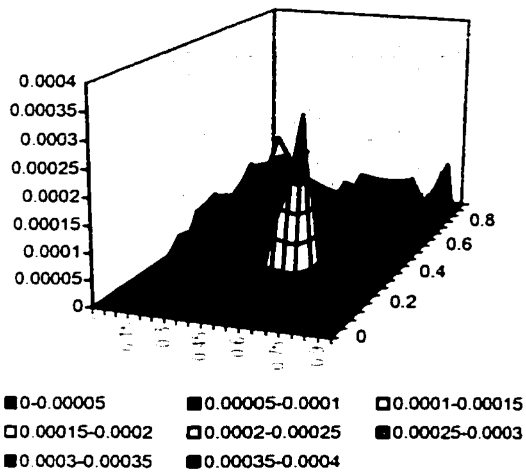


Figure 5.4b Surface Trend of Vacant Land Development to Industrial Use, 1985-1991

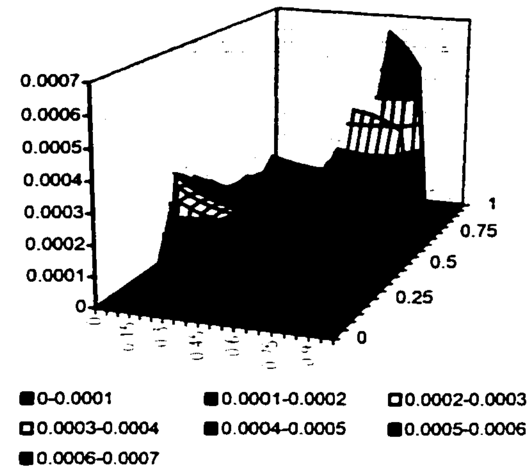


Figure 5.4c Surface Trend of Vacant Land Development to Apartment Use, 1985-1991

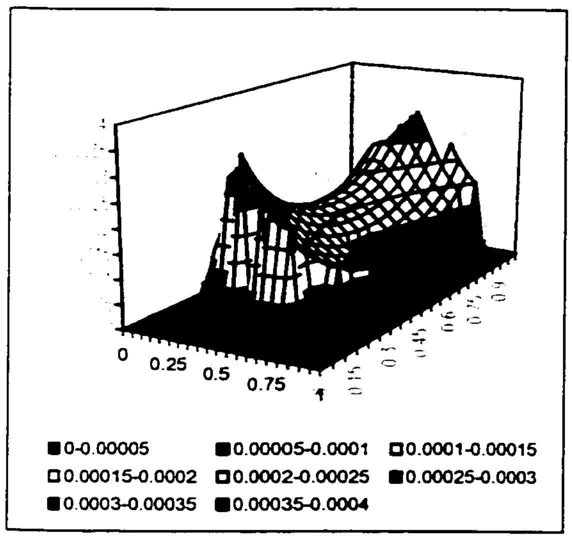
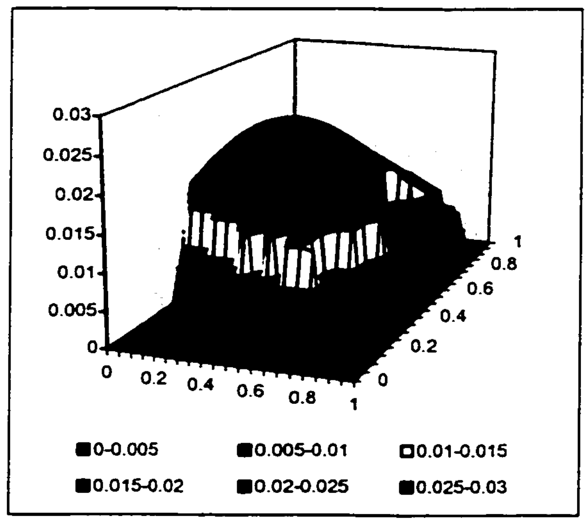


Figure 5.4d Surface Trend of Vacant Land Development to Single Family Use, 1985-1991



* *Vertical axis shows residual probabilities.*

5.2.7 Model Goodness of Fit

Table 5.7 Comparison of Actual and Predicted Results from MNL Vacant Land Development 1985-1991

Change from Vacant Land		Estimated Results from Model					
		Commercial	Industrial	Single Family	Apartment	No-Change	Total
Actual Results	Commercial	**132**	7	23	9	158	329
	Industrial	32	**36**	15	3	57	143
	Single Family	18	28	**1213**	28	1220	2507
	Apartment	12	7	43	**35**	69	166
	No-Change	136	66	1214	92	**4670**	6178
	Total	330	144	2508	167	6174	9323

5.2.8 Comparison between Period 1 and Period 2 Models

Cautions are needed to compare the results of the two study periods. The time spans are different: land use change is identified for a 14 year duration for the first study period, but only 6 years for the second one. Moreover, because of the deficiency with the 1991 land use data set, the population of grid cells we sampled for the second study period is restricted to only part of the region, a restriction that may introduce some bias[15]. Despite of these caveats, the similar way in which these two models are specified and estimated allows us to compare the similarities and differences between them and draw some clues as to the evolution of land use change process during the 20 years.

Important difference between the two models exists for the variables indicating census tract demographic and housing characteristics. Significance levels, signs and magnitude of the parameters are all very dissimilar. Several reasons prevent me from concluding whether the difference is a result of some dramatic change of the underlying response of land use change process to these demographic characteristics. There is

[15] The bias is likely to be small, as the descriptive statistics I presented in Chapter 3 were not that different.

important difference in the time period the variables represent. While for the 1971-1985 model, these census tract level variables indicate the demographic features at the initial year of the study period, for the 1985-1991 model, the tract level variables actually are for 5 years earlier than the beginning of the study period. How big this difference in five years period affects the model results is unknown. More importantly, the estimates in several cases do not conform well to my hypotheses about the direction of the relationships, and no easy explanations exist as to why it is so. Thus it is hard to conjecture as to how the effects of demographic characteristics changed over the period.

The results of accessibility and distance variables are in general consistent for the two periods. Most of the parameter estimates conform qualitatively to our expectations. And the difference that exists between the two models points to the trend that *the importance of accessibility factors have diminished.* This decrease in the significance of accessibility is not so apparent for new industrial land development, but especially obvious for new commercial development, which saw its peak probability moving farther away from downtown, and became much less attracted to freeways.

Site, cost and policy constraints played similar roles to development in the two periods, as variables representing slopes, wetland, geological characteristics, and open space protections, all have consistent estimates for the two periods. The only major change in these aspects seem to be that slope become a less restrictive factor to development during the later period.

As for the effects of neighborhood and adjacent land use characteristics, their effects have been in general consistent over the two periods, but more difference exists on the adjacency effects. There were negative externalities from vacant land in the neighborhoods, but positive spatial externalities for being right adjacent to a vacant site. There were also strong positive interactions between the same land use types, and mixed interactions between different land use types. The significance level of the variables change in either direction, but the overall pattern stayed similar during the two periods.

Finally the surface trends, intended to capture the variations unexplained by the other variables, are considerably more complicated in the later period, possibly indicating a more complicated land use change process as well as a need to improve model specification.

5.3 Urban Land Redevelopment 1971-1985

Table 5.8a Parameter Estimates of MNL of Urban Land Redevelopment: 1971-1985

Variable	Commercial	Industrial	Apartment	Single Family
INIT_APT	0.1771	*-6.7817*	*-10.238*	0.4881
INIT_COM	*-11.6441*	**-2.0215**	**-1.8597**	*12.9041*
INIT_IND	*-11.0451*	*-15.7182*	-0.3018	**15.1861**
INIT_PUB	**2.6131**	**3.0977**	**2.3389**	**16.4166**
INIT_TRA	**-0.9557**	*-11.1775*	-1.1232	*11.4053*
HUDEN	0.000041	**-0.1241**	-0.0353	-0.0572
MDRENT	-0.00202	**-0.00613**	**0.00559**	0.000661
UNIT1P	0.6353	-0.7066	0.3744	**-2.8745**
WHITEP	**-1.6718**	**19.5494**	**-2.2817**	6.1563
BLT10_P	-0.6006	**2.9637**	-0.6438	**2.6987**
TM_BOS2	-0.00107	**-0.00154**	**-0.00406**	**-0.0014**
TIME_BOS	-0.0108	-0.0482	**0.2567**	-0.0649
DIST_HWY	0.00175	0.00201	-0.00207	**0.00871**
DIST_RAL	-0.00093	**-0.0132**	**-0.00533**	**0.00651**
DIST_LU4	-0.0071	**0.0225**	**0.016**	**0.0179**
DIST_LU5	**-0.0115**	**-0.00575**	**0.00798**	**-0.0195**
DIST_LU6	**-0.0272**	**-0.0652**	**-0.0219**	**-0.0304**
SLOPE	-0.1346	-0.0143	-0.1026	-0.0749
GEO6	**-1.9744**	-0.3113	-1.3298	*-9.591*
GEO7	0.4503	0.1388	-0.4059	0.3168
WETLAND	0.4021	*-8.8531*	*-7.6115*	*-5.5847*
OS_FED	*-6.431*	*-5.643*	*-7.8882*	*-7.9235*
OS_STATE	0.1173	*-8.5255*	*-8.201*	-0.4135
OS_LOCAL	**-1.8149**	**-2.5068**	**-1.7374**	**-2.3029**
OS_PRTED	**-1.026**	**-1.3672**	-1.2163	-1.1364
OS_PRTMP	-1.3892	*-9.2874*	*-8.7578*	*-9.869*
NBH_VAC	-0.8184	**3.3295**	0.4113	**5.6086**
NBH_APT	2.6322	-2.1718	**5.6319**	-6.5493
NBH_SIN	-1.2941	-1.2713	**2.2516**	**5.2785**
NBH_COM	**10.1751**	**6.3469**	0.3039	**-8.0113**
NBH_IND	**6.148**	**9.1484**	-0.9059	**-14.1337**
ADJ_VAC	1.1918	-0.3596	0.6529	**-1.3011**
ADJ_APT	-1.362	0.7939	-2.6297	4.7751
ADJ_SIN	-0.502	-1.4943	**-3.009**	**-1.8089**
ADJ_COM	**-3.1467**	-2.5481	1.2555	3.2073
ADJ_IND	-2.1457	0.622	**2.9109**	-1.5297
XX	**-31.9425**	**-11.8658**	-3.2118	-1.2133
XX2	**55.6617**	*-6.0479*	0.9007	**-21.5997**
XX3	**-36.9225**	**14.1714**	-0.9249	**25.3278**
XY	**10.1445**	**11.1384**	2.4843	-4.1292
YY	**-44.2316**	-15.8464	0.2028	**-28.5697**
YY2	**84.3183**	9.8262	-9.3577	**40.8056**
YY3	**-53.9733**	0.9574	7.9358	-13.3364
INTERCEPT	**9.3698**	-14.784	**-7.2152**	-15.1632

* *Shaded parameters show statistical significance at 0.05 level.*

** *l_0 = 19298, l_{est} = 3751, McFadden's R^2 = 0.8056.*

Table 5.8b Elasticity Estimates of MNL of Urban Land Redevelopment: 1971-1985

Variable	Commercial	Industrial	Apartment	Single Family	Variable Mean
INIT_APT	0.0046	-0.1758	-0.2655	0.0127	0.0259328
INIT_COM	-0.5889	**-0.1021**	**-0.0939**	0.6529	0.0505866
INIT_IND	-0.3911	-0.5566	-0.0106	**0.5379**	0.035415
INIT_PUB	**0.3213**	**0.3809**	**0.2875**	**2.0188**	0.1229823
INIT_TRA	**-0.0527**	-0.6169	-0.0620	0.6295	0.0551954
MDRENT	-0.2846	**-0.8637**	**0.7875**	0.0931	140.883955
UNIT1P	0.4434	-0.4934	0.2613	**-2.0069**	0.6981365
WHITEP	**-1.6416**	**19.2041**	**-2.2407**	6.0480	0.9823037
BLT10_P	-0.1382	**0.6824**	-0.1482	**0.6214**	0.2302497
TM_BOS2	-1.2500	**-1.7995**	**-4.7456**	**-1.6358**	1169.09
TIME_BOS	-0.3436	-1.5299	**8.1410**	-2.0596	31.7182967
DIST_HWY	0.1774	0.2038	-0.2099	**0.8832**	101.4001941
DIST_RAL	-0.0496	**-0.7048**	**-0.2846**	**0.3477**	53.3979668
DIST_LU4	-0.1877	**0.5947**	**0.4229**	**0.4731**	26.4327865
DIST_LU5	**-0.9015**	**-0.4507**	**0.6257**	**-1.5287**	78.4005469
DIST_LU6	**-0.5342**	**-1.2807**	**-0.4301**	**-0.5971**	19.6458719
SLOPE	-0.1270	-0.0135	-0.0968	-0.0706	0.9437241
GEO6	**-0.0436**	-0.0069	-0.0293	-0.2117	0.0220737
GEO7	0.0240	0.0074	-0.0216	0.0169	0.0532107
WETLAND	0.0041	-0.0902	-0.0775	-0.0569	0.0101879
OS_FED	-0.0157	-0.0138	-0.0193	-0.0194	0.0024477
OS_STATE	0.0030	-0.2179	-0.2096	-0.0105	0.0255579
OS_LOCAL	**-0.1024**	**-0.1414**	**-0.0980**	**-0.1299**	0.0564303
OS_PRTED	**-0.0532**	**-0.0709**	-0.0631	-0.0589	0.0518656
OS_PRTMP	-0.0133	-0.0891	-0.0840	-0.0947	0.0095925
NBH_VAC	-0.2618	**1.0653**	0.1316	**1.7945**	0.2190192
NBH_APT	0.0692	-0.0571	**0.1480**	-0.1722	0.0264198
NBH_SIN	-0.5207	-0.5115	**0.9059**	**2.1237**	0.4732348
NBH_COM	**0.4171**	**0.2602**	0.0124	**-0.3286**	0.0435016
NBH_IND	**0.1557**	**0.2317**	-0.0230	**-0.3580**	0.0292314
ADJ_VAC	0.2610	-0.0788	0.1429	**-0.2850**	0.319954
ADJ_APT	-0.0360	0.0210	-0.0695	0.1262	0.026286
ADJ_SIN	-0.2373	-0.7069	**-1.4237**	**-0.8558**	0.4023287
ADJ_COM	**-0.1369**	-0.1108	0.0546	0.1395	0.0410053
ADJ_IND	-0.0627	0.0182	**0.0851**	-0.0447	0.0253265
XX	**-15.8457**	**-5.8840**	-1.5902	-0.5985	0.4961791
XX2	**15.7806**	-1.7182	0.2522	**-6.1282**	0.2835673
XX3	**-6.5487**	**2.5154**	-0.1627	**4.4945**	0.1773991
XY	**2.5378**	**2.7865**	0.6210	-1.0339	0.2502299
YY	**-22.4510**	-8.0403	0.1075	**-14.4997**	0.5076824
YY2	**25.4514**	2.9618	-2.8300	**12.3146**	0.3019059
YY3	**-10.6934**	0.1917	1.5745	-2.6408	0.1981599
INTERCEPT	**9.3689**	-14.7849	**-7.2161**	-15.1641	1

5.3.1 Initial Land Use Types

For the urban land redevelopment models, another set of dummy variables are added to the list of explanatory variables indicating the initial use of the grid cell. The one urban use that is left out in the dummy variable set is single family use, thus the coefficients can be interpreted in reference to the single family use: they tell whether a certain initial use is more or less likely, in comparison with initial single family use, to be changed to another type of use.

Note that a number of coefficients are in effect regarded to be infinite because there were too few observed cases. Some of the effects are by definition: commercial use cannot be *changed* into commercial use. Other cases of infinite coefficients occur because there were very few or even no cases that a land use change took place between one use and the other.

The coefficient estimates show that among all the urban land uses, institutional use (*INIT_PUB*) was most likely to have land use change between 1971 and 1985: a grid cell that was institutional in 1971 was two to three times more likely to be changed to commercial, industrial or multifamily use by 1985 than a cell in single family use in 1971. Other urban uses, on the other hand, in general seem less likely than single family use to change use. Apartment (*INIT_APT*) was almost impossible to be changed to industrial use; neither could it change to single family use[16]. Commercial use (*INIT_COM*) was twice less likely than single family use to be changed to either

[16] By definition of the variables, single family use cannot *change* to single family use, therefore the possibility is zero, and the corresponding coefficient is infinitely negative. The coefficient for multifamily use change to single family use show that it is statistically the same as the coefficient of single family to single family use change, thus it is also statistically infinitely negative.

industrial or apartment use. Industrial use (*INIT_IND*) was impossible to be converted to commercial use, while its possibility of changing into apartment use is no different from that of single family use. Finally, the model shows that transport land (*INIT_TRA*) was almost impossible to be changed into industrial land; its possibility of changing to apartment use was similar to that of single family use; and transport land was less likely than single family use to be changed to commercial use.

5.3.2 Neighborhood Demographic Factors

Housing cost, indicated by median rent in a census tract (*MDRENT*), seemed to have opposite effects on business and residential redevelopment: the signs of the coefficients show that the two types of residential redevelopment were attracted to areas with high housing price, while the two business redevelopment types were avoiding high housing price areas. The coefficients, however, were only statistically significant for apartment and industrial redevelopment. Thus, the above effects were very weak for commercial and single family redevelopment but strong for change to multifamily and industrial uses.

The percentage of one-unit housing in census tract (*UNIT1P*) was not a significant variable for any redevelopment except single family housing: somewhat surprisingly, single family housing redevelopment was *less* likely in census tracts with high proportions of one-unit housing.

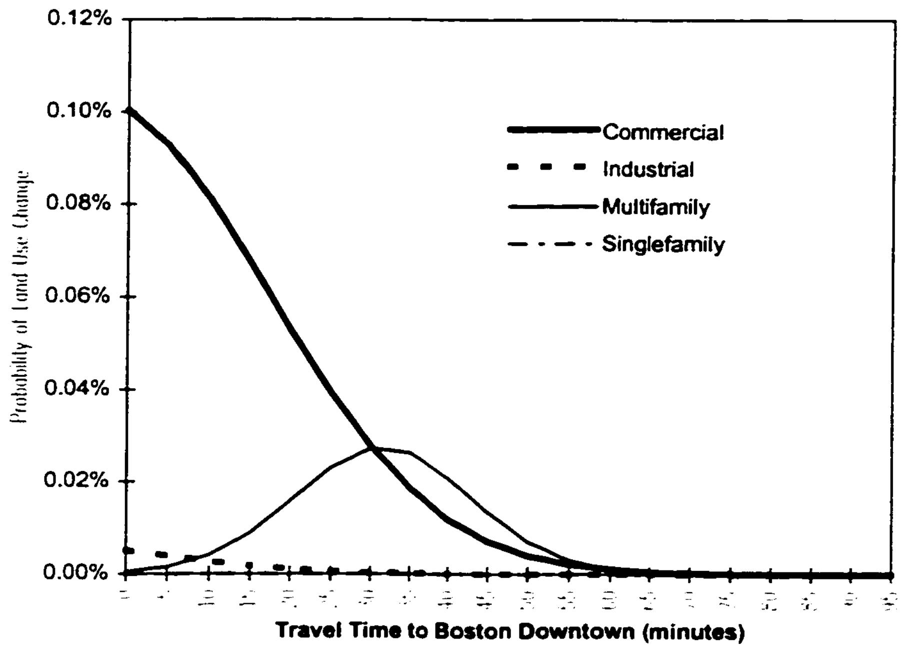
The proportions of white people in census tract (*WHITEP*) had significant impact on all types of redevelopment except those to single family use. During the 1971-85 period, industrial redevelopment in the area seemed to favor white neighborhoods, while commercial and multifamily redeveloped favored non-white census tracts.

Finally, the percentage of new housing units built within the last ten years (*BLT10_P*) had positive impacts on both industrial and single family redevelopment. These two types of redevelopment seemed to favor relatively new neighborhood, while commercial and apartment redevelopment slightly favored older neighborhood, although the latter effect is statistically insignificant.

5.3.3 Distance and Accessibility Effects

The effects of access to the central city on redevelopment is depicted in Figure 5.5. Unlike the case in the vacant land changes where probability gradients are mostly Λ shaped, the gradients for redevelopment are mostly monotonically decreasing except apartment development. For redevelopment to commercial use, although the estimated coefficients do not reach the threshold of significance for both travel time variables, since the estimated average probability of commercial redevelopment by the model is relatively high, the non-linearity of the logit specification dictates that the negative sloping of the gradient is quite significant. Commercial redevelopment seems to quite strongly favor central locations. For redevelopment to industrial and single family land uses, the coefficients for squared travel time are both significantly negative, while those for travel time are both negative but not significant, indicating two monotonously decreasing gradients at quite steep slopes. Because of the low estimated probabilities of redevelopment by the model, the plots are not able to show these trends very clearly. Among the redevelopment types, only change to apartment use has a non-monotonous gradient, with the squared travel time significant and negative, and the travel time significant but positive. The peak probability of redevelopment to multifamily residential use occurred at about 30 minutes away from downtown Boston. It seems that overall, *during the period, redevelopment was more drawn to central locations than new development on vacant land.* This can possibly be explained, at least partially, but the age of housing stock: older buildings are more likely to be redeveloped; as more central areas are more likely to have older building stocks, they are more likely to see redevelopment.

Figure 5.5 Urban Land Redevelopment and Travel Time to Boston Downtown, Relationships according to the MNL (1971-1985)



While access to freeways (*DIST_HWY*) was a positive factor for new development to industrial and commercial use on vacant land, this is not the case for redevelopment to the two business land uses, as the estimated coefficients are both insignificant. In fact, these two redevelopment types seemed to slightly prefer locations far away from highways. For residential redevelopment, while apartment use was also indifferent to access to highways, single family residential redevelopment would actually locate away, rather than close to, highways. Therefore, overall, unlike the case in vacant land development, *highway access was not an important consideration in redevelopment during the first study period.*

Distance to railway (*DIST_RAL*) was not a significant factor for redevelopment to commercial land, but was significant for other types of redevelopment. Industrial and multifamily residential redevelopment was attracted to locations closer to railways, but single family residential redevelopment appeared to locate away from railways. These results are quite similar to those for new development on vacant land for the same period.

The effects of distance on other land uses are similar to those in the vacant land development model: all changes occurred on existing urban land, except for the change to commercial use, seemed to locate away from commercial land, but were attracted to locate closer to both industrial and institutional land. The single exception is that redevelopment to apartment use tended to locate way, rather than close to existing industrial land.

In summary of the effects of accessibility and distance variables, compared with the vacant land development for the same period, in the redevelopment model between 1971 and 1985, *central city seemed to play a stronger role in redevelopment, while the importance of highways was not as significant.* The other distance effects are qualitatively similar between the two models.

5.3.4 Physical, Cost, and Policy Constraints

In comparison to the model results of vacant land change, the redevelopment model indicates that slope was a less restrictive factor for redevelopment than new development: all the coefficients are negative, but none of them are significant. Similarly, the two geological variables also had very little impact on development: only one of the eight coefficients are statistically significant. These results show that site physical characteristics were not much of a consideration in the redevelopment process. This is not surprising, since the initial use was already a developed use. Physical constraints, if any, should have been resolved in the initial development phase.

Redevelopment could occur to wetland only in the case that the initial use was some form of public use that was also wetland. Understandably, this was rare case, and the coefficients of wetland were almost all statistically infinite. There was also rarely any case that redevelopment happened to lands protected by the federal or state agencies. There were, however, a number of cases where redevelopment occurred on lands designated by local agencies as protected open space, but the probabilities of redevelopment on such land was significantly lower than land not protected. All together, the group of policy variables was still significant, but in most case they are irrelevant to redevelopment.

5.3.5 Neighborhood Land Use Effects

Between 1971 and 1985, while new development overall appeared to avoid neighborhoods with high proportions of undeveloped land, redevelopment, on the contrary, in general favored relatively vacant areas. In particular, commercial and apartment redevelopment was indifferent to the existence of vacant land in the neighborhood (compare to the instance of new development on vacant land during the same period, in which both these types were significantly avoiding undeveloped neighborhoods), while industrial and single family housing redevelopment clearly favored relatively undeveloped neighborhoods (compare to new development where both these types of change were insignificant). Therefore, the "undevelopedness" of neighborhood is a less restrictive and even positive factor for redevelopment compared to the case in new development.

Agglomerative economy effects (tendency of change to a particular use to be in areas having higher proportions of land in the same type) were of similar importance to those in new development: all the coefficients between the same land use types are all significantly positive, indicating that redevelopment was more likely to occur in neighborhoods where the same type of land had already dominated. The effects are much stronger compared to the new development model, as indicated by the higher elasticities of the coefficients.

Between the business land uses and residential land uses, single family residential redevelopment clearly was avoiding industrial and commercial neighborhoods, just as in the case of new development. Multifamily housing redevelopment, on the other hand, seemed indifferent to the existence of industrial or commercial land in the neighborhood. Moreover, unlike the case in new development, neither business redevelopment types were sensitive to the existence of residential land in the neighborhood.

Finally, there appeared in general favorable externalities between the two business land uses as well as between the two residential uses. Both industrial and commercial redevelopment would be more likely if there was a higher proportion of the other use in the neighborhood. Similarly, the existence of single family housing enhanced the likelihood of multifamily housing redevelopment. Only single family housing redevelopment responded slightly negatively to the existence of multifamily housing in the neighborhood, although the coefficient is not statistically significant.

In summary, neighborhood land use characteristics played quite important roles in the redevelopment process, more so than for new development. Compared to the new development model, the redevelopment model shows positive instead of negative effects of the existence of vacant land in the neighborhood, stronger agglomeration effects, little interaction between business and residential land uses, and stronger externalities between the two business land uses as well as between the two residential uses.

5.3.6 Adjacent Land Use Effects

Adjacent land use types, compared to neighborhood land use effects, appeared to play a much smaller role in redevelopment during the period, as most of the variables in this group are not significant. Adjacency to vacant land, for instance, which indicates the availability of vacant land in the surrounding area, was a consistently significant factor for new development on vacant land. For redevelopment, however, vacant land adjacency was not significant for all but change to single family use, in which case the effect is negative: single family residential redevelopment was less likely to occur right next to a vacant land parcel.

The interactions between the same uses are more complicated than the cases previously analyzed. While apartment redevelopment was indifferent to the existence of such use right next to the parcel, the probability of industrial redevelopment was significantly raised if the grid cell was right next to another industrial cell. But for single family and commercial redevelopment, the same-use adjacency effect was significantly negative. For commercial redevelopment, this possibly indicates competition effects if two commercial uses were located too close to each other.

The cross-use adjacency effects were very weak during the period. The only significant cases were that, for multifamily redevelopment, adjacency to single family use was a negative factor while adjacency to industrial use was a positive one.

Overall, the adjacency effects in urban redevelopment seemed to be less significant and more complicated than those in new development for the same period.

5.3.7 Spatial Autocorrelation Effects

For commercial redevelopment between 1971 and 1985, the combination of variables other than the x-y coordinates seemed to under-predict redevelopment cases at the west part of the region, as the surface trend showed a sharp rise there. The under prediction for industrial redevelopment, on the hand, was concentrated in the northeast towns of Rockport and Gloucester. The spatial trend surface for multifamily residential redevelopment sees an overall upward sloping to the southwest, suggesting under-prediction of the probability of multifamily redevelopment in this region. Finally, the last figure in the group suggested under-prediction of single family housing redevelopment at two corners: the northwest corner close to Dunstable, and the southwest corner of Middleborough.

Figure 5.6 Surface Trends of Urban Redevelopment Model, 1971-1985

Figure 5.6a Surface Trend of Urban Land Redevelopment to Commercial Use, 1971-1985

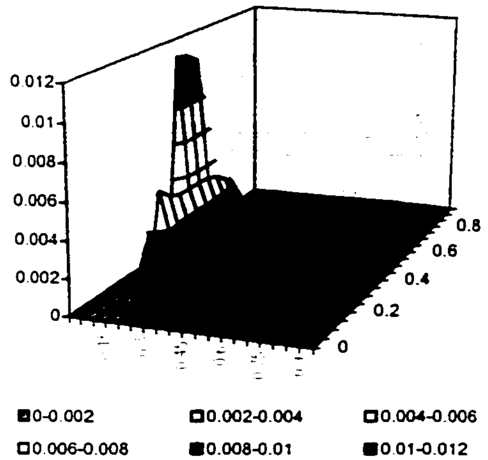


Figure 5.6b Surface Trend of Urban Land Redevelopment to Industrial Use, 1971-1985

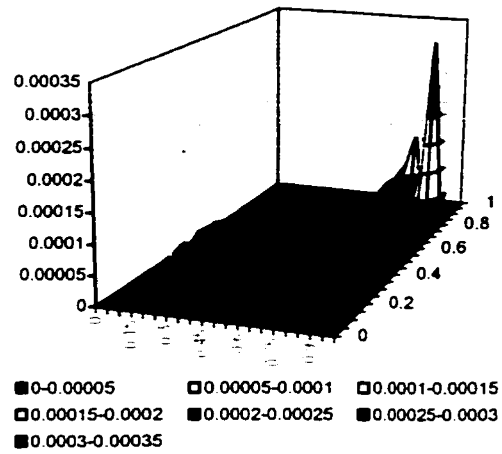


Figure 5.6c Surface Trend of Urban Land Redevelopment to Apartment Use, 1971-1985

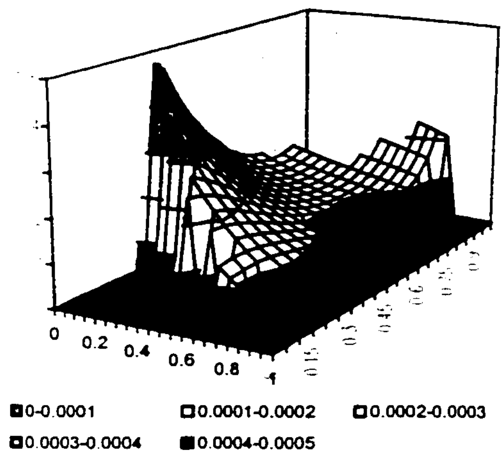
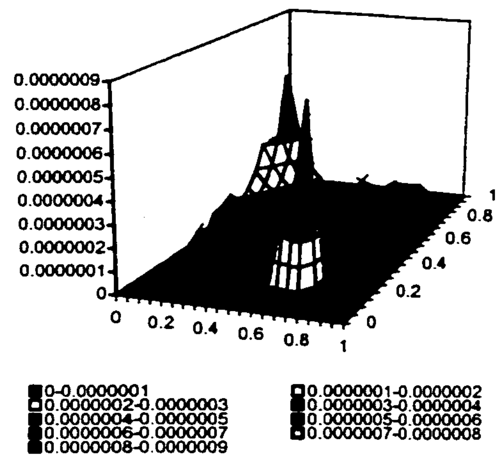


Figure 5.6d Surface Trend of Urban Land Redevelopment to Single Family Use, 1971-1985



* *Vertical axis shows residual probabilities.*

5.3.8 Model Goodness of Fit

Table 5.9 Comparison of Actual and Predicted Results from MNL Urban Land Redevelopment 1971-1985

Change from Urban Land		Estimated Results from Model					
		Commercial	Industrial	Single Family	Apartment	No-Change	Total
Actual Results	Commercial	**52**	10	8	5	41	116
	Industrial	14	**43**	2	7	48	114
	Single Family	5	10	**73**	7	35	130
	Apartment	5	8	6	**17**	48	84
	No-Change	41	44	42	49	**4243**	4419
	Total	117	115	131	85	4415	4863

5.4 Urban Land Redevelopment 1985-1991

Table 5.10a Parameter Estimates of MNL of Urban Land Redevelopment: 1985-1991

Variable	Commercial	Industrial	Apartment	Single Family
INIT_APT	-10.6063	-5.6867	-14.4421	**4.4458**
INIT_COM	-15.4454	-7.9506	-11.3107	1.3653
INIT_IND	-0.0523	-14.2444	**2.4736**	**2.8155**
INIT_PUB	**2.9952**	**4.248**	**4.4056**	**7.3037**
INIT_TRA	**-1.6597**	-0.3916	-5.9559	-5.1962
HUDEN	-0.00002	-0.00004	-0.00027	-0.0001
MDRENT	0.000001285	**-0.00362**	**-0.00374**	**0.00364**
UNIT1P	-0.8063	0.9371	**-4.3248**	0.6953
WHITEP	0.0136	-2.2287	-1.8636	-3.1512
BLT10_P	**4.537**	2.0404	**-7.1217**	0.9107
TM_BOS2	-0.00071	0.000461	**-0.00509**	-0.00025
TIME_BOS	0.0286	**-0.1027**	**0.3444**	0.071
DIST_HWY	-0.00292	**0.00741**	0.000373	-0.00002
DIST_RAL	0.000884	**-0.00496**	**0.0101**	**0.007**
DIST_LU4	**-0.0163**	-0.0105	-0.0123	-0.00305
DIST_LU5	-0.00018	**-0.00689**	**-0.00705**	**-0.00869**
DIST_LU6	**-0.0741**	**-0.0272**	**-0.1162**	**-0.0176**
SLOPE	-0.0855	-0.1491	0.0944	-0.0287
GEO6	-0.4791	**-1.5252**	0.1792	-0.7936
GEO7	0.4872	-0.7119	-8.0127	-0.3132
WETLAND	-6.2379	-5.3732	-5.9328	-5.9475
OS_FED	-5.7133	-8.73	-8.1978	-0.0286
OS_STATE	-8.8504	0.0071	-12.1357	**-1.8367**
OS_LOCAL	**-1.5299**	**-1.699**	**-2.0363**	**-3.5915**
OS_PRTED	**0.9306**	**-1.0632**	**1.5179**	0.0622
OS_PRTMP	0.1434	-8.3098	-7.7289	**-1.7084**
NBH_VAC	**6.2486**	**4.8132**	**2.6433**	**7.2105**
NBH_APT	0.0531	2.2298	-1.136	**7.717**
NBH_SIN	**2.6648**	1.1504	**4.0882**	**7.1479**
NBH_COM	**14.5957**	**5.5833**	-2.2895	**6.1263**
NBH_IND	**11.0047**	**15.2153**	-4.455	-5.469
ADJ_VAC	**-2.6356**	-1.1536	0.3527	-0.6057
ADJ_APT	3.3737	-2.2344	**10.7739**	-5.6287
ADJ_SIN	**-1.8573**	**-3.4199**	-2.0923	**-1.9803**
ADJ_COM	-0.3025	-3.8196	**6.8987**	0.6723
ADJ_IND	**-7.2**	**-3.49**	-0.2235	1.7642
XX	2.2673	**-23.3877**	**43.3696**	**15.5842**
XX2	-7.1679	**42.1234**	**-89.7719**	-19.979
XX3	8.047	**-25.9013**	**49.9398**	4.6352
XY	-4.5889	3.1725	**11.2441**	-1.1007
YY	11.5637	-2.4505	3.4733	10.5458
YY2	-17.2609	-6.719	-13.8084	-17.2934
YY3	9.5453	**10.1099**	4.9103	9.7696
INTERCEPT	**-10.4074**	0.8168	**-14.4756**	**-19.5363**

* *Shaded parameters show statistical significance at 0.05 level.*

** $l_0 = 41434$, $l_{est} = 2815$, *McFadden's* $R^2 = 0.9321$.

Table 5.10b Parameter Estimates of MNL of Urban Land Redevelopment: 1985-1991

Variable	Commercial	Industrial	Apartment	Single Family	Variable Mean
INIT_APT	-0.3637	-0.1950	-0.4952	**0.1525**	0.03429
INIT_COM	-0.8169	-0.4204	-0.5982	0.0723	0.05289
INIT_IND	-0.0022	-0.6142	**0.1067**	**0.1214**	0.04312
INIT_PUB	**0.3090**	**0.4383**	**0.4545**	**0.7536**	0.10319
INIT_TRA	**-0.0923**	-0.0218	-0.3313	-0.2890	0.05563
MDRENT	0.0004	**-1.1071**	**-1.1438**	**1.1132**	305.82630
UNIT1P	-0.5443	0.6326	**-2.9195**	0.4694	0.67507
WHITEP	0.0133	-2.1536	-1.8008	-3.0451	0.96640
BLT10_P	**0.3621**	0.1628	**-0.5685**	0.0727	0.07982
TM_BOS2	-0.9078	0.5896	**-6.5084**	-0.3196	1278.68000
TIME_BOS	0.9492	**-3.4094**	**11.4325**	2.3567	33.19579
DIST_HWY	-0.2839	**0.7206**	0.0363	-0.0019	97.24022
DIST_RAL	0.0514	**-0.2884**	**0.5871**	**0.4069**	58.13278
DIST_LU4	**-0.4175**	-0.2690	-0.3151	-0.0781	25.61829
DIST_LU5	-0.0134	**-0.5145**	**-0.5265**	**-0.6489**	74.68084
DIST_LU6	**-1.3535**	**-0.4967**	**-2.1226**	**-0.3214**	18.26769
SLOPE	-0.0812	-0.1416	0.0897	-0.0273	0.94994
GEO6	-0.0119	**-0.0379**	0.0045	-0.0197	0.02485
GEO7	0.0255	-0.0372	-0.4193	-0.0164	0.05232
WETLAND	-0.0683	-0.0588	-0.0650	-0.0651	0.01095
OS_FED	-0.0140	-0.0214	-0.0201	-0.0001	0.00245
OS_STATE	-0.1903	0.0002	-0.2609	**-0.0395**	0.02150
OS_LOCAL	**-0.0808**	**-0.0898**	**-0.1076**	**-0.1898**	0.05284
OS_PRTED	**0.0440**	**-0.0502**	**0.0717**	0.0029	0.04725
OS_PRTMP	0.0015	-0.0845	-0.0786	**-0.0174**	0.01017
NBH_VAC	**2.0344**	**1.5670**	**0.8604**	**2.3476**	0.22823
NBH_APT	0.0017	0.0699	-0.0356	**0.2419**	0.03222
NBH_SIN	**1.0323**	0.4455	**1.5838**	**2.7694**	0.45385
NBH_COM	**0.6122**	**0.2342**	-0.0961	**0.2569**	0.04518
NBH_IND	**0.3397**	**0.4696**	-0.1375	-0.1688	0.03491
ADJ_VAC	**-0.6015**	-0.2632	0.0806	-0.1382	0.32562
ADJ_APT	0.1087	-0.0720	**0.3471**	-0.1813	0.03135
ADJ_SIN	**-0.8428**	**-1.5520**	-0.9495	**-0.8986**	0.38746
ADJ_COM	-0.0137	-0.1726	**0.3117**	0.0304	0.04195
ADJ_IND	**-0.2513**	**-0.1218**	-0.0078	0.0616	0.03087
XX	1.0938	**-11.2856**	**20.9271**	**7.5197**	0.48254
XX2	-1.9579	**11.5075**	**-24.5236**	-5.4576	0.27318
XX3	1.3720	**-4.4165**	**8.5151**	0.7903	0.17051
XY	-1.1269	0.7792	**2.7614**	-0.2703	0.24558
YY	5.9551	-1.2627	1.7883	5.4308	0.51503
YY2	-5.4495	-2.1209	-4.3594	-5.4598	0.31575
YY3	2.0370	**2.1575**	1.0477	2.0849	0.21343
INTERCEPT	**-10.4058**	0.8184	**-14.4740**	**-19.5347**	1.00000

5.4.1 Initial Land Use Types

The effect of initial land use type on redevelopment between 1985 and 1991 was in general similar to that in the previous period. Institutional land (*INIT_PUB*) was consistently more likely to see redevelopment than other types of initial use. Commercial land (*INIT_COM*), on the other hand, seemed even less likely to be redeveloped than during the previous period; in fact, the parameter estimates for commercial and industrial land were effectively infinitely negative for all types of redevelopment, indicating that neither type of land was likely to see any redevelopment during this later period except to single family use. Industrial land (*INIT_IND*), in comparison to single family use, was more likely to be changed to multifamily use and single family use[17]; its chance of being changed to commercial use was statistically the same as that of single family use. Therefore, compared with the previous period, while commercial land was less likely to be redeveloped, industrial land seemed to become more likely to be changed to another urban use. Finally, the chance of redevelopment on industrial land also diminished during this later period.

5.4.2 Neighborhood Demographic Factors

While industrial redevelopment was found, in both periods, to be less likely in census tracts with higher median rents (*MDRENT*), apartment redevelopment appeared to avoid, instead of favor, as during the 1971-85 period, census tracts with higher median rents. Single family residential redevelopment, which was insensitive to median rent in Period 1 model, was found to be more likely where the rents were higher.

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[17] The latter fact is self-explanatory.

Share of one-unit housing in the census tract (*UNIT1P*) had negative impact on apartment redevelopment in Period 2, and insignificant for all other redevelopment. This compares to the Period 1 model, in which the only significant coefficient is the negative impact on single family housing redevelopment. Unlike the Period 1 model, in which the percentage of white population (*WHITEP*) had either positive or negative impact on almost all types of redevelopment, it had no statistically significant impact on any redevelopment in the Period 2 model.

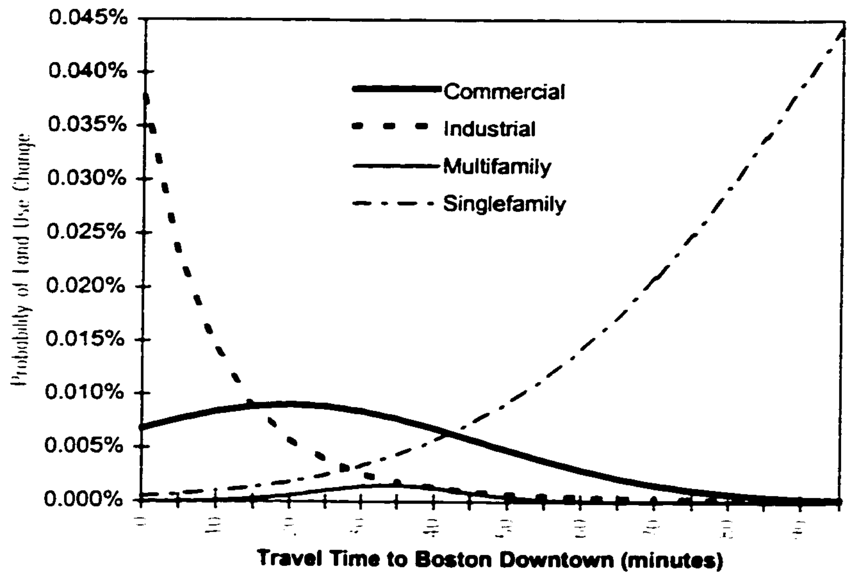
Finally, the percentage of new housing units built between five to ten years before the initial date (*BLT10_P*) had statistically significant influence on two types of redevelopment: commercial redevelopment was more likely in relatively new census tracts, while apartment redevelopment was less likely there. These results are different from those of the Period 1 model, where the variable was positively significant for the other two types of redevelopment.

Overall, as in the case of new development models, these census tract level demographic characteristics had quite different effects between these two periods. As stated earlier, I cannot ascertain whether this resulted from significant changes in the land redevelopment process.

5.4.3 Distance and Accessibility Effects

Figure 5.7 exhibits the effects of access to central city on redevelopment. Most similar to the previous period is its influence on apartment redevelopment: both curves are Λ shaped with peaks approximately 35 minutes away from downtown. The elasticities are also similar. Industrial redevelopment, while also exhibited a declining gradient, was only significant on the linear term of the variable, whereas for the previous period, it was the quadruple term that was negatively significant. This certainly indicates diminished importance of the central city for industrial redevelopment, a fact also evident by comparing the two corresponding curves.

Figure 5.7 Urban Land Redevelopment and Travel Time to Boston Downtown, Relationships according to the MNL (1985-1991)



For commercial redevelopment, travel time to CBD was an insignificant explanatory variable for both periods. Figure 5.7 shows that in fact the average probability of redevelopment to commercial use had very little variation between 0 and 50 minutes away from CBD. Finally, redevelopment to single family residential use exhibited a reverse gradient with probability increasing away from CBD. But neither the linear term nor the quadruple term is statistically significant, therefore we can at most say that access to CBD proved not an important factor in location choices of single family residential redevelopment. Overall, it is apparent that *CBD accessibility was less critical a factor for redevelopment during this later period than the previous one.*

The effects of access to highway (*DIST_HWY*) were similar to the previous period in that redevelopment was either insensitive to distance to highway, or avoiding areas close to a highway (for industrial redevelopment). Thus highway remained an unimportant or even negative factor in redevelopment. On the other hand, the effects of railways to redevelopment (*DIST_RAL*) were also similar to the previous period, except that apartment redevelopment tended to locate away from railways instead of closer.

With regard to distances to other urban uses, their effects on redevelopment were similar in most cases. The main difference was the effect of distance to the closest commercial use (*DIST_LU4*). Whereas being closer to existing commercial land made redevelopment less likely during the period between 1971 and 1985, during the later period, most redevelopment was slightly attracted to locations closer to existing commercial use, although the coefficients were mostly insignificant. The only statistically significant coefficient was for redevelopment to commercial use: there appeared to be some agglomerative effect in commercial redevelopment that was absent during the previous period.

In summary of the accessibility and distance variables in the redevelopment model for 1985-91, the major difference lies in two aspects: the importance of access to CBD decreased, while in the meantime access to the closest commercial use became a more important factor. This was likely a result of the suburbanization of employment and retail activities. When retails were more concentrated in the central city, travel time to

CBD was also a measure to access to retail opportunities. When such activities were decentralized, separate measures would be a better indicator of such opportunities.

5.4.4 Physical, Cost, and Policy Constraints

The effects of physical and cost constraints on redevelopment turned out to be very similar to those in the previous period. Neither slopes nor geological features were very restrictive factors for redevelopment, whereas such land use change, unsurprisingly, almost never occurred on wetland.

Similarly, redevelopment rarely happened on lands protected by the federal or state agencies, while local protection did have a significantly negative impact on the possibilities of land use change. The difference from the previous period was in that open space designated as protected seemed to have higher probability of having redevelopment to commercial and apartment use. These changes are likely to be land development on some public land. It may indicate somewhat loosened government control on open space development.

5.4.5 Neighborhood Land Use Effects

During this second study period, neighborhood land uses had some different impacts on the likelihood of urban land use change than during the first period. One difference is the effect of undeveloped land: while higher proportions of undeveloped land in a neighborhood would enhance the likelihood of redevelopment to industrial and single family residential land during the 1971-85 period, they would enhance the chances of all types of redevelopment during the later period, as the coefficients in the model are all significantly positive for neighborhood vacant land. These results contrast sharply with the new development models where the impact of neighborhood vacant land on development was generally negative. *Whereas new development was more likely in more developed areas, redevelopment was more likely in less developed areas.*

The interactive effects between the same land use types generally retained except for multifamily redevelopment, which did not exhibit increased likelihood of locating in a neighborhood with more multifamily housing. The spillover effects between the business land uses and residential land uses were also quite different from the previous period. There seemed to be statistically significant synergy between commercial use and single family residential use that was absent in the earlier redevelopment model: commercial redevelopment was more likely in areas with more single family residential use, while at the same time the presence of commercial use also enhanced the chance of single family residential redevelopment. Furthermore, single family redevelopment did not seem to avoid industrial neighborhood as it did during the previous period.

Finally, the synergy between the two business land uses and between the two residential uses was qualitatively similar to the effect in the Period 1 model, and quantitatively stronger.

5.4.6 Adjacent Land Use Effects

The adjacency effects between different land uses were more complicated. First, adjacency to vacant land showed no significant impact on redevelopment except use changes to commercial use, in which case the adjacency to vacant land had negative impact.

Second, between the same uses, the interactions were complicated, just as the results in the earlier period model, but in a slightly different way. The effects between multifamily residential uses were significantly positive, those between commercial uses insignificant, while those between single family uses and between industrial uses were both significantly negative.

The cross-use adjacency effects were much stronger than the previous period. Either commercial or industrial redevelopment, for instance, was less likely when right to a single family use. On the other hand, being right next to a commercial use raised the chances of redevelopment to multifamily residential use.

Taken the neighborhood and adjacency use effects as a whole, a comparison between the models showed enhanced importance of these two groups of explanatory variables in urban land redevelopment during the later period model.

5.4.7 Spatial Autocorrelation Effects

The surface trends constructed by the coefficients of the polynomials of the x, y coordinates show that they are more complicated than those for the previous period, a result similar to the difference between the two new development models. For commercial redevelopment, the combination of the other variables would under-predict commercial redevelopment at the northwestern areas, and also in some areas in southeast. Whereas in Period 1 model, the surface trend for industrial redevelopment is fairly simple, the Period 2 one is more complicated, with two peaks – one in the west, the other in northeast. For redevelopment to apartments, the under-prediction is concentrated in the northeast, while for single family residential redevelopment, it is tilted towards the north. Overall, the more complicate patterns suggest more complicated factors influencing redevelopment during the second period, and less explanatory power from the model.

Figure 5.8 Surface Trends of Urban Redevelopment Model, 1985-1991

Figure 5.8a Surface Trend of Urban Land Redevelopment to Commercial Use, 1985-1991

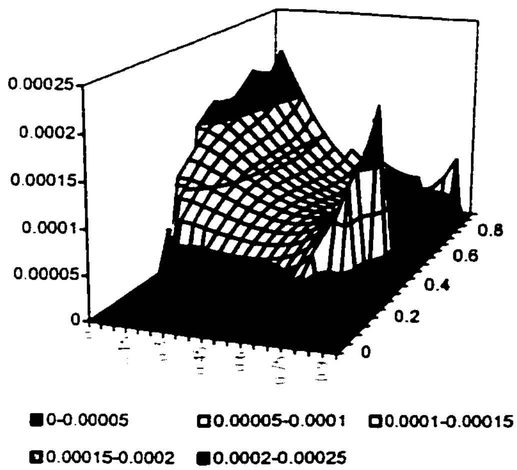


Figure 5.8b Surface Trend of Urban Land Redevelopment to Industrial Use, 1985-1991

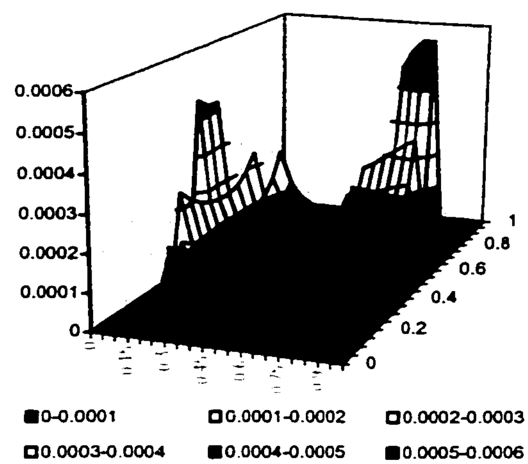


Figure 5.8c Surface Trend of Urban Land Redevelopment to Apartment Use, 1985-1991

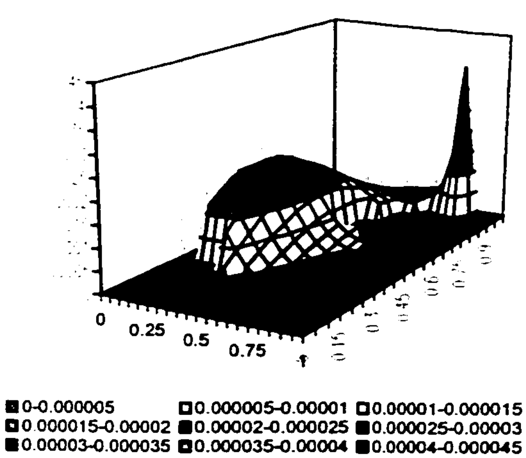
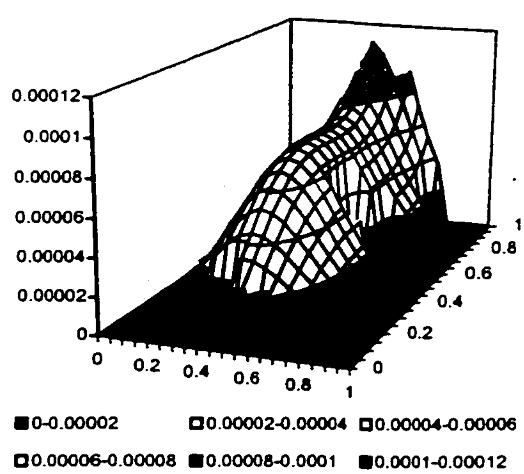


Figure 5.8d Surface Trend of Urban Land Redevelopment to Single Family Use, 1985-1991



* *Vertical axis shows residual probabilities.*

5.4.8 Model Goodness of Fit

Table 5.11 Comparison of Actual and Predicted Results from MNL Urban Land Redevelopment 1985-1991

Change from Urban Land		Estimated Results from Model					
		Commercial	**Industrial**	**Single Family**	**Apartment**	**No-Change**	**Total**
Actual Results	**Commercial**	**50**	2	2	1	47	102
	Industrial	6	**26**	7	1	34	74
	Single Family	6	7	**80**	5	64	162
	Apartment	2	4	5	**16**	24	51
	No-Change	39	36	69	29	**9835**	10008
	Total	103	75	163	52	10004	10397

Chapter Six Conclusions

6.1 Summary of the Results

The story of land use change process, as told from the modeling exercise in the previous chapter, is multi-faceted and seems to become even more complicated over the time. To summarize these results, here I try to address the four questions asked at the beginning of the thesis: (i) what are the common factors that have been important for all types of land use change in the region? (ii) how are new land development and redevelopment similar and dissimilar? (iii) to what extent are the determinants of different types of land use change diverge from each other? (iv) how have the factors changed over time?

6.1.1 Common Factors

The MNL models calibrated for vacant land development and urban land redevelopment for the two periods in the Boston Region demonstrate some common factors that are significant for all types of land use change. Access to the central city, measured by driving time to Boston downtown, was mostly significant. This confirms the results of the monocentric Alonso model, which derived ordering of land use as a function of access to central cities. The models showed, however, that the probability of land use change is often a non-monotonous function of access to the center, and the peak often indicates the intensity of preference for central location for a specific land use change type.

In addition to access to central city, the models showed the importance of other accessibility measures. While access to transportation facilities themselves (highway and railway) are often significant factors, the models showed that distance measures to other land uses (particularly business land uses) are also important determinants. These results demonstrate the importance of accessibility to jobs, shopping and recreation opportunities in a decentralized environment.

The other group of consistently significant variables in the are the characteristics of neighborhood land uses. Four effects have come out from the model results: (i) neighborhood vacancy, representing how urban or rural the area surrounding a site is; (ii) agglomeration or "synergy" effects, when a parcel is more likely to be converted to a particular use if the area surrounding the site has higher proportion of this type land use; (iii) interactions between business and residential uses, which can be either positive or negative; (iv) externalities between the two business land use types and between the two residential land use types. All these four effects are significant in the models one way or another, but their importance stands out in all the models. In comparison, although the same effects also exist for adjacent land uses, the significance and consistency levels are much lower.

Site physical and policy constraints are found to be consistently effective in general. On the other hand, neighborhood demographic characteristics, represented by census indicators at the census tract level, are generally inconsistent across the models and across time periods. The only demographic variable that appears to somewhat consistent is the median rent of a census tract: business land development generally avoids high housing price areas, whereas residential development may or may not seek high price neighborhoods.

6.1.2 New Development and Redevelopment

The comparison between vacant land development models and redevelopment models tells some important difference in the driving forces of land use change between them. The models showed that redevelopment in general has stronger preference for central locations. While railways were similarly important both to new and redevelopment, access to highways is shown to be quite unimportant for redevelopment.

While site physical constraints such as slope are quite important factors for vacant land development, they are much less important in the urban land redevelopment process. Neighborhood land use characteristics are significant for both development processes, but there are some important differences between them. Whereas new development is more likely to occur in areas with higher proportion of urban land, redevelopment is actually more likely to happen in vacant areas. Redevelopment process also showed stronger agglomeration effects between similar land use types, little interaction between business and residential land uses, but stronger externality effects between the commercial and industrial uses and between apartment and single family residential uses. Finally the adjacency effects between land uses are more complicated in the case of land redevelopment.

6.1.3 Different Land Uses

The MNL model results in the study showed that different land use types have different preferences in terms of locational choices. In summary, for new land development from vacant land, *commercial development* is more likely to be in central locations, less likely to be in predominantly vacant neighborhoods, and more likely to be adjacent to existing commercial land. The impact of physical and policy constraints are also quite strong for new commercial development. New *Industrial development* is more likely to follow housing development (where new population have moved in), more likely to be in neighborhoods with more white people. It also has shown strong preference for central locations with its monotonously decreasing bid rent curve. Among the land use changes, it has the strongest preference for highways, and it also avoids to be in predominantly single family housing neighborhoods. New *apartment development*, compared to other development, is less likely to occur in predominantly undeveloped neighborhoods. It was especially more likely to be found in commercial neighborhoods but was less likely to locate in single family residential or industrial neighborhoods. Finally, new *single family residential development* would seek areas with higher housing price and higher recent demand. It has the least preference for central location among all the development types, while also avoiding railways. It is more likely to occur in predominantly residential neighborhoods, less likely in business neighborhoods, and would avoid sites right adjacent to a commercial use.

Locational preferences of different land use changes are different in the redevelopment process. In summary, *redevelopment to commercial use* is less likely in white neighborhoods, un-affected by transportation access, more likely in neighborhoods with existing business land uses, but would avoid being right next to another commercial use. *Redevelopment to industrial use* occurs more often in low density areas with predominantly undeveloped land and low housing price but high recent housing demand. It would prefer more central location, and areas already with some business land uses. Conversion of urban land to *apartment use* is more likely to occur in areas with high housing rent, fewer white population, predominantly residential neighborhood and quite some distance away from the center. Such conversion is also unlikely to be found right next to an existing single family residential area. Finally, change from urban land to *single family residential area* is more likely to occur on existing public and industrial land where there is high housing demand recently. Such redevelopment prefers more central location in vacant or single family neighborhoods, but it would avoid being close to highways and railways, and also avoid neighborhoods with a lot of existing business land uses.

6.1.4 Change over Time

Comparisons of the 1971-1985 models and 1985-1991 models reveal that while there are consistencies in terms of the effects of different variables, there are also some important changes between the periods. For new land development, the significance of access to the central city generally decreased during the second period, especially for new industrial development. Site physical constraints, especially slope, became less important. The effects of neighborhood land use characteristics were quite consistent over the two periods, with some strengthening of the agglomeration effects between the same land use type, but the adjacency effects are quite different between Period 1 and 2. Overall, the new land development process became more complicated over the time, as shown by the residual graphs.

The observations of the changing importance of determining factors over the two periods are also shown in urban land redevelopment. Similar to new development, redevelopment process also demonstrated decreasing importance of access to the center and increasing importance of neighborhood and adjacent land use characteristics. Moreover, during the second period, redevelopment was also more likely to occur on existing industrial land, less likely on commercial land. It showed stronger preference for sites close to some commercial areas, and is more likely to occur in "non-urban" neighborhoods. There are also some positive externalities between commercial use and single family use which were absent during the previous period. Overall, as in the case of new development, the process appeared to become more complicated, with the set of variables in the model less able to explain the changes.

6.2 Understanding Land Use Change: Methodological Issues and Future Improvement

In addition to these conclusions from the modeling work, this study also contributes to the understanding of the land use change process and metropolitan urban transformation in a number of other aspects.

First, this study provides a detailed and comprehensive *descriptive analysis* of land use and land use changes for a metropolitan region, based on comprehensive survey data covering the whole region. The analysis (Chapter 4) provides abundant information on how the physical features of the metropolitan region changed over a 20 year period, where the changes occurred, how much was the change, the spatial relationship between land use changes and existing land use, and the forms. The descriptive analysis also relates the land use changes to some spatial factors such as driving time to Boston downtown and distance to highways. In this way it provides descriptive but informative spatial picture.

Second, this study bases its empirical model on a theoretical framework consistent with the more traditional urban economic framework. In particular, it established the linkage between the multinomial logit model of land use and the bid-rent model, and showed how the MNL structure can be derived from profit/utility maximization. The calibration results from the empirical models confirm some of the assertions of the traditional bid-rent models, but the model structure is also able to incorporate more complicated factors, which have proven to be increasingly more important than traditional access factors. This grounding of the empirical models on the theoretical framework also provides clearer guidance on the explanation of the modeling results and provides more confidence on the use of the model structure for future projection and simulation (Landis and Zhang 1998).

Third, it is also the first time that models with a qualitative response dependent variable have accounted for spatial autocorrelations. This is done partly by including the polynomials of the coordinates to derive a spatial trend. More importantly, statistics of land use in the neighborhood of a site are used as independent variables, in a way similar to the inclusion of lagged time variables in a time-series models. These spatially lagged variables turned out to be important determinants of the future status of a site, with some indication that their importance even increased over the years. Introduction of these spatial variables in the MNLs also make these models to work like the cellular automata models in the sense that the status of one cell is partly affected by the status of the cells surrounding it. In this way, the models are more "spatial".

Finally, the study is able to calibrate both the new development and redevelopment models for two time periods, and has enabled us to examine the difference in the process and how it changed over the time. The results show that cautions are needed to use the calibration results to future projection. While the model provides fairly solid ground for short-term projection, the forecast should not be extended too far ahead since the underlying determinants can change over the years. However, with more readily available land use data sources (from survey, aero- or satellite images), more frequent calibration can be conducted to make the projection more likely to be reliable.

There are a number of ways the methods and analyses adopted in this study can be further improved. First, this study calibrated land use change models for only one region. The question is to what extent can the results be applicable to other regions, and whether they are general trend or specific to Boston. To answer the question will need similar exercises for more metropolitan regions[18]. Second, in terms of the choice of independent variables, the current model structure has been limited by the lack of information of agents (land owners, developers, residents, etc.). If real parcel level data are available which contain information about land owners and/or users, I expect model performance to be greatly improved. Third, one powerful application of the modeling framework is to test the impact and effectiveness of particular policy instruments, such as zoning, growth boundaries, development impact fees, property taxes, etc. As a result of lack of data, this study has not demonstrated usage in this important aspects, but the current model structure can still be effectively used to test these policy implications. Finally, the model structure and calibration results, if used cautiously, can help to project future metropolitan development trends, and simulate the implications of different policy scenarios (see Landis and Zhang 1998 for application for California).

[18] For the results from the MNL of the San Francisco Bay Area see Landis and Zhang (1998).

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