EXPLORING AND MODELING THE URBAN LAND DEVELOPMENT PROCESS IN HAMILTON, ONTARIO

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ABSTRACT

The form of many Canadian cities has dramatically evolved over the past six decades due to urban sprawl. Several patterns can characterize this evolution including unlimited horizontal expansion of the city, scattered, leapfrog, and power center retail development. Hamilton, Ontario is an example of a Canadian city that has experienced such patterns of development. The evolution of urban form is mainly driven by the land development process. Since land developers are the drivers of such process, their behaviour is an important factor contributing to the spatial configuration of urban areas. However, our knowledge of the residential development process and the behaviour of land developers is still limited. This thesis has two objectives. First, it explores the spatio-temporal patterns of the land development process in Hamilton between 1950 and 2003. Second, it explains the major locational factors affecting the behaviour of land developers with respect to the choice of the housing type when they develop a site for residential use. For the first objective, a number of spatial statistics techniques, namely kernel estimation and K-function estimation, are used to examine the locational patterns of urban land development. The study is based on parcel level data for the period 1950 – 2003. The findings indicate that sprawl and suburbanization have been evolving Hamilton's urban form from monocentric to polycentric over the study period. Furthermore, time lagged co-clustering between the locational patterns of commercial and residential land development is pronounced in the 1990's. For the second objective, several Multinomial Logit Models that explain the housing-type choice behaviour of land developers are estimated. Four alternative type-choices facing developers are modeled: detached, semi-detached, row-link, and condominium housing. The specification of the four utilities includes road infrastructure, residential amenities, and general site characteristics variables. The results suggest that developers supply detached, row-link, and semi-detached houses at locations that exhibit suburban characteristics. However, semi-detached development is attracted to locations in suburban municipalities at sites that have more urbanized characteristics. In addition, the row-link housing type is attracted to suburban locations that enjoy very high levels of mobility and accessibility to amenities and road infrastructure. Finally, the condominium housing type is attracted to locations that exhibit the most urbanized features.

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CHAPTER ONE

Introduction

1.1 Research Context

In the spring of 2006, the Ontario's Ministry of Public Infrastructure Renewal published the Growth Plan for the Greater Golden Horseshoe (GGH) region. The Plan was presented as a framework for implementing the Government of Ontario vision on building stronger and prosperous communities based on an effective growth management in the region up to 2031. Driven by the growth pressures facing the GGH (a forecasted population growth of 11.5 million people up to 2031), the Plan intends to lead strategic decisions on transportation, infrastructure planning, land-use planning, urban form, housing, natural heritage, and resource protection while achieving economic prosperity (Ontario Ministry of Public Infrastructure Renewal, 2006).

The significance of this policy document is twofold. First, it emphasizes the distinct characteristics of the GGH's economy as the driving forces for the region's competitiveness and prosperity. Second, it explicitly names urban sprawl as a potential factor that would undermine this competitiveness and prosperity. Specifically, this official plan identifies ongoing urban sprawl as a prime contributor to the degradation of Ontario's natural environment, air quality and water resources, as well as to the loss of rural lands and other natural resources. Moreover, the Plan recognizes the inefficacy of existing sprawled urban areas to support efficient and viable transit systems. It also underlines the direct relationship between sprawling communities and automobile dependency that has been congesting transportation corridors. Lastly, the Plan highlights the observed high levels of inefficiency caused by sprawling land development since additional infrastructure is required for servicing new and lower density areas while the use of existing infrastructure in older neighborhoods is not optimized.

In general lines, the approach adopted in the Growth Plan for the GGH can be summarized as follows. At first, the Plan acknowledges the driving forces of economic growth in Ontario. Subsequently, it argues about the challenging impacts (urban sprawl and its implications) induced by rapid growth in the absence of an effective growth management. Finally, it proceeds with establishing policy directions that intend to tackle the unwanted implications of expected future growth. The policy directions concentrate on building compact communities as well as on mitigating urban sprawl through the integration of transit system, the protection of natural resources, and the efficient investment in infrastructure (Ontario Ministry of Public Infrastructure Renewal, 2006).

In essence, what is acknowledged by the Ministry's Growth Plan is that urban sprawl, as the observed result of the high rate of growth in the region, might impair the GGH's economic prosperity and sustainability. It is known that growth carves its spatial footprint on a region through land development. Land development converts land and develops it to uses capable of accommodating various human activities. Thus, the question to be raised here is how land development leads to urban sprawl. In more detail, what are the leading factors that determine the nature of the land development process and give rise to sprawling communities?

To answer these questions, the spatial characteristics of urban sprawl in general as well as the specific characteristics of it in the GGH region should be studied. Understanding the counterpart of sprawl, this of compact land development, is also imperative. Yet, the most important task should be to bring evidence from real data on the way the land development process produces sprawled urban form within the regional context of Ontario. Thus, unraveling the relationship between land development and the resulting urban sprawl involves studying the underlying forces of the land development process. It also requires the understanding of the factors that trigger land development. Lastly, it entails the identification of the prime agents driving the land development process and the explanation of their behaviour.

Although the existing literature on urban sprawl and the evolution of urban form is ample, empirical research that provides evidence on the way the process of land development configures urban space is scarce. Most of the research that has been conducted on the evolution of urban form is based on the analysis of the land development's outcome. This is usually done by studying the change in population and/or employment density, measured at a zonal level (i.e. census tract), with the distance from the city centre (Cuthbert and Anderson, 2002a,b). However, research exploring the spatial process that brings land development to its final spatial outcome is desired. That is, further research is required on how the actual process of land development, which is materialized through the conversion of land over time and space, gives rise to a particular type of urban form. For this purpose, data on land development are necessary at a fine spatial level and for an extensive time period (historical and micro-level data). Under these conditions, the trends in the process and the spatial pattern of its driving forces can be revealed and documented for future reference and use.

Mitigating the implications of urban sprawl in the future requires precise knowledge on the factors that produce this type of urban form. This implies that we need to build our understanding of the factors that guide land development to create a particular spatial arrangement of land uses in an urban area. In other words, we need to advance our knowledge regarding the reasons that lead the land development process to produce a specific land use type at a certain location in the urban or exurban area. To achieve this, we must first identify the prime agents that are active in the process and then explain their behaviour since the behaviour of these agents is responsible for the conversion of land. However, the existing evidence concerning the factors affecting the supply of the various land-use types at different locations in space is fragmented and limited.

The present study contributes to the literature regarding urban form by bringing empirical evidence on the spatio-temporal trends and patterns in the land development process that gave rise to a sprawled urban form in Hamilton, Ontario. In addition, using the city of Hamilton as a case study, this analysis advances the current state of knowledge concerning the spatial factors that influence the supply of different types of residential development in the GGH region.

1.2 Research Objectives

The main objective of this study is to highlight the particular dynamics in the land development process that contributed to the formation of Hamilton's contemporary urban form; and to identify the key spatial factors that affect the land developers' choice on the construction of a certain housing type at a specific location in the city. Specifically, there are two main research objectives that will be pursued in this analysis:

1. Explore the spatial and temporal trends and patterns in land development that took place in the city of Hamilton between 1950 and 2003; and investigate their role on the evolution of Hamilton's urban form.
2. Explain the major locational factors affecting the behaviour of land developers with respect to the choice of the housing type when they develop a site for residential use.

Meeting these objectives will provide an insight into the process that produces sprawling communities in the GGH as well as it will reveal some important factors that affect the outcome of residential land development in the region. This wealth of knowledge could be used as an input to inform future actions taken in an attempt to implement the principles and guidelines of the GGH Growth Plan.

1.3 Thesis Outline

This thesis consists of six chapters. **Chapter Two** starts with a review of the literature on the process of land development, the meaning of urban form, and its relationship with transportation. Next, it proceeds with an evaluation of the literature related to the study and the exploration of urban form. Lastly, it provides an appraisal of the existing knowledge on modeling the land development process in general and the behaviour of land developers in particular. **Chapter Three** consists of a preliminary presentation of the study area, which introduces the reader to some of its basic characteristics such as distribution of population and dwellings density and road infrastructure. This is followed by an overview of the data as well as the methods used for their analysis. Exploration techniques and the applied modeling approach are described in detail. **Chapter Four** presents the research findings from the exploratory analysis of land development in Hamilton between 1950 and 2003. Specifically, the spatio-temporal trends in land development are presented and described by charts and diagrams. Subsequently, a series of maps illustrating the surfaces produced by the Kernel density estimates for the residential and commercial floorspace development are used to document the spatial pattern of land development. Lastly, diagrams of the univariate and bivariate K-functions estimated from the point patterns generated by the developed land parcels are used to depict potential spatial dependencies and clustering in the dataset. **Chapter Five** presents the specification and the estimation results of the discrete choice models for the developers' choices on the types of residential development. Finally, **Chapter Six** summarizes the most important findings from the exploratory and the explanatory analysis of the land development process in Hamilton. This is followed by a discussion of the planning and policy implications of the research findings and the directions for further research in the future.

CHAPTER TWO

Literature Review

2.1 Introduction

The purpose of this chapter is to review the literature on the land development process, urban form, and land developer's behaviour. By assessing the studies related to these topics, we intend to find answers to questions such as:

- What is the relation between land development and urban form?
- What does trigger land development?
- Where does new development locate?
- Which are the factors that influence the locational behaviour of developers?

This review will also identify concepts, methods and techniques that have been used to study the land development process. As will be presented in this chapter, there are two major groups of studies related to land development. The first is focused on smaller scale empirical model applications whereas the second relates to large scale modeling approaches of land use and transportation models.

2.2 Land Development, Urban Form, and Transportation System

2.2.1 Land Development as a Process

When asked "what makes the study of land development an important issue?", an urban analyst would reply that it contributes to advancing knowledge on a process that has significant impact on the formation and evolution of the spatial structure of urban systems (Wu and Gar-On Yeh, 1997). As Bourne (1989) explains, the formation and evolution of urban space and form is a complex and multidimensional process that cannot be studied only by a unilateral perspective or a single research approach. This composite process, also known as urban development, has demographic, socio-economic, political and institutional dimensions that encompass components such as land development (Bourne, 1989). By studying the land development process we enhance our understanding of the formation of the urban spatial structure and form. Some recent research proposes that the evolution of urban form occurs through the conversion of land and the land development process (Wu and Gar-On Yeh, 1997; Cuthbert and Anderson, 2002a).

In short, land development is a process that exerts a strong but not exclusive influence on the nature and evolution of urban form. The latter is a concept that has received broad attention in academic literature during the past two decades (Malpezzi and Guo, 2001). A considerable amount of research has been carried out on the evolution of urban form (Bourne, 1989; Annas et al., 1998), its typology (Ewing, 1994, 1997; Gordon and Richardson, 1997; Weitz and Moore, 1998), measurement (Malpezzi and Guo, 2001; Song and Knaap, 2004; Tsai, 2005; Torrens, 2008) as well as on urban form's relationship with sustainable urban development (Gar-On Yeh and Li, 2001; Camagni et al., 2002; Holden, 2004; Behan et al., 2008) and transportation (Frank and Pivo, 1994; Cervero and Gorham, 1995; Anderson et al., 1996; Cervero and Kockelman, 1997; Boarnet and Crane, 2001; Kanaroglou and Scott, 2002). The question to be raised here is how far does our knowledge go with respect to the relationship between the land development process and urban form?

2.2.2 The Meaning of Urban Form

In simple terms, urban form can be perceived as the spatial outcome of urban development. It can also be conceptualized as the result of a multitude of factors and processes. Among these, we could argue that the land development process, the locational behaviour of agents operating within the urban system; and, the demographic, economic, and planning processes, are all influencing urban form (Kanaroglou and Scott, 2002). The common characteristic of all these factors is that they exert major influence on the formation of the land use system within an urban area.

Anderson et al. (1996) define urban form as "the spatial configuration of fixed elements within a metropolitan region" (p. 9) and clarify that the term encompasses the spatial structure of land use and transportation system. Land development may be defined as the process that creates and distributes over space the floorspace required to accommodate various human activities. Since land use reflects the spatial distribution of activities within an urban system (Cuthbert, 2002), emerging land development contributes to the configuration and evolution of the land use system. The resulting land use pattern, on the one hand, shapes the form of the emerging urban area. On the other hand, land development affects the locational behaviour of agents, namely households, firms and public institutions, operating within the urban system; and, in turn, the locational decisions of these agents induce changes in urban form (Kanaroglou and Scott, 2002). In short, it could be claimed that the land development process configures the land use system; the latter gives rise to urban form, and influences agents' locational behaviour. Finally, the agents' behaviour leads to further changes in urban form.

Differences in the way the various dimensions - demographic, socio-economic, political and institutional - of urban development interact with each other produce different types of land development; and, consequently, give rise to different typologies of urban form. According to the literature, two general categories of urban form can be identified; the compact and the dispersed (Gar-On Yeh and Li, 2001). Although no general definition for compact development is acknowledged, Tsai (2005) points out that concentration of development has been used as a common concept to define compactness. Other efforts to further explain the meaning of compactness include mixture of land uses (Ewing, 1997), minimization of land consumption (Galster et al., 2001), as well as high-density or monocentric form (Gordon and Richardson, 1997).

The definition of dispersed development is also not fully agreed upon in the literature. Anderson et al. (1996) note that during the previous century, the evolution of urban areas was mainly driven by two concurrent trends; the first was the phenomenon of urbanization and the second was what "is commonly referred to as urban sprawl" (p. 12). Since the 1950s, the increasing dependency on private automobiles and the continuous investment in road infrastructure projects have been providing and improving accessibility to new locations around existing urban areas. These new locations were integrated gradually to existing urban systems, contributing in that way to the emergence of a new polycentric urban form (Maoh and Kanaroglou, 2007a). Over the decades, urban development has witnessed decentralization and dispersion of land uses and activities from the traditional central core of the city to the suburban areas (Gar-On Yeh and Li, 2001). This decentralization of population and employment altered the spatial pattern of where people live and work (Maoh and Kanaroglou, 2007a) and contributed to the change in urban form from monocentric to dispersed, sprawled, or even multinucleated (Cuthbert and Anderson, 2002b).

Hence, four 'archetypes' of sprawl (Weitz and Moore, 1998), as they were firstly identified by Ewing (1994), offer a generally accepted definition of dispersed development. This definition is based on four distinct land use characteristics: commercial strip development, leapfrog development, scattered development, and continuous low-density development (Tsai, 2005). According to Weitz and Moore (1998, p. 430) commercial strips "are lines of independent stores stretching along an arterial". Leapfrog development is a pattern of non-contiguous development occurring on large parcels of moderate priced land located outside existing urban areas (Ewing, 1994). New development takes place on sites outside the urban fringe and separates itself from the urban edge by vacant or lightly developed land (Weitz and Moore, 1998). Generally speaking, the development process skips this land and preserves it for commercial or higher-density residential development in the future, when the area will be mature enough to support it (Ewing, 1994). Following the description of Southworth and Owens (1993, p. 277), scattered development is the outcome of a process that makes new development to appear "in a seemingly random or shotgun pattern". Moreover, Fujii and Hartshorn (1995) consider scattered development as the extensive dispersion of activities and functions in multiple locations over space. Finally, the continuous low-density development pattern is characterized by large expanses of private land properties that are covered by single and segregated land uses (Ewing, 1997). For a more comprehensive and detailed description of the characteristics and the consequences of sprawl, the reader is referred to Torrens (2006, pp. 248-50).

The debate between scholars on whether compact or sprawled forms of development are more desirable has been going on for more than two decades (Gar-On Yeh and Li, 2001; Ewing, 1997; Gordon and Richardson, 1997). Although the topic is still a subject of controversy in academia, the majority of urban planners are against scattered and leapfrog development patterns; and consider urban sprawl an undesirable, costly and inefficient form of development (Gar-On Yeh and Li, 2001; Weitz and Moore, 1998). In addition, one could argue that compact forms of development have been receiving increased institutional acceptance since the beginning of the 1990s. This can be confirmed by the European Commission's choice to adopt, in 1990, the idea of compact cities in its *Green Paper on the Urban Environment* as part of its sustainability measures (Kanaroglou and Scott, 2002).

2.2.3 Linking Urban Form to Transportation

During the past three decades, a rich knowledge of the relationship between urban form and transportation has been generated in the field of transportation planning (Miller et al., 2004). Research findings provide an insight to the bi-directional interaction between the transportation and land use systems (Kanaroglou and Scott, 2002). The

Transportation system is a comprehensive term embracing peoples' travel behaviour and networks' characteristics. More specifically, the concept of travel behaviour can be interpreted as the various choices made by traveling actors to fulfill various travel needs, under different circumstances within a given transportation network. A *Transportation network* is the infrastructure and the services, including characteristics such as capacity and level of service, which provide the means for the movement of people and goods.

As mentioned earlier in this chapter, the occurring land development gives rise to a land use pattern, which, in turn, contributes to the formation of urban form. Following this notation, we could conceptualize the relation between land use and transportation as follows. The land use system provides the locations that generate and attract travel, as well as define the volume of it; and the transportation system accommodates the generated travel and formulates the spatial interactions between locations in an urban system. Consequently, changes occurring to land use induce changes to transportation and vice versa. This bi-directional interaction between the land use and transportation system has been depicted successfully by Wegener (1995), as shown in figure 2.1, and emphasized by Kanaroglou and Scott (2002). What requires further investigation is the role of the land development process in the formation of the land use pattern within an urban system and, consequently, on transportation and urban form. To connect this to Wegener's figure on the land use/transportation feedback cycle, one can argue that it is very important to study the figure's "*Location decisions of investors*" component as it sits at the core of the land development process.

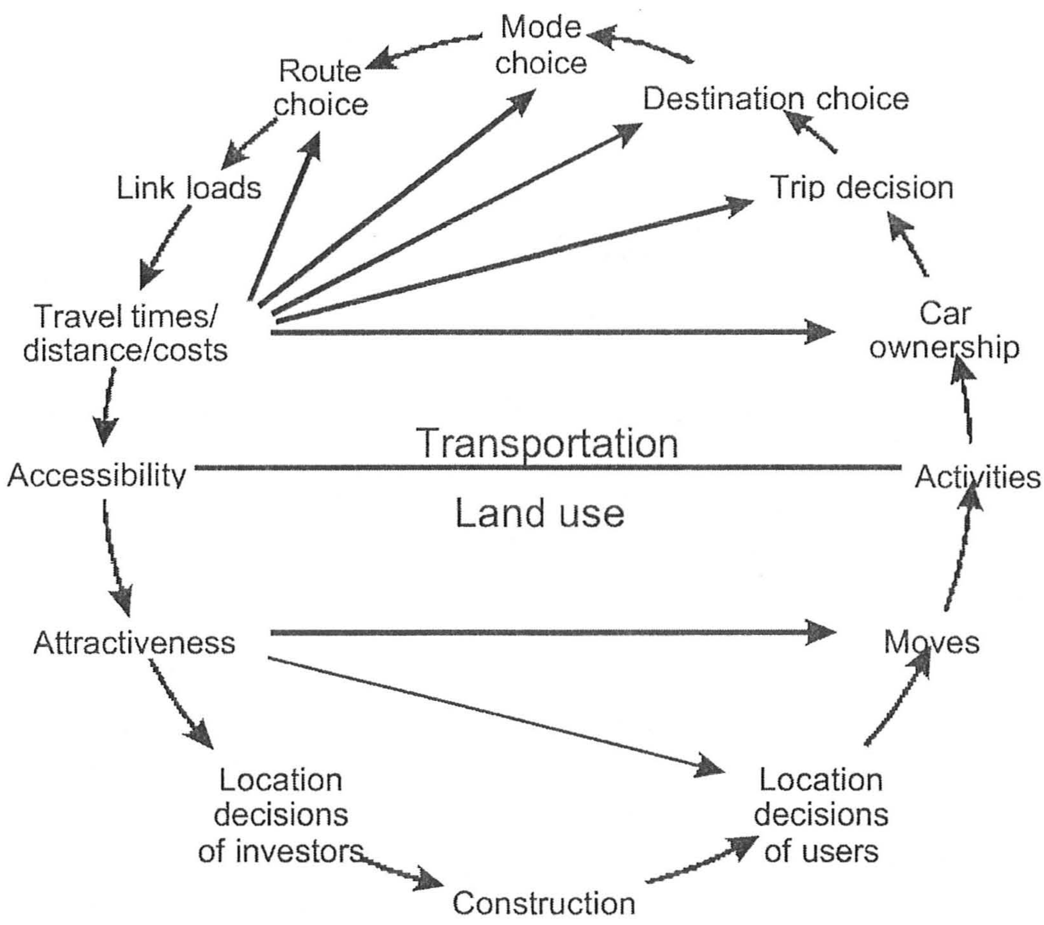


Figure 2.1: The Land Use/Transportation Feedback Cycle (*Source*: Wegener, 1995)

The interrelationship between land development, urban form, and the transportation system fuels the dynamic evolution of the spatial structure of an urban system. The in-depth analysis of this relationship is crucial to planners as well as to decision makers when forming planning policies. In addition, such analysis is vital for the development of simulation models, which can be used to generate future growth alternatives in cities (Gar-On Yeh and Li, 2001). This concept is well explained in the work of Haider and Miller (2004) on modeling location choices of housing builders in the

Greater Toronto Area (GTA). The authors explain how the combination of residential development and transportation infrastructure affects urban form. On the one hand, they note that the construction within the downtown area of a city gives rise to high-density communities with high access to the public transit network. On the other hand, low-density residential development in suburbs deploys areas that "cannot be served efficiently by public transit" (p. 148), and consequently increases the dependency to private automobile.

2.3 Studying and Exploring the Evolution of Urban Form

Before we proceed to the review of research related to the developers' locational behaviour, we present here the geographical literature that has documented the evolution of urban form. The bulk of work that has been done to date and to our knowledge is empirical research that explores the evolution of urban form mainly by using the negative exponential density function (Cuthbert and Anderson, 2002a,b). Nevertheless, the use of other alternative approaches to the study of the urban spatial structure is not absent in the literature. Paez and Scott (2004) present a review of alternatives to the negative exponential function techniques that are based on the recent developments in spatial statistics as well as on local methods of spatial analysis. Also, the work of Anas et al. (1998), as highlighted by Maoh and Kanaroglou (2007a), provides an extensive review of statistical methods that have been used in studying the regularities of urban form. In the Canadian context, Maoh and Kanaroglou (2007a) and Cuthbert and Anderson (2002b) employ spatial statistics techniques to explore and explain the evolution of urban form in Hamilton, Ontario and Halifax, Nova Scotia respectively.

In more detail, according to Cuthbert and Anderson (2002b), many empirical studies have examined the evolution of urban form and the gradual change in the pattern of population and employment locations. The literature proposes that the locational choices of population and employment are moving towards the outskirts of urban areas under the effect of a decentralizing trend that generally tends to reshape cities. The major implication of this trend is the disruption of the traditional monocentric urban form. However, the spatial outcome of this phenomenon may vary "from dispersion and urban sprawl to multinucleation" (Cuthbert and Anderson, 2002b, p. 521). As an example of a study that brings evidence on the erosion of the monocentric form of a Canadian urban area, one could consider the recent work of Maoh and Kanaroglou (2007a). The findings of their empirical study on geographic clustering of firms in the urban area of Hamilton, Ontario suggest that during the first half of the 1990's both population and firms exhibit a decentralizing trend.

Moreover, as noted by Cuthbert and Anderson (2002b), empirical research has indicated that, in general, the decentralizing trend is different for population and employment as the latter is observed to form a less decentralized pattern. More specifically, some studies attribute this difference to "a lag between the decentralization of population and the decentralization of employment" (Cuthbert and Anderson, 2002b, p. 521). This is why the same authors mention that the emergence of a polycentric urban form requires a temporally continuous and spatially concentrated decentralization of employment.

To depict the evolution of urban form over time, the negative exponential density function could be used as follows. At first, we construct a diagram that represents the population or employment density at different points or zones within an urban area as a function of the distance of these points from the CBD. This diagram depicts how the density of population or employment at a specific point in time changes with distance from the CBD. The second step of this method necessitates the availability of temporal data for the density of population and/or employment. If such data is available, then we can construct the density function for multiple instances in time and compare the changes on the function's gradient over time. The expected general form of the density function for a monocentric city is the negative exponential. That is, for a monocentric city the density of population and/or employment should be decreasing exponentially while the distance from the CBD is increasing. In the presence of temporal data, if a decline in density at short distances from the CBD is observed along with an increase at long distances over a sufficiently long period of time then the method suggests the existence of a decentralizing trend in the study area (Maoh and Kanaroglou, 2007a).

According to Maoh and Kanaroglou (2007a), the second approach that Anas *et al.* (1998) identified in literature includes methods examining the local variability of activities that may contribute to the emergence of a dispersed or polycentric form. The most common methods are three: the polycentric density function, the fractal geometry, and the point pattern analysis.

In short, the polycentric density function is a method that evolves from the traditional Clark's negative exponential density function and incorporates improvements purporting to take into consideration the effects stemming from the multinucleated urban form. The fractal geometry approach makes use of the mathematical concept of fractals. A fractal is a geometric element that always replicates itself when viewed at smaller and smaller scale and, consequently, it has a similar shape regardless the scale used for viewing it (Maoh and Kanaroglou, 2007a; Anas *et al.*, 1998). The use of this method in applications related to urban form aims to investigate *"the regularity of the line making the outer edge of urban development in a particular urban region"* (Anas *et al.*, 1998, p. 1432). Finally, the point pattern analysis implements a number of spatial statistical techniques in order to investigate whether any spatial association exists among a set of point events within an urban area. Point events are identified by their spatial coordinates and may signify the location of firms, households, or land parcels that accommodate new construction. In addition, events can be listed by several time periods. The analysis of events along with their aforementioned attributes aims to spot high-density spatial clusters and to explore their evolution over time in order to describe changes occurring to urban form (Maoh and Kanaroglou, 2007a).

As mentioned earlier in this section, most of the empirical research that has explored the evolution of urban form has employed the method of negative exponential function. However, several authors have stressed the major disadvantages of this method when used to study the complex systems of contemporary cities (Mieszkowski and Mills, 1993; Cuthbert and Anderson, 2002b; Paez and Scott, 2004). Specifically, Mieszkowski and Mills (1993) argue that the use of the exponential density function and the monocentric model in understanding the evolution of cities is becoming *"increasingly irrelevant"* (p.144) in the current context of decentralized and dispersed urban areas. Cuthbert and Anderson (2002b) agree with this argument and note that the exponential function is not adequate for modern cities *"because it attempts to summarize a complex pattern with a simple parameter"* (p.521). Paez and Scott (2004) add to that by noting that this method is not sophisticated enough *"to explain the spatial variability observed in many empirical situations"* (p.62). Clearly, all the above arguments indicate that the use of exponential function is not appropriate for the study of contemporary cities. This is because this method assumes that the urban area has only a city centre and measures the change in the density gradient with the distance from this single centre. Hence, this method is not able to capture the effect of other subcenters that exist in the same urban area and contribute the evolution of its form.

The second major disadvantage of the exponential density function, pointed out by Cuthbert and Anderson (2002b), is related to the type of data required for the estimation of it. According to the authors, most of the studies employed aggregate zonal data of population and/or employment density. Zonal data are exposed to problems such as the Modifiable Areal Unit Problem (MAUP) as well as weaknesses related to the configuration of the zones. Furthermore, using zonal data incorporates significant errors, especially at the peripheral zones of an urban area. This is because peripheral zones are in general extensive in size and their population appears to occupy a small proportion of the land. In short, data collected at the zonal level is not able to fully depict the variables' local variability produced by the urban growth over space.

We conclude that the use of the traditional density function along with the aggregate zonal data is not powerful enough to study changes in urban form. Therefore, our research effort adopts an alternative approach. This approach applies spatial statistical methods and specifically the point pattern analysis to analyze the configuration of land use within an urban area. This method has only recently received attention in the context of studying the urban spatial structure (Cuthbert and Anderson, 2002b). According to these authors, the use of disaggregate, individual-level parcel data along with the point pattern analysis of their centroids can provide a solution for the problems inherited in the exponential density function. Furthermore, as Maoh and Kanaroglou highlighted recently (2007a), only a limited number of studies have employed the point pattern analysis in the study of the changing urban form.

2.4 Modeling the Land Development Process

2.4.1 Land Development as a Decision Making Process

The first question that may be raised by someone seeking a better understanding of the land development process is what triggers this process. Healey and Barrett (1990) note that various activities taking place in an urban system necessitate the production of space in terms of buildings as well as sites. As Bourne (1976) states, private developers construct the majority but not all of the new building stock in which households and firms can relocate. In other words, the demand for floorspace initiates a sequence of land use changes stemming from decisions made by different agents, namely private corporations, public service agencies and policy-making bodies (Bourne, 1976).

The author's approach to the evolution of urban structure offers an answer to the question of how land development occurs. He perceives land use change as being the result of the interaction, which "essentially involves the resolution of conflicts of interests through the urban land market", between the various decision agents (Bourne, 1976, p. 539). Healey and Barrett (1990) suggest a similar framework. They highlight that any attempt to analyze how development occurs should involve an explicit consideration of the relationship between strategies, interests and actions of the various agents - landowners, investors, developers, consultants, public agency planning officers, politicians and community groups- and their economical, political and, ethical background that shapes their decision-making behaviour. Moreover, Schaeffer and Hopkins (1987) examine the land development process from the stand point of the main decision-maker/agent involved in the process, the private developer, and state that development occurs in three separate phases: the acquisition of land, the approval of the proposed project, and the construction phases.

Thus far, our findings from the literature can be summarized in the following statements:

- land development occurs as a response to the need for floorspace,
- it is carried out mostly by private developers, at least in the Canadian context,

- it is the result of the resolution of conflicts of interest on land market between the developers, the public service agencies, and the policy-making bodies;
- and, it is materialized in three separate phases; the acquisition, approval and construction phases.

2.4.2 Land Developer's Behaviour

In their critical review of conceptual models of land development, Gore and Nicholson (1991) list and summarize four principal types of approaches to modeling the way the development process occurs. Among these main types, they identify the group of behavioral or decision-making approaches. These approaches put the emphasis on the role of the different agents engaged in the process, and on the decisions and actions they take within its occurrence. This belief is shared by Healey and Barrett (1990) who propose that a deeper investigation of the dynamic interplay between agents during the negotiations of particular development projects is required in order to understand how the investment decisions are made. In addition, they suggest that in such an agent-based approach empirical research should be focused on how existing rules, which are imposed by the economical, political, and ethical structure of a society; resources available to the agents; and, agents' "ideas and ideology" affect the definition and implementation of their strategies.

Yet the most important question is what drives the behaviour of those agents. Most findings from the literature adopt or call for an agent-based, micro-economic and micro-level approach (Kaiser, 1968; Bourne, 1976; Lee, 1979; Schaeffer and Hopkins, 1987; DiPasquale, 1999; Haider and Miller, 2004; Sugiki et al., 2005). However, studies that elucidate the process responsible for the supply of built space (land development) in North American cities are scarce. Healey and Barrett (1990) note that little attention has been given to the processes that produce "buildings and sites for various activities" (p. 89). Moreover, most of the attention in the existing literature has been paid to the residential development process. Still, papers studying this subsection of land development underscore that little research has been conducted on the residential housing supply (Haider and Miller, 2004; DiPasquale, 1999). Specifically, DiPasquale (1999) concludes his paper "Why Don't We Know More About Housing Supply" by stating that "we need to build our understanding of the micro-foundations of housing supply" (p. 21) and by suggesting that we should acquire knowledge on how actors -builders, investors and landlords- related to the development process perceive the marketplace, make their decisions and, consequently, form the housing supply.

From the viewpoint of the agent based micro-economic framework, the private developer is an entrepreneur and can be considered as a profit maximizing firm that seeks to optimize net returns from its production (Kaiser, 1968; Kaiser and Weiss, 1970; Bourne, 1976; Landis and Zhang, 1998a; Irwin and Geoghegan, 2001; Haider and Miller, 2004). The developer firm produces floorspace and the final output, the product, is the outcome of the transformation of inputs according to the technical constraints imposed by the firm's production function. In simple terms, micro-economic theory specifies that, by using the technology available to it, a firm maximizes profit by choosing inputs and outputs of production. When choosing to invest in a specific site, the developer firm selects the land-input that is expected to maximize its net profit when "ceteris paribus".

In more detail, the profit-maximizing locational decisions of a developer can be explained by three factors: the site, the decision-agent characteristics (Kaiser, 1968); and the present market conditions (Landis and Zhang, 1998a). For a developer, land is the major input of her/his firm; and, land is of heterogeneous quality over space (Schaeffer and Hopkins, 1987). Specifically, the quality of land depends on the peculiarities of each site. These peculiarities stem from the physical characteristics of land, i.e. lot size, slope, and topography; the locational characteristics, i.e. accessibility to employment, availability of infrastructure, and quality of neighborhood; and, the regulations imposed on land by policy-making agencies, i.e. zoning by law, and local tax rates (Kaiser, 1968; Schaeffer and Hopkins, 1987). The developer is expected to select the site that will maximize the difference between the expected revenues from selling the product and the overall cost related to the acquisition, approval and construction phases of the production.

According to Kaiser (1968), the developer's characteristics that could affect its locational decisions are the type, scale of operation, entrepreneurial approach, and life cycle of the firm. In a comprehensive effort to explore the developers' investment and locational behaviour for new development projects, Bourne (1976) carried out two series of interviews in 1971 and 1974 with residential and commercial developers operating within the Toronto metropolitan area. In his paper, the author presents the major conclusions from a sample of thirty-two interviews by acknowledging that although their results do not provide an output that enables statistical inference they are capable to portray the general image of the process. The main finding of these interviews is that the developers' locational behaviour is directly related to the cost and ease of land assembly. Hence, their site selection decisions are directly related to the economic feasibility of the project. The results suggest that the most important location factors influencing the developers' site selection are the prior ownership or availability of land, and the constraints imposed by existing planning policies, primarily zoning bylaws (Bourne, 1976).

Interestingly, the importance of the availability of land factor appeared in the results in multiple ways (Bourne, 1976). For instance, the size of the site is perceived by the developers as a cost as well as an administrative consideration. That is, the larger the sites involved in the project the fewer the number of existing owners to contact. This translates to lower indirect expenses stemming from related transactions, less burden for the developer, and reduced potentiality of resistance by the existing land owners. Finally, the interviews revealed that developers assign moderate importance to neighborhood characteristics when assessing sites to locate their projects. Precisely, they tend to avoid locations associated with negative images as places to live. They also tend to avoid neighborhoods where the residents are well organized, present obstacles as well as resistance to new development projects. Such locations increase the risk of an investment, thus developers avoid selecting them for their projects (Bourne, 1976).

Finally, the present market conditions that could play a role in a developer's locational decisions are macro-economic indicators, such as interest rates and inflation, as well as the characteristics pertaining to consumers, which the developer will intend to address with her/his product (Kaiser, 1968).

2.5 Modeling the Location Decisions of land Developers

As described earlier in this chapter (section 2.2.), the bi-directional interaction between the land use and transportation system contributes to the formation of urban form. Furthermore, it was noted that the land use pattern of an urban area is the spatial outcome of the development process that takes place in the area. It was also shown that the locational decision of developer is the core component of this development process. Finally, the need for further investigation on the developer's locational behaviour was highlighted as the task that will provide an insight into the role of land development in the formation of urban form. In a previous section (section 2.3.), we presented findings from literature on what drives the behaviour of land developers. There seems to be a consensus among authors on the opinion that developers operate under the profit seeking and maximizing state. It was also suggested that the selection of land by developers for their projects (investments) is directly related to their profit maximizing efforts. In other words, the locational decisions of developers are directly connected to their economic behaviour. More interestingly, the limited findings in literature highlighted that developers tend to put more emphasis on the marketability of their product and on the revenue they can acquire from it rather than on the financial cost of producing the product.

In the two following sections, we present findings from empirical studies that examined and modeled the locational behaviour of land developers.

2.5.1 Explanatory Land Development Models

The number of studies that report on explanatory land development models is very limited. Hence, our findings from the literature can be classified into two groups of studies as summarized in table 2.1. The first group consists of old studies conducted in the 1960's, 1970's, and 19980's. The second contains recent studies that were conducted during the past nine years.

2.5.1.1 Old Explanatory Models

Weiss, Donnelly and Kaiser (1966), study urban growth patterns in a number of cities in North Carolina, USA by applying multiple regression to evaluate the effect of 14 explanatory variables on the land development process. Their study area included Greensboro and Winston-Salem and was divided into 3980 grid-cells, with each cell having an area of 23 acres. The dependent variable in their analysis is the amount of land in urban use and the unit of analysis is the grid cell. The independent variables tested that have a positive relation on land development are: accessibility to work areas, availability of public sewerage and city water, and dwellings density. On the other hand, the explanatory variables with negative parameters were distance to a major street, distance to an elementary school, distance to a playground or recreation area, distance to shopping areas, and land not suitable for building. It is worth mentioning here that the authors discussed the importance of a group of variables that was not available to them. These are variables related to ownership characteristics and owners' intentions for development.

Table 2.1: Reviewed Studies of Explanatory Land Development Models

Authors	Study Purpose	Method	Unit of Analysis	Explanatory Variables
Weiss, Donnelly & Kaiser (1966)	Land Development in Greensboro & Winston-Salem, North Carolina	Multivariate Regression	23 Acres Grid Cell	Accessibility, Infrastructure, Dwelling Density, Proximity to Major Urban Features (Streets, schools etc.)
Chapin & Weiss (1968)	Residential Land Development in Greensboro, North Carolina	Multivariate Regression	23 Acres Grid Cell	Accessibility, Infrastructure, Zoning, Land Value, Proximity to Major Urban Features (Streets, schools etc.)
Kaiser (1968)	Residential Land Development & Locational Behaviour of Developers in Greensboro, North Carolina	Goodman-Kruskal Index of Association	2.5 Acres Grid Cell	Zoning, Infrastructure, Socioeconomic Rank, Proximity to Employment Areas, Proximity to Major Urban Features (Streets, schools, CBD etc.)
Lee (1979)	The Land Conversion Process in Urbandale, Iowa	Multivariate Regression	20 Acres Grid Cell	Infrastructure, Existing Development in Adjacent Cells, Proximity to Major Urban Features (Streets, schools etc.), Accessibility
McMillen (1989)	Prediction of Land Use Type for Properties in an Urban Fringe Area of Chicago	MNL Model	Land Parcel	Size of Property, Proximity to Chicago and Close By Towns, Land Use Characteristics of the Surrounding Area
Mohammadian & Kanaroglou (2003)	Choice of Housing Type for Projects of Residential Development in GTA	Spatial MNL Model	Land Parcel	Price, Development Charges, Existing Physical Development, Accessibilities, Residential Inventory
Haider & Miller (2004)	Allocation of Housing Starts (Projects) by Type of Development to TAZs in GTA	MNL Model	TAZs Based on the TTS Zones	General Zone Characteristics (Percentage of Housing Stock, Existing Physical Development), Residential Amenities (Accessibilities, Retail Density in a Zone etc.)

Chapin and Weiss (1968) carried out a study on urban growth in an attempt to establish an approach for analyzing several factors, which are known to influence the distribution and intensity of metropolitan land development. In their study, they formulate and test a model capable of forecasting residential land development for the city of Greensboro, North Carolina. In conceptualizing an approach to study land development, they assume the process as a consequence of a plethora of decisions and actions. Moreover, they classify these actions into "priming" and "secondary" by explaining that the priming actions trigger secondary actions.

In the residential development process, priming actions are concerned with the placement of major infrastructure (expressways, route locations for rail rapid transit, major industrial installations etc). Secondary actions include location decisions of firms, institutions, and housing developers. According to the authors, the priming actions are decisions that may have structuring effect on the sequence of development events. In other words, the location and the intensity of urban growth are determined by the priming actions whereas the pattern of urban growth is manifested by the secondary actions.

In the implementation of the model, the authors used multiple regression along with a similar data set to the one used by Weiss, Donnely and Kaiser (1966). They also used similar dependent variables and the same unit of analysis that were used by Weiss, Donnely and Kaiser (1966). Although their purpose was to formulate a residential land development model for Greensboro, they used the total amount of land in urban use as the dependent variable in order to explore the factors that are strongly related to growth at the periphery of an urban area. The independent variables are separated into two groups;

the priming and the secondary. Priming labeled variables with negative parameters in the model are: distance to the nearest major street and distance to the nearest elementary school. The availability of sewerage, zoning protection, and accessibility to work areas are priming variables with positive parameters. Positive secondary variables in the model included proximity to mixed uses, assessed value, and a variable labeled "Residential Amenity" that was not defined by the authors. Finally, negative secondary variables included marginal land not in urban use, distance to nearest shopping area and distance to nearest playground or recreation area.

In his study of the residential development process, Kaiser (1968) draws on microeconomic theory to empirically examine developers' locational behaviour in the production of single family residential subdivisions. The developer is approached as a profit maximizing entrepreneur and a univariate statistical analysis (Goodman-Kruskal index of order-association) is applied to examine the relationship between the spatial distribution of locational decisions of developers and the characteristics of the sites developed to a residential use. The study area is the Greensboro metropolitan area and includes the city and part of the county surrounding it. The area is divided into 35,820 cells and each cell has an area of 2.5 acres.

The dependent variable is organized into several categories that are defined by various combinations of three characteristics pertaining to a grid cell. These characteristics are the development status of the cell (in residential subdivision or not), the type of developer firm invoked in the subdivision, and the average price of residential units in the subdivision. In more detail, the author uses two approaches for the definition of the dependent variable. The first approach classifies each cell into one of seven categories that comprise the dependent variable. For further details on the definition of these seven categories the reader is referred to Kaiser (1968, pp. 357-358).

Though, the second approach followed by Kaiser (1968) is of our interest here. The definition of the dependent variable consists of two aggregate and opposing categories: the subdivided for residential use, and the not subdivided for residential use grid-cells. As such, the developer's locational decision is represented as a binary variable that takes the value 0 or 1. The value 0 means that the land in the grid-cell was not subdivided for residential use (remained vacant or developed for another use); whereas the value 1 means that the land was developed for residential use.

The independent variables that describe each cell's characteristics and were found to have a positive correlation with the development of single family houses are: distance to nearest major street, amount of contiguous residential development, amount of contiguous recent residential subdivision, zoning protection for incompatible uses, availability of public utilities, and socioeconomic rank of the location (an index based on occupation, education, income, and housing value census characteristics of the census tract the cell is located in). Variables found to have negative correlation with the development of single family houses included portion of poor soil, distance to nearest elementary school, distance to central business district, and distance to employment opportunity areas.

Lee (1979) adopts a micro perspective by following microeconomic theory to study the land conversion process from 1950 to 1974 at the community of Urbandale, Iowa. Using a series of aerial photography, the author divides the study area into 302 grid cells, each cell with an area of 20 acres. Consequently, the unit of analysis is the grid cell. Multiple regression analysis is performed over several time periods to examine the conversion of land at the urban-rural boundary. The model attempts to explain the conversion of agricultural land to urban land. The dependent variable is the percentage increase of urban land at time $t+1$ of a cell that was fully agricultural at time t. The explanatory variables include proxies of the availability of public utilities, i.e. distance from water line and sewer service, presence of an elementary school within one-half mile distance from a cell, percentage of land developed in the four adjacent cells of a given cell (effect of existing development in vicinity), accessibility variables such as travel time from a cell to the nearest city centre, and distance in miles from a cell to the nearest interstate highway. The results of the multiple regressions suggested that accessibility and existing development variables have the most significant influence on the conversion of rural land to urban uses. The closer a cell to the city centre the more likely that urban uses will be developed. Also, the greater the change in the percentage of land development to urban uses within the four cells adjacent to a cell in rural state at the beginning of the period, the more urban development occurs to this cell.

McMillen (1989) reports an empirical model used to predict the land use type of a property (lot) at the time of its sale for an urban fringe area (McHenry County) of Chicago. Specifically, a MultiNomial Logit (MNL) model was estimated in order to provide the probability on whether land was in agricultural, residential, or vacant use when sold. Explanatory variables used in the logit model included the size of the property, distances from Chicago and other towns, and variables related to land use characteristics of the area surrounding the property. Precisely, the variables of the land use characteristics were defined as proportions of surrounding land in various uses such as residential, transportation, communications, utilities, railroad rights of way, open space, and agricultural at the beginning of the time period. The results of the model suggested that it was more likely for a property to be in residential use than in agricultural at the time of sale for small size lots and for properties closer to a large town. Moreover, it was found that land is more likely to be in residential use than vacant for properties surrounded by areas covered by low proportion of railroads, and greater proportions of residential, transportation, communication, and utilities uses. Also, the model results confirmed that the size of residential lots tends to be smaller than the size of vacant or agricultural lots. Finally, it was revealed that railroads were a disamenity for residential use.

2.5.1.2 Recent Explanatory Models

Mohammadian and Kanaroglou (2003) present the derivation and development of a spatial multinomial logit model that was applied to explain a housing type choice problem. They extended the standard multinomial logit model by adding to it a spatial dependency term. These term aims to capture the spatial dependencies in the choice type due to the choices made on the development type of close by parcels. For the purpose of the model development the authors used a sample of a data set of housing starts in the Greater Toronto Area (GTA). This data set contained information on the type, location, size, developer, and price of housing development projects constructed in the GTA from 1997 to 2001; and, the sample consisted of 1384 housing projects. The dependent variable is a choice set of four alternative housing types for each housing project. These alternative housing types are: Detached, Semi-detached, Apartment, and Other types. The independent variables used as the vector of site characteristics in the systematic component of the logit utility functions are the following: price of the housing unit, municipal charge for development, road intersection density, school and employment accessibility, built up area, and inventory of residential units.

The price variable entered the utilities of Detached (D), Semi-detached (S), and Others (O) as generic. The estimated parameter of price has a positive sign, which confirms the hypothesis that housing projects with higher prices are more likely to be developed for all three alternative housing types. Municipal development charge variable entered the utilities of D, S, and O as alternative specific and generated negative parameters, which confirms the hypothesis that the development projects charged with higher municipal charges are less likely to be developed. Furthermore, the model results for the road intersection density indicated that within the more developed parts of the urban area, where the intersection density is higher, the propensity of developing apartments is higher than the propensity of building detached and semi-detached houses. For the school accessibility variable the results indicate that new projects located in areas with higher accessibility to school are more likely to be of detached and semi-detached type.

On the contrary, the results for the accessibility to jobs and employment variable indicates that locations with higher accessibility are more likely to accommodate apartment housing projects and less likely to accommodate detached and semi-detached houses. In addition, the results for the built-up variable indicate that the new projects located in an area, where the availability of land parcels is limited, are more likely to be apartments. Finally, the inventory of residential units variable is observed to have a negative sign in the utility of the apartment projects. This suggests that apartment-building projects are less likely to be located in areas where large number of housing units exists because such areas contain large developable tracts that are more attractive to detached or semi-detached type of projects.

Based on the findings from Mohammadian and Kanaroglou (2003), the type of a new housing project located to a site is affected by variables related to residential amenities available to the site, and to general characteristics of the site. Residential amenities variables include school and employment accessibility. General site characteristics include variables related to the relative location of the site within the urban area such as intersection density, built-up area, and inventory of residential units.

In their study, Haider and Miller (2004) model the spatial choice behaviour of housing builders in the GTA. They make use of a spatially disaggregate database of 126,462 new housing units and a plethora of characteristics that describe the sites (zones) that may accommodate the new housing projects. Specifically, they use a data set that consists of 1,384 housing projects classified into four types: single family Detached (D), Semi-detached (S), Condominium (C), and row-link housing (R). The method they follow relies on estimating destination choice models related to the choice behaviour of each home builder.

In their model, a decision maker (home builder) that intends to locate a new housing project is facing a choice set of alternative locations. For the purposes of their analysis, the authors used the zone system of the Transportation Tomorrow Survey (TTS), which consists of 706 zones within the GTA to represent the alternative locations. For the estimation of the model, the authors apply a technique that picks nine randomly simulated alternative locations (zones) along with the actual one that was chosen by the home builder. These nine randomly picked locations along with the selected one become the reduced choice set of ten alternative locations used to model the location choice of the home builder. For each type of housing (D, S, C, and R) one discrete choice (logit) model is specified. The utility functions corresponding to the 10 modeled alternatives are specified using the zonal characteristics devised by the authors. Hence, in this approach there is a decision maker (the home builder) who is trying to locate her/his housing project and facing a choice set of ten alternative zones. The characteristics of each zone (explanatory variables) enter a utility function specified according to the type of the housing project and reveal the home builder's choice of zone to locate the housing project.

Variables included in the model for single family detached houses can be grouped into two categories: the general zone characteristics and the residential amenities. Variables of the general zone characteristics that have positive relation with the likelihood of D housing construction in a zone are the amount of open developable space, the inventory of D housing units and the percentage of D housing stock (spatial inertia). General zone characteristics variables that have negative association with the likelihood of D housing construction in a zone are those depicting the level of existing physical development, i.e. intersection density and length of roads. Positive residential amenities variables increasing the likelihood of D construction are the accessibility to green space and schools. Among negative residential amenities variables which decrease D construction is retail density.

General zone characteristics variables included in the model for condominium housing are the distance to the central business district and the percentage of condominium housing stock (spatial inertia variable) in the zone. The former variable has a negative association with the likelihood of condominium construction, whereas the latter one has a positive association. Positive residential amenities variables included in the model for condominium construction which increase the likelihood of condominium construction in a zone are the proximity to subway system, accessibility to employment and to retail centers. The accessibility to green space was found to have a negative association with condominium construction. In general, variables serving as proxies for high-density neighborhoods and built urban form were found to be repulsing the development of D, S, and R housing construction. However, such variable tend to attract condominium housing. D, S, and R construction is favored in zones with suburban characteristics, whereas C construction is favored in zones with high proximity to central areas, employment, subway, and shopping amenities. Lastly, the D, S and C housing construction in a zone is in positive association with the concept of spatial inertia, whereas the construction of row-link housing is in negative association with it.

2.5.2 Land Development in Large Scale Simulation Models

According to Strauch et al. (2003), the major modeling projects that have implemented advanced microsimulation techniques within the framework of the Integrated Urban Models (IUMs) are the Urban Simulation (UrbanSim) model, the Integrated Land Use, Transport and Environment (ILUTE) model, the Transport and Land Use Model Integration Program (TLUMIP) of the Department of Transportation of the state of Oregon, USA, the Integrated Land-Use Modeling and Transportation System Simulation (ILUMASS), and the California Urban Futures (CUF) model. In 1998, the CUF model was upgraded to the CUF 2 version, a newer and more sophisticated one. Table 2.2 summarizes these modeling efforts and provides some basic information about their components that model the land development process.

2.5.2.1 The CUF Model

CUF 2 (Landis and Zhang, 1998a,b) is a land use model equipped with a sophisticated discrete choice Land Use Change (LUC) submodel. The discussion presented here focuses on the modeling effort that treats explicitly the supply-side of the land development process. Arguing that the land use change process is a discrete and not a continuous phenomenon, the authors note that the use of the discrete choice framework is a more suitable choice.

Table 2.2: Land Development Components in Large Scale Simulation Models

Model Name	Authors	Modeling Approach	Unit of Analysis	Prominent Factors
CUF 2	Landis and Zhang, (1998a,b)	Random Profit Theory, Profit Maximization and MNL Models	100x100 metres Grid Cell	Initial Site Use, Site Characteristics, Accessibility, Community Characteristics, Policy Factors, and Neighborhood Effects
UrbanSim	Waddell, (2002); Waddell et *al*., (2003); Waddell and Ulfarsson, (2003)	Utility Maximization, MNL Models and Monte Carlo Simulation	150x150 metres Grid Cell	Site Characteristics (i.e. Land Use Plan), Urban Design-Scale Effects (i.e. Proximity to Highway), Regional Accessibility (i.e. Access to Employment), and Market Conditions (i.e. Vacancy Rates)
ILUTE	Miller et *al*., (2004)	Utility Maximization and MNL or Nested Logit Models	Grid Based or Building Based	Vacancy Rates and Prices
ILUMAS	Strauch *et al*., (2003); Wagner and Wegener, (2007)	Microsimulation (No Further Details Reported by the Authors)	100x100 metres Grid Cell	Accessibility, Neighborhood Characteristics, Environmental Quality, Land Price
MUSSA	Martinez, (1996)	Bid-Choice Theory, Supply and Demand Equilibrium, Utility Maximization and MNL Models	Allocation Zone	Zone Characteristics (i.e. Land Use Types in the Zone), Dwelling Attributes (i.e. Lot Size), and Accessibility

In this respect, the heart of the CUF 2 model is the LUC submodel that consists of several probabilistic equations based on the multinomial logit model. The authors model nine different types of land use transitions by assigning one multinomial logit equation to each transition type and by relating land-use changes to a plethora of site and community characteristics as explanatory variables. Among the nine types of land use transitions considered in the LUC we find the change from undeveloped to single family residential use, to apartment use, to office or retail use, to industrial use; several cases of redevelopment, and the cases of no change in undeveloped land, as well as no change in developed land. The analysis in CUF2 is based on a grid that covers the study area. As such, the unit of analysis is the grid cell, which has the size of a hectare (100m x 100m cells). The authors propose that the ideal unit of analysis for modeling the land use change is the land parcel. However, such data were not available to them. To overcome this issue, they used a database readily available to them that included the land uses in 1985 and 1995 organized into one hectare grid cells for all nine counties of the San Francisco Bay Area.

In CUF 2 the land use change process is modeled on the basis of the following fundamental insights: the process is discrete, path dependent, and prone to neighborhood effects. The first means that urban growth stems from the conversion of individual land parcels from one land use type to another. The second means that the currently observed land use type depends on the order in which a series of past events affect the land use change process. The last insight implies that the conversion of a site to a specific land use type is affected by the types of land uses that already exist in the neighboring area.

The most significant improvement of CUF 2 when compared to previous modeling efforts is that it adapts the multinomial logit model to explain the land use change process. More specifically, Landis and Zhang (1998a) put forward the idea of transforming random utility theory widely used to model consumer choices into random profit theory in order to model developer's behaviour and specify multinomial logit functions of land use change. The authors assume that a developer's decision to develop a site will be based on the evaluation of the potential profit associated with alternative types of land uses. Under this assumption, the developer will chose to convert the site to the land use that is expected to generate the highest profit. The evaluation of the profit potential from each alternative land use type is based on a set of site characteristics. However, it is assumed that some characteristics cannot be observed or determined by the analyst. For that reason, the land use change function is adjusted to accommodate a component that addresses the effect of unobserved characteristics and it becomes probabilistic. Finally, under the assumption that the unobserved characteristics follow a Gumbel type 1 extreme value distribution the probabilistic land use change function takes the form of a multinomial logit model.

According to the general specification of the LUC submodel (Landis and Zhang, 1998a,b), the factors that explain the land use process are: the initial site use, the site characteristics, the site accessibility, community characteristics, policy factors and the relationship to neighboring sites. Following this general specification, each multinomial logit model that is assigned to each of the nine land use transitions modeled in the LUC submodule makes use of variables that fall into one of the six listed factors. Several variables are used as covariates in the multinomial logit equation for the conversion of vacant land to single family residential use. These variables are: percentage of employment and household change between 1980 and 1985, number of households in 1980, level of employment in 1980, jobs to households ratio in 1980, distance to freeway interchanges and the nearest rail transit (BART), distance to major city centres, percentage of slope, percentage of other uses (residential, commercial, industrial, public, and transportation uses) in the adjacent grid cells, distance to the nearest commercial, industrial, and public use, whether the cell contains prime agricultural land, the existence of vacant land supplies around each cell, and the distance to the nearest sphere of influence, which is a proxy for costs related to the non-existence of required infrastructure and urban services.

2.5.2.2 The UrbanSim Model

According to Waddel (2002), the TLUMIP project had two goals during its first period. The first goal was the implementation of an integrated land use and transportation model at the state wide level. This first generation of the state wide system became operational and undergone numerous enhancements (Hunt *et al.*, 2004) until the end of the 1990s when work started on the design and development of the second generation of the system, which was named Oregon 2 (Hunt *et al.*, 2001; 2004) and is a work in progress. The second goal of the TLUMIP project was the development of a new metropolitan scale land use model that would be able to interact with transportation models (Waddel, 2002). The outcome of this effort was the development of the UrbanSim model (Waddel, 2002; Waddel *et al.*, 2003).

The second IUM reviewed here is UrbanSim presented by Waddell (2000), Waddell (2002) and Waddell et *al.* (2003). The model has a component dedicated to real estate development. This is the developer model, which simulates the construction of new real estate at the spatial unit of a grid cell, specified as 150x150 metres in resolution. In broad terms, the developer model predicts the probability for each cell to accommodate a development event, and identifies which is the most probable type of development to occur in each one of these cells. During the data preparation for the model, parcel data is preprocessed and intersected with the grid cells.

More precisely, using the year-built values in the land parcels' historical data, the model produces for each cell a development-events index that contains the pairs of all occurred transitions from a development type to another (including the cases of intensification, which results in increasing density but not in a change of development type) within each year of a user-specified historical time frame (Waddell et *al.*, 2003). For the preparation of the development-events index, the annual status of existing development on each land parcel within this specified historical time frame is identified from the land parcels' historical dataset. Then, on the basis of this parcel's annual status of development, each grid cell is intersected with the underlying parcels; according to its real estate composition, the cell is classified to a specific development type, which is drawn from a predefined set of "Development Types". Finally, the index is produced and used along with a set of independent variables as input for the estimation of a number of multinomial logit models designed to predict development-type transition probabilities for each simulation year and for every grid cell. The variables used in the logit models can be grouped into the broader categories of site characteristics (existing development characteristics, land use plan, environmental constraints), urban design-scale effects (proximity to highway, arterials and existing development, neighborhood land use mix and property values, recent development in neighborhood), regional accessibility (access to population and employment, travel time to CBD and airport), and market conditions (vacancy rates).

Specifically, for each one of the existing development types, a multinomial logit model is estimated by using the above variables as covariates to model the transition from one development type (including vacant land) to another. The information for the transitions is derived from the development-events index and the values for the independent variables are extracted from the grid cell database. Once the logit models are estimated, constraints on development outcomes are imposed to each cell through GIS overlay techniques. These constraints might represent the land use planning designations and/or restrictions of policy scenarios to be tested. Finally, the multinomial logit models are used to calculate the probabilities of each valid development type alternative in every cell of the grid. Having estimated these probabilities, the model proceeds to the simulation of the development occurrence by using a Monte Carlo sampling process.

2.5.2.3 The ILUTE Model

Although the ILUTE model, presented in Miller et *al.* (2004), has not been fully operational, several components of it have made important progress. Specifically, the model has a component handling the land development process. The general purpose of this component is to predict "the growth overtime of the built environment within which household and business activities locate" (p. 30). The ILUTE research team proposes two different approaches: the grid-based and the building based.

In the grid-based approach, the development model is behavioral and the decisions of land owners (developers) are simulated according to how they can improve their properties. For each grid cell, the model simulates three decisions of the developers. The first is the initiation or not of a development-redevelopment project. The second is the type of land use to be developed, and the third is the amount of space to be created. Each decision is modeled by a logit model. For each decision, the utility functions for the alternatives of each choice set are based on vacancy rates and prices. The values of these variables are calculated by another ILUTE's component, which models the location choices of actors operating in the urban system. In essence, the developers' decisions are based on current prices and vacancy rates. The changes stemming from these decisions are assigned to the grid cells representing land by a method based on probabilities from random utility models.

In the building-based approach, the focus is only on the residential housing market and housing starts are modeled in two stages. The first stage is a "macro" model that predicts region-wide housing starts at time t using a combination of regression and time series forecasting techniques. The second stage receives these forecasted regional totals and uses a micro model that predicts the spatial distribution of new starts as the outcome of a spatial choice process of real estate developers. In this microsimulation model, the agents are the developers and the decisions modeled are the developer's choices on: a) starting or not a new building project, b) the type of housing to build; and c) where to build. These interconnected decisions are modeled with the use of a nested logit model (Miller et *al.*, 2004).

2.5.2.4 The ILUMAS Model

The project ILUMAS (2002-2006) is an effort for the development and implementation of a fully microscopic model that would integrate three different models, the urban land use, the transport, and the environment, into one complete modeling system (Wagner and Wegener, 2007). The intention of ILUMAS is to become a European counterpart to several North American modeling projects that incorporate advanced microsimulation approaches (Strauch *et al.*, 2003). Although the full modeling system was never completed, the development of the individual micro-level models has made important progress (Wagner and Wegener, 2007).

The land use model of ILUMAS contains a residential development submodel used to simulate the decisions of private developers. The decisions simulated in this submodel are both development and redevelopment of buildings for residential use. The unit of analysis is the grid cell with a specified resolution of 100x100 metres. Wagner and Wegener (2007) note that the model simulates the behaviour of developers "as a function of supply and demand on the housing market and profitability expectations" (p. 46). However, no further details about the modeling approach used in the submodel are provided by the authors. In addition, the factors that are assumed to influence the developer's locational behaviour in the model are limited to some basic site characteristics. Specifically, the developer's site selection is modeled as a decision process affected by the accessibility of the location, the neighborhood characteristics, the environmental quality, and the land price of the site (Wagner and Wegener, 2007; Strauch *et al.*, 2003).

2.5.2.5 The MUSSA Model

MUSSA is a land use model that combines the Bid-Rent microeconomic theory introduced by Alonso with the discrete choice random utility theory into a uniform, stochastic and behavioral framework able to produce land use forecasts (Martinez, 1996). The combination of these two theories and the interaction of the land use model with a transport model enable MUSSA to accommodate urban market forces and development tendencies (Martinez, 1996). The model simulates the land market (demand and supply for locations) operation by pursuing static equilibrium. This means that the model can produce future forecasts of city development under the condition that the demand for and the supply of locations must be met for each simulation period. Hence, the land development process can be seen as the result of a market clearing process. In this respect, the need for land use stems from the demand of activities (households and firms) for a location to locate.

The market equilibrium is achieved by the spatial distribution of activities when two conditions are fulfilled simultaneously. The first is that each consumer is located in a zone that maximizes the difference between the consumer's willingness to pay (WP) and the actual price (P). That is, the consumer's surplus (CS). The second condition is that the consumer located to a location has to be the maximum bidder, because this guarantees the maximization of the owner's profit. The consumer that bids the maximum for a location is the consumer with the maximum willingness to pay. In MUSSA there is one WP function for each consumer, that is, for each household and firm operating within the urban system. According to Martinez (1996), a consumer's willingness to pay is a function of a vector of attributes that describe each of the allocation zones available to the consumer, and of a vector of attributes that describe the characteristics of the dwelling types available to the consumer. The WP of each consumer is constrained by the income available to her/him, by the characteristics of her/his taste, and by the maximum utility level that she/he can achieve with the given income.

In the implementation of the model, the WP function described above becomes the utility function of a consumer (household or firm) that consists of a vector of zone characteristics, a vector of dwelling attributes, two constraining factors, which are the income and the maximum utility of consumer, and a set of parameters describing consumer's tastes. The vector of zone characteristics includes the land use types in the zone, average household income in the zone, and accessibility (for households) or attractiveness (for firms) of the zone. The vector of dwelling attributes includes lot size and floorspace variables. Under the multinomial logit assumptions (error terms identically and independently distributed following Gumbel type 1 distribution), the WP utility function of a consumer becomes the probability that this consumer will be the highest bidder for a dwelling in a zone. Consequently, each consumer selects her/his preferred zone and dwelling according to their attributes, as well as according to her/his tastes, budget, and maximum utility constraints. Finally, the consumer places her/his bid for the combination of the dwelling and zone that she/he selected.

Two implications stem from the above approach. First, the multinomial logit function, which is calibrated with real data, allows the modeler to use it as a policy handle for the simulation of future land development. This can be done by exogenously applying changes on the attributes that describe the zones of the urban area. Such changes can reflect regulations and policies like zoning and development strategies. The second implication is that each consumer becomes an alternative in the choice set faced by the owner of a location.

The key point here is that the model assumes equilibrium. This means that every consumer should be assigned to a location. If the available locations are not enough to serve the demand, then the model generates more supply according to the following conditions. Each location that accommodates a consumer has to fulfill simultaneously the condition of maximum utility for the consumer and the condition of maximum bid for the owner of the location. Thus, the land development is modeled as the profit maximizing behaviour of developer (Walker *et al.*, 2007) that respond to the demand for locations of utility maximizing consumers. The second condition is that the market equilibrium should be achieved in a way that takes into account the maximum available land at each zone. The last condition is that the dwelling supply has to comply with the behaviour of the developers, as it is revealed from past trends. In the model, this is achieved by making use of a dynamic supply function which is derived by a time series analysis of real data from the application area (Santiago). This analysis reveals the combination of dwelling type and allocation zone that is more likely to be supplied by developers in a simulation period.

In essence, the supply function reflects the behaviour of developers with respect to their past supply-choices on combinations of dwelling types and allocation zones. Specifically, the supply function is calculated for each simulation period and for each dwelling type in an allocation zone. The function computes the difference in rent prices of a dwelling type located in a zone between two sequential simulation periods. Hence, this calculation reveals the dwelling type and allocation zone combinations that have a positive difference in rent prices between two consequent periods. Sorting these combinations according to their value of positive difference in rent prices reveals the order of combinations that are more likely to be supplied by developers. This argument is valid since developers are modeled as profit maximizing agents.

2.6 Conclusion

In this chapter we discussed theories related to the land development process, the evolution of urban form, and the behaviour of land developers. Moreover, we presented methodologies for the study of the evolving urban form as well as pointed out a new and promising technique that we will use to examine urban form in Hamilton.

In addition, this review presented several studies, empirical models and components of large scale urban models that study, explain, and simulate respectively the behaviour of land developers. What we learned is that our knowledge on the process that supplies the dwellings for households is still limited and fragmented (DiPasquale, 1999). Even more limited is our knowledge on more specific issues such as how residential developers chose to locate the types of housing construction in an urban area. This review found and presented only two recent studies (Mohammadian and Kanaroglou, 2003; Haider and Miller, 2004) related to the locational behaviour of developers that construct different types of housing products. Starting from the DiPasquale's (1999) statement that "we need to build our understanding of the micro-foundations of housing supply" (p. 21) and the general consensus in the literature that we need a decision-agent, micro-economic and micro-level approach to the land development process, this current research proceeds to the formulation and estimation of a parcel level, discrete choice and behavioral model of housing type residential development as will be presented in the next chapter.

CHAPTER THREE

Data and Methods of Analysis

3.1 Introduction

This chapter starts by presenting the land development process conceptual framework, and then proceeds to the description of the basic geographical characteristics of the study area. The basic features of Hamilton's urban form are described and some emphasis is given to the existing road infrastructure and land use configuration. Furthermore, the primary and secondary data sets employed in the analysis utilized in this thesis are described. Following this, the methods used to explore the data are presented and explained. Three major techniques are presented here: the Kernel density maps, the Univariate and the Bivariate K-functions used for the second-order analysis of spatial point patterns. In the last part of this chapter, the conceptual framework for modeling the residential land development process is presented. As will be shown, the framework relies on the multinomial logit model to explain the choice behaviour of housing type projects in the study area.

3.2 Conceptual Framework

When conceptualizing the land development process, we consider the behaviour of the agents (i.e. land developers) who are the main actors driving the process. A land developer considers a land parcel for development or re-development. Development occurs by developing vacant parcels where as re-development occurs by developing an already developed parcel. In both cases, the land developer considers whether to initiate the development process to the parcel, or leave the parcel in its current state. If the development is to occur, then the developer has to choose the type of development. The process can be described according to the nested decision structure shown in figure 3.1.

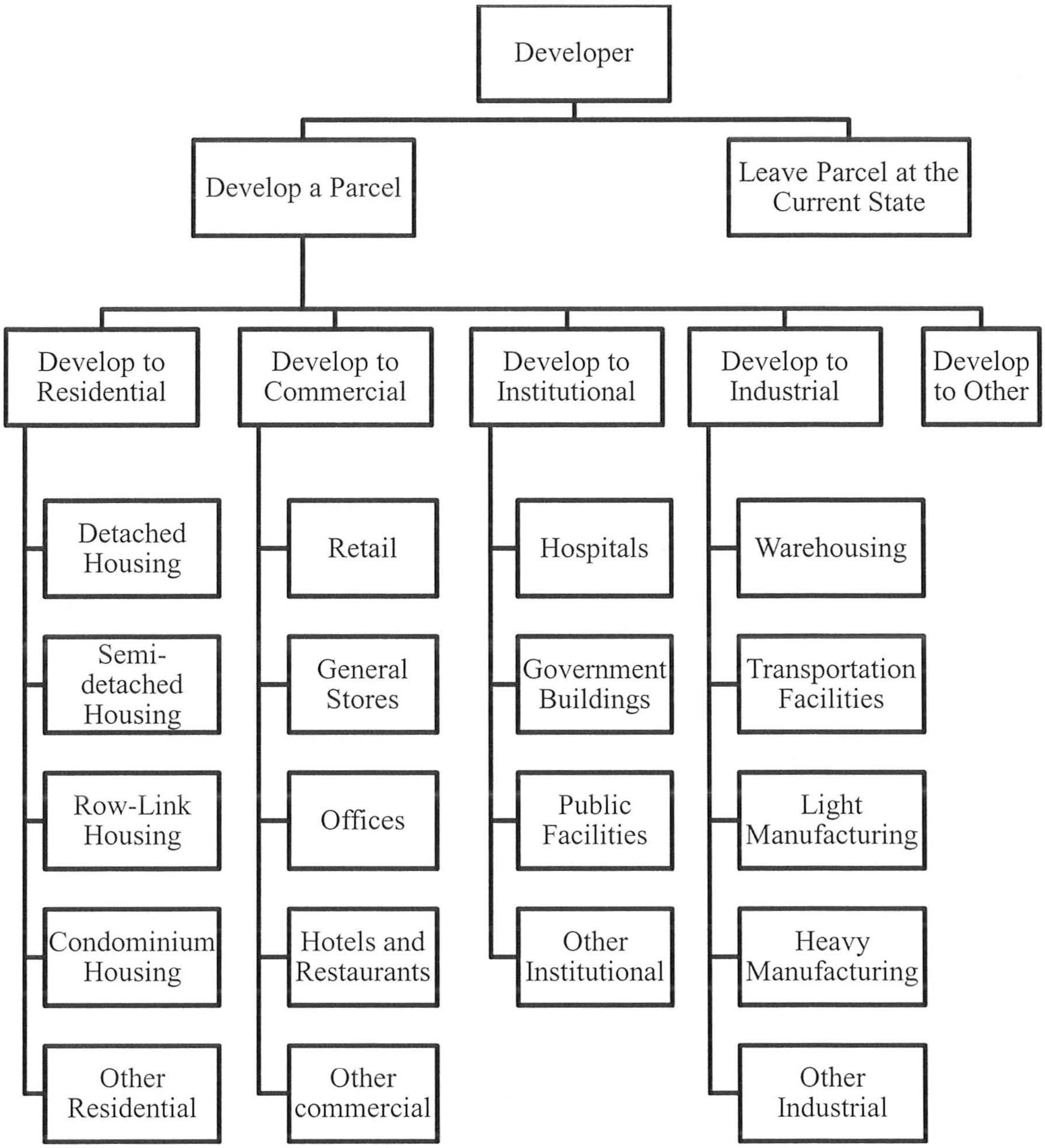


Figure 3.1: The Land Development Process Conceptual Framework

When developing the parcel, four general types can be considered: (1) develop to residential, (2) develop to commercial, (3) developed to institutional, (4) develop to industrial, or (5) develop to other land use type. To a large extent, the choice of development type is affected by the zoning regulations that are imposed by the city. However, other locational and non-locational factors play a major role in the choice of the development type. Examples of locational factors may include the nature of the existing infrastructure in the vicinity of the developed parcel. On the other hand, non-locational factors pertain to the characteristics of the developer firm. An example of the latter may include the size of the firm or the existing capital available for the development project.

Upon determining the general type of land use that the parcel will be developed for, the developer will have to consider the specific type of land use development. If the parcel is to be developed for residential use, then four specific housing types could be considered: (1) detached housing (D), (2) semi-detached housing (S), (3) row-link housing (R), (4) condominium housing (C), or (5) other housing types. Several site characteristics that reflect the nature of the location in the vicinity of the developed parcel could be considered. These may be classified into three broad groups of variables that include road infrastructure, locational amenities and other general site characteristics. In contrast, if the parcel is to be developed for commercial use, then five specific types could be considered: (1) retail, (2) general stores, (3) offices, (4) hotels and restaurants and (5) other commercial types. Again, several site characteristics reflecting the nature of the road infrastructure, locational amenities and other side characteristics could be considered when choosing the type.

If the decision made is to develop the parcel to institutional use, then several specific institutional types of development could be considered: (1) hospitals, (2) government buildings, (3) public facilities, or (4) other types of institutional development. Similar to the other types of development, road infrastructure variables, locational amenities and general site characteristics will impact the specific type chosen for development. If the developer chooses to develop the parcel to industrial use, then several specific industrial types of development could be considered: (1) warehousing, (2) transportation facilities, (3) light manufacturing, (4) heavy manufacturing or (5) other industrial uses. As in the case of other types of development, different locational factors-including the availability of road infrastructure, proximity to large vacant lots, proximity to similar types of industrial uses, to name a few-will impact the chosen type for development. Finally, if none of the three general types (namely residential, commercial and industrial) of development is chosen, then the developer might be developing the parcel to other land use types that may include amusement parks or golf courses, among other types.

It is worth noting that the process related to the residential parcel development, namely the choice type of residential housing will be modeled in this thesis.

3.3 The Study Area

This study takes place in the City of Hamilton, Ontario, Canada. The general location of the city and its surrounding area is shown in figure 3.2. Hamilton is located equidistant between the US border at Niagara Falls and Toronto, Ontario, on the western shore of Lake Ontario. The Niagara escarpment crosses the area and creates a natural border that separates the city into a lower coastal part that extends from the escarpment to the harbor, and a highland above the escarpment that stretches to the south. The lower part of the city is originally the part that accommodated the initial population growth. Now days, the city has expanded above and beyond the escarpment and the lower part is considered as the old city.

Like many North American cities, Hamilton has an extensive and dense road network that provides accessibility to the suburban areas and downtown via radial major roads and circumferential highways (figure 3.2). Specifically, Hamilton has direct access to a number of major highways (highway 5, 6, 8, 403, QEW) and expressways (Lincoln M. Alexander) that serve the peripheral areas as well as connect the city to the rest of the Greater Toronto Area. Also, there are four malls located in the region; three (Downtown, Centre, and Eastgate malls) are found in the old part of the city and one (Lime Ridge mall) on upper Hamilton. During the past two decades, however, it is the area above the escarpment that has been attracting most of the new establishments of retail complexes (i.e. the Meadowlands centre).

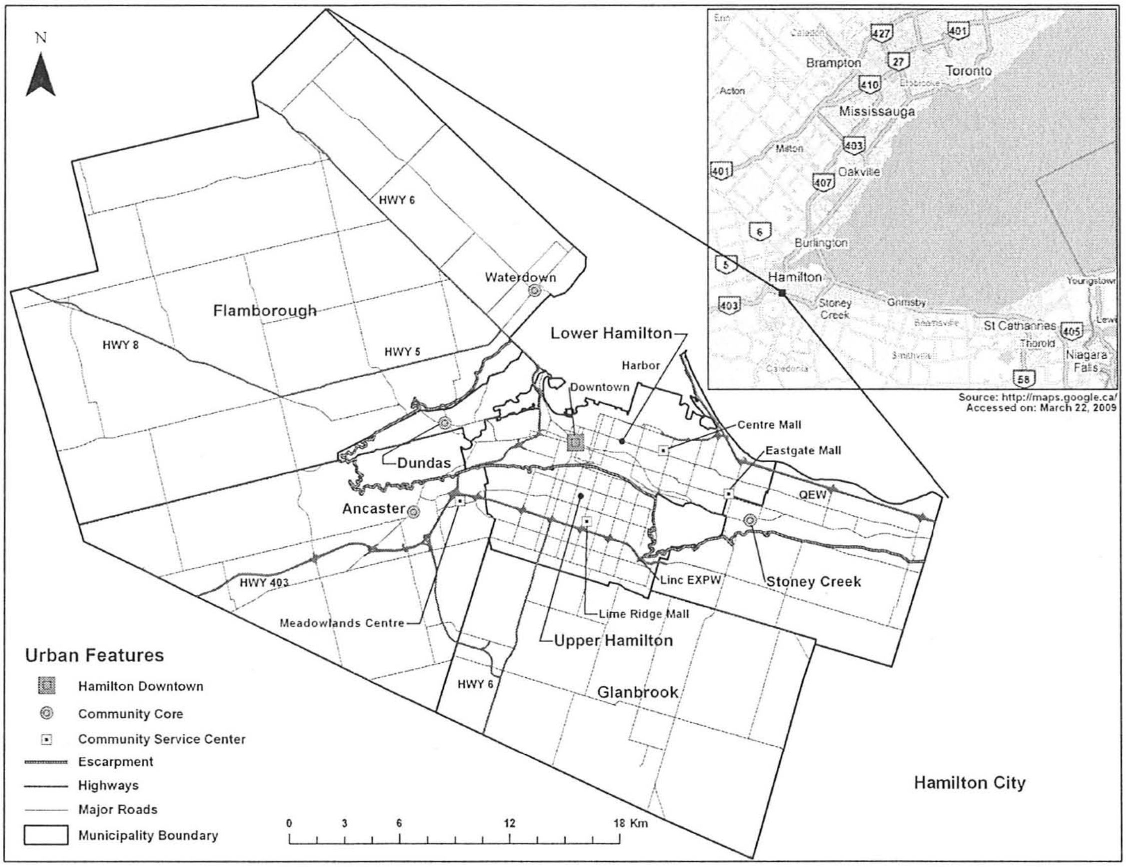


Figure 3.2: The City of Hamilton and its Road Infrastructure in the Regional Context

In 2001, the city of Hamilton was amalgamated from the previously separate municipalities of Hamilton, Ancaster, Dundas, Flamborough, Glanbrook, and Stoney Creek. Consequently, the current area and boundaries of the city of Hamilton are identical with the ones of the former Regional Municipality of Hamilton-Wentworth. For the purposes of our research we visualize the municipality of Hamilton as two separate areas, the Lower Hamilton (or old city), which is the area below the escarpment, and the Upper Hamilton (or inner suburbs), which is the area above the escarpment. Over the last twenty five years of the previous century the population of Hamilton increased by 19 percent or 80,000 people or 3,200 people per year. The total population of the city of

Hamilton in 2001 was approximately 510,000, ranking it as the sixth most populated of Ontario's forty nine regions, districts and counties (Dillon Consulting Limited and City of Hamilton, 2006).

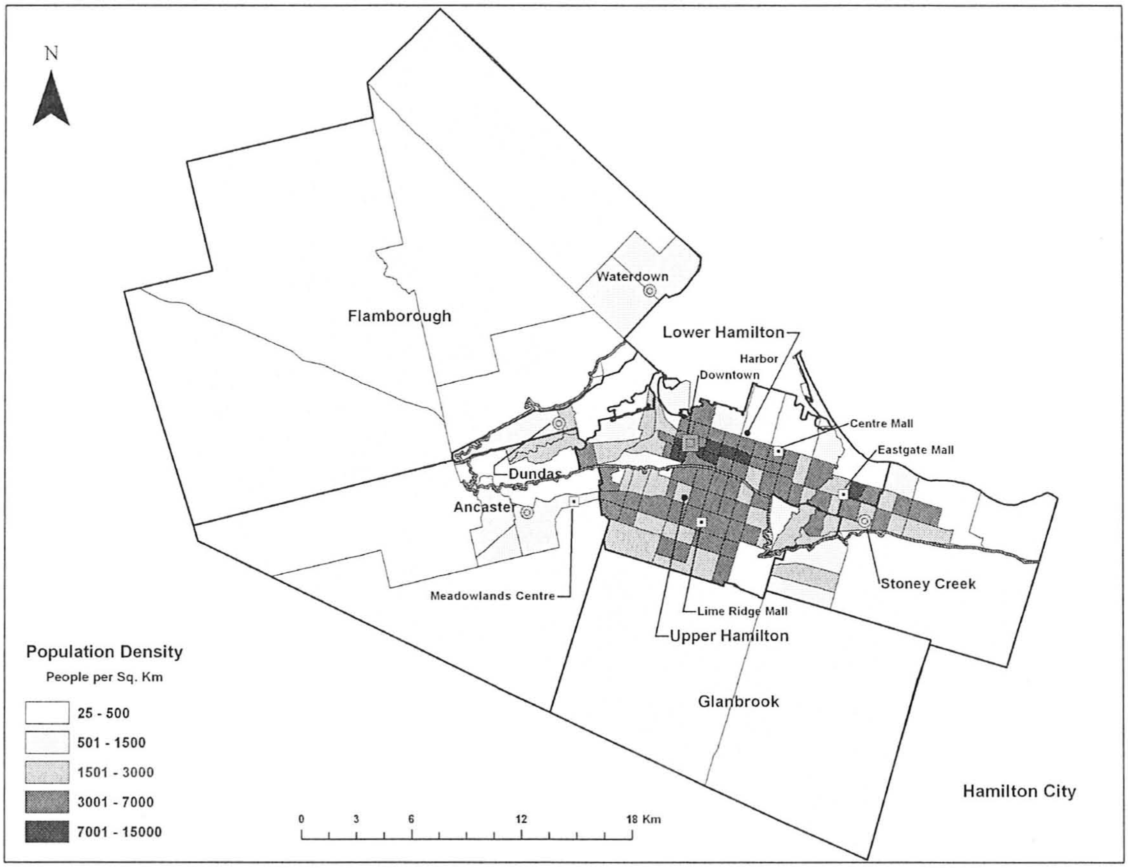


Figure 3.3: Spatial Distribution of Population Density in the City of Hamilton

The same year, the approximate number of households and dwelling units in the city was 190,000 and 189,000 respectively (Dillon Consulting Limited and City of Hamilton, 2006). In addition, the number of jobs and firms in the city in 2002 was around 223,000 and 12,000 respectively (Maoh and Kanaroglou, 2007b). Seen in a more disaggregate way and according to the four basic housing types, the total number of 189,000 dwelling units, translates into 113,000 single family detached houses, 6,000 semi-detached units, 16,000 row house (townhouses) dwellings, and 54,000 apartment units (Dillon Consulting Limited and City of Hamilton, 2006).

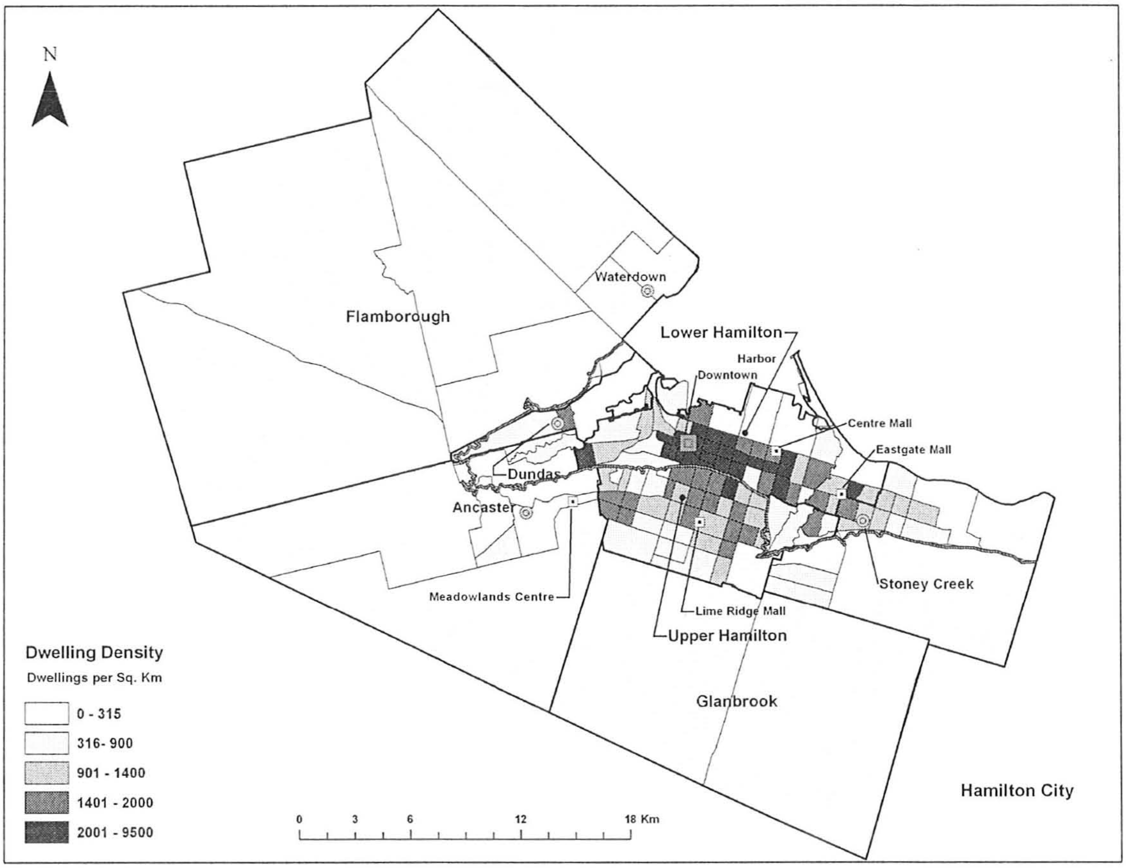


Figure 3.4: Spatial Distribution of Dwelling Density in the City of Hamilton

The spatial distribution of population and dwelling units over the study area in 2001 is depicted in figures 3.3 and 3.4 respectively. More precisely, as presented in figure 3.3, areas (census tracts) with higher population density (people per square kilometre) are mainly located in lower Hamilton, upper Hamilton, and around the historic downtowns of Stoney Creek and Dundas (to a lesser degree). This observation is confirmed by figure 3.4, which presents the spatial distribution of dwelling density (number of dwellings per square kilometre) across the census tracts of the city. It is clear that lower Hamilton, and in particular the areas around downtown Hamilton, as well as the Centre and the Eastgate Malls, have the highest density of dwelling units. Upper Hamilton is the next most densely populated, in terms of number of dwellings, with the denser areas being located around the Lime Ridge mall, close to escarpment and Meadowlands.

3.4 Overview of the Data

3.4.1 Land Parcel Data

3.4.1.1 General Data Format and Characteristics

The analysis conducted in this thesis relies on micro-level (disaggregate) land-parcel data, which are available for the period 1950 to 2003. The dataset was acquired by the Centre for Spatial Analysis (CSpA) from both the city of Hamilton and TERANET Inc., as a Geographic Information System (GIS) Shapefile layer. The latter consists of 141,834 polygons (land-parcels) that comprise the study area. Each parcel corresponds to a property (lot) and the database includes the following information: location and current land use type of a parcel, the date (year) of conversion to the current land use type, the floorspace created by this conversion and the size of the parcel. One of the most important strengths of this data set is the fine details it contains on the type of land use for each lot.

In the database, each lot is represented by a record and is attributed a code representing the general class of land use type it belongs to. The general category codes are nine and they span from 100 to 900 with a step of 100. In that way, the code 100 represents residential land use, code 200 institutional, codes 300 and 400 commercial (office and retail), codes 500 and 600 industrial, code 700 infrastructure, code 800 open space and code 900 mixed land use. However, the data set contains an even finer level of detail. Each land parcel is also attributed a code that represents the sub-category of land use type within the aforementioned nine general classes. Hence, for a land parcel that belongs to the class of residential land use (class code 100) we are able to know whether it is occupied by a single family detached house (property code 301) or a semi-detached (property code 311) and so on.

The land parcel database made the extraction of parcel-level point data possible. Specifically, points denoting the existing parcel polygons were derived as centroids. The geographic coordinates, stored in the UTM coordinate system, of these points were used to define the location (X and Y coordinates) of land use pertaining to land parcels. The derived point data along with spatial statistical techniques were employed for the purposes of the exploratory analysis reported in the next chapter. In addition, the majority of the variables used in the modeling exercise in chapter 5 were derived from this point data by making use of the GIS tools available in the ESRI's ArcGIS 9.2.

3.4.1.2 Derived Data Attributes

Variables created from the parcel-level point data can be grouped into two broad categories: proximity to various land use types and measures of several types of existing development and vacant land. The proximity variables were created in ArcGIS 9.2 by using the standard spatial query function. For each land parcel, the existence or absence of another parcel in a specific land use type within a given distance was verified and coded accordingly in the parcel's record in the shapefile. The creation of the binary variable *Proximity to an Existing site in Industrial Use*, for example, was done in GIS to select all the land parcels located within a distance (i.e. 400 m or 800 m) from any land parcel in industrial use. The parcels verifying this condition were selected and the field representing this variable in the database was coded with the value 1. The rest of the parcels were coded with 0. The measures of different types of existing development around each parcel were calculated in ESRI's ArcView 3.3 using an Extension written in the Avenue programming language by Dr. Hanna Maoh. Two kinds of measures were applied: number of parcels of a given land use type and within a selected distance around each parcel; and, amount of existing floorspace of a given land use type within a selected distance around each parcel. Variables created and used in the modeling exercise will be presented in more detail in chapter 5.

3.4.2 Other GIS and Census Data

Other variables employed in the analysis were created using data obtained from two additional sources; Statistics Canada and DMTI's CanMap Streetfiles. The DMTI's Streetfiles data acquired from the library's map/GIS collection contain spatial information stored in GIS layers (Shapefiles) for the street network of the Province of Ontario. The appropriate segments of the street network required for our analysis were extracted from the shapefiles containing the complete street network of Ontario. Specifically, the data extracted from the CanMap streetfiles were the polyline shapefiles that contain the highways and major roads of Hamilton.

Basic socioeconomic data at the census tract level for Hamilton Census Metropolitan Area (CMA) were obtained from Statistics Canada. We collected data on population size, average household income, average value of dwelling, and area of census tract for the year 1991 and 1996. Using the population size and the census tract area we calculated the population density for each tract in the CMA. All aggregate level data collected from Statistics Canada for the Hamilton CMA were tabulated according to their census tract code and then were joined to the attribute table of the census tract shapefile in GIS. The Hamilton's CMA shapefile contains the geometric shapes of the census tracts along with their respective codes. This file was available to us from the IMULATE's (Integrated Model of Urban LAnd use, Transportation, and Environment analysis) database. Finally, the shapefile of the census tracts containing the aggregate data was joined to the shapefile of the disaggregate land parcel data set via the spatial join GIS operation. In that way, each land parcel inherits the values of the aggregate data according to the census tract within which the parcel's centroid is located.

Also, some additional data were acquired from the following sources. We obtained the morning peak-period travel times between census tracts within Hamilton city and the level of employment (number of jobs) at each census tract, both for the year 1996, from the IMPACT's (Integrated Model for Population Aging Consequences on Transportation) database. Lastly, maps available in the Growth Related Integrated Development Strategy (GRIDS) final report of the City of Hamilton were imported to the ArcGIS, georeferenced on the basis of the existing shapefiles, and then digitized. These maps provided us with the spatial data on the location of community cores for Ancaster, Dundas, Stoney Creek and Waterdown. The data also identify the location of community service centers (retail complexes) such as the Meadowlands and the several malls over the city.

3.5 Methods

3.5.1 Exploration Techniques

3.5.1.1 Kernel Estimation

We employed a variety of spatial statistical techniques and GIS analysis to conduct the exploratory analysis presented in the next chapter. More specifically, we used Kernel Estimation to measure and visualize the intensity of land development over time and space in the area under study. Kernel density surfaces and Kernel maps were computed and presented in ArcGIS 9.2. The calculations were conducted using the Spatial Analyst Extension.

Kernel estimation is one of several techniques used in geography to visualize data, trace trends and examine patterns of spatial configuration. This technique measures the variation in the mean value or intensity of a process over space. In simple terms, the kernel estimate measures the number of observed events (i.e. land parcels developed for residential use) per unit area (Cuthbert and Anderson, 2002a). It offers an estimate that can be plotted on a surface map depicting the spatial variation of the magnitude of events (i.e. parcels developed for residential use) produced by a process (i.e. land development). It can also be used along with a quantitative measure (weight) of a characteristic (i.e. floorspace constructed) of the observed events. Using the latter, the kernel estimate produces a surface map that depicts the spatial variation of the intensity of the characteristic (i.e. floorspace constructed) pertaining to the event (i.e. parcel developed for residential use).

In order to produce the estimate, the technique requires as input a point pattern, such as the locations of land parcels of residential development or the locations of those parcels along with the amount of floorspace developed on them. Next, it calculates the density of events or the density of floorspace produced by the events within a specified distance radius around those events. The distance is defined by the analyst and depends mainly on the nature of the process under study. The outcome of the technique is a continuous surface over the study area that maps the intensity of parcels in residential use or the intensity of residential floorspace per unit area.

According to Bailey and Gatrell (1995), the generation of a kernel surface is based on estimating a bivariate probability density. Specifically, if **s** represents a general location (i.e. grid cell) in R (study area), ($\mathbf{s}_1$, $\mathbf{s}_2$, …, $\mathbf{s}_n$) are the locations of the **n** observed events (i.e. developed land parcels), and (y_1, y_2, …, y_n) are the values of the characteristic (i.e. floorspace) associated with the observed events, then the intensity $\lambda_\tau(\mathbf{s})$ at location **s** is estimated by:

$$\lambda_\tau(\mathrm{s}) = \frac{\sum_{i=1}^{n} k\left(\frac{(s - s_i)}{\tau}\right) y_i}{\sum_{i=1}^{n} k\left(\frac{(s - s_i)}{\tau}\right)}$$

where:

- $k()$, quartic kernel bivariate probability density function, which is symmetric about the origin

- and τ, a positive parameter (bandwidth), which determines the amount of smoothing of the estimated surface. It is the radius of a disc centered on **s** within which points $\mathbf{s}_i$ -along with the value of the characteristic (y_i) pertaining to them- are utilized to calculate $\lambda_\tau(\mathbf{s})$

For further details on the kernel estimation technique the reader is referred to Bailey and Gatrell (1995, pp. 84-87).

3.5.1.2 Univariate K-Function

Furthermore, the exploration analysis examines second-order effects in the data. Accordingly, we used the locations of new residential and commercial land parcels to identify where households and employment sites are locating. The Univariate-K and Bivariate K-function analysis were performed in the SPLANCS (Spatial Point Pattern Analysis Code) package of R, which is a free software for statistical analysis.

The Univariate K-function, which is a technique for *second-order analysis* in spatial statistics, provides a way to test for randomness, dispersion or clustering among points of a *spatial point pattern* produced by a *spatial process*. A *spatial point pattern* can be defined as any data that form a set of points distributed over space; and, a *spatial point process* as any stochastic mechanism that produces a number of events in an area (Diggle, 1983). *Second-order analysis* is the analysis of the distribution of distances between all points of a spatial point pattern created by a spatial process (Getis, 1983).

This type of analysis intends to explore and reveal the spatial arrangement and covariation in a set of points (Getis, 1983). However, there is one assumption involved in this analysis that should not be ignored: that is the assumptions of stationarity (Getis, 1983). Under stationarity, the surface of the area on which the point pattern is observed should be homogeneous. That is, all possible locations over the surface of the study area have equal probability to accommodate an event of the spatial process. In addition, under stationarity, it is assumed that there is no bias stemming from directional effects in the point data set (isotropy) (Getis and Boots, 1978; Diglee, 1983; Getis, 1983).

The second-order analysis and the K-function in particular, seek to compare the results of an observed point pattern against a theoretical pattern generated under certain assumptions. The hypothesis usually employed attempts to test for *complete spatial randomness* against other types of spatial relationship (clustering or for diffusion) in a point pattern. This test is based on the hypothesis that the observed point pattern arises from *a homogeneous Planar Poisson point process* (Bailey and Gatrell, 1995).

By definition, this type of process has two fundamental properties which, according to Getis and Boots (1978, pp. 18-20), Diggle (1983, pp. 4-5), and Upton and Fingleton (1985, pp. 10-12), are the following. First, the set of point events in a planar region, R, follows a Poisson distribution with mean $\lambda(R)$. The parameter λ is the *intensity* of the process under study, defined as the expected number of events per unit area, and does not vary over R. Second, this set of point events is an independent random sample from the uniform distribution in R. This second property implies the conditions of uniformity and independence. As explained above, uniformity guarantees that all locations over R have equal probability of receiving an event; that is, the surface of the study area is regarded as homogeneous and undifferentiated in space. Finally, the independence condition guarantees that the placement of one event at a location does not influence the placement (selection of location) of any other event over the area R.

In our research, the univariate K-function allowed us to test the alternative hypothesis of spatial dependence (clustering) among residential land parcels or among commercial land parcels against the null hypothesis of complete spatial randomness (CSR). Following this approach, which has been employed in a handful of studies (Getis, 1983; Barff, 1987; Cuthbert and Anderson, 2002b; Maoh and Kanaroglou, 2007a), we used the location coordinates of residential land parcels to estimate the K-function as the expected number of residential land parcels within a vector of given distances from a randomly selected parcel in residential use, divided by the overall intensity of residential parcels. The vector of distances extends from 200 metres to 2000 metres away from each randomly selected parcel with a step of 200 metres at a time. Next, the estimated K-function was compared to a number of simulated K-functions that were computed under the CSR assumption for the same number of land parcels. This was repeated for all the decades of the time period that our study explores (i.e. 1950-2003). The same exercise was repeated for commercial land parcels.

As presented above, after estimating the K-function for the observed point pattern, we proceed to compute 99 simulations of the same number of points, as the ones in the observed pattern, under CSR. Each simulation produces a random point pattern, which contains the same number of points, as the observed point-set, within the boundary of the (same) study area. Here, the term random point pattern refers to a realization of a point pattern that arises from a homogeneous planar Poisson point process under the conditions of stationarity and independence as explained earlier.

Next, for each random point pattern created a K-function is estimated. The latter will be referred to as simulated K-functions. All simulated K-functions are sorted according to their value from the lowest to the highest and are ranked from 1 to 99. Thus, the K-function with the lowest value is ranked 1st and the one with the highest value is ranked 99th. In that way, the two extreme sides, the lower and the upper, of the simulated random process are identified, and the confidence bounds of the test are set. These two extremes define what is referred to as the simulation envelop. Because the hypothesis test we apply assumes CSR, it is hypothesized that the observed K-function (the one we estimated for the observed point pattern) was derived from a random point pattern. For this reason, the observed K-function is put together with the simulated K-functions, and its rank is estimated according to its value. Because CSR assumes stationarity and independence, the probability for each one of these 100 K-functions (99 simulated and 1 observed) to belong to a random point pattern is 1/100 (Diggle and Milne, 1983). In other words, if the observed point pattern is random, then its chance to be found among the 100 K-functions is 1%. As such, clustering in the observed point pattern is discerned at the 99% confidence level if the observed K-function is not found among the 99 simulated curves and specifically when it is above the upper simulation envelop.

For the purpose of our analysis, we compute 99 simulations in order to achieve a 99% confidence level. Two K-function curves, the one with the lowest and the one with the highest values, among the simulated ones are selected and plotted on a diagram, creating the lower and the upper simulation envelops. By doing so, we create a test of significance with the confidence intervals being defined by the lower and the upper simulation envelops. Finally, we plot in the same diagram the K-function estimated from the observed point pattern.

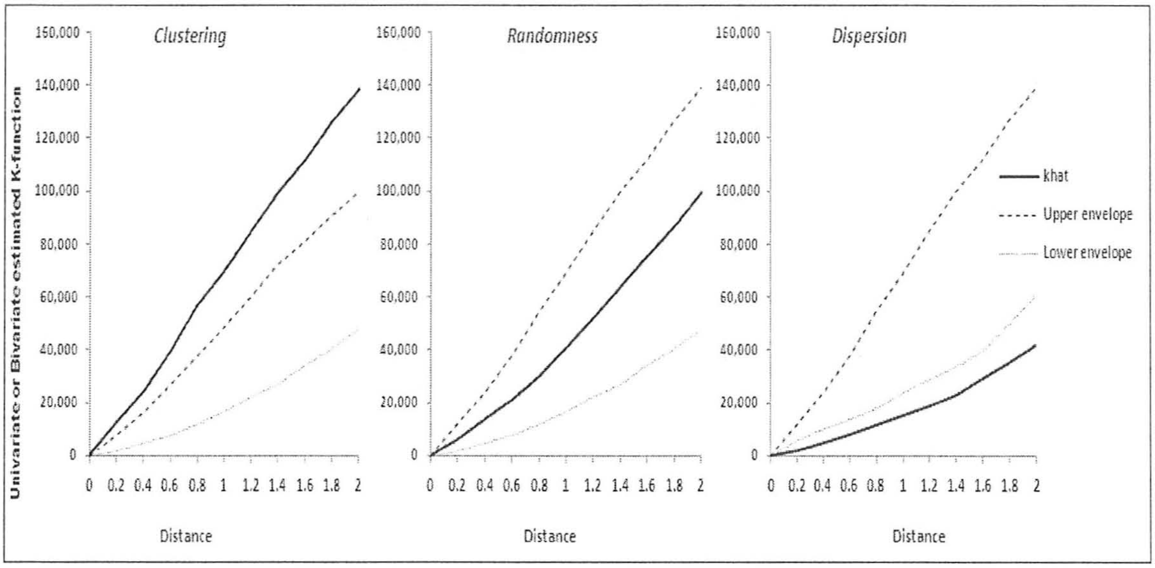


Figure 3.5: Examples of estimated K-Function plots for Clustered, Random, and Dispersed Point Patterns

According to Bailey and Gatrell (1995), the aforementioned confidence intervals provide the means to assess departures of the estimated K-function (Khat) $K(h)$ from its theoretical value. By observing the plot, we can conclude whether there is clustering or dispersion among the residential land parcels and at which distances (see figure 3.5). If the estimated K-function is above the upper confidence interval then clustering among the points of the observed pattern is present at distance h. If the estimated K-function is below the lower confidence interval then dispersion among the points of the observed pattern is present. Lastly, if the estimated K-function falls between the lower and the upper confidence intervals then we have an indication of a random point pattern (Cuthbert and Anderson, 2002b).

Following the notation in Bailey and Gatrell (1995), the univariate K-function for the point sets representing land parcels per study period for residential and commercial land use is derived as follows. The intensity or mean number of parcels, λ, in region **R** is calculated by:

$$\lambda = \frac{n}{R}$$

where n is the number of parcels and R is the area of region **R**. For each of the n parcels, the expected number of parcels within distance h is given as follows:

$\lambda K(h)$ = E (number of parcels within distance h of a randomly selected parcel)

where E( ) is the normal expectation operator. If the number of parcels in the region is determined by:

$$n = \lambda R$$

and the expected number of events within distance h of a specified parcel is given by:

$$\lambda \mathrm{K}(h)$$

then the expected number of ordered pairs of parcels within distance h is given by:

$$(\lambda R)(\lambda K(h)) = \lambda^2 RK(h)$$

If d_{ij} is the distance between the i-th and j-th observed parcel in **R** and $I_h(d_{ij})$ is an indicator function that is 1 if $d_{ij} \leq h$ and 0 otherwise, then the observed number of such ordered pairs is :

$$\sum_{i=1}^{n} \sum_{j=1}^{n} I_h(d_{ij})$$

Combining the two previous equations and rearranging, $K(h)$ can be estimated as follows:

$$\lambda^2 R\widehat{K}(h) = \sum_{i=1}^{n}\sum_{j=1}^{n} I_h(d_{ij})$$

$$\widehat{K}(h) = \frac{1}{\lambda^2 R}\sum_{i=1}^{n}\sum_{j=1}^{n} I_h(d_{ij})$$

$$\widehat{K}(h) = \frac{R}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} I_h(d_{ij})$$

The above estimate of $K(h)$ should incorporate a modification to account for edge effects as a result of events near the area's boundary. The equation excludes pairs of parcels for which the second parcel, parcel j, is located outside of region **R**. In order to derive an edge-corrected estimate, we consider the following. Assume a circle centered on parcel i and passing through parcel j. Let w_{ij} represent the proportion of the circumference of the circle that lies within **R**. This w_{ij} is the conditional probability that a parcel is observed in **R**, given that it is at distance d_{ij} from the i-th parcel. The edge-corrected estimate becomes:

$$\widehat{K}(h) = \frac{R}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n} \frac{I_h(d_{ij})}{w_{ij}}$$

3.5.1.3 Bivariate K-Function

The Bivariate K-function was used to investigate the relationship between two spatial processes under the assumption of independence. This function provides a method to test for spatial dependence (co-clustering) between the locations of new residential and new commercial land parcels over the time period of our study. We estimated the bivariate K-function to explore whether the spatial distribution of the point pattern of residential land parcels is related to the spatial distribution of the point pattern of commercial parcels and vice versa.

We used the location coordinates of residential and commercial land parcel points to estimate the bivariate K-function as the expected number of residential parcels within a given distance from a randomly selected parcel in commercial use, divided by the overall intensity of the points in residential use. The vector of distances extends from 200 metres to 3000 metres away of each randomly selected parcel with a step of 200 metres at a time. This was done to check the hypothesis that the spatial distribution (or pattern) of occurrences of residential development is spatially interdependent with the spatial distribution of occurrences of commercial development. Next, the estimated bivariate K-function was plotted and compared to a number of simulated bivariate K-functions computed under CSR as will be described further on in this section. Lastly, one bivariate K-function was estimated for each decade of our study period (1950-2003).

The location coordinates of commercial and residential land parcels were used to estimate a set of ten bivariate K-functions. This was done to test for spatial dependence between commercial and residential development in the period 1990 to 1999. The purpose of the test is to examine the temporal lags between commercial and residential land development. Each K-function is defined as the expected number of commercial land parcels within a vector of given distances from a randomly selected parcel in residential use, divided by the overall intensity of the parcels in commercial use. The estimation of the K-functions was performed using a number of point-sets of commercial development (cases) and a specific point-set of residential development (control). Specifically, we used the point-set representing the developed parcels for residential use in the period 1986 to 1990 as the control set. A point-set representing newly developed land parcels for commercial use in a given period during the 1990's was used as a case set. For the latter, parcels of commercial development during the following periods are utilized: 1990, 1990-1991, 1990-1992, 1990-1993, 1990-1994, 1990-1995, 1990-1996, 1990-1997, 1990-1998, and 1990-1999. This approach is applied to test the hypothesis: New commercial development takes x years to co-cluster around an existing residential development that has already occurred in the time period $[t, t + 5]$; $x \geq t + 5$.

For each one of the ten bivariate K-functions estimated for the ten distinct pairs of commercial and residential point-sets, we simulated a number of bivariate K-functions under the CSR assumption. Specifically, we computed 99 and 999 simulations of random bivariate K-functions in order to examine the significance of co-clustering at a 0.01 and a 0.001 level of significance respectively. Next, each estimated bivariate K-function was plotted and compared to the simulated bivariate K-functions. Finally, the observed and simulated functions are plotted on a diagram for further investigation. As a result, ten diagrams are produced, one for each of the periods commercial development took place (i.e. 1990, 1990-1991, 1990-1992, and so on).

In a similar manner, we used the location coordinates of residential and commercial land parcels to estimate nine bivariate K-functions to test for spatial interdependence between the occurrence of commercial development from 1991 to 1995 and the residential development that followed up from 1995 to 2003. Here, we used incremental periods of residential development in an attempt to test for interdependence along with an up to nine years temporal lag between the two point patterns. The incremental periods of residential development we used are: 1995, 1995-1996, 1995-1997, 1995-1998, ..., 1995-2003. Again, for each estimated bivariate K-function from the observed pair of point-sets, a number of simulated bivariate K-functions were computed under the CSR assumption. Lastly, both the observed and the simulated functions of each period were plotted on a diagram for further assessment.

As described above, after estimating the bivariate K-function for the pair of point patterns under investigation, we proceed to computing the 99 (0.01 significance level) and the 999 (0.001 significance level) simulations of bivariate K-function under CSR. In these simulations the point pattern in land use type 1 (residential or commercial) is held at its position and the point pattern in type 2 (residential or commercial) is randomly shifted according to a random toroidal shift relative to the point pattern in type 1 (Rowlingson and Diggle, 1993; Bivand and Gebhardt, 2000; Cuthbert and Anderson, 2002b). Each random toroidal shift represents a simulation. For a more detailed presentation of this technique the reader is refered to Lotwick and Silverman (1982, p 410), Diggle and Milne (1983, p 14) as well as Upton and Fingleton (1985, pp 253-254).

For each simulation, a bivariate K-function is estimated. Two bivariate K-functions, the one with the lowest and the one with the highest values, among the simulated ones are selected and plotted on a diagram, creating the lower and the upper simulation envelops. Finally, we plot in the same diagram the bivariate K-function we estimated using the two observed point patterns. Again, by examining the plot, we can conclude whether there is clustering or dispersion among the land parcels in land use type 1 (i.e. residential) relatively to the land parcels in land use type 2 (i.e. commercial) and at which distances. If the estimated bivariate K-function is above the upper confidence interval then clustering among the points of the two observed patterns is present. If the estimated bivariate K-function is below the lower confidence interval then dispersion among the two observed point patterns is present. Lastly, if the estimated bivariate K-function falls between the lower and the upper confidence intervals then we have an indication of two randomly distributed point patterns relative to each other (Cuthbert and Anderson, 2002b).

Following Lotwick and Silverman (1982), Rowlingson and Diggle (1993), and Cuthbert and Anderson (2002b), we define the bivariate K-function $K_{12}(h)$ as the expected number of points of pattern 1 within a specified distance h of an arbitrary point of pattern 2, divided by the overall density of the points in pattern 1. Following the same notation used for the univariate K-function, the edge-corrected $K_{ij}(h)$ is defined as:

$$\widehat{K}_{12}(h) = \frac{R}{n_1 n_2} \sum_{i=1}^{n_1} \sum_{j=1}^{n_2} \frac{I_h(d_{ij})}{w_{ij}}$$

where R is the area of the region **R**, n_1 is the number of points (parcels) in point pattern 1, n_2 is the number of points (parcels) in point pattern 2, d_{ij} is the distance between the *i*-th parcel of point pattern 1 and the *j*-th parcel of point pattern 2, $I_h(d_{ij})$ is the indicator function that takes on the value 1 if $d_{ij} \leq h$ and 0 otherwise, and w_{ij} is proportional to the circumference of a circle that is centered on the *i*-th type 1 parcel, passing through the *j*-th type 2 parcel which lies within **R**.

3.5.2 Econometric Modeling

3.5.2.1 Model Formulation

The objective of the modeling exercise in this research is to explain the underlying factors that affect the type of residential land development. As has already been documented in the section 2.3, land development occurs as a response to the need for floorspace and it is carried out mostly by private developers. It was also shown that the private developer is a profit motivated entrepreneur that seeks to maximize its net returns from developing land parcels. Lastly, the discussion in chapter 2 also noted to the fact that the developer's locational behaviour is a major element of her/his effort to maximize profit.

The modeling exercise undertaken here intends to explain a component of the residential development process that relates to the housing type choice development. In this respect, land developers are faced with the choice to develop a land parcel to one of the following four types (outcomes) of housing projects: single family Detached (D), Semi-detached (S), Row-link (R), and Condominium (C).

Preferences of an individual for choice can be approached by the concept of utility maximization. Utility can be explained as the perceived benefit a choice-maker expects to receive by choosing one of the alternatives available to her/him. In the context of this study, each housing development project (to be applied to a parcel) has a utility associated with it. This utility reflects the attributes of a site as a potential location for the construction of one of the four housing types (D, S, R, and C).

McFadden (1975) uses the concept of utility maximization to provide a complete model of individual choices. He defines the utility of individual n facing choice i as a function of two types of variables: attributes of the alternative choices and characteristics of the choice makers.

$$U_{ni} = U(\mathrm{x}_{ni}, \mathrm{s}_{ni})$$

where x_{ni} are the attributes and s_{ni} are the characteristics. Within the utility maximization framework, the decision maker is modeled as selecting the alternative with the highest utility. Ben-Akiva and Lerman (1985) define the modeling of choice from a set of mutually exclusive and collectively exhaustive alternatives as the basic problem confronted by discrete choice analysis. The utility of the alternatives are considered as random variables and the probability that an alternative will be chosen is defined as the probability that it has the greatest utility among the available alternatives. Furthermore, a joint probability distribution is assumed for the set of random utilities and the choice probability can be derived. Hence, the utility can be written as the function:

$$U_{ni} = V(x_{ni}, s_{ni}) + \varepsilon(x_{ni}, s_{ni})$$

Where $V(x_{ni}, s_{ni})$ is the systematic part of the utility, or the part of the utility which is influenced by factors that can be observed or known, and $\varepsilon(x_{ni}, s_{ni})$ is the random component, or the disturbance term representing that part of the utility which cannot be known to the analyst.

If we assume that individual n is going to choose alternative i from a set of discrete alternatives J_n, (here J_n = {D, S, R, C}) then the probability that alternative i is chosen is the probability that the utility of alternative i exceeds the utility af all other variable alternatives. Thus,

$$P_{ni} = \Pr(U_{ni} > U_{nj} \text{ for all } i \neq j)$$

If we assume that the disturbances ε are Independently and Identically Distributed (IID) and follow a Gumbel type 1 distribution, then the probability P_{ni} can be mathematically solved and expressed by the following formula:

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j=1}^{Jn} e^{V_{jn}}} \qquad [3.1]$$

This equation is the general formula of the multinomial logit model. Estimation of the parameters that form the utility function can be derived via the maximum likelihood estimation method.

In our modeling problem, since the developer seeks to maximize her/his utility by developing a parcel to type i, then the choice of a housing type for residential use can be modeled as a discrete choice problem among four choices. Following the work of McFadden (1975), each choice (outcome) has a utility associated with it. U_D is the utility of single family detached housing, U_S is the utility of semi-detached housing, U_R is the utility of row-link housing, and U_C is the utility of condominium housing and can be defined as the following functions:

$$U_D = V_D + \varepsilon_D$$

$$U_S = V_S + \varepsilon_S$$

$$U_R = V_R + \varepsilon_R$$

$$U_C = V_C + \varepsilon_C$$

where V is the systematic component of the utility defined by the land parcel's attributes (characteristics); and, ε is the disturbance term. If we make the assumption that the disturbances ε are independently and identically distributed and follow a Gumbel type 1 distribution then the developer's choice problem of the type of housing project can be modeled via the conventional multinomial logit model. That is, the probability of developing parcel n to housing type i is given according to equation [3.1], where $J_n = \{D, S, R, C\}$.

Selecting the four alternative types of housing projects to be modeled is based on the results of the exploratory analysis of residential development in the 1996-2000 period. Table 3.1 presented below summarizes the breakdown of the developed parcels. As illustrated, the most prevalent type of residential development is that of single detached housing projects. It is followed by the Row-Link projects, then by the Semi-detached houses and finally by the Condominium projects. The group labeled as 'Other' in this table contains various other types of residential projects that were developed over the period under study (1996-2000). However, this group of types is dropped from the choice set of developers and is not modeled. This is done because the number of land parcels developed to these types of housing projects is very limited. In addition, an attempt to model an alternative that consists of different in nature types of housing projects would not lead to meaningful and interpretable results.

Table 3.1: Floorspace and Land Parcels Developed by Alternative Type of Residential Development in Hamilton, 1996-2000

Type of Residential Development	1996-2000	
	Number of Parcels	Floorspace in m^2
Single Detached (Property Code 301)	5,430 (83.5)	1,051,146 (86.9)
Semi Detached (Property Code 311)	163 (2.5)	21,396 (1.8)
Row-Link (Property Codes 309 and 305)	820 (12.6)	111,691 (9.2)
Condominium (Property Code 370)	69 (1.1)	9,596 (0.8)
Other	24 (0.3)	16,435 (1.3)
Total Development	6,506 (100)	1,210,264 (100)

Note: Values in Brackets are percentages

3.6 Conclusion

This section provided an overview of the study area and the data that are used in this Thesis. Hamilton's urban form was briefly described and the reader was introduced to the structure of the micro-level land parcel data-set used in the analysis. The exploratory techniques, namely Kernel density estimation as well as the univariate and bivariate K-function analysis were presented. Finally, the basic concepts of discrete choice theory and utility maximization were introduced in order to support and clarify the formulation of the model used to explain the developer's locational choice of housing type projects applied to land parcels in the study area.

CHAPTER FOUR

Exploratory Analysis of the Land Development Process in Hamilton, Ontario

4.1 Introduction

It is generally accepted that throughout the twentieth century urban form has undergone dramatic changes. Since the early 1950s traditional monocentric cities have been facing continuous decentralization of population and employment. As a result, many of these cities evolved to exhibit a polycentric structure. The emergence of polycentrism has been accompanied by excessive growth of built up land in suburban areas. This phenomenon is well documented in the literature as urban sprawl. The latter has been an observed trend in many cities around the world including Canada. Like these cities, Hamilton has suffered a clear decentralization and suburbanization and has exhibited a sprawled development pattern over time (Maoh and Kanaroglou, 2007a). Characteristics of sprawl can include unlimited outward expansion of land development, low-density residential developments, leapfrog development, widespread strip commercial development, segregation of types of land use in different zones and excessive dependence on the automobile. The change in urban form and the emergence of urban sprawl can impact the sustainability of cities. As such, an exploration of the land development process can help to inform urban planning practices and promote a more sustainable future.

The objective of this chapter is to conduct an exploratory analysis to examine the locational patterns of residential and commercial land use development over time for the period 1950 – 2003. The analysis will also examine the changes in the city's urban form as a result of the observed spatio-temporal patterns of land development. The methods described in chapter 3 will be employed to analyze the point source data extracted from the land use parcel GIS layer for Hamilton.

4.2. Trends in Land Development and Urban Form, 1950 – 2003

4.2.1 Descriptive Trends in Land Development

4.2.1.1 Overview of General Trends in Land Development

In order to describe the general trend of land development during the period 1950 to 2003, information on the amount of floorspace created and on the number of land parcels developed was extracted from the available data. Figure 4.1 depicts the amount of land development allocated to each geographic region of Hamilton during each decade of the study period. On the other hand, figure 4.2 reveals the trend of the amount of land development over time for the five geographic regions that received the majority of it. Both figures are based on percentages of floorspace created over each period and all values illustrated in those figures are presented in Table A.1 in the Appendix.

During the period 1950-1980, the majority of land development happened in lower and upper Hamilton. Lower Hamilton attracted most of the development among regions during the 1960's and 1970's; however, past that period, high levels of development ceased in this geographic region. On the contrary, Stoney Creek and Ancaster had their peak period during the decades of 1980's and 1990's. During the 1990's, Flamborough received a high amount of new development, which almost reached the levels of Stoney Creek and Ancaster. Lastly, Glanbrook and Dundas retained an almost constant amount of new development during the studied 5 decades.

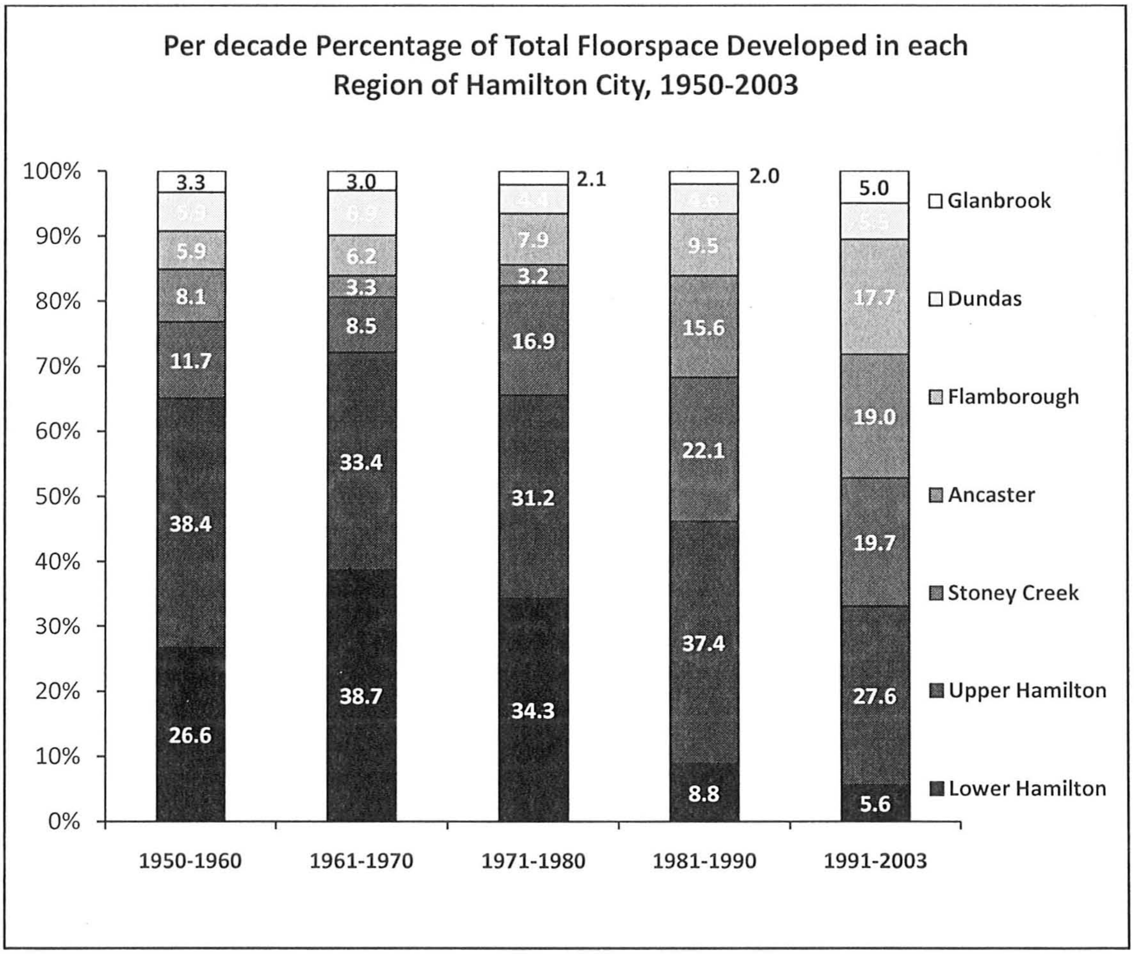


Figure 4.1: Developed Floorspace (percentage of each decade's total) in the City of Hamilton (1950-2003)

Lower Hamilton attracted 26.6% of the floorspace created during 1950-1960, 38.7% during 1961-1970, and 34.3% during 1971-1980. During the following two periods, 1981-1990 and 1991-2003, development in this region was limited to minimal levels and specifically to 8.8% and 5.6% respectively. On the other hand, upper Hamilton received most of the development (38.4%) and ranked first among the regions forming the city of Hamilton in the period 1950-1960; and second during the 1960's and the

1970's. During the 1980's and 1990's, it was again ranked first. However, in the latter decade the region's percentage dropped below 30% mainly due to the increased development in suburban municipalities, namely Flamborough and Ancaster.

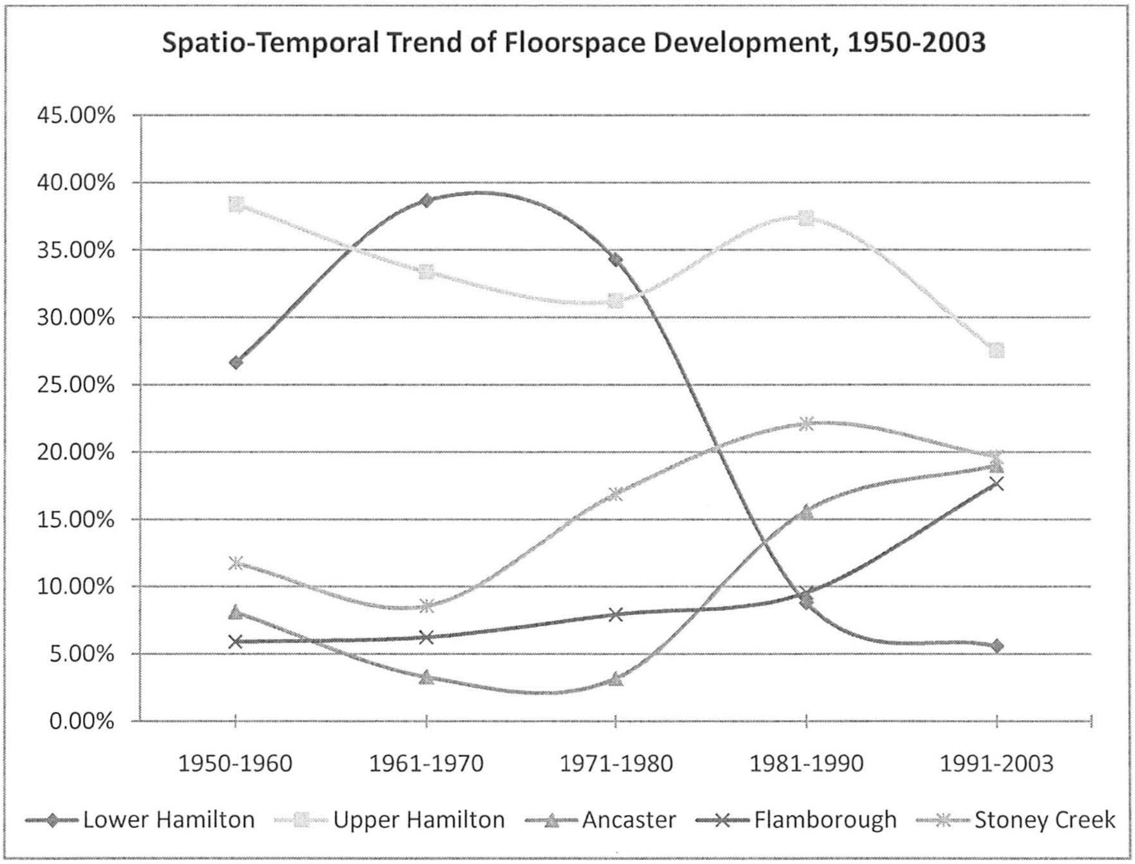


Figure 4.2: Spatio-Temporal Trend of Floorspace Development (percentage of each decade's total) in the City of Hamilton (1950-2003)

Figure 4.2 clearly depicts the decreasing trend of floorspace development in lower Hamilton[1]. After the peak period between 1950 and 1970 the land development activity decreased dramatically in this part of the city. Development trends in upper Hamilton fluctuated over time. It was decreasing between 1961 and 1980, increasing during the 1980's and then again decreasing in the 1990's. The diagram illustrates effectively the

[1] The municipalities of Dundas and Glanbrook were not included in figure 4.2 due to their very low values.

two simultaneous trends after 1971: on the one hand, development in lower Hamilton (existing urban core) radically decreases. On the other hand, development in Stoney Creek, Ancaster and Flamborough (communities in the periphery, future suburban areas) drastically increased. At the same time, development in upper Hamilton (the inner suburban area of the urban core) remains at high levels from 1950 to 1980 and then decreases to medium levels.

Table 4.1 summarizes the allocation of the total amount of floorspace, which was created in the city of Hamilton during each decade of our study, to the three basic land use types: Residential, Commercial, and Industrial. Residential development produces on average 3,000,000 m^2 of floorspace or 80% of the total construction in each decade. Each of the commercial and industrial development contributes to the total construction an average of 6% per decade.

Table 4.1: Allocation of Total Development to the Three Major Land Use Types

Hamilton City	**Floorspace Constructed in m^2**					
Land Use	**1950-1960**	**1961-1970**	**1971-1980**	**1981-1990**	**1991-2003**	**Average 51-03**
Residential	3,059,429	2,674,481	3,061,112	3,423,767	3,162,325	3,076,223
Commercial	234,916	224,997	342,131	247,626	135,320	236,998
Industrial	160,340	272,658	351,218	284,238	36,870	221,065
Total Development	3,788,385	3,586,945	4,100,597	4,208,431	3,567,415	3,850,355

Hamilton City	**Percentage of Floorspace Constructed**					
Land Use	**1950-1960**	**1961-1970**	**1971-1980**	**1981-1990**	**1991-2003**	**Average 51-03**
Residential	80.76%	74.56%	74.65%	81.35%	88.64%	79.99%
Commercial	6.20%	6.27%	8.34%	5.88%	3.79%	6.10%
Industrial	4.23%	7.60%	8.57%	6.75%	1.03%	5.64%
Total Development	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

The residential floorspace created in 1950's contributed 81% of the total floorspace constructed in Hamilton, 75% in 1960's and 1970's contributed the 75%, 81%

in 1980's, and 89% in the period 1990-2003. It is worth noting that the residential construction during the last period of our study is almost 9% above the average of the five periods of analysis.

As presented in Table 4.1, commercial development has a 6% average per decade of the share of floorspace constructed over the study period. In 1950's and 1960's the decade's share for commercial development was approximately 6.2%, only to increase to 8.3% in 1970's. However, the percentage of commercial floorspace created in the next two periods decreased to 5.9% in 1981-1990 and to 3.8% in 1991-2003, being 2% below the average of the five decades under study.

Moreover, industrial development produced on average 5.6% of the total floorspace created per decade. During 1970's, it produced almost 9% of the decade's total floorspace created. In 1990's, the amount of floorspace added to industrial use was minimal and barely represented 1% of the total floorspace created in Hamilton during that decade.

4.2.1.2 Spatial Variation in Residential land Development

In our attempt to explore the overall trend of land development in Hamilton during the period between 1950 and 2003, we proceed to answer the following question: "where was residential development allocated over the study area and during the study period?" By examining figure 4.3, we can easily observe that upper Hamilton received the majority of residential development (in terms of floorspace) during the fifty four years of the study period. This region had been receiving approximately 40% of each decade's residential development for the decades between the years 1950 and 1990, when its share was reduced to 28% for the last period (1991-2003).

Lower Hamilton, where the city's major urban core is located, received a large proportion of each decade's residential development for the periods between 1950 and 1980. After 1981, the amount of residential development that occurred in this geographic region was reduced to a very low level, which was below the 5% of the total residential floorspace construction for both the decades of 1980's and 1990's.

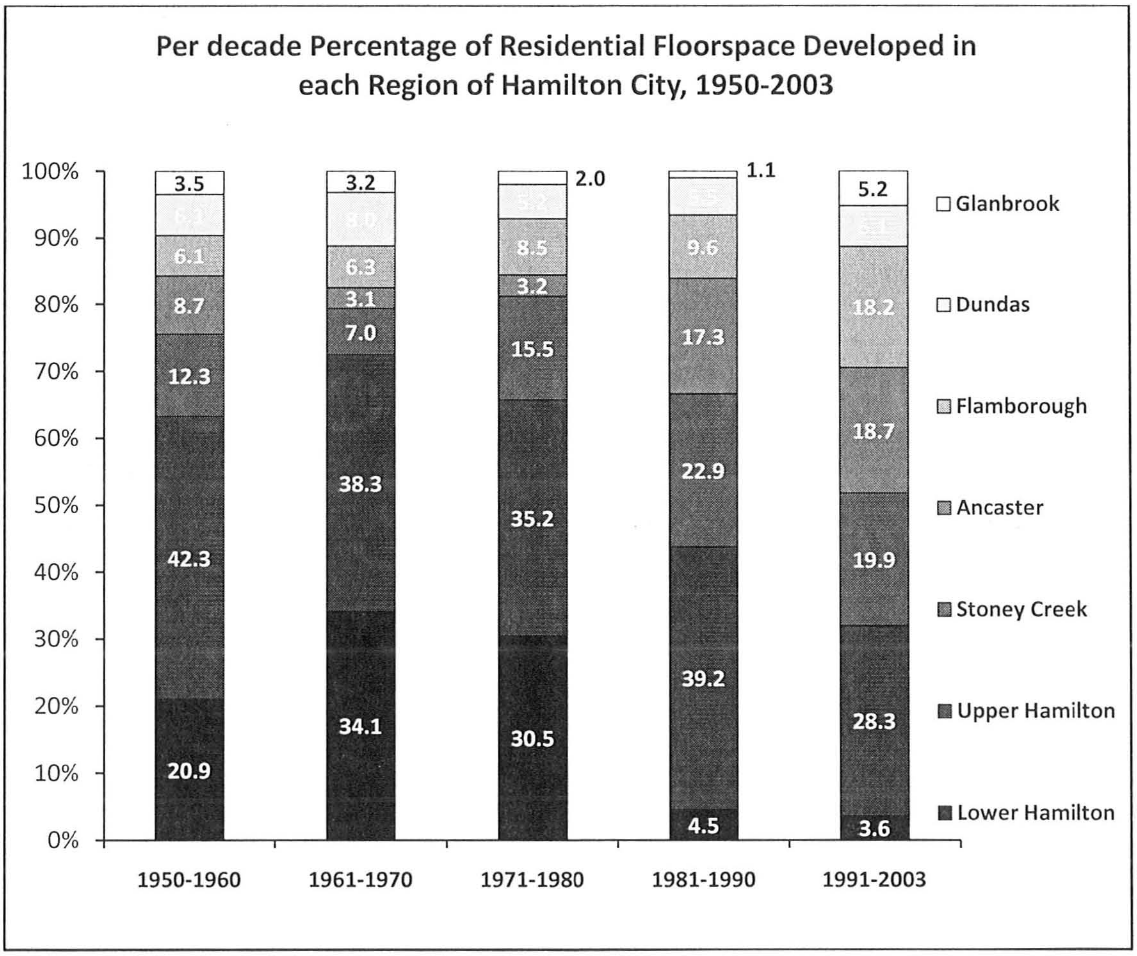


Figure 4.3: Residential Floorspace Developed (percentage of each decade's total residential) in the City of Hamilton (1950-2003)

During the 1980's the contribution of Stoney Creek in terms of residential floorspace development was increased by 7% (from 15.5% to 22.8%) compared to the previous decade. Also, the contribution of Ancaster was increased by 14% (from 3.2% to 17.2%) compared to the 1970's. Additionally, during the period 1991-2003, Ancaster and Stoney Creek exhibited a stable and close to 20% of the decade's total residential development. Interestingly, Flamborough doubled its amount of floorspace development during the 1980's. More specifically, Flamborough's residential development reached 18% during the 1990's, jumping from only 9.5% during the 1980's.

New residential floorspace development in Glanbrook and Dundas was fairly stable and low over the study period. On a decade basis, Dundas received approximately 5% of new residential development whereas Glanbrook received approximately 3.5%. However, it is worth mentioning that residential development in Glanbrook was reduced to a very low level of 2% and 1% during the decades of 1970 and 1980, respectively. Yet, during the period 1991-2003, the level of residential development in Glanbrook was restored to 5.2%.

The trend of residential development over space and time is depicted in figure 4.4[2]. As expected, it is very similar to the trend generated by the total development because residential development accounts for approximately 80% of the total development. Residential development in lower Hamilton was intense during the decades of 1950, 1960, and 1970. Its peak was during 1961-1970 when it reached the 35% of the total residential floorspace constructed during that decade. The next decade (1971-1980)

[2] The municipalities of Dundas and Glanbrook were not included in figure 4.4 due to their very low values.

development was decreased but remained above 30% of the total development. Finally, the amount of residential development dropped below 5% of the total and remained at these levels since 1981.

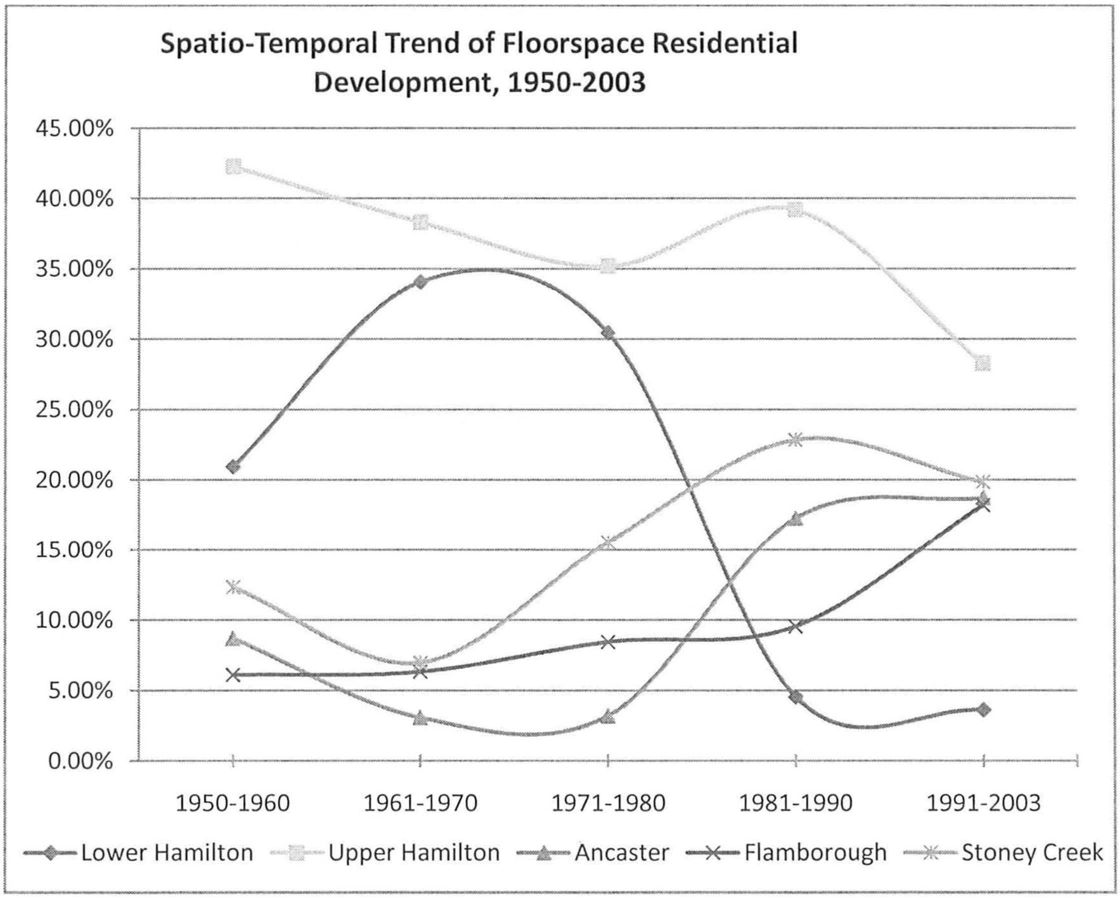


Figure 4.4: Spatio-Temporal Trend of Residential Floorspace Development (percentage of each decade's total residential) in the City of Hamilton (1950-2003)

Although upper Hamilton is the region that received most of residential development during the period of our study, figure 4.4 clearly depicts that the trend pertaining to upper Hamilton was declining over the years. The percentage of the region's contribution was close to 45% in the 1950's and close to 25% in the 1990's. As we observe in this graph, from the year 1951 to the year 1980 the percentage declined.

During the 1980's, it fluctuated and followed a positive trend similar to the one observed in Ancaster and Stoney Creek. However, development trends returned to the negative slope during the last period (1991-2003).

Stoney Creek, Ancaster and Flamborough have been following a positive and increasing trend since 1960. In the period between 1991 and 2003, each of these regions contributed an approximately 20% of the total residential floorspace constructed. That is, Ancaster, Stoney Creek, and Flamborough accommodated 56.8% of the total residential development that occurred in the city of Hamilton between 1991 and 2003.

4.2.1.3 Spatial Variation in Commercial Land Development

The next step in our attempt to explore the overall trend of land development in Hamilton during the period between 1950 and 2003, is to answer the following question: "where was commercial development allocated over the study area and during the study period"?

Examining the figure 4.5 shows that the majority (more than 50%) of commercial development in the 1950's, 1960's, and 1970's was allocated to lower Hamilton. In each one of these decades, upper Hamilton received the second largest share of commercial floorspace after lower Hamilton. Specifically, upper Hamilton accommodated 30% of the total commercial development in the 1950's, 25% in the 1960's, and 23% in the 1970's. Stoney Creek was the third major contributor in commercial floorspace development from 1950 to 1980 by having an approximate share of 10% per decade. An exception to that was the decade of 1960, when commercial development in Stoney Creek was reduced to 4.5%.

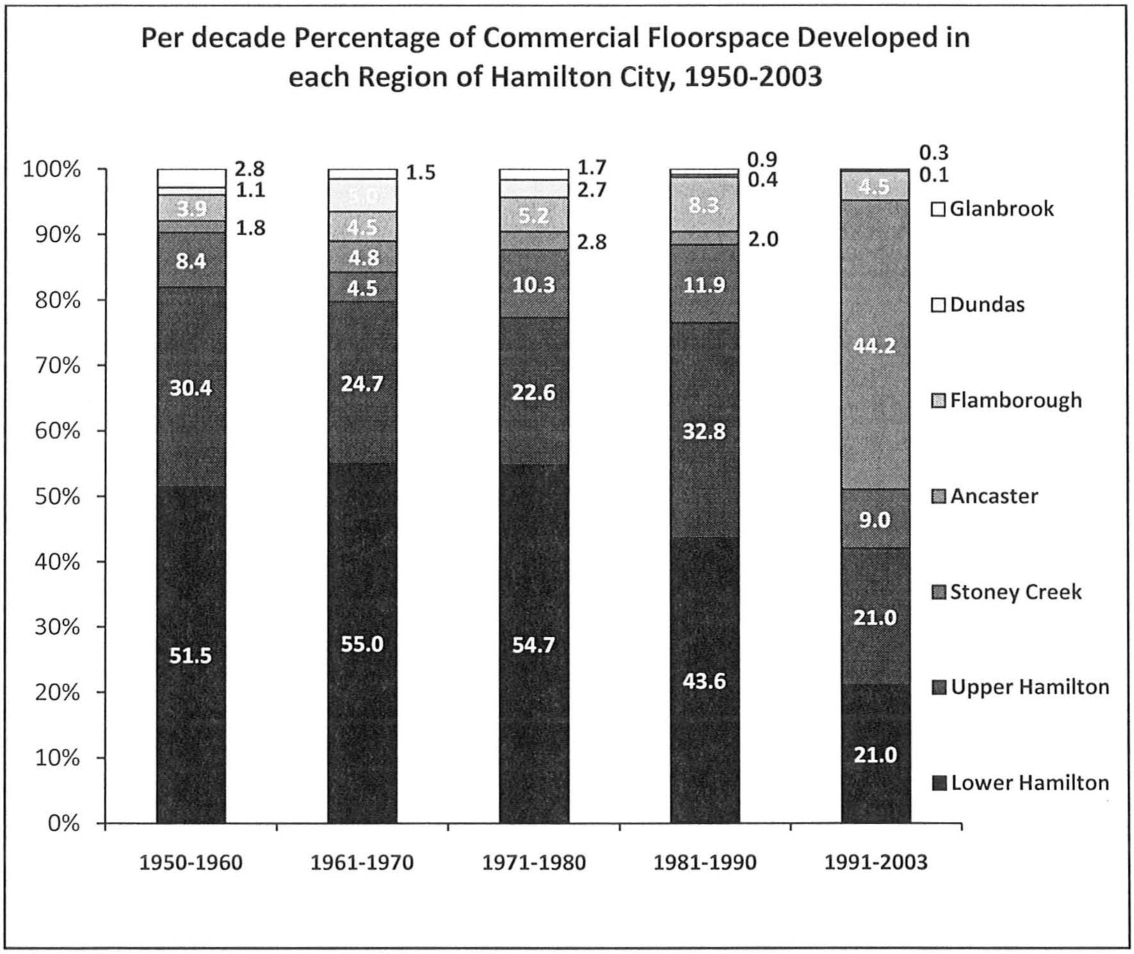


Figure 4.5: Commercial Floorspace Developed (percentage of each decade's total commercial) in the City of Hamilton (1950-2003)

In the 1980's, the overall pattern of commercial development in Hamilton was alike the patterns observed in the three previous decades. However, new commercial construction was reduced by 11% in lower Hamilton (from 54.7% to 43.6%) while it was increased by 10% in upper Hamilton. Stoney Creek was again ranked third with a share of 12% and Flamborough followed with an important share of 8.3%. In general though, it is clear that the pattern of commercial development in Hamilton remains unchanged from

1950 to 1990. That is, lower Hamilton received approximately the 50% of commercial development, upper Hamilton the next largest share (around 30%), and Stoney Creek the third (around 10%).

Finally, the period between 1991 and 2003 reveals a completely different pattern of commercial development. An almost 45% of it took place in Ancaster while lower and upper Hamilton received just a 21% each, and Stoney Creek had a 9% share. What we observe is a massive allocation of commercial floorspace in Ancaster, a municipality of Hamilton that accommodated less than 5% of commercial development on a decade basis between 1950 and 1990.

Figure 4.6 depicts the trend of commercial floorspace development over the study period[3]. Two conclusions can be easily supported. First, the percentage of commercial development in lower Hamilton followed a steep declining trend after 1981 as opposed to the period between 1950 and 1980. Second, the line depicting the trend of commercial development in Ancaster during 1991-2003 has a positive and steep slope, which reveals a sudden change in trend. It is clear that although all other regions were facing a declining trend in commercial development in the 1990's, Ancaster had an extreme peak of commercial construction during that period. It is worth mentioning here that this peak happened after three decades of declining trend and low levels of commercial construction in Ancaster.

Commercial development in upper Hamilton was generally declining over the study period, but it went through a major positive peak during the 1980's. Flamborough

[3] The municipalities of Dundas and Glanbrook were not included in figure 4.6 due to their very low values.

and Stoney Creek faced a lightly increasing trend between 1960 and 1990, but commercial development in that municipalities slowed down in the 1990's. The same slow down took also place in upper and lower Hamilton during that period.

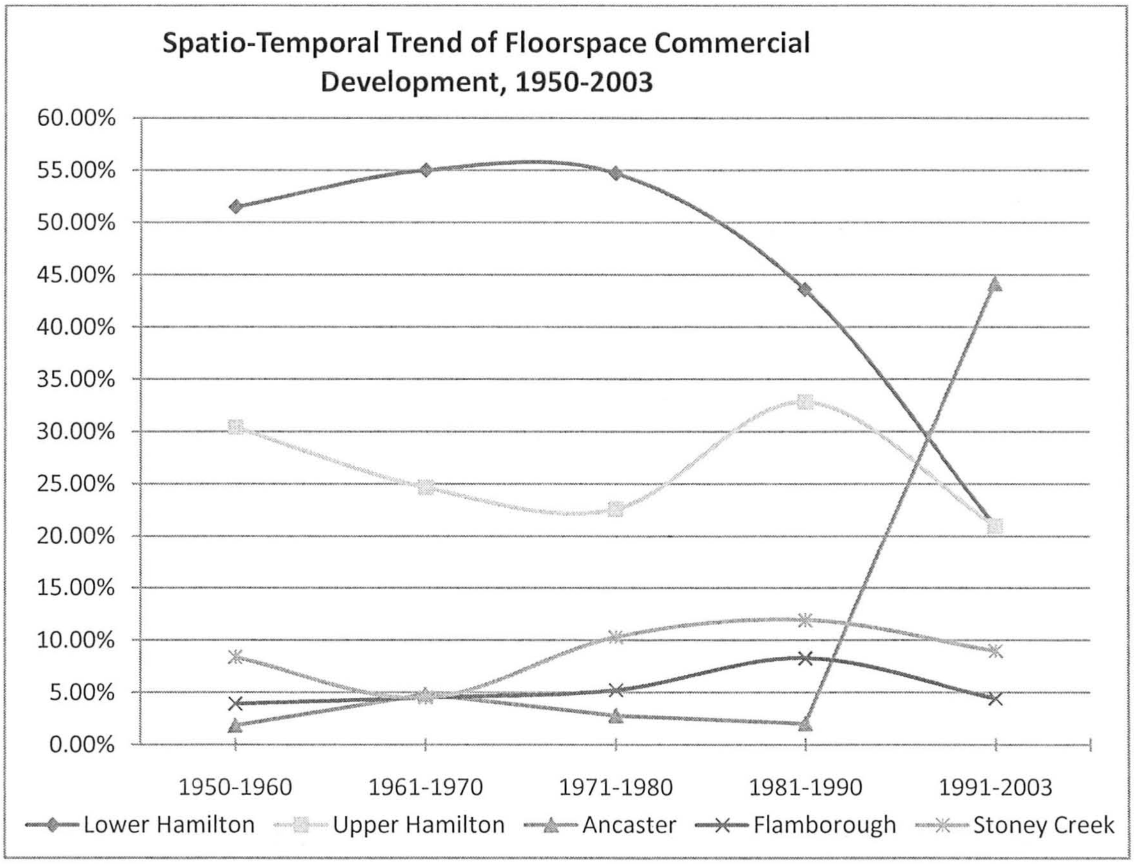


Figure 4.6: Spatio-Temporal Trend of Commercial Floorspace Development (percentage of each decade's total commercial) in the City of Hamilton (1950-2003)

4.2.1.4 General Trends in Disaggregate Land Use Types

The micro-level land parcel data allow for a better insight into the land use composition of land development over time. By using the detailed property codes attributing the land parcels we present on a decade basis the five most prevailing land use types among the total development that took place in Hamilton from 1950 to 2003. The ranking is based on the amount of floorspace that was created over each decade; however, table A.2 in the Appendix includes also the count of land parcels that correspond to the top five land uses.

As we observe in this table, the land use code 301, which represents the single family detached housing, is the dominant land use over the study period. This land use contributed approximately the 70% of the total floorspace constructed in the decade of 1950, 1980, and 1990. In the decades of 1950, 1960, and 1970, the second most prevailing land use type is the high rise apartment buildings (code 340). It ranks second because of its contribution to the residential floorspace created (7.37%) during each decade and not because of the number of land parcels converted to apartment buildings. It is worth noting that during the 1960's and the 1970's high rise apartment buildings contributed the 30% and the 23% respectively of the total floorspace constructed in the city.

Moreover, it is of great importance to mention that the land use type with the code 605, which represents elementary and secondary schools (including private), is the third most prevailing in terms of floorspace created for the periods 1950-1960, 1961-1970, and 1991-2003. Clearly, we observe a continuous increase of the educational floorspace which accompanies the city's population growth. Construction of industrial floorspace holds an important position in the land development process during the decades of 1950, 1960, 1970, and 1980, which reflects the prevalence of industrial activity and growth in Hamilton during those decades. This also explains fifth place held by the warehouse land type (code 530) in the top five land uses constructed during the decade of 1960.

Another interesting observation that can be derived from the same table (Table A.1 in the Appendix), is that the amount of construction related to the commercial sector appears for the first time in a decade's top five chart during the decade of 1980. This is when the neighborhood shopping centres (code 430) are ranked third contributing 110,140 m^2 of floorspace to the total development occurred during the decade. The next appearance of a commercial land use in a top five chart is in 1991-2003, when the construction of department stores contributed an almost 60,000 m^2 or 2% of floorspace to the total amount of land development in Hamilton. Lastly, it should be noted that the last period of our analysis (1991-2003) witnessed a significant increase in the floorspace created by the rowhouse and semi-detached types of development to the extent that rowhouse development created the 6.1% and semi-detached housing created the 2% of the total floorspace constructed during this period.

As it was previously shown in this section, the majority of land development during each decade consists of residential land use types. Table 1 presented above that on average residential development accounts for the 80% of the total floorspace created between 1950 and 2003. Table A.3 in the Appendix disaggregates residential development to the various types of housing and presents the top five types of residential land use development during each decade of our study period.

The observed pattern in residential development is reasonably clear. The most prevalent housing type developed over the decades is the single family detached, which ranks first in all decades. Apartment building construction ranks second in 1950-1960, 1961-1970, and 1971-1980. It undergoes its peak period during the two decades between the years 1961 and 1980 by creating the 40% of the total residential floorspace in the former decade and the 31% in the latter.

Another two types of residential development that appear to be relatively prevalent are the semi-detached and the rowhouse housing. They are among the top five types of residential development in the four out of five decades of our analysis. Specifically, semi-detached housing (code 311) is not ranked among the top five residential uses only during the decade of 1980; and rowhouse housing is not present only in the top five of the 1950s. Finally, the link housing type enters the top five charts from the decade of 1970 and on. In the 1970s, it contributes the 1.2%, in the 1980s the 2.7% and in the 1990s the 0.8% of the total residential floorspace constructed in each decade.

In the last study period (1991-2003) we observe the following pattern. The single family detached is the most prevalent type contributing the 86% of floorspace created, the rowhouse type ranks second producing the 7% of the period's total, semi-detached ranks third with a 2.2%, apartment buildings rank fourth with a 1.1%, and link houses type rank fifth with a 0.75% of the period's total. As mentioned earlier, all the above percentages are based on the amount of floorspace a conversion of a land parcel creates.

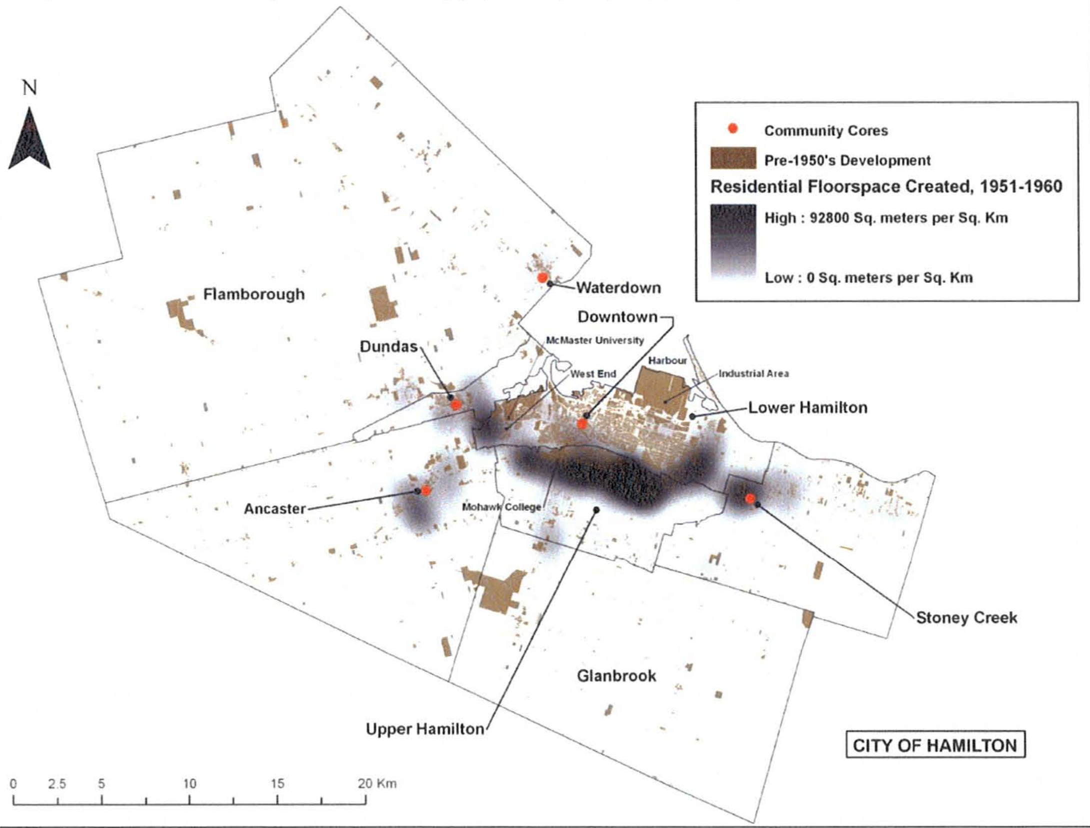
It is of some importance to report the number of land parcels that correspond to the floorspace development. In the period between 1991 and 2003, the 2,711,387 m^2 (or the 85% of the total residential floorspace created in this period) of single family detached floorspace translates to 13,820 or the 84.3% of the total number of land parcels developed to a residential use over that period. The 218,220 m^2 or the 6.9% of rowhouse floorspace translates to 1,567 or the 9.5% of the total number of parcels, the 70,603 m^2 or the 2.2% of semi-detached floorspace was provided by the conversion of 507 land parcels or 3% of their total number; and the 23,671 m^2 or the 0.75% of link house floorspace was produced by the conversion of 165 land parcels or the 1% of the total number of parcels developed to a residential use. Finally, the 34,324 m^2 (or the 1% of the total residential floorspace constructed in that period) of apartment building floorspace was created by the conversion of 9 land parcels or the 0.05% of the total number of parcels converted to a residential use during that period.

4.2.2 Spatial Patterns of Land Development and Urban Form

In this section, the spatial pattern of land development in Hamilton in the period 1950-2003 is explored to assess its impact on urban form. In order to perform this task, we employ the residential and commercial land development data that were extracted from the micro-level land parcel dataset. Specifically, the parcels that were developed for residential and commercial use were extracted from the dataset per decade for the period 1950-2003. For each land use and decade we computed a Kernel density surface of the new floorspace constructed. The generated surfaces are mapped and analyzed.

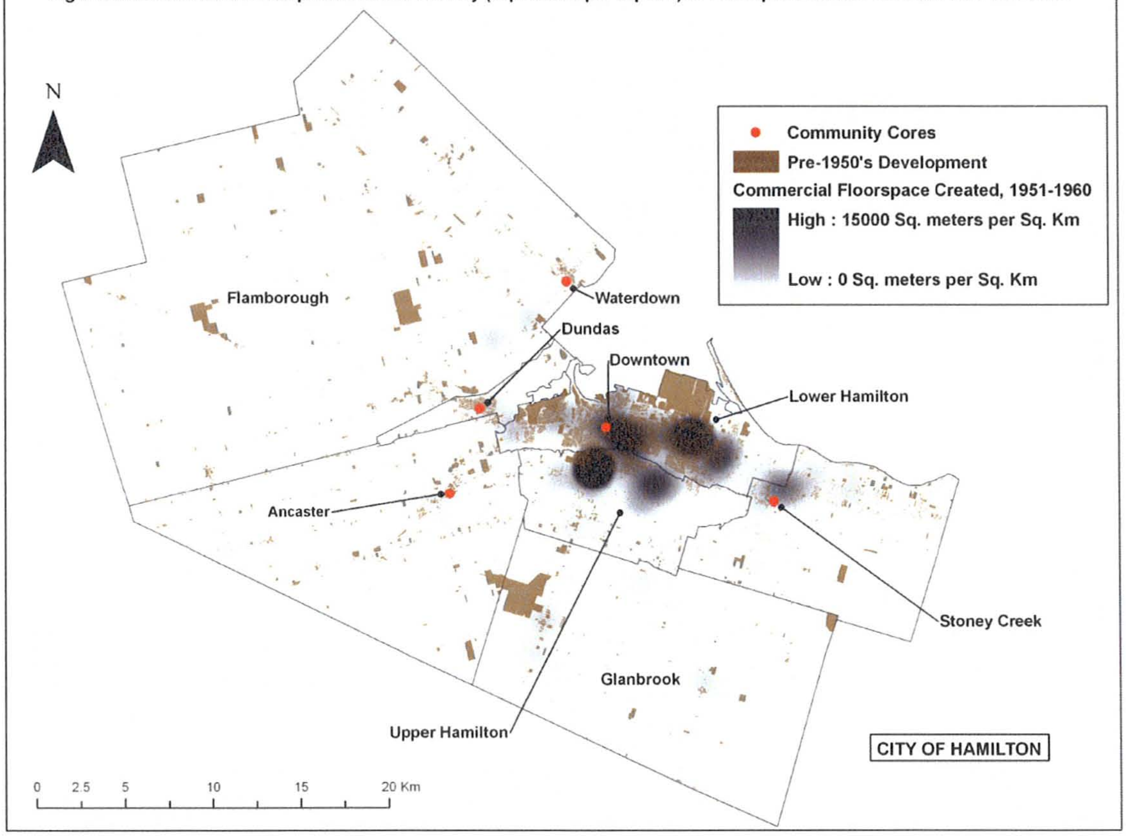
To analyze the Kernel maps, we examine the shading black colour that appears as a "cloud-like" surface. These areas highlight the intensity of land development (residential or commercial). The level of floorspace intensity is depicted by the intensity of the black colour of the surface on the map. The white colour of the surface corresponds to the lowest intensity and the black colour to the highest. In general, areas covered by the white colour represent locations with light intensity of land development. The generated maps enabled us to investigate the evolving nature of land use and urban form in Hamilton. Exploring the surfaces can help us determine if sprawl, decentralization, leapfrog development and even multinucleation has been taking place.

Figure 4.7 Residential Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1951 and 1960.



Starting with the decade of the 1950's, we visualize the initial state of the city in figure 4.7 and 4.8. At the beginning of this period, the majority of urban development was located in the lower Hamilton region, which is the area below the escarpment. The major core of the urban area was extending from the downtown to the west, where McMaster University and West End are located; and to the east, where the industrial sites of the city are located. The urban core around downtown was the most intensely developed and the existing development was spanning southwards towards the escarpment. Above the escarpment and within a maximum distance of 2 Km away from it towards the south, the first community of upper Hamilton was already developed. It was a strip of development extending along the escarpment parallel and equally distant from the downtown to the industrial site.

Figure 4.8 Commercial Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1951 and 1960.



Hamilton's urban area was surrounded by three satellite villages, Dundas to the west, Ancaster to the south-west, and Stoney Creek to the east; as well as by one township, Waterdown to the north-west. The community centres of those places were distinct and separate from Hamilton's urban area and their Euclidian distance from downtown Hamilton was between 8 and 10 Km.

Examining figures 4.7 and 4.8, indicates that the areas receiving most of the residential development during the 1950's are located at the outskirts of the existing and already developed urban area. Clusters of new residential and commercial development are located above the escarpment and near the existing neighborhoods. The clusters are moving towards the south, south-east and the south-west areas, while expanding to new and undeveloped land in a contiguous way.

Residential development in lower Hamilton is less intense and almost non-existing around the central core of the city. The majority of residential development taking place in lower Hamilton occurs at the edges of the region; to the west, close to McMaster University, and to the east, at the outskirts of the existing neighborhoods and mainly towards the escarpment. There is also a light cluster located close to the industrial area and within the existing urban core, a fact that indicates the presence of an infill process. This is confirmed and explained by the intense cluster of commercial development that takes place at the same location (see figure 4.8). Among this development is also included the construction of the Centre Mall. However, new commercial development was highly intense around downtown and had a south-east direction.

The findings indicate that the city was expanding towards the urban fringe and new development arose outside the core, in upper Hamilton. Yet, most of the development took place close to the escarpment and at locations adjacent to development. Overall, residential development appeared to be contiguous but distant from the urban core and mainly favoring undeveloped areas at the outskirts of the city. It is also worth mentioning that clusters of intense development arose around the community cores of Stoney Creek, Ancaster, and Dundas.

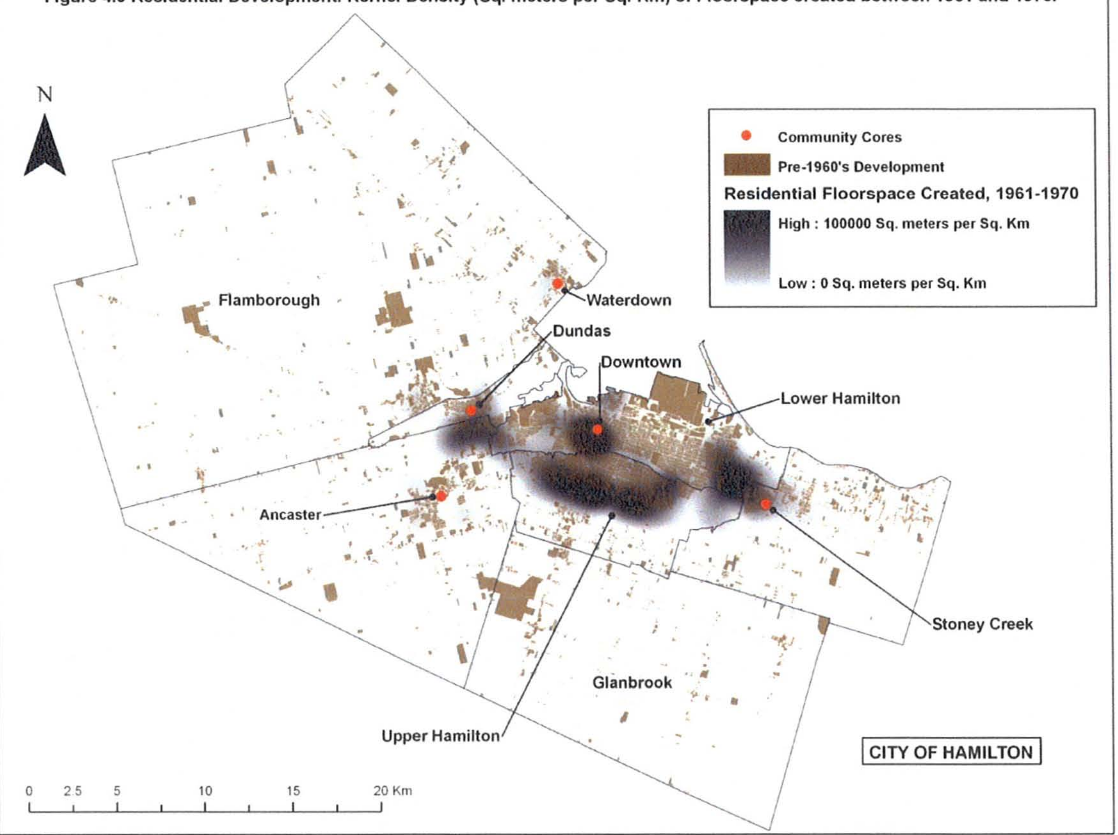
The pattern of development that occurred in 1961-1970 (figure 4.9 and 4.10) was characterized by two opposite trends: sprawl and infill. The locations of the four major clusters or "hot spots" of residential development in figure 4.9 suggest that the two processes were taking place simultaneously. The sprawling development was the outcome of new residential floorspace that was added at the edges of the urban area and in close proximity to existing built-up areas far from the core. This development was contiguous with the existing land parcels; although, most of it was targeting new and undeveloped sites. Consequently, the built environment expanded towards the south, extending the boundary of the city to rural land.

Looking at the Kernel map (figure 4.9), two hot spots in close proximity to each other appear in the upper Hamilton region. The larger one is more spread out and expands along the escarpment, while the smaller one is more compact and confined. The clusters observed in the map indicate that portion of the new development took place within the neighborhoods that were partially developed during the previous period (1950-1960). We also observe that another portion of the new development was targeting undeveloped locations near existing neighborhoods.

Another intense peripheral cluster of residential development is located in lower Hamilton, between the community core of Stoney Creek and the eastern edge of Hamilton's urban core. This brings additional evidence on the expansion of the urban area to new undeveloped land. The cluster itself is the continuation of a lighter cluster of residential development that had already started during the previous period (1950-1960, figure 4.7)

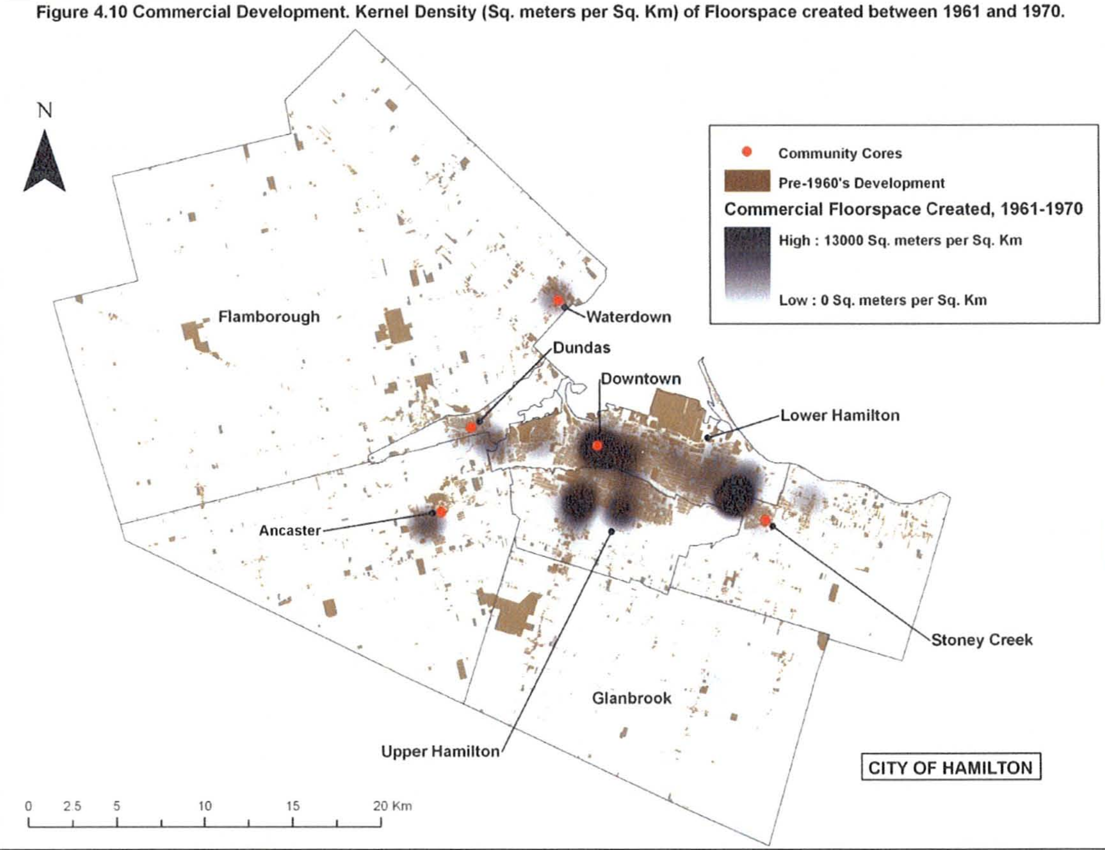
The second type of development that occurred in Hamilton in 1961-1970 was the infill of the downtown area. The high intensity cluster depicted in the Kernel map reveals that a great amount of residential floorspace was constructed to the west and south-west of downtown. The occurred development in these areas consisted mostly of high rise buildings as has already been mentioned in section 4.2.1. As for the satellite villages around Hamilton, clusters of medium intensity of residential development are observed around the community cores of Stoney Creek, Dundas and Waterdown.

Figure 4.9 Residential Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1961 and 1970.



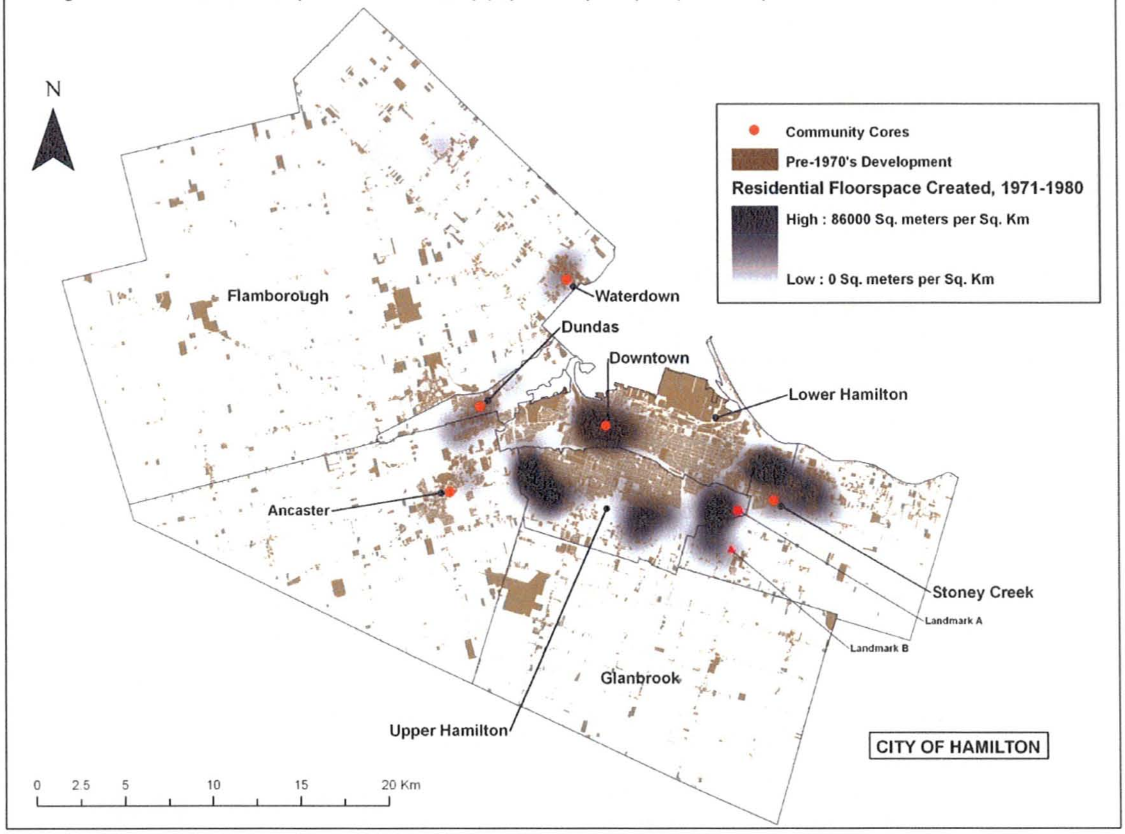
The spatial pattern of commercial development in 1961-1970 was almost identical with the one of residential. Four major commercial clusters (figure 4.10) are identified at the locations where the residential clusters are found. However, the most intense commercial development in terms of floorspace took place in the downtown as well as in the area between Stoney Creek and the eastern edge of the urban core of Hamilton. It is worth noting that the community cores of Waterdown, Dundas, and especially Ancaster received medium intensity of commercial development.

Figure 4.10 Commercial Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1961 and 1970.



During the next decade (1971-1980), new residential development (figure 4.11) continued to exhibit a spatial pattern similar to the one from the previous period. The infill process in downtown continued and significant amount of new floorspace was constructed around the centre of the city as well as towards the harbor. Additionally, the sprawling development at the periphery of the urban core continued since the new development took place even further away from the existing urban area.

Figure 4.11 Residential Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1971 and 1980.

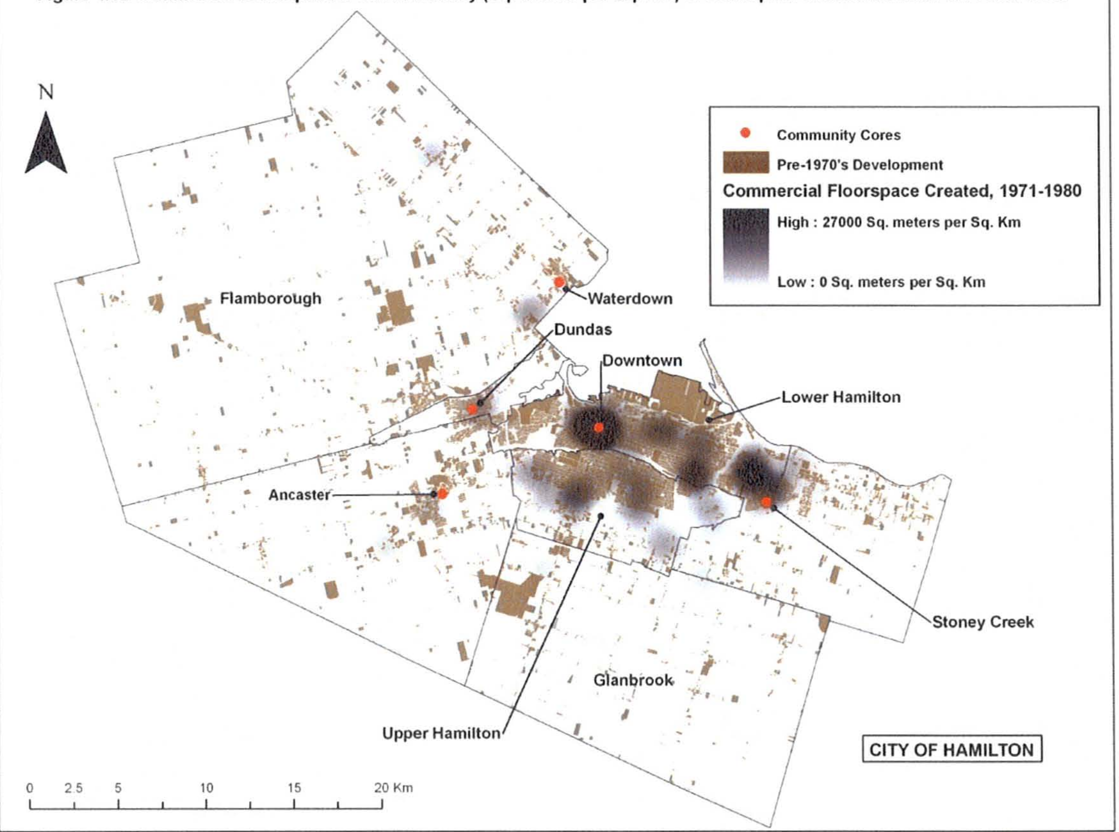


As we observed in the 1960's, three clusters of new residential development were active at the periphery, two of them in upper Hamilton (in close proximity to each other) and one nearby the community centre of Stoney Creek. During the 1970's, the two clusters in upper Hamilton continued to be intense; yet, they shifted towards the opposite directions and separated from each other. The more prevalent of the two moved to new undeveloped land towards the south-west side and close to the border that separates upper Hamilton from Ancaster. The other cluster expanded to new undeveloped land towards the south-east side of upper Hamilton. As a result, new development skipped the vacant land located in between the clusters. In essence, this pattern of residential development set the stage for a leapfrog process. This is clarified by the figure 4.13, which reveals that the reserved land was utilized by the infill process that took place in the next period (1981-1990).

During the 1970's however, another location in the study area accommodated new residential floorspace as a result of leapfrog development. This is the area marked with the Landmark A in figure 4.11. At this site, a cluster of high intensity residential construction appeared on vacant land located at the east border that separates upper Hamilton from Stoney Creek. This cluster skipped vacant land in areas adjacent to the existing (already developed) land parcels to the north, north-west, and north-east. The cluster extended to the south, where its intensity degraded to a medium level (see Landmark B in figure 4.11). At this location, subsequent contiguous development in the next two periods (1981-1990 and 1991-2003) gave rise to an isolated large cluster in the periphery (see figure 4.13 and 4.15).

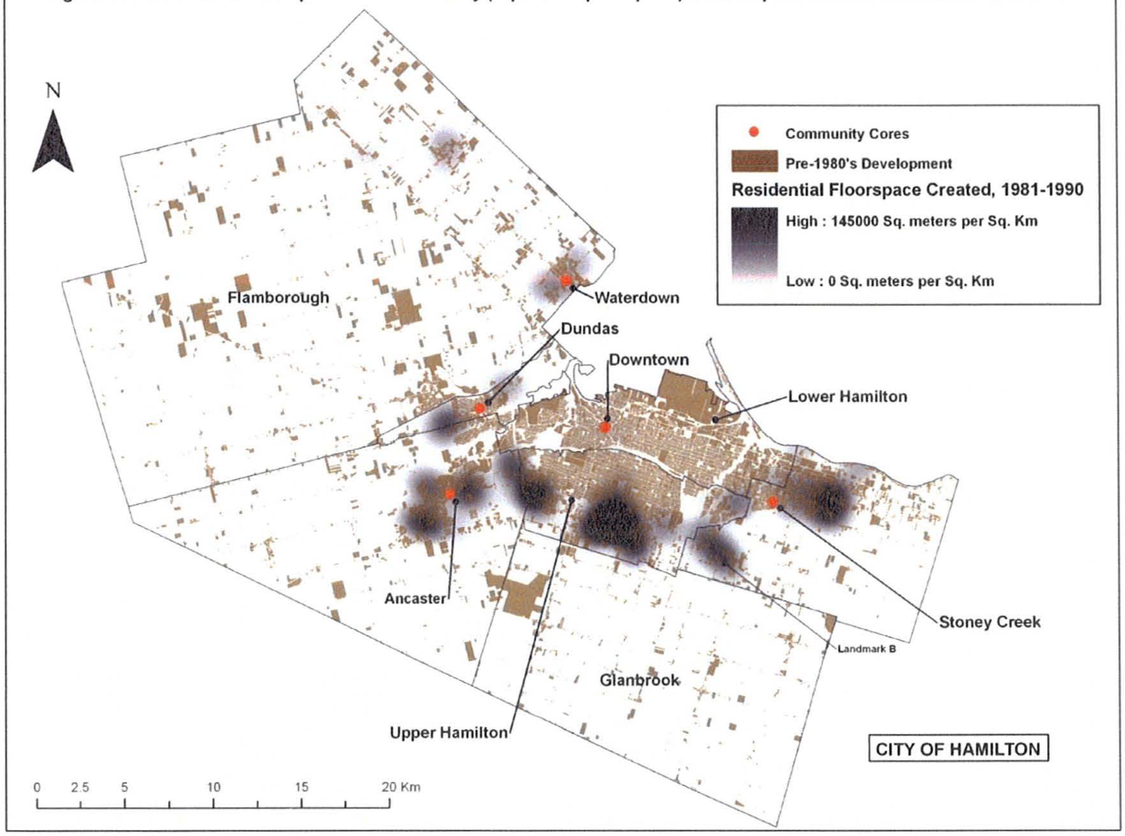
The Kernel maps of residential and commercial development for the period 1971-1980 provide proof for an emerging sub-centre in the region. Figure 4.11 shows that the intense cluster between Stoney Creek and east Hamilton remained highly active and moved slightly towards the latter place. In addition, residential development of medium intensity appeared around the community core of Stoney Creek and especially to the east side of it. Moreover, the intensity of commercial development in this area remained at high levels (figure 4.12). The construction of the East Gate mall confirms that the area was a focal point of commercial development at that time. It is apparent that this area has been witnessing a major urbanization process since the 1950's. The intensity of residential and commercial development has been high for thirty years; and, as it is shown in figure 4.13 and 4.14, the intensity of development remained high even during the next decade (1981-1990). The above arguments bring evidence on an emerging sub-centre in the region, which in turn is an initial indication of an emerging multinucleation process in the city of Hamilton.

Figure 4.12 Commercial Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1971 and 1980.



Finally, the commercial land parcel development in 1971-1980, as illustrated in figure 4.12, appeared to be highly centralized. Most of the development occurred in the lower Hamilton region and the highest intensity was observed around downtown. Smaller clusters of medium intensity were also apparent close to the newly added residential areas of upper Hamilton, Ancaster, Dundas, and Waterdown.

Figure 4.13 Residential Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1981 and 1990.

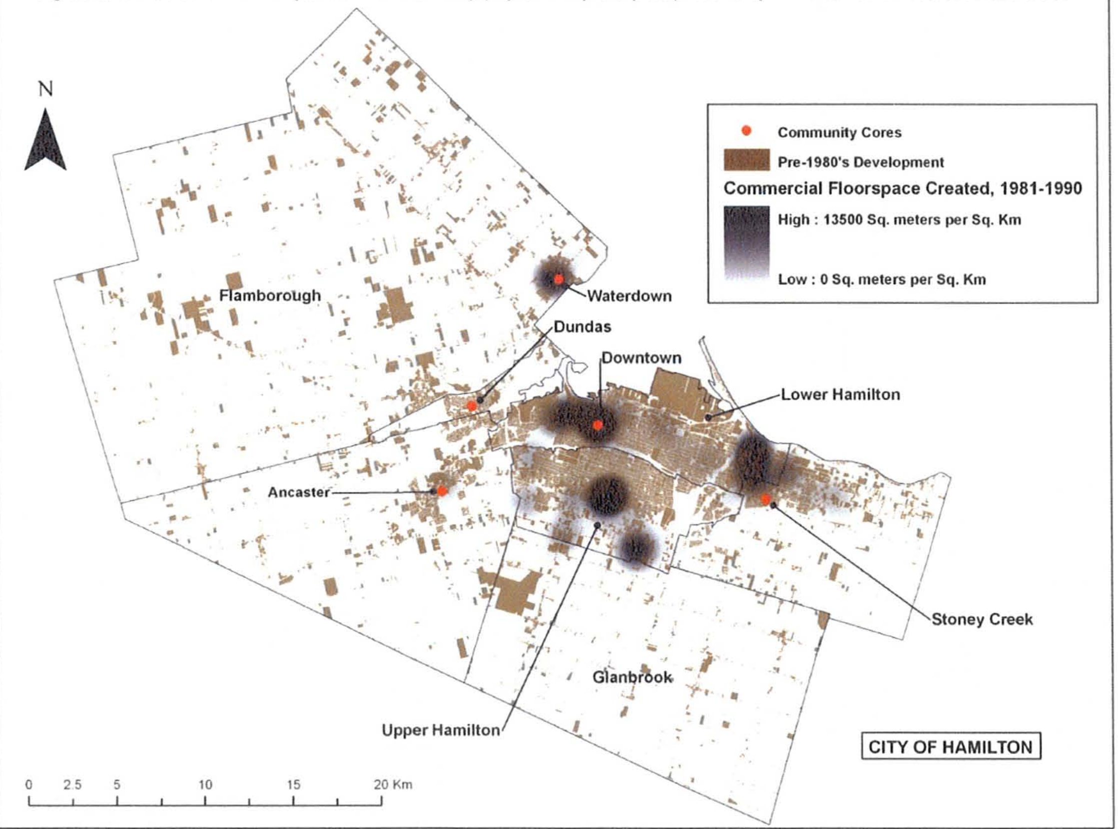


In the next decade (1981-1990), the new residential development moved again further away from the existing urban core and occurred primarily at the periphery. The Kernel map (figure 4.13) reveals three major clusters, two in upper Hamilton and one in Stoney Creek. The most intense cluster in upper Hamilton was located on land that was not considered by the development process during the previous period (1971-1980). Infill and contiguous development added residential land parcels on the available land that had been skipped by the leapfrog development in 1970's. The second cluster in upper Hamilton was the one located on the west side of the region and nearby its border with Ancaster. In essence, this cluster was a southward expansion of the cluster located in the area during the previous decade. New residential floorspace was added by a combined infill and contiguous development that expanded the built-up environment across the border with the region of Ancaster. The third cluster was in the region of Stoney Creek. It was displaced towards the east and to an area where some development already existed as a result of scattered development that had happened in previous decades. Lastly, the Kernel map reveals a medium-high intensity of residential development that occurred in Waterdown and Dundas.

The results from the Kernel estimate for commercial development in the 1980's, as illustrated in figure 4.14, provide the first indication of a decentralizing process in commercial land use. Specifically, this Kernel map depicts two clusters of high-intensity commercial development in upper Hamilton, one located in the area where the Lime Ridge mall was built, and the other in the southern-east edge of the region and by its border with Glanbrook. The Kernel surface also reveals two more clusters of medium-low intensity at the west side of upper Hamilton and another cluster of high intensity located in Waterdown.

Although intense clusters of commercial development are observed in areas away from the central core in this period (1981-1990), it is again the downtown and its surrounding area that attracted a major cluster of commercial development. It should be noted though that the high-intensity cluster located in the east side of lower Hamilton and close to the emerging area of Stoney Creek verifies the existence of a decentralizing trend in commercial development. This is further clarified and confirmed by figure 4.16, which depicts the "hot spots" of commercial development in the last study period (1991-2003). This figure clearly informs us that new commercial development took place in the periphery of the study area. The most intense clusters are located in Ancaster and in the southern edge of upper Hamilton whereas the area around downtown receives low intensity of new commercial development.

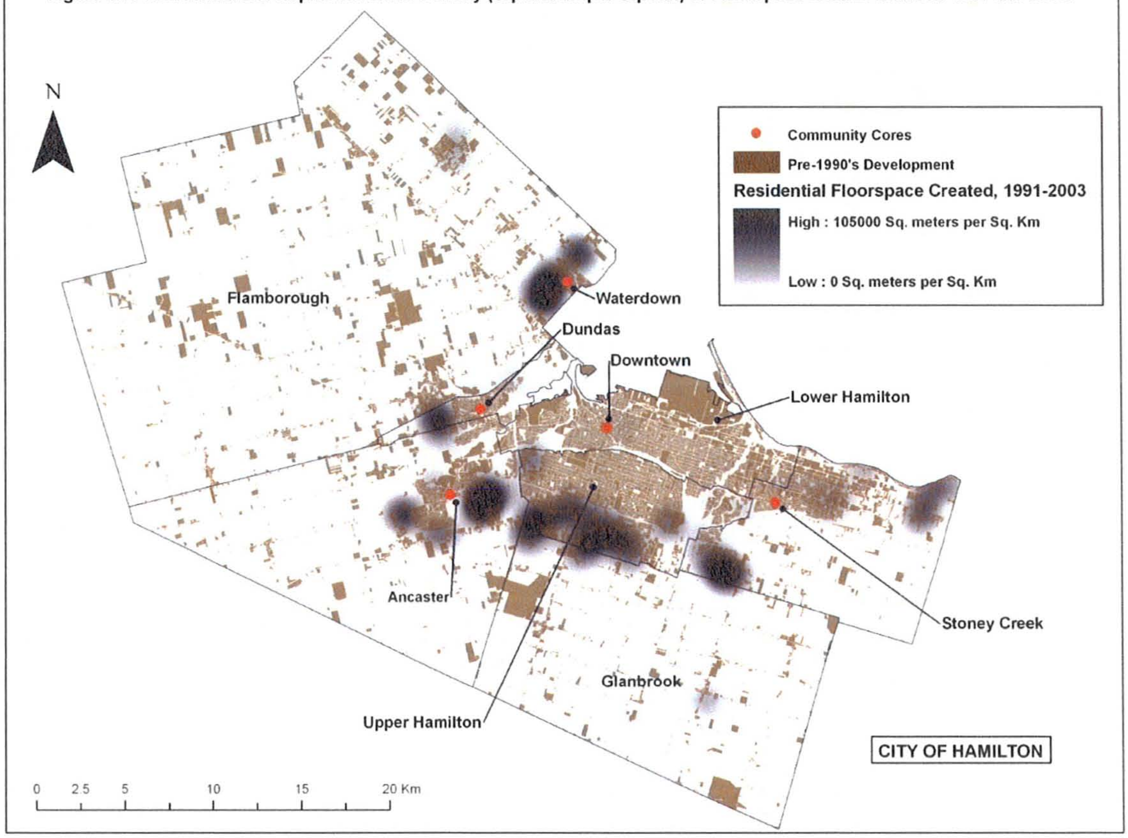
Figure 4.14 Commercial Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1981 and 1990.



However, the most important component of the residential development process in 1981-1990 is the pattern revealed in Ancaster. Figure 4.13 depicts three scattered clusters of medium-high intensity taking place in this region. As we mentioned in section 4.2.1.2, Ancaster received a 17% of the total residential floorspace created in this period over the study area. This residential growth continued in the next study period (1991-2003), during which Ancaster received a 19% of the total residential growth. This is visualized in figure 4.15, which presents one large cluster of high intensity and two other clusters of medium intensity being located in Ancaster. Clearly, the area around the community centre of Ancaster has been receiving high intensity of residential development since 1981, which suggests an emerging sub-centre in the vicinity.

The above argument is further supported by the findings in figure 4.16. Specifically, the Kernel surface for commercial development in 1991-2003 depicts two high-intensity clusters located in Ancaster. It is evident that the intense residential development in the area during the 1980's and 1990's was complemented by an intense commercial development during 1991-2003. This provides additional proof for the emergence of a sub-centre in Ancaster; which, in turn, is another indication of an underlying multinucleation process in the city of Hamilton.

Figure 4.15 Residential Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1991 and 2003.

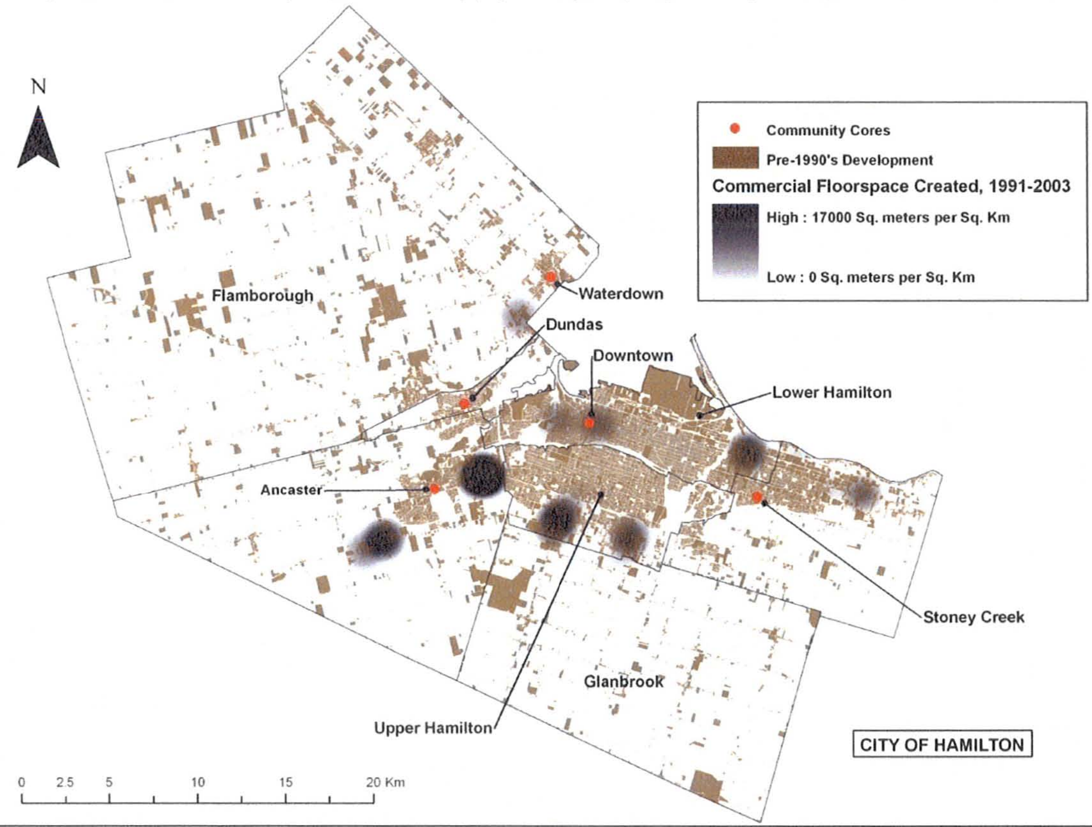


Finally, figure 4.15 brings additional evidence on the sprawling and decentralizing pattern of residential development over time in Hamilton. In 1991-2003, all clusters of development were located in the outskirts of the existing urban area, moving further away from the "hot spots" of the previous period (1981-1990), and consequently increasing their distance from the initial urban core. The intensity of residential development in lower Hamilton is at the lowest level. The clusters of new development in upper Hamilton are close to the border shared with Glanbrook and at certain sites they exceed it towards the south. Interestingly, Waterdown received a significant amount of residential development during this period. On the other hand, Dundas received a medium cluster. Lastly, a cluster of medium intensity appears at the very east edge of Stoney Creek. This provides clear evidence of leapfrog development since the vacant land between the existing built up area of Stoney Creek and its north-east side (edge) was skipped.

The results from the Kernel maps (figures 4.7 to 4.16) on the patterns of residential and commercial development during the period 1950-2003 provide clear insight about the evolution of urban form in Hamilton. The spatial and temporal pattern of residential and commercial development as documented in our analysis thus far, describe the evolution of two major forces responsible for the configuration of urban form.

Evidence was presented on the gradual expansion of development to the periphery of the urban area following contiguous, leapfrog and infill patterns. On a decade to decade basis, new development observed to be continuously moving further away from the existing urban core and consuming rural land at the urban fringe. During the fifty-year time period of our study, the city witnessed horizontal expansion towards the south, south-west, and east.

Figure 4.16 Commercial Development. Kernel Density (Sq. meters per Sq. Km) of Floorspace created between 1991 and 2003.



In the twenty years of the period 1950 and 1970, the regions receiving most of the residential development form an "arc-shaped" visual effect, which surrounds the urban area from the coast close to Dundas to upper Hamilton and then to the coast close to the harbor. In the same period, commercial development appeared to be more concentrated to local clusters, which however coincide with the residential ones, taking place in lower Hamilton around downtown and to the east, nearby the industrial facilities; as well as in upper Hamilton, at the emerging residential area along the escarpment (figures 4.8 and

4.10). Hence, commercial development reveals a more centralized pattern. Still at the same time, commercial development appears to be intensive at the emerging neighborhoods at the outskirts of the city following them in order to serve the needs of the local population.

In 1971-1980, residential development is intense around downtown because of an infill process that added high rise buildings and has been active in the area since the 1960's. However, the majority of residential development is located in peripheral clusters (upper Hamilton, Stoney Creek, and Dundas). Those clusters are moving along the same lines with the ones from the previous period but they have proceeded further away from the main urban core and have become separate by allowing some distance from each other. The commercial development remains mostly centralized during this period with the exception of an intense cluster at Stoney Creek. During the same period, light commercial development also occurred in upper Hamilton to service new residential areas.

In 1981-1990, new residential development took place at the periphery with several emerging clusters at large distances from the central core and even outside the upper Hamilton suburban area. This is the fourth decade of decentralizing residential development. At that time, several satellite community centres have already received a considerable amount of residential development and to a lesser extent commercial development. These observations suggest a potential multinucleation process that is in progress. This assertion is supported by the pattern of commercial development in the 1980's. In figure 4.14 we observe four focal points of high intensity and several others of medium intensity located in the periphery. In addition, this hypothesis is further supported by the pattern of focal points of commercial development as revealed in figure 4.16. The majority of commercial floorspace constructed over the period 1991 to 2003 was clearly decentralized with most intense clusters taking place in Ancaster and the south edge of upper Hamilton. Lastly, the spatial pattern of residential development within this time period (figure 4.15) provides additional evidence on the decentralizing urban form. All medium and high intensity clusters are located in peripheral areas such as Waterdown, south-west Dundas, Ancaster, south upper Hamilton, south Stoney Creek, and north-east Stoney Creek.

Finally, it is worth noting that in certain cases the clusters of commercial development appear to follow the ones of residential development within the same decade (figure 4.7-4.10, 4.13-4.14) and to some extent within a period of 20 years (figure 4.13 and 4.16). This implies the potential presence of a temporal lag between the construction of new residential and commercial floorspace at neighboring locations in the period 1981-2003. This is revealed by the Kernel surfaces in figure 4.13 and 4.16. The figures show intense residential development in Ancaster and in the south-west edge of upper Hamilton during the 1980's. Furthermore, the maps indicate a consequent intense commercial development in the area during the 1990's.

Two questions may arise from the aforementioned observations. The first is whether the locational patterns of residential and commercial development exert influence on each other (co-clustering). The second question is whether a locational time-lag exists between the co-clustering of these two types of development during the last two periods of our analysis. In the next section we present several results of the univariate and bivariate K-function analysis with the objective of answering the above questions.

4.3 The Relationship between Residential and Commercial Land Development

4.3.1 General Clustering Trends

The univariate K-function technique is employed to examine if there is any spatial dependence among the land parcels developed for residential or commercial use. Figure 4.17 presents the results of the estimated univariate K-function for residential land parcels that were developed during the 1950's. The curve presenting the estimated K-function is above the upper simulation envelop, which indicates clustering at all distances. The results of the univariate K-function for residential development for all other decades suggest clustering of developed land parcels, as illustrated by figures A.1 to A.4 in the Appendix. The results of the univariate K-function for commercial development are similar to the results for residential development. Clustering of commercial development is occurring at all spatial scales and for all the time periods of our study, as shown in the figures A.5 to A.9 listed in the Appendix.

The estimated bivariate K-function for residential and commercial land parcels for each of the five decades of our study are illustrated in figures 4.18 and 4.19 as well as in figures A.10 to A.12 in the Appendix. Figure 4.18 presents the result of the bivariate K-function for the period 1950-1960. The line representing the estimated K_{12} function falls between the upper and the lower envelops indicating that there is no clustering between the patterns of residential and commercial land parcel development during the period

1950-1960. Similar results are obtained for the periods 1961-1970, 1971-1980, and 1981-1990 as shown in figures A.10 to A.12 located in the Appendix. However, figure 4.19, which presents the estimated bivariate K-function for residential and commercial development in the period 1991-2003, reveals a different trend.

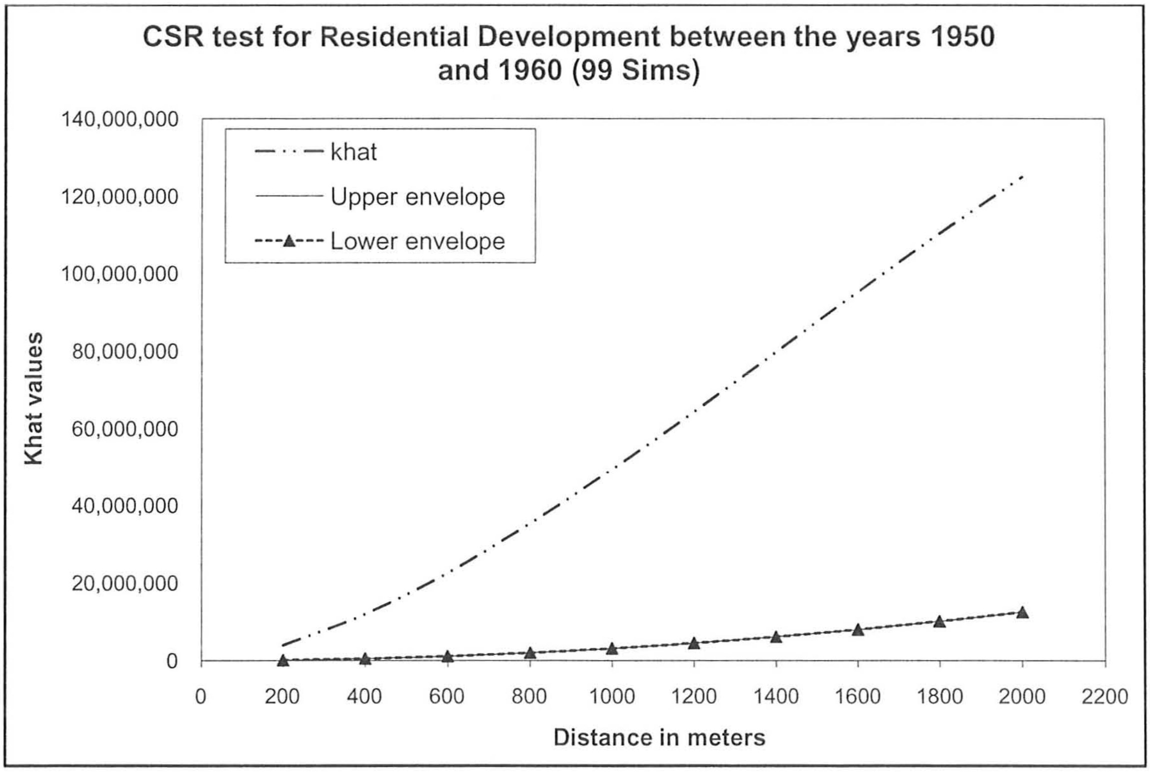


Figure 4.17: Univariate K-function for Residential Development in Hamilton, 1950-1960

The results in the figure (4.19) provide evidence on co-clustering between residential and commercial parcels developed in the 1990's and early 2000's. The findings indicate co-clustering at distances between 1.6 and 2 Km. This is because the line depicting the bivariate K function is above the upper simulation envelop at these distances. However, no clustering is occurring at any other distances.

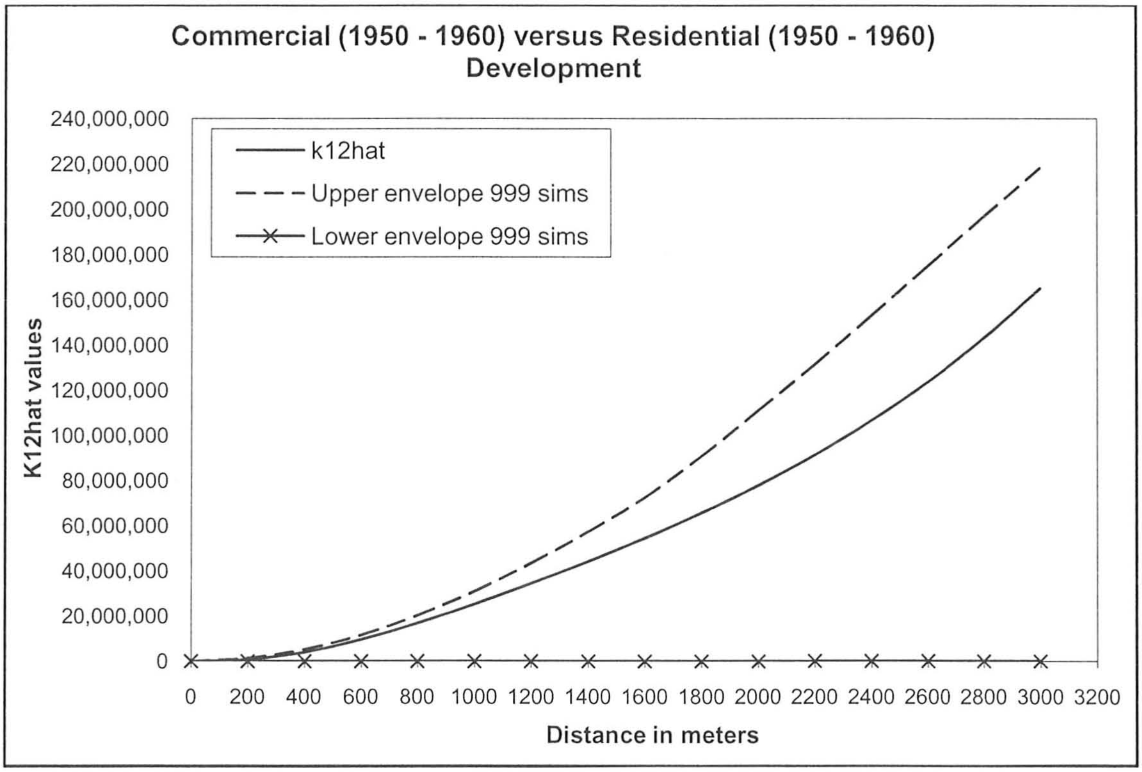


Figure 4.18: Bivariate K-function for Residential and Commercial Development in Hamilton, 1950-1960

4.3.2 Co-Clustering of Commercial and Residential Development

4.3.2.1 New Commercial versus Existing Residential Development

The indication for some clustering between the two point patterns during the last thirteen years of our study period provided the impetus to investigate the spatial distribution of the two land development types in the period 1991-2003. Consequently, we consider the two following cases. First, we examine if residential development that took place in the five-year period between 1986 and 1990 has attracted commercial development after 1990 and until 1999. Second, we test if commercial development that took place in the five-year period 1991-1995 has attracted the residential development built in the period 1995-2003.

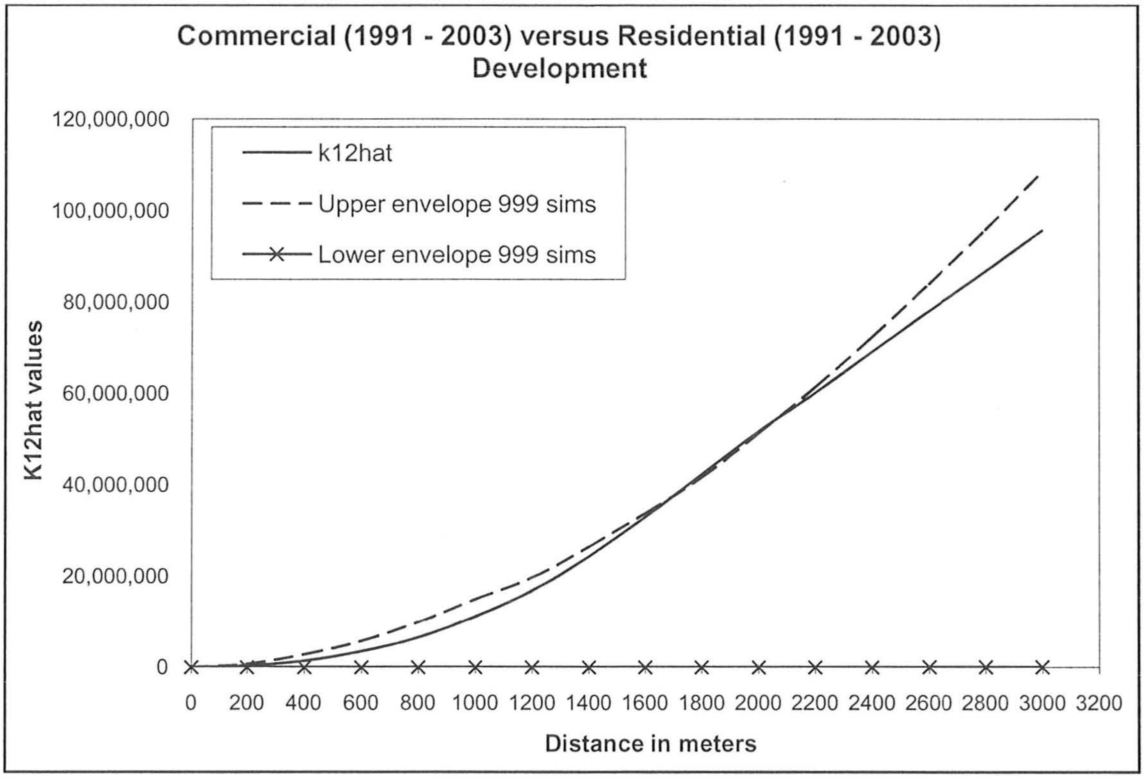


Figure 4.19: Bivariate K-function for Residential and Commercial Development in Hamilton, 1991-2003

The results from the first test are ten graphs that are presented in figure 4.20 and in figures A.13 to A.21 attached at the Appendix. In each figure, clustering is tested at the 0.01 and 0.001 significance levels. The estimated bivariate K-function for the new residential development occurred in 1986-1990 and the subsequent commercial development occurred in 1990 shows no clustering at any distance at the 0.001 level and clustering from 0.8 Km to 1.8 Km at the 0.01 significance level.

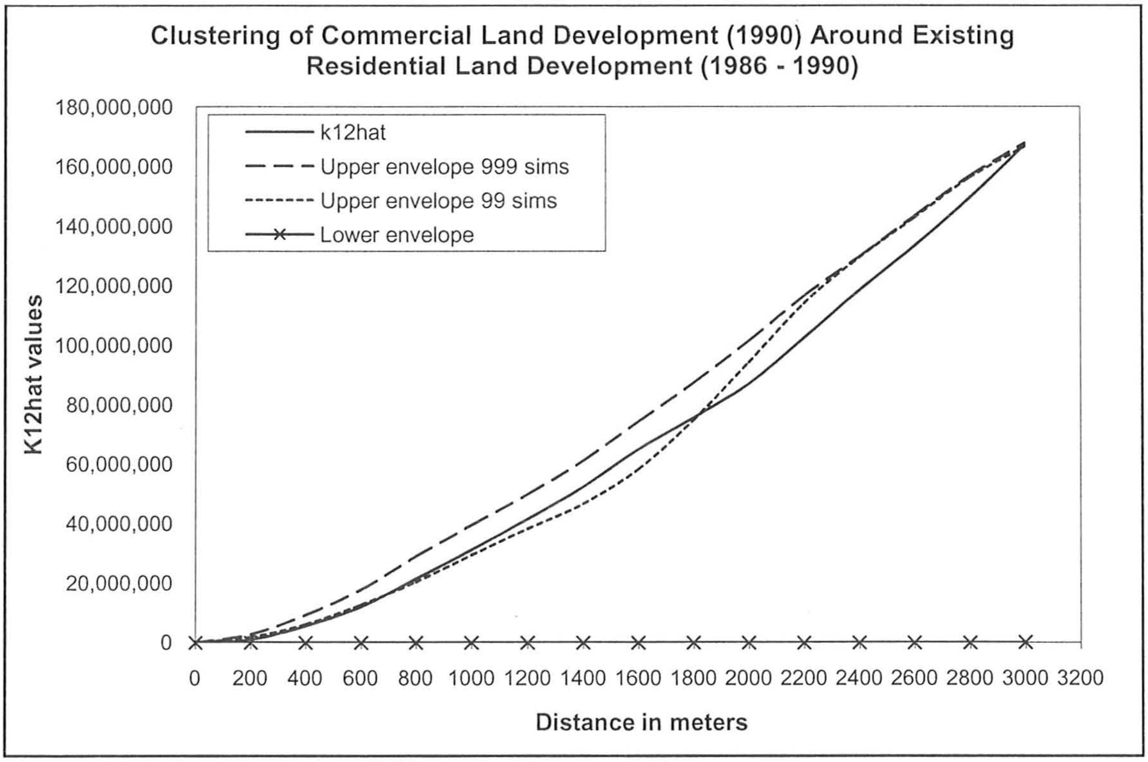


Figure 4.20: Bivariate K-function for Commercial (1990) and Residential (1986-1990) Land Development in Hamilton

For the new commercial development that occurred one year after the period when residential development (1986-1990) happened, the bivariate K-function reveals clustering at distances greater than 0.2 Km at the 0.01 significance level and no clustering at the 0.001 (figure A.13 in the Appendix). For the incremental periods 1990-1992 up to 1990-1997 (figures A.14 to A.19 in the Appendix), the estimated K-functions provide evidence on clustering between the two patterns of development for distances greater than 0.2 Km at the 99% confidence level. At the same confidence level, clustering of the two patterns is observed at distances greater than 0.6 Km for new commercial development occurring in 1990-1998 (figure A.20 in the Appendix), and at distances greater than 1 Km for new commercial development in 1990-1999 (figure A.21 in the Appendix).

At the 0.001 significance level, co-clustering is observed at distances between 2.4 Km and 3 Km for commercial development that happened two years after 1990 (figure A.14 in the Appendix). For the next incremental period (1990-1993), the line of the bivariate K-function is very close to the line of the upper simulation envelop at the 0.001 significance level (figure A.15 in the Appendix). The estimated K is above the upper envelop from 0.4 Km to 0.6 Km, at 1.6 Km, and again from 2.4 Km to 3 Km. This diagram provides the first evidence of co-clustering between an existing residential development and new commercial development. Here, a time lag of three years is indicated.

Furthermore, at the strict significance level of 0.001, no evidence of clustering is found for new commercial development in 1990-1994 (figure A.16 in the Appendix), but clustering is evident at distances greater than 2 Km in 1990-1995 (figure A.17 in the Appendix). Clustering is evident at distances greater than 1.6 Km for the period 1990 to 1996 (figure A.18 in the Appendix), and at distances greater than 2 Km in 1990-1997 (figure A.19 in the Appendix). Moreover, new commercial development that took place over the nine years (1990-1998) after the initial residential development (1986-1990) appears to exhibit no clustering at distances less than 2.8 Km. However, as depicted in figure A.20 in the Appendix, the curve representing the bivariate K-function is very close to the upper simulation envelop of 999 simulations at distances greater than 1.4 Km. Because the 0.001 significance level imposes a very strict test, one could argue that clustering is evident during this period at distances greater than 1.4 Km. Lastly, for the period 1990-1999, figure A.21 in the Appendix provides evidence on co-clustering at distances greater than 2.2 Km.

Based on the results presented above, we conclude a time lag between commercial and residential development. The strict test at the 0.001 significance level revealed co-clustering of the patterns with a time lag of 3 to 4, and 6 to 7 years after the initial residential development at almost all tested distances (0.2 Km – 3 Km).

4.3.2.2 New Residential versus Existing Commercial Development

The second test we examined in this analysis generated nine graphs, which include figure 4.21 and figures A.22 to A.29 in the Appendix. In each figure, the upper envelop is plotted for the 0.01 significance level, which is produced from 99 simulations, as well as for the 0.001 significance level, which is produced from 999 simulations. The results presented here are based on the 0.001 significance level.

The estimated bivariate K-function for the new commercial development occurred during 1991-1995 and the subsequent residential development occurred in 1995 shows no clustering at any distances at the 0.001 significance level as the plotted line depicting the estimated bivariate K-function falls between the upper and the lower simulation envelop lines. It is important to note here that the bivariate K-function is very close to the upper envelop at distances between 2 Km and 2.2 Km. For parcels developed for residential use two years after 1995, the bivariate K-function depicts clustering of the two patterns at the 0.001 significance level and at distances between 1.8 Km and 2.2 Km (figure A.22 in the

Appendix). However, the line representing the estimated bivariate K-function slightly exceeds the upper simulation envelop. Clustering is evident and more prominent for residential parcels developed three years later from the time commercial development happened. As depicted in figure A.23 in the Appendix the line presenting the estimated bivariate K-function is well above the upper simulation envelop at distances between 1.6 Km and 2.4 Km. This graph enables us to conclude that co-clustering between an existing commercial development and a new residential development occurs at a time lag of three years.

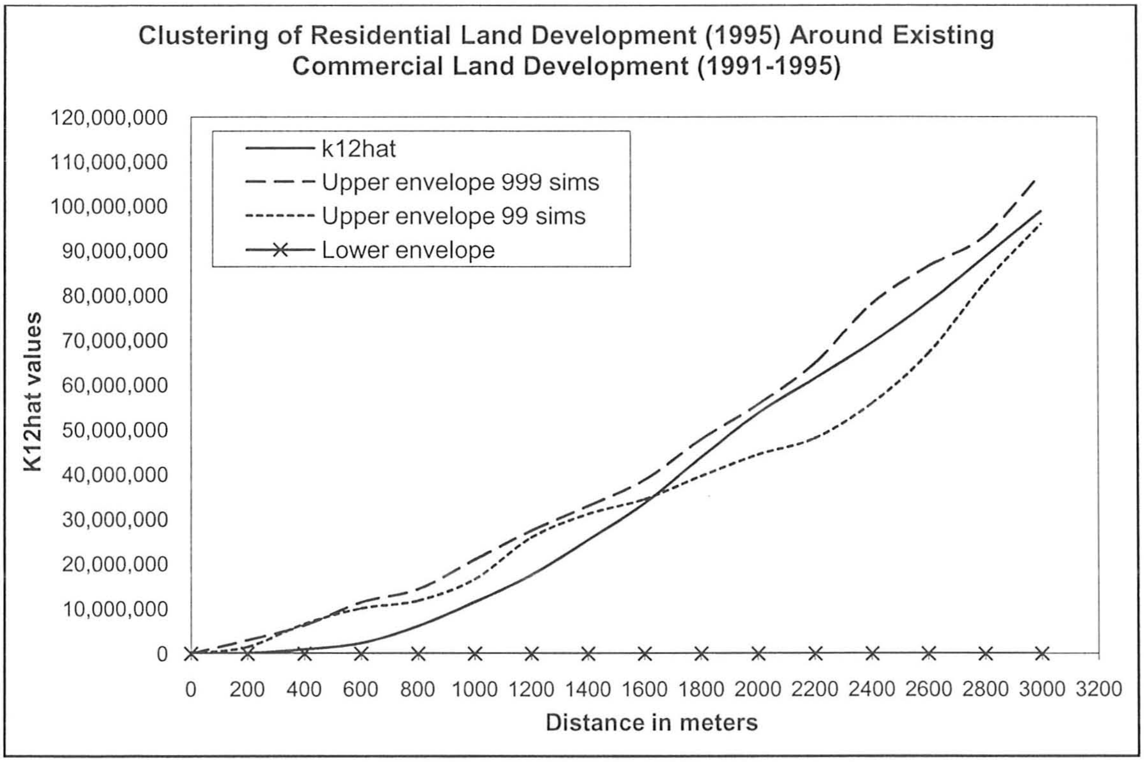


Figure 4.21: Bivariate K-function for Residential (1995) and Commercial (1991-1995) Land Development in Hamilton

For the parcels developed for residential use in the period 1995-1998, the estimated bivariate K-function (figure A.24 in the Appendix) indicates some clustering at distances between 1.8 Km and 2.2 Km since the K-function curve marginally exceeds the upper envelop. Furthermore, figure A.25 located in the Appendix indicates clustering for the new residential development that occurred four years from the previously emerged pattern of commercial development. Here again, the line of the bivariate K-function is above the upper envelop of the 999 simulations at distances greater than 1.8 Km. Co-clustering of the two point patterns is also evident for the residential development occuring five years later from the existing commercial development. This co-clustering is observed at distances between 1.4 Km and 2.4 Km (figure A.26 in the Appendix).

For the new residential development in 1995-2001, the estimated bivariate K-function in figure A.27 in the Appendix indicates clustering of the residential pattern and the existing commercial at distances between 1.8 Km and 2.4 Km at the 0.001 significance level. Co-clustering is also observed between the patterns of new residential development in 1995-2002 and commercial development in 1991-1995 (figure A.28 in the Appendix). It is confirmed for distances between 1.4 Km and 3 Km. Finally, figure A.29 in the Appendix suggests clustering between the new residential development in 1995-2003 and the commercial development that occurred in 1991-1995 at distances in the range between 1.8 Km and 3 Km. This figure informs us that residential development is attracted by commercial development even after a period of nine years.

Some general conclusions can be drawn from the results of the bivariate K-function estimation. First, residential development during the 1990's is attracted to areas where commercial development took place in the recent past, i.e. within a time frame of five to ten years. More specifically, residential development appears to co-locate with existing commercial development in relatively new developed areas and at relatively short distances of 1.4 Km and 2.4 Km with a time lag of 3 to 5 years. As time goes on and moves further away from the period during which the commercial development took place, residential development tends to cluster around this commercial locations but at longer distances that are generally greater than 1.8 Km. This can be explained partially by the argument that residential development initially consumes the land closer to the existing commercial land and then proceeds to relatively more distant locations.

Another important conclusion is related to the observed minimum distance from which clustering starts. The 0.001 significance level test revealed that new residential development does not cluster with existing and recently constructed commercial development (i.e. from 1 to 5 years before the residential development) to a distance less than 1400 m. This may be explained by two facts: the size of the commercial clusters and the characteristics of the residential land use. Kernel maps from the previous section revealed that the type of commercial development is concentrated at specific nodes around the city. In other words, commercial development in the 1990's occurred mostly in clusters constructed on large parcels of land where only business establishments would locate. Such type of development is basically the retail box development (i.e. power centres) constructed on large lots in the form of plazas. These commercial areas attract high volumes of traffic, which makes it unattractive for residential development to locate in very close proximity to these areas.

4.4 Conclusion

In this chapter, a micro-level land parcel dataset for the city of Hamilton was used to explore the evolution of Hamilton's urban form in the period 1950-2003. Disaggregate land use information at the land parcel level is utilized to run a number of spatial statistical techniques to study the transformation of land use patterns in the city. By examining the spatio-temporal evolution of new land development during the study period, we presented evidence on the sprawled structured of the urban area, the decentralizing trend in population and employment and the potential multinucleation process that has been emerging in the study area to date.

The city expanded towards the rural area and, as a result, land use activities were moved away from the central core. Land development extended the city horizontally by imposing multiple spatial patterns such as scattered, infill, contiguous and leapfrog development. New development was found to be favoring locations far away from the existing urban core, thus contributing to the disruption of the monocentric urban form. The processes of residential and commercial development appeared to work in tandem as two major driving forces of urban change. While each type of land development exhibited clustering on its own, co-clustering was also evident. The findings suggested a bidirectional relationship that brought one land use type close to the location of the other with time lags of three and five years.

CHAPTER FIVE

Modeling Residential Land Use Development in Hamilton, Ontario

5.1 Introduction

In chapter two, the bi-directional interaction between the land use and transportation systems was highlighted as one of the most important factors that contribute to the formation of urban form. It was then presented that the land use pattern of an urban area is the outcome of the land development process that takes place over space. Lastly, it was argued that the driver of the land development process is the locational decisions and behaviour of developers.

However, after examining the existing literature on the land development process and the behaviour of land developers, we come to realize that our knowledge on the process that supplies the dwellings for households is still limited and fragmented (DiPasquale, 1999). Even more limited is our knowledge on more specific issues such as how residential developers choose the types of housing projects in an urban area. Our review of literature identified only two studies (Mohammadian and Kanaroglou, 2003; Haider and Miller, 2004) that are related to the locational behaviour of developers who construct different types of housing products. Both of these studies were conducted in the Greater Toronto Area, but no study was found for the city of Hamilton.

Therefore, starting from the DiPasquale's (1999) statement that "we need to build our understanding of the micro-foundations of housing supply" (p. 21) and the general consensus in the literature that we need a decision-agent, micro-economic and micro-level approach to study the land development process, this current research proceeds to formulate and estimate a parcel level model for the choice type of residential development projects. As noted in chapter three, econometric analysis via the MNL model has been a common practice to examine the underlying factors that could explain the outcomes of land development. In this chapter, we focus our attention on the recent residential land development that occurred during the 1990's to identify the locational factors that influence this development by type.

The remainder of this chapter is organized as follows. First, we present the specification of the MNL utilities of the land development model. Next, we present and discuss the estimation results. Finally, we provide a conclusion to our study.

5.2 Econometric Model Specification

As already stated in the section 3.4.2.1, this modeling effort purports to identify and explain the underlying factors that influence the developer's choice on the type of residential land development. The model will be used to determine the conditional probabilities that a land parcel will be developed to one of the following four housing types: detached (D), Semi Detached (S), Row-Link (R) or Condominium (C), given that the parcel will be developed for residential use.

Given the disaggregate parcel level dataset available to us as well as the information gathered from the literature on the factors affecting the residential land development process, and in particular its outcome (housing type), we summarize the explanatory variables into three classes. These three classes of location based factors are the road infrastructure, the residential amenities, and the general site characteristics observed at each site where residential development took place. Provided that we are modeling four outcomes, four utility functions can be specified and estimated on the basis of the three classes of factors.

Explanatory variables can be introduced in the utility functions in the form of generic or alternative specific but the choice of their specification is related to the analyst's expectation with respect to the variable's impact on the utilities of the different alternatives (Maoh and Kanaroglou, 2007b). Generally, as it was mentioned in the section 3.4.2.1 of the methodology, the independent variables that can be introduced in the systematic component of a utility function in a discrete choice model can be characteristics of the alternative choices and attributes of the choice makers (McFadden, 1975; Ben-Akiva and Lerman, 1985). However, given the type of data available for this analysis, only characteristics pertaining to the developed parcels are specified in the utility functions. This approach has been followed in previous land development modeling studies (see for example: Landis and Zhang, 1998a; Waddell et *al*, 2003, Mohammadian and Kanaroglou, 2003). The utility function in our MNL model is formulated as follows:

$$U(t) = \Sigma_{\mathrm{i}} \beta^{f}_{i} X^{f}_{i} + \Sigma_{\mathrm{j}} \beta^{a}_{j} X^{a}_{j} + \Sigma_{\mathrm{k}} \beta^{s}_{k} X^{s}_{k}$$

where,

$U(t)$ is the utility of residential development type t, t = {D, S, R and C},
X^{f}_{i} is a vector of covariates related to road infrastructure,
X^{a}_{j} is a vector of covariates related to residential amenities,

X^{s}_{k} is a vector of covariates related to general site characteristics,
β^{f}_{i} , β^{a}_{j} and β^{s}_{k} are parameters to be estimated.

On the one hand, road infrastructure attempts to capture the level of accessibility at any given site. On the other hand, residential amenities variables attempt to capture the qualities related to the site (for instance proximity to school). Finally, the third class (general site characteristics) corresponds to more general type of factors that reflect the general nature of the site to be developed. An example of such variable could be proximity to the lake shore. In what follows, we will list the different variables within each class and will discuss the way these variables were constructed from the data available to us and for the purpose of the modeling exercise presented here.

5.2.1 Road Infrastructure Variables

Table 5.1 shows a number of road infrastructure variables that were created to reflect the nature of road infrastructure and the level of accessibility in the vicinity of a given location developed for residential use. Proximity to highways and major roads at a given distance *k* represents one of these road infrastructure variables. Here, *k* took on values 100 metres, 200 metres, 400 metres, and 600 metres. Not only this variable reflects the site's accessibility at the city and the region wide level, but also is considered as a proxy for the availability of basic infrastructure (sewerage, electricity and telephone services etc). Furthermore, at the short distances of 100 and 200 metres, this variable can reflect possible negative associations with noise and emission levels stemming from the traffic taking place on the road network. The hypothesis being tested is that the existence of a land parcel within a distance *k* from a highway or major road will give rise to a particular type of residential development, other things being equal. The introduction of a particular variable in any of the utility functions was determined by our findings from the literature and by exploring the maps depicting the location of a particular type of residential development relative to a highway or a major road. Furthermore, several model runs with trials of introducing the variable in one of the utilities was useful to provide the final specification in the model.

Table 5.1: Variables Reflecting Road Infrastructure

Variable's Label	Variable's Definition
Road Infrastructure	
M1HWYMRD	Proximity to Highways and Major Roads; 1 if the developed land parcel is within a distance of 100 metres from an existing highway or major road (in 1995); 0 otherwise
M2HWYMRD	Proximity to Highways and Major Roads; 1 if the developed land parcel is within a distance of 200 metres from an existing highway or major road (in 1995); 0 otherwise
M4HWYMRD	Proximity to Highways and Major Roads; 1 if the developed land parcel is within a distance of 400 metres from an existing highway or major road (in 1995); 0 otherwise
M6HWYMRD	Proximity to Highways and Major Roads; 1 if the developed land parcel is within a distance of 600 metres from an existing highway or major road (in 1995); 0 otherwise
M2HWRAMP	Proximity to Highway Ramps; 1 if the developed land parcel is within a distance of 200 metres from an existing highway ramp (in 1995); 0 otherwise
M8HWYRAMP	Proximity to Highway Ramps; 1 if the developed land parcel is within a distance of 800 metres from an existing highway ramp (in 1995); 0 otherwise

Another variable that reflects a site's level of accessibility to road infrastructure is the proximity to highway ramps at some distance *k*. The values of the distance *k* that were used along with this proximity measure are 200 and 800 metres. The principal idea embedded in this covariate is that the site's proximity to highway ramps increases the level of mobility of residents who will be living at that developed site. This variable was favored against the selection of the variable proximity to highways since it is a better proxy for mobility. Proximity to highways by itself does not guarantee actual access to the highway. The use of the highway ramps variable enabled us to capture the effect of mobility in a more realistic way. For instance, roads cutting through particular site in proximity to developed land parcels do not necessitate easy access to those roads, whereas proximity to ramps assures access to them.

Again, the hypothesis being tested here is that the existence of a land parcel within a distance *k* from a highway ramp will increase the attractiveness of the parcel to be developed to a particular type of residential development, other things being equal. As before, the introduction of a particular variable in any of the utility functions was informed by the literature and the exploration of the maps depicting the location of a particular type of residential development relative to highway ramps. Lastly, several model runs with trials of introducing the variable in one of the utilities was used to provide the final specification in the model.

5.2.2 Residential Amenities Variables

Table 5.2 presents the residential amenities variables that were created to reflect the quality of the developed sites. Residential amenities are conceptualized as location characteristics that serve and satisfy specific needs of the residents choosing the developed sites. Therefore, this class of variables intends to capture the effect of this type of location characteristics on the developer's choice to construct a specific housing type in a given site. For a developer firm, each housing type is a product in the housing market. The developed product (housing type) incorporates a set of specific characteristics that intend to satisfy the demand for a particular type of residential floorspace.

Table 5.2: Variables Reflecting Residential Amenities

Variable's Label	Variable's Definition
Residential Amenities	
K1CNTR9	Proximity to Community Centres (4 community cores, 4 community service centres and downtown Hamilton); 1 if the developed land parcel is within a distance of 1000 metres from at least one of the community centres; 0 otherwise
M15CNTR9	Proximity to Community Centres (4 community cores, 4 community service centres and downtown Hamilton); 1 if the developed land parcel is within a distance of 1500 metres from at least one of the community centres; 0 otherwise
M6SCHO95	Proximity to elementary or secondary schools; 1 if the developed land parcel is within a distance of 600 metres from at least one elementary school; 0 otherwise
EMD96100	Accessibility to Employment; the summation of the products between the number of jobs in 1995 at each employment centre, defined as the centroid of each census track of Hamilton, divided by the distance in metres of each developed land parcel to each employment centre; value divided by one hundred (100)
WOOD400	Proximity to woodlots; 1 if the developed land parcel is within a distance of 400 metres from at least one land parcel covered by trees; 0 otherwise
OPEN200	Proximity to parks and recreational land use; 1 if the developed land parcel is within a distance of 200 metres from a Park (parcel codes 103, 710 and 725) or a golf course (parcel code 490) or a recreational land use (parcel code 720); 0 otherwise
OPEN400	Proximity to parks and recreational land use; 1 if the developed land parcel is within a distance of 400 metres from a Park (parcel codes 103, 710 and 725) or a golf course (parcel code 490) or a recreational land use (parcel code 720); 0 otherwise
OPEN500	Proximity to parks and recreational land use; 1 if the developed land parcel is within a distance of 500 metres from a Park (parcel codes 103, 710 and 725) or a golf course (parcel code 490) or a recreational land use (parcel code 720); 0 otherwise
M4C95430	Proximity to neighbourhood shopping centres; 1 if the developed land parcel is within a distance of 400 metres from a neighbourhood shopping centre (parcel code 430); 0 otherwise

As an example of two distinct housing products, one could consider the different consumers (households) who will choose a condominium unit or a single family detached house. According to the findings from the literature (section 2.4.1), it is more likely that the single family detached house will be chosen by a household that prefers to follow the suburban lifestyle and live in a house in a fairly isolated, low density, and prestigious area surrounded by green space. Conversely, it is more likely that a condominium unit will be selected by a household that shows preference to a more urbanized lifestyle as this is realized at locations in proximity to community cores as well as in proximity to land use activities related to employment, shopping, and leisure.

Proximity to community centres at a given distance *k* represents one of these residential amenities variables. This is a binary covariate that takes on the value 1 when the land parcel is located within a specified distance *k* from a community centre in the study area and 0 otherwise. The location of each community centre was identified by using the maps that the City's planning department has included in the Growth Related Integrated Development Strategy (see section 3.3.2). These locations are nine in total number and represent the major central places over the city's region as designated by the City's planning department. In more detail, these nine point locations denote the main centres of activity over the study area, as shown in figure 3.1 of section 3.2. Four of these nine locations represent the suburban downtown cores of the communities of Ancaster, Dundas, Stoney Creek, and Waterdown (community cores). The fifth corresponds to Hamilton downtown, while the remaining four are the community service centres of Lime Ridge mall, Eastgate mall, Centre mall, and the Meadowlands power centre.

The values of distance *k* that were included in the specification of the proximity to community centres variable are 1000 metres and 1500 metres. The choice of these distances was based on the combination of two criteria. The first was the argument that a community centre's sphere of influence gradually fades with distances greater than 1.5 to 2 kilometres. The second was the observations we made by exploring the maps that denote the location of new residential development relative to the location of community centres. Additionally, several model runs with trials of values ranging from 500 metres to 2 kilometres were also used to select the value of distance *k*.

The community centres over the study area are the locations that practically accommodate most of the commercial (retail and services) activities. They also are the locations where a considerable number of jobs are located as well as the locations that attract a large volume of traffic. Therefore, sites in close proximity to any community centre derive benefit from higher accessibility to retail and service activities. They also benefit from minimizing work-trip transportation costs, although are subjected to burden stemming from the increased levels of traffic activities in the vicinity. Given these location characteristics, the hypothesis being tested with this variable is that the development of a land parcel within a distance *k* from community centre(s) will give rise to a particular type of housing, other things being equal.

The proximity to schools at 600 metres is a binary variable takes on the value 1 when the land parcel is located within 600 metres of straight distance from an existing elementary or secondary school in 1996; and 0 otherwise. The location of schools is identified from the polygons in the land parcel dataset that are attributed the land use code 605. The choice of the 600 metres for distance was based on the idea that this is an acceptable distance a child could walk on foot to access the school.

According to the findings from the literature (section 2.4.1), this variable has a positive association with residential development and specifically with the detached and semi-detached housing types. It is argued that sites in proximity to existing schools tend to accommodate detached or semi-detached development. This is because such locations attract households with young children that prefer to live in these types of houses or in row-link houses.

Another residential amenities variable is the accessibility to employment. In general, households choose to reside at a location which can provide accessibility to the place of work. In other words, different types of occupation lead people to reside at different locations and in different types of houses. This is because households intend, to a certain extent, to live close to their jobs or at least to locations which reduce the cost of the household work-trips in terms of money and/or travel time.

The variable representing accessibility to employment attempts to capture the positive externalities of a site's access to jobs on the developers' choice to construct a certain type of housing product at a specific location, other things being equal. In order to construct this variable, we applied the standard formula of potential accessibility. We used the number of existing jobs in 1996 at the centroid j of the census tracts forming the city of Hamilton; and the straight distance between each tracts's centroid j and the parcel-centroid i pertaining to each of the land parcels that were developed during the study period (1996-2000). The formula used to calculate accessibility is the following:

$$A_i = \sum_j \frac{E_j}{d_{ij}^{\beta}}$$

where,

A_i is the accessibility of land parcel i to employment,
E_j is the employment of census tract j,
d_{ij} is the straight distance between land parcel i and the tract j;

and, β is a weighting factor that can be applied on the distance measure to reflect the difference in the importance assigned to the distance between the observation and the opportunity under study.

The accessibility measure produces lower values for greater distances between the observation and the opportunity location. Moreover, when the weight β is set to values greater than 1, the effect of the increasing distance is magnified and reflects an increasing friction of distance on the value of the accessibility measure. For the purposes of our study, the parameter β was set to the value 1 in order to preserve a linear relation between the distance and the returned value of the accessibility measure. By doing so, we hypothesize that a household perceives a location of a housing unit as less accessible when the distance between that house and the employment opportunity increases.

The next residential amenities variable included in the model is proximity to woodlots within a distance of 400 metres. This is a binary variable that takes on the value 1 when a land parcel developed to a residential use between 1996 and 2000 is within 400 metres from a land parcel covered by trees in 1995; and 0 otherwise. The selection of 400 metres as distance was based on the exploration of maps depicting the locations of a particular type of residential development relative to woodlots as well as by several model runs with trials of different values for the variable. The variable is included in the model because it reflects natural and landscape qualities of the location to be developed for residential use type *t*. The hypothesis being tested here is whether the proximity of a land parcel within 400 metres to a woodlot has any influence on the type of housing constructed in this parcel other things being equal.

Another variable included in the model of residential amenities is the proximity to parks and recreational land use within distance *k*. This dummy variable takes on value 1 when a land parcel developed to residential use was located within distance *k* from a parcel in recreational use or from a park at the end of 1995; and 0 otherwise. The parcels pertaining to parks or recreational use were extracted from the micro level land parcel dataset. In this dataset, the parks are the land parcels attributed with the code 103; and the recreational uses included in this variable consist of the codes 490 (golf courses), 710 (recreational sports clubs), 720 (sports complexes, pools, arenas, stadiums), and 725 (amusement parks).

The distance *k* in this specification took on values 200, 400, and 500 metres. Here again, the distance values were specified after examining the maps depicting the relative location of parcel developed to residential use in respect to the location of parks or recreational sites; as well as after several trial runs of the model with different specifications of distances.

Following the findings from the literature, the inclusion of this variable in our model captures the locational qualities that are considered as attractive factors for residential development. In particular, these locational qualities are associated with the suburban lifestyle and with areas that enjoy availability of space. By introducing this variable in the model, we intend to examine the hypothesis that the presence of these types of land use in proximity to land parcels developed to residential use will affect the type of the housing outcome of that development, other things being equal.

The last variable included in the specification of the residential amenities model is the proximity to neighborhood shopping centres at the distance of 400 metres. The land parcels representing the neighborhood shopping centres were extracted from the micro level land parcel dataset. These consist of the parcels attributed with the code 430 in the database. The variable takes on the value 1 if a land parcel developed to a residential use between 1996 and 2000 was within a distance of 400 metres from a neighborhood shopping centre at the end of 1995; and 0 otherwise. The distance of 400 metres was selected again after several model runs with trials of different distance values.

Evidence from the literature supports the argument that sites in proximity to shopping centres are more likely to be developed to residential types that exhibit urbanized characteristics. Locations in close proximity to neighborhood shopping centres are generally found in more centralized and built up areas and do not fit with the profile of suburban lifestyle. Hence, at these locations, the expectation of residential development types which are not strictly associated with suburban characteristics is considerably reasonable. In other words, we introduce this variable in the model to test the hypothesis that the existence of a land parcel in close proximity to a neighborhood shopping centre will give rise to a particular type of residential development, other things being equal.

5.2.3 General Site Characteristics Variables

Table 5.3 illustrates the general site characteristics variables that were created to reflect other features and attributes of the sites that were developed to one of the four types of housing in the period 1996-2000. The purpose of these variables is to introduce to the model covariates that have been reported in the literature to be important in explaining the residential development process; and variables that we considered important after exploring the maps of residential development in Hamilton for the study period.

Table 5.3: Variables Reflecting General Site Characteristics

Variable's Label	Variable's Definition
General Site Characteristics	
PD96SKBT	1996 Population density of the census tract the developed land parcel belongs to; number of people per square kilometre; value divided by ten thousands (10.000)
M8I56X95	Proximity to any type of industrial land use; 1 if the developed land parcel is within a distance of 800 metres from any existing (in 1995) industrial site; 0 otherwise
K5FAD10K	Total residential floorspace (in sq.m) created between 1991 and 1995 within a radius of 1500m from each land parcel that was developed to **D**, **S**, **R-L**, **C** residential type between 1996 and 2000; sq.m of floorspace divided by ten thousands (10.000)
DKAV61BH	Difference in $CAD of the average house value of the census tract the developed land parcel belongs to between 1995 and 1991; value divided by one hundred (100,000)
M8NEXPRW	Proximity to a recently constructed Express way; 1 if the developed land parcel is within a distance of 800 metres from a recently constructed express way; 0 otherwise
M2NEXPRW	Proximity to a recently constructed Express way; 1 if the developed land parcel is within a distance of 200 metres from a recently constructed express way; 0 otherwise
M4NEXPRW	Proximity to a recently constructed Express way; 1 if the developed land parcel is within a distance of 400 metres from a recently constructed express way; 0 otherwise
M6COAST	Proximity to the lakeshore; 1 if the developed land parcel is within a distance of 600 metres from the lakeshore; 0 otherwise
M75N5CND	Number of land parcels developed to **C** residential type between 1991 and 1995 within a radius of 750m from each land parcel that was developed to **C** residential type between 1996 and 2000

Population density in 1996 is the first variable introduced in the general site characteristics model. This variable was constructed by making use of the data available from Statistics Canada at the census tract level. Specifically, the value of the population density, measured as the number of people per square kilometre, was calculated as the ratio of the population in each census tract to the area of the tract. The population density value, calculated at the census tract level, was afterwards assigned to each land parcel of residential development according to the parcel's location. As such, each land parcel developed to a residential use during the study period inherited the population density value of the census tract it belonged to in 1996.

The population density variable is a proxy for the built up areas and the more central locations of the urban space[4]. It is known from the literature that lower population density areas are mainly suburban. The literature also supports that detached, semi-detached, and row-link development prefer to locate in low density suburban areas whereas condominiums prefer areas with higher density. By introducing this variable in the different utility functions of our model and by trying several model runs, we intend to test the hypothesis that locations with different density levels will give rise to different types of residential development.

The next variable introduced to the site characteristics model is the proximity to industrial land use within a distance of 800 metres. The land parcels denoting the industrial land uses have the codes 500 and 600. The variable takes on the value 1 if the land parcel developed to one of the four residential types is within 800 metres from an industrial site at the beginning of 1996; and 0 otherwise. The choice of the 800 metres distance was again based on map inspections and on several trial model runs where we introduced the variable in the different utilities and for several distance values. The hypothesis being tested with this variable is whether the presence of industrial land uses in proximity to a developed parcel would impose a disutility on the selection of the type

[4] To some extent, the population density variable serves as a proxy for zoning regulations regarding low or high density residential areas. In that respect, introducing this variable to the model specification enables us to capture some of the effect that zoning has on the outcome (housing type) of residential development.

of housing. That is, by using this variable, we attempt to explore the developer's behaviour in choosing a specific housing type when developing a land parcel that is in proximity to hazard.

Another variable reflecting general site characteristics was the total residential floorspace created between 1991 and 1995 within a distance of 1500 metres from each land parcel developed to residential use between 1996 and 2000. The variable is created by calculating the square metres of floorspace developed during the previous five years around each land parcel that was developed during the next five years. The measures were based on the land parcels we extracted from the micro level land parcel dataset; and the calculations where based on the "floorspace-created" attribute that is stored in the database for each land parcel record. We divided the total amount of floorspace created around each observation by the value 10,000.

The creation and inclusion of this variable in the model is based on the observations we made from the exploratory analysis reported in chapter four. From that analysis, we were able to conclude that new residential development takes place in clusters that constantly move further away from the central urban core of the city. Moreover, by examining the maps produced by the exploratory analysis, we observed that the cluster surfaces depicting the areas with the highest density of new residential development had a width of 1500 to 2000 metres. Therefore, the exploration of the process suggested that new residential development occurs at sites that are located within the vicinity of recent residential development. In other words, a major characteristic of the new residential development occurring in Hamilton is the expansion of the urban area toward new and undeveloped land; a development characteristic that is commonly referred to as urban sprawl.

The inclusion of this variable in the model will test the hypothesis that the intensity of the 1991-1995 residential development, which took place within a radius of 1500 metres from a land parcel developed to residential use during 1996-2000, affected the type of housing that was constructed on this parcel during the latter period. With this variable, we are able to study the association of each housing type with the level of residential development that took place during the previous five-year period. In that way, we are enabled to observe which housing types are choosing to locate in proximity to new residential areas. Given the trends observed during the 1990's, new residential development took place in mainly suburban areas. Hence, this variable is a proxy for urban sprawl, which is likely to impact the outcome of a residential development at a land parcel.

The next variable included in the site characteristics model is the difference in the average house value between the beginning of the study period (1996) and the beginning of the previous period (1991). The values were obtained from Statistics Canada at the census tract level. The variable represents the difference between the two values in Canadian dollars divided by 100,000. Lastly, the value of the variable for a particular census tract was assigned to the land parcels that have their centre within the boundary of that census.

A positive and high value of this variable means that the average house value in this area increased between the beginning of 1991 and the beginning of 1996. This, in turn, implies that the demand for houses in this area has increased. This also signifies an enhancement of the prestige of the area in terms of residential use. We introduce this variable in the model to test the hypothesis that changes in the housing prestige of an area will give rise to a particular type of residential development, other things being equal.

Another covariate reflecting general site characteristics is proximity (at some distance k) to a recently constructed expressway. A recently constructed expressway implies a major road infrastructure project that was under construction and is known to the residential developers who constructed housing units during the study period. This means that developers were aware of the existence of a major road infrastructure project in the vicinity before making their decision to initiate a residential development somewhere in the study area. This is important since such road infrastructure usually increases the attractiveness of land parcels in the vicinity. This variable takes on value 1 when a land parcel is located within a distance k from the expressway under construction, and on 0 otherwise. The variable is calculated at different distances k that took on values 200, 400, and 800 metres. The selection of these distances was based on the inspection of the maps depicting the location of a particular type of residential development relative to the expressway under construction, namely the Lincoln Alexander Expressway that was opened to the public in 1997. Furthermore, several model runs with trials of different distance values were useful to provide the final specification in the model. Lastly, the hypothesis being tested here is that the existence of a land parcel within a distance k from an expressway under construction will give rise to a particular type of residential development, other things being equal.

Proximity to the lakeshore at 600 metres is a dummy variable that intends to capture the effect of the landscape quality on the construction of a specific type of residential use. It is assumed that developers assess locations with favorable landscape features, such as the proximity to the shore of Lake Ontario, and construct housing units that enjoy natural scenery such as the view to the lake[5]. We introduce this variable to the model to test the hypothesis that the proximity of a land parcel to the lake shore will give rise to a particular type of residential development, other things being equal. The variable takes the value 1 if the land parcel is within 600 metres from the shore, and 0 otherwise. The selection of the distance value was based on exploring the location of the developed parcels relative to the shore line.

The last covariate among the general site characteristics factors is an alternative specific one. The variable counts the number of land parcels developed to the condominium housing type during the five-year period before the period under study. Specifically, the variable is a count of the number of land parcels that were developed to condominium between 1991 and 1995 within a radius of 750 metres from a land parcel that was developed to condominium between 1996 and 2000. The parcels, on which the counts were based, were extracted from the micro level dataset. The 750 metres as distance was again specified after several model runs with trials of different distance values. For the specification of the distance, exploration of the maps depicting the

[5] Another important landscape feature in Hamilton is the Niagara escarpment. A dummy variable similar to the proximity to the lakeshore was created for the proximity of developed land parcels to the escarpment. We used this variable to test the hypothesis that the proximity of a land parcel to the escarpment will give rise to a particular type of residential development, other things being equal. However, this variable was dropped from the specification of the general site characteristics model. This was done because the model estimation returned an insignificant parameter for this variable.

location of the condominium type of residential development was used along with the trial model runs.

This variable is introduced in the model in order to check for the so called phenomenon of spatial inertia. Findings from the literature suggest that the existing stock pertaining to a specific type of housing in an area will attract more construction of the same type in the future. Accordingly, we examine the spatial inertia phenomenon for condominium development. The hypothesis being tested here is that a larger number of condominium buildings constructed between 1991 and 1995 within a distance radius of 750 metres from a site to be constructed to a residential type between 1996 and 2000 will give rise to condominium development, other things being equal.

5.3 Results and Discussion

5.3.1 Road Infrastructure Model

The results from the road infrastructure model estimation are presented in Table 5.4 under the column labeled "Model 1". The model's fit, measured by the naïve ρ^2 (=0.6309), is relatively lower than the ρ^2 achieved in the full model. This is expected since the road infrastructure model includes only some of the variables used in the full model. The naïve ρ^2 is calculated as follows:

$$\text{naive } \rho^2 = 1 - \frac{L(\beta)}{L(0)}$$

where, $L(\beta)$ represents the maximized value of the log-likelihood of the MNL probability function with the final parameter estimates, and $L(0)$ represents the initial value of the log-likelihood calculated with the values of the constants and of the parameters set to zero. It should be noted here that for the full model estimation we will also provide a restricted measure of fit, which is calculated as follows:

$$\text{restricted } \rho^2 = 1 - \frac{L(\beta)}{L(c)}$$

Where, $L(\beta)$ is again the maximized value of the log-likelihood with the final parameter estimates, and $L(c)$ is the log-likelihood value calculated with only the constants of the model.

All parameters in the model are statistically significant at the 95% confidence level, and the signs of the coefficients meet our a priori expectations. The alternative specific constant for the semi-detached housing retains a negative sign. This means that unobserved factors, which the constant captures, reflect a disutility for the semi-detached housing outcome. That is, factors other than the ones included in the utility function of the semi-detached housing outcome are important in explaining the process of semi-detached housing construction. More specifically, these factors tend to decrease the likelihood of a semi-detached construction in a land parcel.

Both of the variables introduced in the utility function of the detached housing type as alternative specific variables returned negative and highly significant coefficients. Specifically, the negative parameter of the proximity to highways and major roads variable suggests that it is less likely for a land parcel located within 200 metres from a highway or major road to be developed into a detached housing type, other things being equal. Furthermore, the likelihood of detached construction in a land parcel decreases relative to the other three alternatives when this land parcel is located within 200 metres from a highway ramp. Both the results meet our a priori expectations since the detached housing is known to target locations that fit the suburban lifestyle. That is, locations that have the following two characteristics: are prone to accommodate large houses; and are to some extent isolated and distanced from other activities.

For the row-link housing type, two alternative specific variables were introduced in the utility function. Both of these variables came out with positive and highly significant coefficients. The first variable is the proximity to highway and major roads within 100 metres and the second is the proximity to highway ramps within 800 metres. These variables suggest that the propensity for row-link housing construction increases relative to the other three alternative types of housing (detached, semi-detached, and condominium) for locations that enjoy high accessibility to activities (proximity to highway and major roads within 100 metres) and offer high levels of mobility to their residents (proximity to highway ramps within 800 metres). It should be noted that this result does not cancel the suburban oriented character of this type of housing. It is known that in Hamilton all the highways are located in the suburban area; and that the majority of development occurs in the periphery of the region (see chapter four). The result of this variable simply suggests that this type of housing favors locations with higher accessibility.

Finally, one alternative specific road infrastructure variable is specified in the utilities of the semi-detached and condominium housing. The model suggests that a land parcel located within 400 metres from a highway or major road is more likely to be developed to the semi-detached housing type relative to the three other alternatives (detached, row-link, and condominium). On the contrary, the model suggests that condominium construction is less likely to occur in locations that are within a distance of 600 metres from a highway or major road.

It is significant to note here that the variable proximity to highway ramps within 800 metres was initially included in the specification of the condominium housing utility function, and the estimated coefficient was positive and significant. This suggests that condominium development is more likely to be attracted by a location that offers high levels of mobility to the residents relative to the other three alternatives other things being equal. However, this variable was dropped from the specification of the condominium utility because it turned to be insignificant in the full model estimation.

5.3.2 Residential Amenities Model

The results from the residential amenities model estimation are presented in Table 5.4 under the column labeled "Model 2". As before, the model's goodness of fit, as measured by the naïve ρ^2, is lower than the goodness of fit achieved in the full model. However, this model resulted in the best fit among the three estimated models (Model 1, Model 2, and Model 3).

All parameters in the model are statistically significant at the 95% confidence level, and the signs of the coefficients meet our a priori expectations. The model indicates that the chance of constructing semi-detached and condominium housing is higher than the chance of constructing detached or row-link housing for parcels within a distance of 1 Km from the community centres. Moreover, the model confirms the suburban orientation of row-link development by returning negative and highly significant coefficient for the proximity to community centres within 1500 metres variable. The likelihood of row-link housing construction decreases relative to all other alternatives when a land parcel is located within 1500 metres away from a community centre, other things being equal.

On the other hand, the chance of developing detached and row-link housing is higher relative to semi-detached and condominium when a land parcel is located within 600 metres from an elementary or secondary school. This result is expected since these types of housing units are, in general, occupied by families with children. In addition, detached housing is more likely to be built in locations with higher accessibility to employment opportunities compared to all other alternatives, other things being equal. Compared to the findings from GTA (Haider and Miller, 2004), this result is not counterintuitive. On the contrary, it is in tandem with the evolution of the city's urban form and the distribution of employment. As it was presented in the exploratory part of this thesis, employment has been decentralizing and locating at the periphery of the city's region since the 1980's. This process has shifted employment opportunities to several locations in the suburbs where the majority of the detached housing construction has been occurring since the 1950's.

The model also indicated that the proximity of a land parcel to areas covered by trees increases the likelihood of building detached, semi-detached, and condominium housing types, while decreases the likelihood of row-link development. Additionally, the proximity of a land parcel to parks and recreational land uses at 200, 400, and 500 metres increases the likelihood of condominium, detached, and row-link housing construction respectively. Lastly, the model suggests that land parcels in close proximity (400 metres) to neighborhood shopping centres have higher chance of attracting row-link and condominium housing types, and lower chance of attracting detached and semi-detached construction. Again, this result confirms the argument that detached and semi-detached housing follow the suburban lifestyle and locate to areas with clear suburban characteristics and uniform residential structure. This result also confirms that the row-link housing type locates closer to more urbanized land use activities; and that the condominium housing type is highly associated with accessibility to shopping centres.

5.3.3 General Site Characteristics Model

The results from the general site characteristics model estimation are presented in Table 5.4 under the column labeled "Model 3". The model's goodness of fit, based on the naïve ρ^2, is 0.6252. This model shows the lowest fit among the three models specified here.

All parameters in the model except for the alternative specific constant (*Constant 2* of the semi-detached housing type) are statistically significant at the 95% confidence level; and the signs of the coefficients meet our a priori expectations. The fact that the alternative specific constant for the semi-detached housing turned to be insignificant proposes that the semi-detached and the condominium housing, which is the alternative without an alternative specific constant, have more or less the same market share in the model. In other words, the number of observations for the semi-detached and the condominium development are very close to each other; and both of them are much lower than the number of observations for detached and row-link development.

The result of the model with respect to the population density variable indicates that the chance for constructing row-link housing type is higher for land parcels located in census tracts with higher population density, while the chance of building detached, semi-detached, and condominium housing types is lower for parcels located in census tracts with higher population density. The result is partially in accordance with the results of a relevant study for the GTA (Haider and Miller, 2004). High population density is mainly observed in central areas of a city; hence, the detached, semi-detached, and row-link types of housing that follow the suburban lifestyle do not locate there. In contrast, condominium buildings have the tendency to be developed in more central places where the population density is typically high. This is observed in the GTA (Haider and Miller, 2004) where the downtown area of Toronto is vibrant, highly centralized and prestigious. In contrast, Hamilton's downtown has been decaying over the past three decades. Thus, it is not attractive for the condominium housing type, which is a product that mainly targets very high income consumers showing preference to the urbanized lifestyle.

Furthermore, the model indicates negative association of detached, row-link, and condominium housing with sites located in vicinities where intense residential development took place between 1991 and 1995. It is less likely that detached, row-link, and condominium construction will occur in land parcels located in recently developed areas relative to semi-detached construction. The model shows that most of the new residential development avoids locations where new development took place in the recent past (the past five-year period). This result clearly reflects the sprawling pattern of residential development in Hamilton. In addition, negative association with industrial uses is identified for the detached housing. Specifically, the propensity of developing a site to detached housing decreases relative to the three other alternatives (semi-detached, row-link, and condominium) when this site is located within 800 metres from an industrial site other things being equal. This result is related to the nature of the detached housing type as a product that targets families with children. The developers tend to avoid locating detached houses in proximity to hazard because families avoid buying houses placed in close proximity to sites associated with poor environmental quality.

The results from the general site characteristics model indicated that two more alternative specific variables have a positive influence on the prevalence of the detached housing type. The model suggests that, other things being equal, the chance for a site to be developed to detached housing is higher when the site is located in a census tract that had an increase in the average housing value during the five-year period between 1991 and 1995. It should be reported here that the same result was returned from the model for the row-link housing type. These results imply that both detached and row-link housing are attracted to prestigious areas or to areas populated by high income residents.

The second alternative specific variable that is positively affecting detached development is the proximity of a land parcel to a recently constructed expressway. The model shows that, other things being equal, the likelihood of detached housing construction increases relative to all other alternatives when a land parcel is located within 800 metres from an expressway under construction. The same argument holds for row-link development when a parcel is located within 200 metres from an expressway under construction; and for condominium development when a parcel is within 400 metres from an expressway under construction. This result explains that the construction of an expressway increases the attractiveness and the value of an area. Consequently, developers prefer to locate their projects in such areas in their attempt to capitalize on the opportunity offered by this infrastructure investment and to make their product more competitive.

The results of the general site characteristics model suggest that the proximity to the lake shore at 600 metres has a positive and significant effect on row-link and condominium development. In more detail, the chance for a parcel to be developed to row-link housing type increases relative to all other alternatives when the site is within a distance of 600 metres from the lake shore, other things being equal. The same argument holds for the condominium housing type of residential development. Again, the explanation for this result is related to the developers' profit maximizing behaviour. Construction in areas that enjoy natural beauty attaches to their product (housing type) a feature that increases its value and attracts higher income clients. Lastly, the model brings evidence on the existence of the spatial inertia factor in the housing market for condominiums. It is shown that new condominium development is attracted to sites that are within a distance of 750 metres from locations that were developed in the condominium housing type during the past five years from the beginning (1996) of the study period.

5.3.4 Full Model

The results from the estimation of the full model specification are presented in Table 5.4 under the column labeled "Full Model". The goodness of fit of the model, as measured by the naïve ρ^2, is fairly high (0.6826). The restricted ρ^2 is 0.2013, which shows a reasonable fit. The full model included variables from all of the previous three models reported in table 5.4.

All the parameters in the model retained their exact signs. Except for two, all other parameters in the model are statistically significant at the 95% confidence level. The parameters that turned out to be insignificant are the alternative specific constant (*Constant 2*) for the semi-detached development and the parameter for the proximity to the lakeshore at 600 metres variable that was introduced to the utility of the row-link housing as alternative specific.

The significance of the alternative specific constants used in the specification of the utility function of the detached and row-link housing are explained here. The positive signs of the constants suggest that, on average, factors other than the ones specified in both the utilities of detached and row-link housing types are important in explaining the process of detached and the process of row-link housing type construction. Such factors can be unobserved variables related to land and house prices, vacancy rates in an area, cost of construction materials etc. It is also possible that the significant constants could be absorbing the effect of unobserved factors stemming from the developer firms characteristics for which no data were available to us.

The highly significant and positive constant of the detached housing type suggests something extra. An alternative specific constant captures the market share of the particular alternative that includes this constant. Hence, a high and positive constant for the alternative of the detached housing type indicates a large number of observations for this alternative. Lastly, the constant of the utility of the semi-detached housing type is insignificant and fails to capture any of the aforementioned information. A possible explanation for this can be the almost equivalent number of observations between the semi-detached and condominium housing types, which possibly led to the absorption of the most of the variability in the observed data from the condominium housing type.

The full model specification included all variables from the previous three individual specifications, namely the general site characteristics, the residential amenities and the road infrastructure models. As already mentioned, all parameters pertaining to the variables are statistically significant except for one. This is the parameter for the proximity to the lakeshore at 600 metres variable, which was introduced in the utility of the row-link housing. This means that the explanatory power of that variable is diminished in the presence of other explanatory variables.

However, the majority of the parameters either retained or suffered a slight decrease in their explanatory power when compared to the estimation results of the individual models. Examples of variables that retained their explanatory power in the full model specification are the following: the variable proximity to a recently constructed express way within 400 metres introduced in the utility of condominium housing. Also, the variable proximity to parks and recreational land uses within 400 metres specified in the utility of single family detached housing. An example of variables that lost some of their explanatory power in the full model is the proximity to industrial land uses within 800 metres used in the utility of the detached housing type. Another example is the proximity to community centres within 1000 metres for the semi-detached and condominium housing.

Interestingly, the significance of several parameters in the full model estimation appears to be enhanced when compared to the estimation results of the individual models. An example of such variables is the proximity to highways and major roads within 100 metres specified in the utility of row-link housing. Another example is the proximity to highways and major roads within 200 metres introduced in the utility of single family detached housing. These results confirm the highly significant role of the road infrastructure factors in the choice of the housing type by residential developers.

A few other variables that appeared to be highly significant in the full model estimation are summarized here. The first is the population density variable specified in the utilities of detached, semi-detached, and condominium housing types. It has a negative and highly significant parameter, which suggests that the likelihood of observing those types of residential development compared to row-link housing is lower in census tracts with high population densities. On the other hand, a variable with positive and highly significant parameter is the difference in the average house values between 1996 and 1991 at the census tract level. This variable is introduced in the utility of detached housing and provides an important insight into the developers' profit maximizing behaviour. In essence, developers tend to favor the development of single family detached houses in land parcels located in areas associated with increasing housing values. This is because these increasing housing values may indicate locations with increased housing demand. In turn, the increasing demand at specific locations signals the potential of high profit from sales made by the developers. Thus, developers tend to develop the type of product that potentially can allow them to achieve the highest profit, which is the single family detached.

Another interesting result is related to the variable that intends to capture the phenomenon of spatial inertia in condominium development. This variable is a count of the number of parcels developed in condominium housing between 1991 and 1995 within a distance of 750 metres from each parcel that was developed for condominium housing between 1996 and 2000. The estimated parameter is positive and highly significant. This indicates the important influence that the spatial inertia exerts on the developers' decision to develop a parcel for condominium housing. That is, when a parcel is to be developed for residential use, then the number of parcels that were developed into condominium housing in the vicinity of that parcel during the recent past may influence the choice of condominium housing type. Precisely, larger numbers of parcels developed to condominium housing in the vicinity increase the propensity for condominium development in the parcel to be developed, other things being equal. This result of the full model provides us with an excellent example of the spatial momentum of investments in the housing market of Hamilton. It is worth noting that this result is consistent with findings of another similar study on residential development (Haider and Miller, 2004, p. 155).

Accessibility to employment is another highly significant explanatory variable in the full model. This covariate is introduced in the utility specification of detached housing and the estimated parameter retains its positive sign when compared to the individual model of residential amenities. This result suggests that developers place high importance on levels of accessibility to employment when they consider developing a parcel for detached housing. Specifically, the higher the level of accessibility to employment that a parcel enjoys, the more likely it is to be developed into detached housing, as compared to the three other alternative types, other things being equal. In essence, the model explains that developers consider a location's level of accessibility to employment as a very attractive factor for potential buyers of single family detached houses. Hence, developers tend to provide that housing type at locations with high accessibility to employment.

Finally, the variable with the highest significance in the full model is presented here. Proximity of land parcels to neighborhood shopping centres within 400 metres is positive and highly significant for the row-link and condominium housing type choice. As presented in table 5.4, this variable is specified in the utilities of row-link and condominium types using the same coefficient. This form of specification implies that proximity to neighborhood shopping centres does not affect the relative utilities of row-link and condominium housing but rather each one's utility as compared to detached and semi-detached types of housing. The highly significant result suggests that developers place great importance on a parcel's close proximity to neighborhood shopping centres when deciding to develop it for row-link or condominium housing. In that respect, the model brings evidence on the locational strategic behaviour of the developer's firm. That is, other things being equal, developers attempt to make their row-link and condominium housing products more attractive by developing parcels that are in proximity to an important residential amenity, namely the neighborhood shopping centres.

Table 5.4: Multinomial Logit Model of Types of Residential Development in Hamilton, Ontario. 1996-2000

		Model 1		Model 2		Model 3		Full Model	
Covariate	**Alternative**	**beta**	**t-stats**	**beta**	**t-stats**	**beta**	**t-stats**	**beta**	**t-stats**
Constant 1	D	3.5753	19.015	2.9877	18.165	6.2839	26.005	4.7756	10.748
Constant 2	S	-1.4217	-4.525	1.2712	7.962	0.3164	1.114	-0.3919	-0.942
Constant 3	R	0.9259	4.744	2.1635	13.341	3.5569	13.6	2.1538	4.66
Road Infrastructure Model									
Proximity to Highways and Major Roads, 100m	R	0.7418	7.767					0.8135	8.062
Proximity to Highways and Major Roads, 200m	D	-0.6669	-7.398					-0.7798	-8.365
Proximity to Highways and Major Roads, 400m	S	1.2806	3.869					1.0283	3.365
Proximity to Highways and Major Roads, 600m	C	-1.4261	-6.023					-1.1383	-3.748
Proximity to Highway Ramps (1995), 200m	D	-0.9657	-5.788					-0.7178	-4.003
Proximity to Highway Ramps (1995), 800m	R	0.7468	7.114					0.7305	5.494
Residential Amenities Model									
Proximity to Community Centres, 1000m	S, C			1.0066	5.342			0.8207	3.984
Proximity to Community Centres, 1500m	R			-1.0252	-8.872			-0.9268	-7.154
Proximity to Schools, 600m	D, R			0.6466	4.366			0.383	2.408
Accessibility to Employment (distance)	D			6.4798	16.162			7.2501	13.605
Proximity to Woodlots, 400m	D, S, C			0.7795	5.005			0.4564	2.769
Proximity to Parks and Recreational Land Uses, 200m	C			1.3936	4.341			2.0026	5.754
Proximity to Parks and Recreational Land Uses, 400m	D			0.6752	7.56			0.7882	7.716
Proximity to Parks and Recreational Land Uses, 500m	R			1.128	11.321			0.9274	8.593
Proximity to Neighbourhood Shopping Centres, 400m	R, C			1.4305	14.984			1.581	13.779

D: Detached, **S**: Semi-Detached, **R**: Row-Link, **C**: Condominium

Table 5.4 (continued): Multinomial Logit Model of Types of Residential Development in Hamilton, Ontario. 1996-2000

		Model 1		Model 2		Model 3		Full Model	
Covariate	**Alternative**	**beta**	**t-stats**	**beta**	**t-stats**	**beta**	**t-stats**	**beta**	**t-stats**
General Site Characteristics Model									
Pop. Density in 1996 (Census Tract)	**D, S, C**					-2.2887	-6.699	-3.7506	-7.396
Proximity to Industrial (All) Land Uses, 800m	**D**					-0.5977	-7.825	-0.2981	-3.321
Total Residential Floorspace Created between 1991 and 1995 within a Radius of 1500m	**D, R, C**					-0.1752	-7.553	-0.083	-3.712
Difference in Av. House Value between 1996 and 1991 (Census Tract)	**D**					3.0093	8.696	4.2441	6.907
Difference in Av. House Value between 1996 and 1991 (Census Tract)	**R**					1.8571	4.781	2.1412	3.118
Proximity to a recently constructed Express way, 800m	**D**					0.7657	5.421	0.679	4.116
Proximity to a recently constructed Express way, 200m	**R**					1.0957	3.145	1.8667	4.882
Proximity to a recently constructed Express way, 400m	**C**					1.4894	2.418	1.9352	2.948
Proximity to the Lakeshore, 600m	**R**					1.0468	5.985	0.2574	1.22
Proximity to the Lakeshore, 600m	**C**					2.1999	4.977	2.0572	4.486
Number of Land Parcels Developed as Condominiums between 1991 and 1995 within a radius of 750m	**C**					0.3896	10.189	0.4316	10.155
Number of Observations		6482		6482		6482		6482	
Log-Likelihood at zero		-8985.93		-8985.93		-8985.93		-8985.93	
Log-Likelihood constants only		-3570.71		-3570.71		-3570.71		-3570.71	
Log-Likelihood at convergence		-3316.31		-3243.47		-3367.71		-2851.96	
ρ^2 restricted		0.0712		0.0916		0.0568		0.2013	
ρ^2 naive		0.6309		0.6390		0.6252		0.6826	

D: Detached, **S**: Semi-Detached, **R**: Row-Link, **C**: Condominium

5.4 Conclusion

In this chapter, we presented the specification and the estimation of the conditional multinomial logit model for the type (outcome) of residential development process in Hamilton between the beginning of the year 1996 and the end of the year 2000. The purpose of our modeling exercise was to bring some evidence on the behaviour of residential land developers with respect to the location factors influencing their choices on constructing particular types of housing.

Four conditional MNL models were specified and estimated in an attempt to classify and test the major factors influencing the housing type choices. Each group of factors corresponded to one of the four specifications. The first group of factors relates to the role of the road infrastructure in the study area. The second group of factors intends to explain the effect of the residential qualities of different locations on the housing type choices of residential developers. The third group of factors intends to test the effect of several generic urban form characteristics on the residential development process. The last group of factors consists of the combination of the three groups above and attempts to apply a more holistic test on the process in order to achieve a more global view for the process under study.

The variables that were used in the models were constructed mainly by making use of the micro-level land parcel dataset available to us and some more data sources mainly acquired at the level of census tract from the census records of Statistics Canada. Variables that were tested in the models include proximity to highways and major roads, proximity to various land uses (shopping centres, recreational uses, industrial etc.), proximity to landscape characteristics (lakeshore, woodlots), population density and others. The major findings from the model are related to location characteristics that attract or repel different types of housing development.

CHAPTER SIX

Conclusion

6.1 Thesis Conclusions

This research has focused on the study of the land development process that took place in Hamilton, Ontario between 1950 and 2003. Specifically, two main tasks were carried out throughout the analysis conducted here. The first was the exploration of spatial and temporal patterns in total development as well as in residential and commercial development that occurred in the period between 1950 and 2003. The second was the modeling of developers' spatial behaviour that influenced their choices on the type of residential land development during the five-year period between 1996 and 2000.

In more detail, the purpose of the exploratory analysis of the land development process was to reveal the trends in the evolution of urban form over space and time. In order to understand the outcome of the process, the dynamics of its intensity and spatial pattern over the study period were presented for the total land development; and, for the residential as well as for commercial types of development. The intensity and spatial pattern of total land development were outlined in a descriptive manner that portrayed the overall profile and picture of the process. Furthermore, the intensity and spatial pattern of residential and commercial development were examined in our attempt to extract information on the two separate, yet interconnected, processes (i.e. residential and commercial) that are generally considered as responsible for the configuration of urban form.

The methods that were employed for the exploratory part of this thesis include descriptive tables and diagrams, kernel density maps and point pattern analysis. Precisely, the tables and diagrams were used to depict the trends in the amount of floorspace created in each region of Hamilton city and during each decade of the study period. Kernel density maps were used to illustrate the intensity of new residential and commercial floorspace developed by the process over the study area and during each decade of analysis. Consequently, the 'hot spots' of new development and their spatial paths over time were traced and visualized. Lastly, point pattern analysis along with the locations of land parcels that accommodated new residential or commercial development were employed in the investigation for spatial dependence (clustering) among the points of each pattern (univariate analysis); i.e. clustering among the points that denote parcels developed for residential use. Point pattern analysis along with the above point patterns was also used to investigate spatial dependency (co-clustering) between the two observed patterns (bivariate analysis); that is, between the point pattern of parcels developed in residential use and the point pattern of parcels developed in commercial use.

The findings from the exploration revealed that between 1950 and 2003 the trend of land development was decentralizing and the majority of new floorspace construction was occurring in locations outside and away from the existing urban core (lower Hamilton). In particular, the new residential floorspace constructions was sprawling towards new and undeveloped land at the urban fringe; and was occurring as contiguous or leapfrog development at a continuously increasing distance from the city centre during the study period. This decentralizing trend became more prevalent after 1980 when residential development at the peripheral regions of Flamborough, Ancaster, Stoney Creek and to a less extent Dundas became intensive. Moreover, new commercial floorspace construction appeared to be more centralized until the end of the 1970's. However, commercial development revealed a decentralizing trend after 1980, while the majority of it was focused at the peripheral regions during the 1990's. The evidence brought from this part of the exploratory analysis provided us with an indication of a potential multinucleation process that is in progress. Finally, the last part of the exploratory analysis provided proof for co-clustering of residential and commercial development during the 1990's with a temporal lag of 3-7 years approximately.

The second main area of analysis in this research was the modeling of the housing-type choice of developers involved in residential land development. The purpose of the modeling exercise was to identify and explain the spatial factors that influenced the developers' choices on the type of housing they construct on each land parcel they develop. Four major outcomes of residential development were modeled as the possible alternative choices for developers; those were the detached, semi-detached, row-link, and condominium housing types. Following previous efforts in the literature, the model used to explain the choices of developers was the conditional multinomial logit. The data employed in the model were mostly based on the micro-level land parcel dataset available to us for the city of Hamilton. Three groups of spatial variables were constructed and introduced in the utilities of the four alternatives according to findings from the literature as well as to our own understanding of the land development process.

These three groups were road infrastructure, residential amenities, and general site characteristics variables.

The results from the logit model provided us with a wealth of information related to the influence that various spatial characteristics of a land parcel (site) have on the housing type a developer selects to construct on a site. Briefly, the construction of detached housing is more likely to occur on sites located in areas with suburban characteristics such as low population density, proximity to parks, recreational uses, schools, and greenspace as well as distance from highway and major roads, and from shopping centres. Semi-detached housing is attracted to sites that combine some suburban characteristics such as low population density and proximity to greenspace, with some design features such as proximity to highways and major roads and proximity to community centres that are offered by sites found at more central locations. The construction of row-link housing is more likely to occur on sites located in areas that combine residential qualities such as proximity to schools, parks, recreational uses, and neighbourhood shopping centres with high levels of accessibility and mobility such as proximity to highway ramps etc. Lastly, condominium housing is attracted to sites located in new residential areas with prestigious landscape features and low population density, but in relative proximity to community centres, as well as to shopping and leisure activities.

6.2 Planning and Policy Implications

The results of this research as presented in chapter 4 and 5 and briefly summarized in the previous section provided us with insights about the land development process that took place in Hamilton from 1950 to 2003. The results from exploration brought evidence on how land development evolved the city's urban form over time as well as on which are the driving forces of this evolution. In addition, the results of modeling explained some of the very basic locational factors that influence the type of residential development at the very fine (micro) level of site development.

What we learned is that the pattern of residential and commercial development over the past five decades contributed to the horizontal expansion of the city by consuming large amounts of new and undeveloped land. This land was located outside and in distance from the existing urban core of the city. Land development sprawled by following two major patterns that gave rise to a large urban setting. The first pattern was manifested as contiguous and low density expansion occurring in an ever increasing distance from the old city and mainly at the outskirts of the urban area. The second pattern took place outside of the urban fringe forming preliminary local clusters of isolated leapfrog development.

The oversized urban setting along with the low-density neighbourhoods made the viability of transit system almost impossible and the dependence on private automobile almost inevitable. The continuous residential expansion consumed the rural land that was surrounding the urban area. This development pattern also led the old city and especially the downtown to deterioration. In addition, the horizontal expansion of the city revealed the need for more road infrastructure. The consequent increase in the supply of that infrastructure created new opportunities for additional sprawling development. In short, this study revealed the negative implications of residential and commercial land development on the sustainability of Hamilton. The evolution of urban form during the fifty-four years of the study period induced impacts that do not promote a sustainable future for the city. Examples of those impacts include major loss of rural land, increased energy consumption and emissions of greenhouse gases stemming from the extensive automobile usage, as well as environmental impacts such as pollution of land and air.

As it was highlighted earlier in this thesis (chapter 2) urban planners consider urban sprawl an undesirable, costly and inefficient form of development. A land development process in Hamilton that will continue to be occurring in the future according to its pattern in the past guarantees an inefficient and non sustainable prospect for the city. Hence, the strategic design and implementation of a policy that will mitigate if not confine the current dynamics in urban form should be a major priority for the City.

For the importance and the potential use of our modeling results, it should be stated here that the work done in this thesis can serve as input to a planning support system. The specified and estimated model is able to capture the behaviour of land developers related to their choices of housing types when they construct residential projects. In other words, the choices of developers on the types of residential construction are seen and interpreted through the three groups of spatial variables that were used in the model.

These variables can be used as policy handles and can serve in the testing of different alternative growth scenarios. More specifically, in the presence of a growth scenario that intends to apply a policy related to land use planning or road infrastructure, the variables of the model could be measured on the basis of the spatial data (GIS layers) that reflect the policy rules. Then these variables can be used to run a simulation that will check the reaction of developers to the specified policy. Consequently, land use planning policies that designate parks, recreational land uses, greenspace, industrial areas, and shopping centres can be tested in the model in order to check the resulting outcomes of the residential land development. In a similar manner, road infrastructure policies, i.e. the construction of a new highway or of a new expressway can be tested in the model in order to explore their implications on the types of future residential development. Accordingly, the model provides a tool for checking the implications of various land use and/or road infrastructure policies on the evolution of urban form. This is justified by the fact that the development of different housing types promotes different typologies of urban form (i.e. the difference between detached and row-link housing).

6.3 Directions for Future Research

Within the discrete choice framework and under the concept of utility maximization, a model of individual choices includes a utility function for each alternative choice faced by each decision maker. There are two types of variables that can enter the utility function of each alternative: attributes of the alternative choices and characteristics of the decision maker. However, the conditional MNL models that were presented in chapter 5 lack data regarding the decision maker characteristics.

Specifically, our models of the housing-type choice of developer firms included variables that only reflected attributes of the four alternative types as observed at the land parcel level. Information representing the attributes of the firms responsible for choices on the housing-type of residential projects was not available to us. Thus, variables describing the characteristics of developer firms were not included in the specifications of our models. It should be noted here that data on the type, size, scale of operation, entrepreneurial approach, lifecycle, and product specialization of a firm could improve the explanatory capability of the models and should be incorporated when data become available.

Other data that could be used in the models in order to improve their explanatory power are land prices at the land parcel level and house prices per square foot for each housing type. The former price variable represents the cost of the major input in the production of a developer firm and the latter depicts the expected revenue from each possible output (product) of the firm. These two variables would have been useful in revealing the impact that the cost of land and the profitability of each outcome have on the developer's choice of housing type. Additionally, data related to macro-economic factors such as interest and inflation rates would have provided a more complete picture of the market conditions and their effect on the housing type choices of developers. Lastly, a variable that would have been important for a better depiction of the market conditions during the modeled period is the vacancy rates per housing type collected at the finest possible geographic level. This variable would reveal the effect of the demand levels by housing type on the developers' supply behaviour.

Another suggestion for future research that could improve the models explanatory power and overall performance is related to the random component of the utility function. In discrete choice models, the random component or disturbance term represents the part of the utility which cannot be observed by or known to the analyst and thus, is uncertain. When modeling the developers' choice on housing type of residential development we assume that the developers' decision is influenced by the characteristics of the site (land parcel) to be developed. However, Mohammadian and Kanaroglou (2003) argue that a developer's decision on the construction of a particular type of housing will be influenced by the existing housing types in the neighbourhood of the land parcel to be developed and, in essence, by past decisions of other developers. Hence, if no variable is able to capture the effect of this neighbourhood factor, then the unobserved attributes of the utility, which are captured by the disturbance term, tend to be correlated. This is believed to be a valid case, at least to some extent, in our models. In order to alleviate the effect of the above issue on the explanatory power, future research should extend the existing model by following the statistical approach suggested by Mohammadian and Kanaroglou (2003) to account for spatial dependency in the choices of developers.

Lastly, the need for modeling the factors affecting the types of non-residential development should be highlighted here. An attempt to explain the land development process in a complete and comprehensive manner requires the modeling of residential as well as non-residential land development. Thus, the specification of a model capable of explaining the most influential factors that give rise to the various types of commercial, institutional, and industrial development would allow for a better insight into the development process. As such, a full set of models that would treat the total supply of floorspace for activities over the region of Hamilton could be developed and used along with transportation models for planning and research purposes.

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APPENDIX

Tables and Figures Generated from the Exploratory Analysis of the Land Development Process in Hamilton, Ontario

Table A.1: Developed Floorspace per Decade and Geographic Area

1950-1960

Land Use	Lower Hamilton	Upper Hamilton	Ancaster	Dundas	Flamborough	Glanbrook	Stoney Creek	Total of Land Use
Residential	640,366 (63.4)	1,292,998 (88.9)	266,330 (86.8)	187,722 (83.4)	187,100 (84.0)	107,578 (86.2)	377,335 (84.9)	3,059,429 (80.8)
Commercial	120,943 (12.0)	71,418 (4.9)	4,316 (1.4)	2,663 (1.2)	9,257 (4.2)	6,664 (5.3)	19,655 (4.4)	234,916 (6.2)
Industrial	129,215 (12.8)	3,480 (0.2)	1,117 (0.4)	13,526 (6.0)	2,983 (1.3)	608 (0.5)	9,411 (2.1)	160,340 (4.2)
Other	118,912 (11.8)	87,536 (6.0)	34,895 (11.4)	21,218 (9.4)	23,480 (10.5)	9,922 (8.0)	37,894 (8.5)	333,858 (8.8)
Total Development	1,009,518 (100)	1,455,192 (100)	306,659 (100)	225,129 (100)	222,819 (100)	124,773 (100)	444,295 (100)	3,788,385 (100)

1961-1970

Land Use	Lower Hamilton	Upper Hamilton	Ancaster	Dundas	Flamborough	Glanbrook	Stoney Creek	Total of Land Use
Residential	911,182 (65.7)	1,024,854 (85.6)	82,439 (69.9)	214,187 (86.5)	169,574 (76.0)	85,609 (80.0)	186,634 (60.9)	2,674,481 (74.6)
Commercial	123,780 (8.9)	55,493 (4.6)	10,796 (9.2)	11,195 (4.5)	10,202 (4.6)	3,414 (3.2)	10,117 (3.3)	224,997 (6.3)
Industrial	193,381 (13.9)	3,849 (0.3)	4,314 (3.7)	8,306 (3.4)	6,846 (3.1)	2,561 (2.4)	53,400 (17.4)	272,658 (7.6)
Other	159,075 (11.5)	113,035 (9.4)	20,333 (17.2)	14,029 (5.7)	36,542 (16.4)	15,405 (14.4)	56,389 (18.4)	414,809 (11.6)
Total Development	1,387,41 8 (100)	1,197,232 (100)	117,882 (100)	247,718 (100)	223,165 (100)	106,990 (100)	306,541 (100)	3,586,945 (100)

Note: **(values in brackets are percentages)**

Table A.1 (continued): Developed Floorspace per Decade and Geographic Area

1971-1980

Land Use	Lower Hamilton	Upper Hamilton	Ancaster	Dundas	Flamborough	Glanbrook	Stoney Creek	Total of Land Use
Residential	932,785 (66.3)	1,076,438 (84.1)	98,106 (75.5)	157,689 (87.6)	258,830 (79.8)	61,408 (70.1)	475,856 (68.7)	3,061,112 (74.7)
Commercial	187,169 (13.3)	77,365 (6.0)	9,555 (7.4)	9,222 (5.1)	17,937 (5.5)	5,647 (6.5)	35,235 (5.1)	342,131 (8.3)
Industrial	146,595 (10.4)	21,987 (1.7)	6,246 (4.8)	5,839 (3.2)	3,561 (1.1)	1,344 (1.5)	165,646 (23.9)	351,218 (8.6)
Other	140,216 (10.0)	104,225 (8.1)	15,991 (12.3)	7,217 (4.0)	43,828 (13.5)	19,148 (21.9)	15,512 (2.2)	346,135 (8.4)
Total Development	1,406,765 (100)	1,280,015 (100)	129,898 (100)	179,966 (100)	324,156 (100)	87,548 (100)	692,249 (100)	4,100,597 (100)

1981-1990

Land Use	Lower Hamilton	Upper Hamilton	Ancaster	Dundas	Flamborough	Glanbrook	Stoney Creek	Total of Land Use
Residential	155,530 (42.0)	1,341,563 (85.3)	590,955 (89.8)	189,793 (98.8)	327,464 (81.7)	36,009 (42.4)	782,453 (84.2)	3,423,767 (81.4)
Commercial	107,987 (29.2)	81,331 (5.2)	5,041 (0.8)	951 (0.5)	20,540 (5.1)	2,199 (2.6)	29,576 (3.2)	247,626 (5.9)
Industrial	31,661 (8.6)	121,860 (7.7)	28,367 (4.3)	1,092 (0.6)	9,334 (2.3)	8,871 (10.4)	83,053 (8.9)	284,238 (6.8)
Other	74,694 (20.2)	27,922 (1.8)	33,873 (5.1)	355 (0.2)	43,610 (10.9)	37,860 (44.6)	34,487 (3.7)	252,801 (6.0)
Total Development	369,871 (100)	1,572,675 (100)	658,236 (100)	192,191 (100)	400,949 (100)	84,940 (100)	929,569 (100)	4,208,431 (100)

Note: **(values in brackets are percentages)**

Table A.1 (continued): Developed Floorspace per Decade and Geographic Area

1991-2003

Land Use	Lower Hamilton	Upper Hamilton	Ancaster	Dundas	Flamborough	Glanbrook	Stoney Creek	Total of Land Use
Residential	114,318 (57.5)	894,492 (91.0)	592,361 (87.3)	192,573 (97.5)	575,914 (91.3)	164,830 (93.0)	627,835 (89.5)	3,162,325 (88.6)
Commercial	28,416 (14.3)	28,390 (2.9)	59,798 (8.8)	103 (0.1)	6,023 (1.0)	442 (0.2)	12,147 (1.7)	135,320 (3.8)
Industrial	12,207 (6.1)	8,898 (0.9)	2,174 (0.3)	742 (0.4)	5,458 (0.9)	0 (0.0)	7,390 (1.1)	36,870 (1.0)
Other	43,883 (22.1)	51,478 (5.2)	24,050 (3.5)	4,178 (2.1)	43,076 (6.8)	12,052 (6.8)	54,183 (7.7)	232,900 (6.5)
Total Development	198,825 (100)	983,258 (100)	678,383 (100)	197,597 (100)	630,472 (100)	177,324 (100)	701,555 (100)	3,567,415 (100)

Note: **(values in brackets are percentages)**

Table A.2: The top five land uses of occurred development per decade sorted by floorspace created

1950-1960

Land use code	Floorspace in Sq. Metres	%	Count	%
301	2,629,796.48	69.41	23,273	91.91
340	279,329.58	7.37	163	0.64
605	165,754.87	4.38	62	0.24
520	56,458.86	1.49	88	0.35
701	52,792.10	1.39	87	0.34
Subtotal	3,184,131.89	84.05	23,673	93.49
Other	604,410.28	15.95	1,649	6.51
Total	3,788,542.17	100.00	25,322	100.00

1961-1970

Land use code	Floorspace in Sq. Metres	%	Count	%
301	1,368,891.44	38.16	11,130	84.22
340	1,084,661.01	30.24	208	1.57
605	242,680.35	6.77	56	0.42
520	93,920.69	2.62	137	1.04
530	68,678.00	1.91	31	0.23
Subtotal	2,858,831.49	79.70	11,562	87.48
Other	728,113.04	20.30	1,654	12.52
Total	3,586,944.53	100.00	13,216	100.00

1971-1980

Land use code	Floorspace in Sq. Metres	%	Count	%
301	1,624,909.26	39.63	11,809	72.75
340	972,574.19	23.72	102	0.63
311	247,019.99	6.02	2,332	14.37
520	124,383.25	3.03	150	0.92
605	115,954.81	2.83	27	0.17
Subtotal	3,084,841.49	75.23	14,420	88.83
Other	1,015,755.22	24.77	1,813	11.17
Total	4,100,596.71	100.00	16,233	100.00

1981-1990

Land use code	Floorspace in Sq. Metres	%	Count	%
301	2,956,939.00	70.26	15,140	86.49
374	129,888.69	3.09	11	0.06
430	110,140.20	2.62	82	0.47
520	108,571.12	2.58	134	0.77
580	94,294.99	2.24	57	0.33
Subtotal	3,399,833.99	80.79	15,424	88.11
Other	808,597.51	19.21	2,081	11.89
Total	4,208,431.50	100.00	17,505	100.00

Table A.2 (continued): The top five land uses of occurred development per decade sorted by floorspace created

1991-2003

Land use code	Floorspace in Sq. Metres	%	Count	%
301	2,721,204.41	76.28	13,860	82.11
309	219,887.33	6.16	1,579	9.35
605	124,024.10	3.48	16	0.09
311	70,968.54	1.99	509	3.02
431	59,978.47	1.68	10	0.06
Subtotal	3,196,062.85	89.59	15,974	94.63
Other	371,351.96	10.41	906	5.37
Total	3,567,414.81	100.00	16,880	100.00

Table A.3: The top five land uses of residential development per decade sorted by floorspace created

1950-1960

Land use code	Floorspace in Sq. Metres	%	Count	%
301	2,620,889.41	85.67	23,208	96.39
340	279,329.58	9.13	163	0.68
373	26,663.23	0.87	15	0.06
332	23,271.91	0.76	131	0.54
311	19,034.93	0.62	195	0.81
Subtotal	2,969,189.07	97.05	23,712	98.49
Other	90,239.90	2.95	364	1.51
Total	3,059,428.97	100.00	24,076	100.00

1961-1970

Land use code	Floorspace in Sq. Metres	%	Count	%
301	1,361,885.67	50.92	11,085	91.60
340	1,084,661.01	40.56	208	1.72
352	57,685.79	2.16	16	0.13
311	55,340.44	2.07	517	4.27
625	30,974.53	1.16	2	0.02
Subtotal	2,590,547.44	96.86	11,828	97.74
Other	83,933.29	3.14	274	2.26
Total	2,674,480.73	100.00	12,102	100.00

Table A.3 (continued): The top five land uses of residential development per decade sorted by floorspace created

1971-1980

Land use code	Floorspace in Sq. Metres	%	Count	%
301	1,610,779.44	52.62	11,737	78.02
340	958,127.40	31.30	101	0.67
311	247,019.99	8.07	2,332	15.50
352	80,984.83	2.65	20	0.13
305	36,394.04	1.19	294	1.95
Subtotal	2,933,305.70	95.82	14,484	96.28
Other	127,806.52	4.18	560	3.72
Total	3,061,112.23	100.00	15,044	100.00

1981-1990

Land use code	Floorspace in Sq. Metres	%	Count	%
301	2,946,690.64	86.07	15,094	91.32
374	129,888.69	3.79	11	0.07
305	93,415.13	2.73	637	3.85
309	65,080.26	1.90	393	2.38
340	53,764.57	1.57	17	0.10
Subtotal	3,288,839.30	96.06	16,152	97.73
Other	134,927.50	3.94	376	2.27
Total	3,423,766.79	100.00	16,528	100.00

1991-2003

Land use code	Floorspace in Sq. Metres	%	Count	%
301	2,711,387.30	85.74	13,820	84.30
309	218,220.06	6.90	1,567	9.56
311	70,603.26	2.23	507	3.09
340	34,324.69	1.09	9	0.05
305	23,671.20	0.75	165	1.01
Subtotal	3,058,206.50	96.71	16,068	98.01
Other	104,118.05	3.29	326	1.99
Total	3,162,324.55	100.00	16,394	100.00

Figure A.1: CSR test for Residential Development between the years 1961 and 1970 (99 Sims)

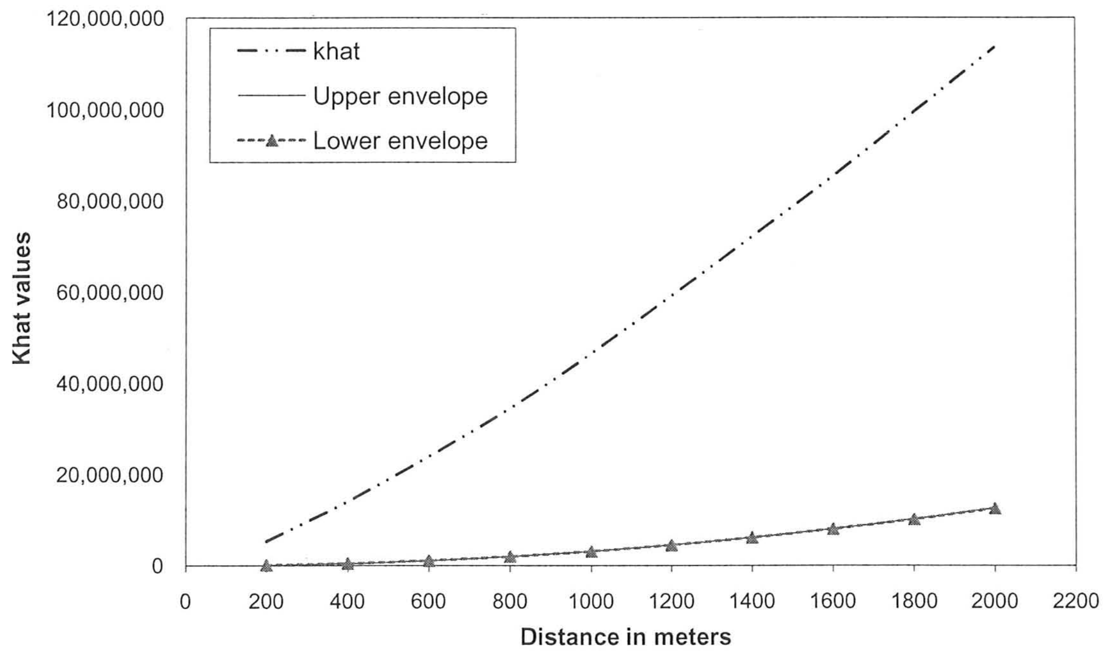


Figure A.2: CSR test for Residential Development between the years 1971 and 1980 (99 Sims)

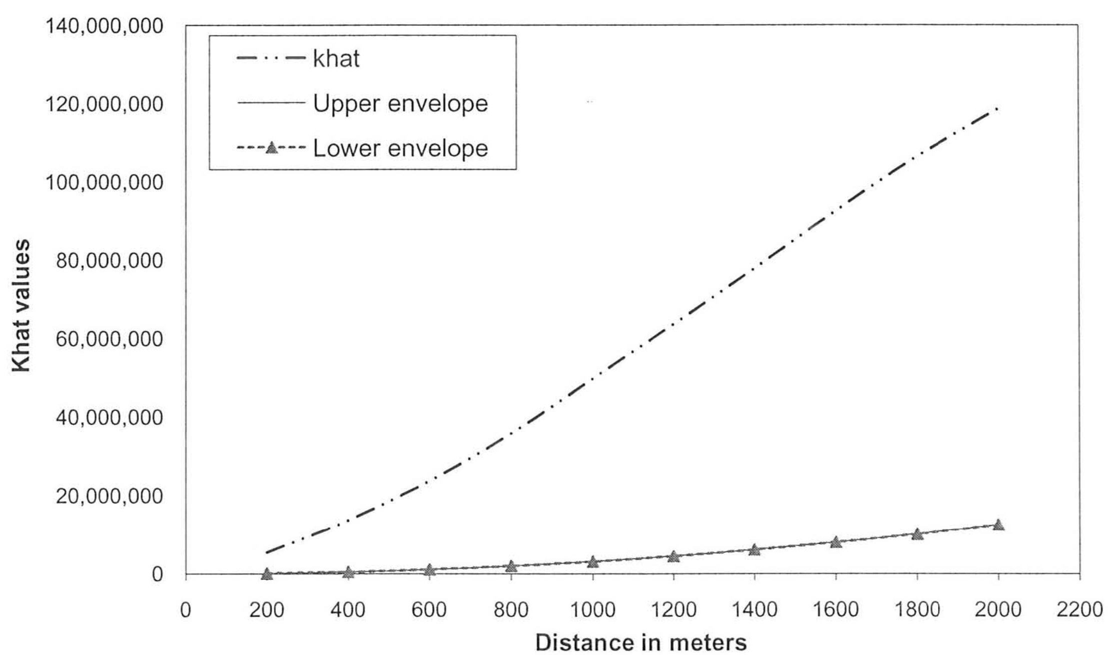


Figure A.3: CSR test for Residential Development between the years 1981 and 1990 (99 Sims)

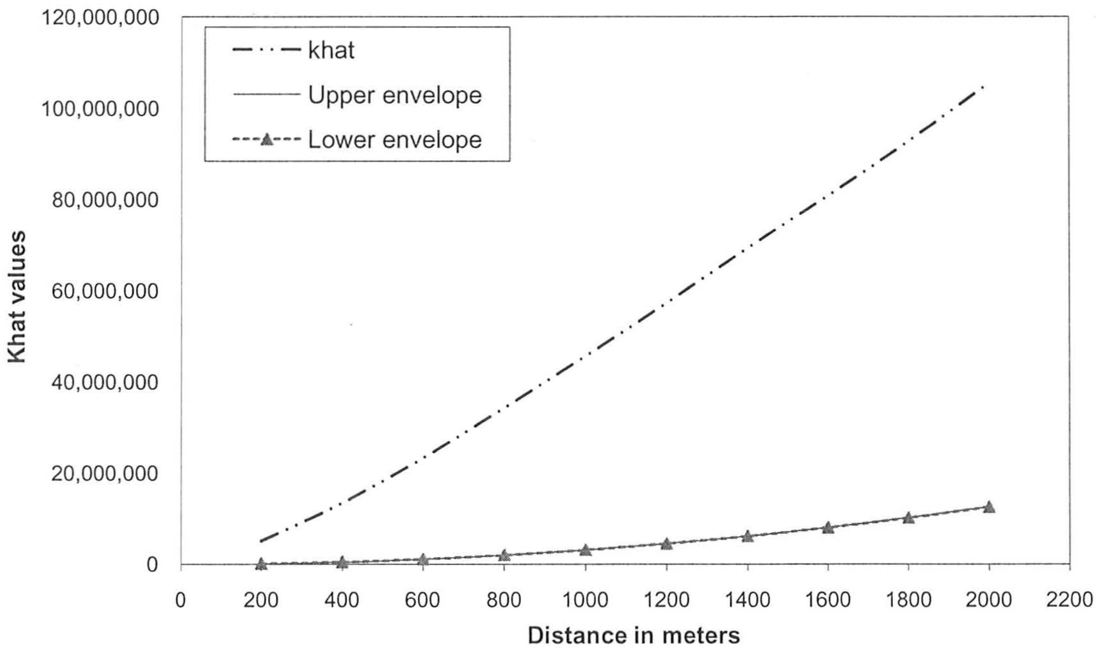


Figure A.4: CSR test for Residential Development between the years 1991 and 2003 (99 Sims)

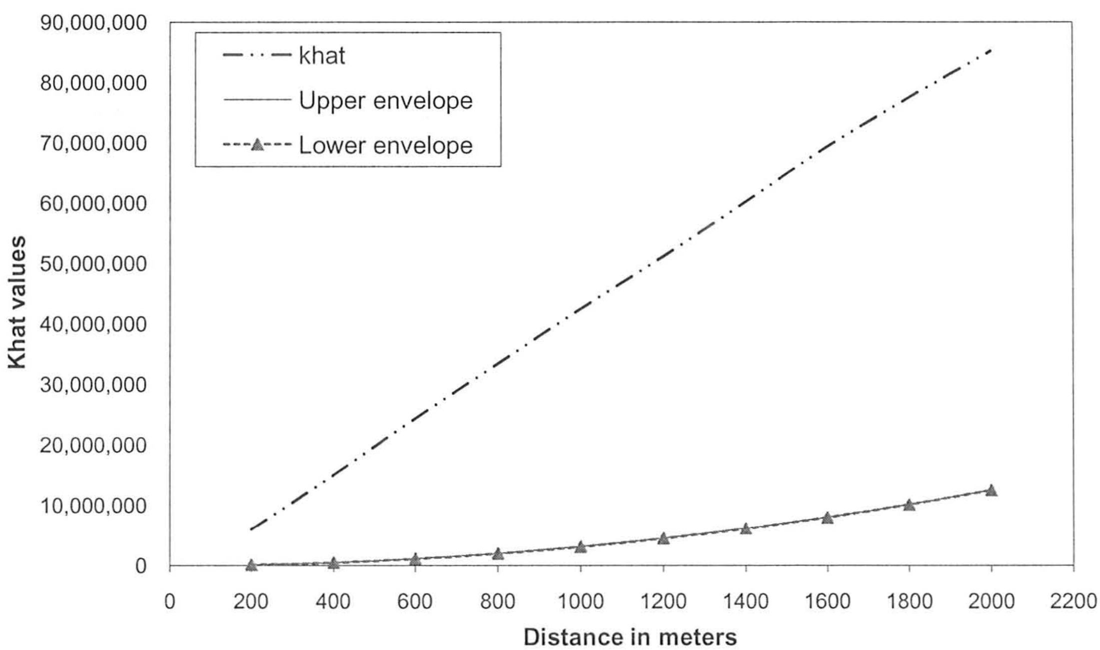


Figure A.5: CSR test for Commercial Development between the years 1951 and 1960 (99 Sims)

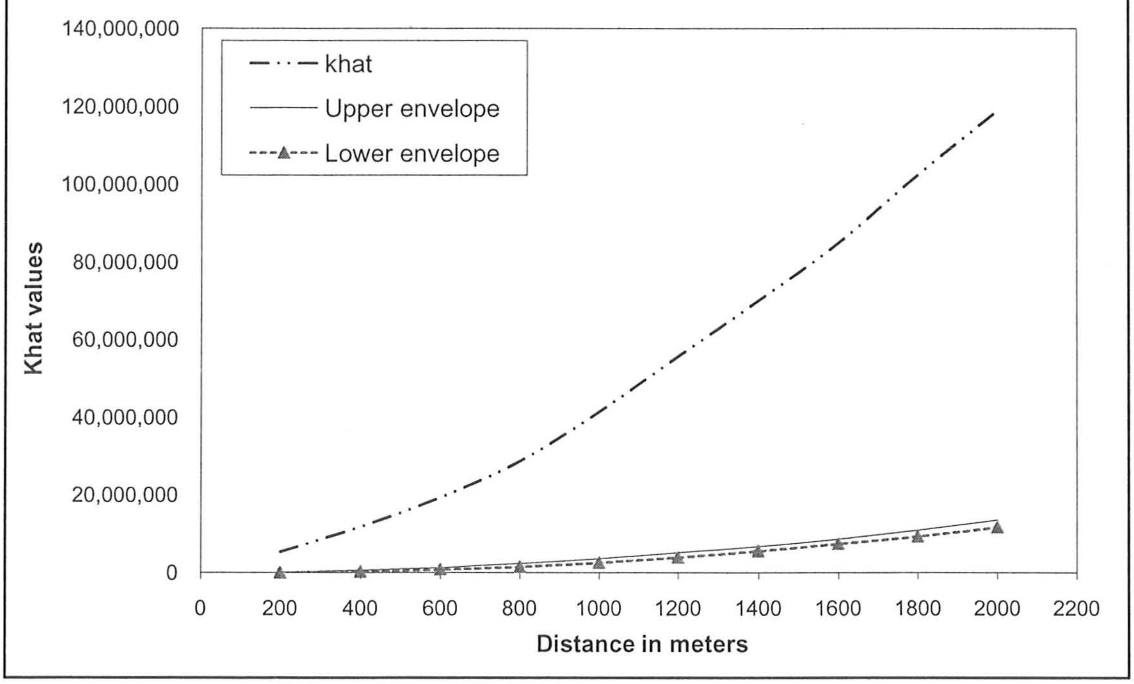


Figure A.6: CSR test for Commercial Development between the years 1961 and 1970 (99 Sims)

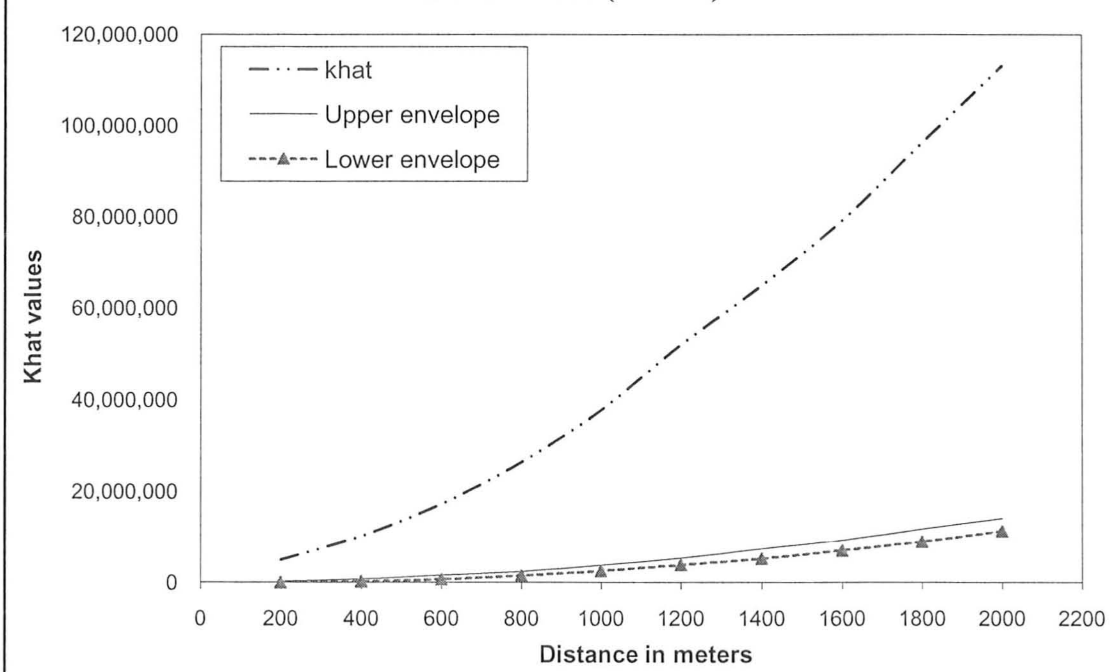


Figure A.7: CSR test for Commercial Development between the years 1971 and 1980 (99 Sims)

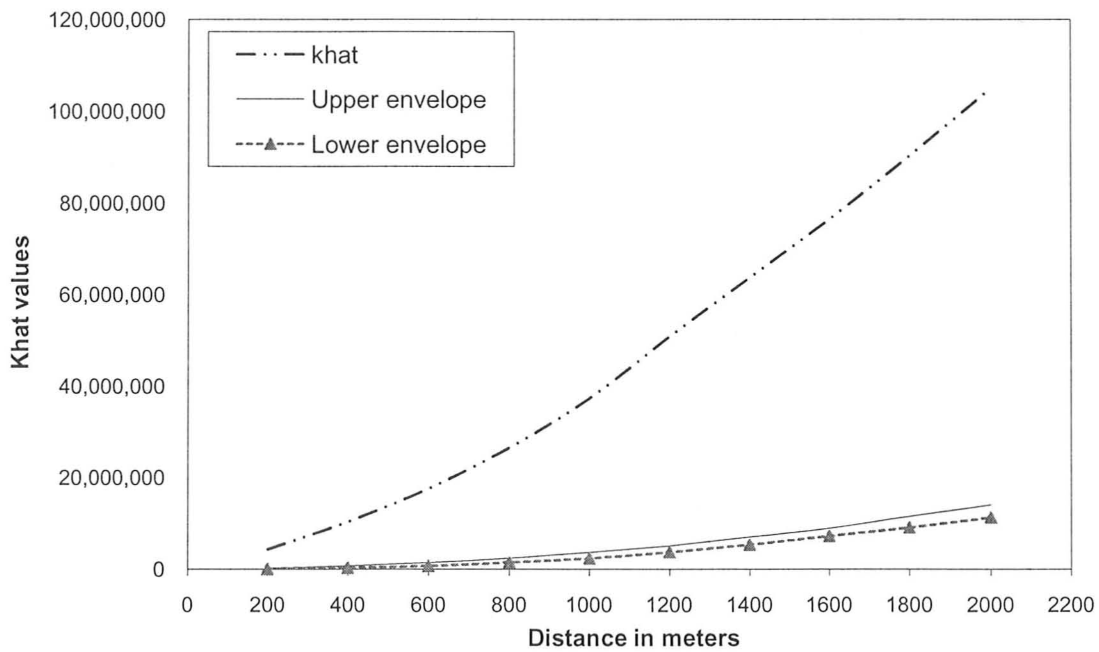


Figure A.8: CSR test for Commercial Development between the years 1981 and 1990 (99 Sims)

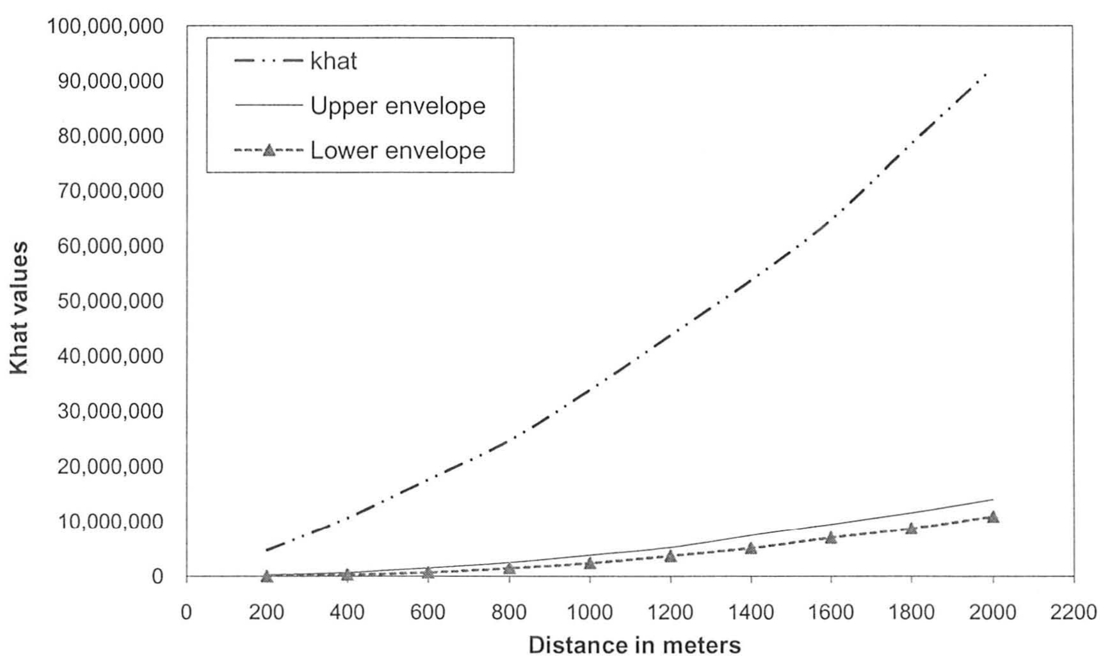


Figure A.9: CSR test for Commercial Development between the years 1991 and 2003 (99 Sims)

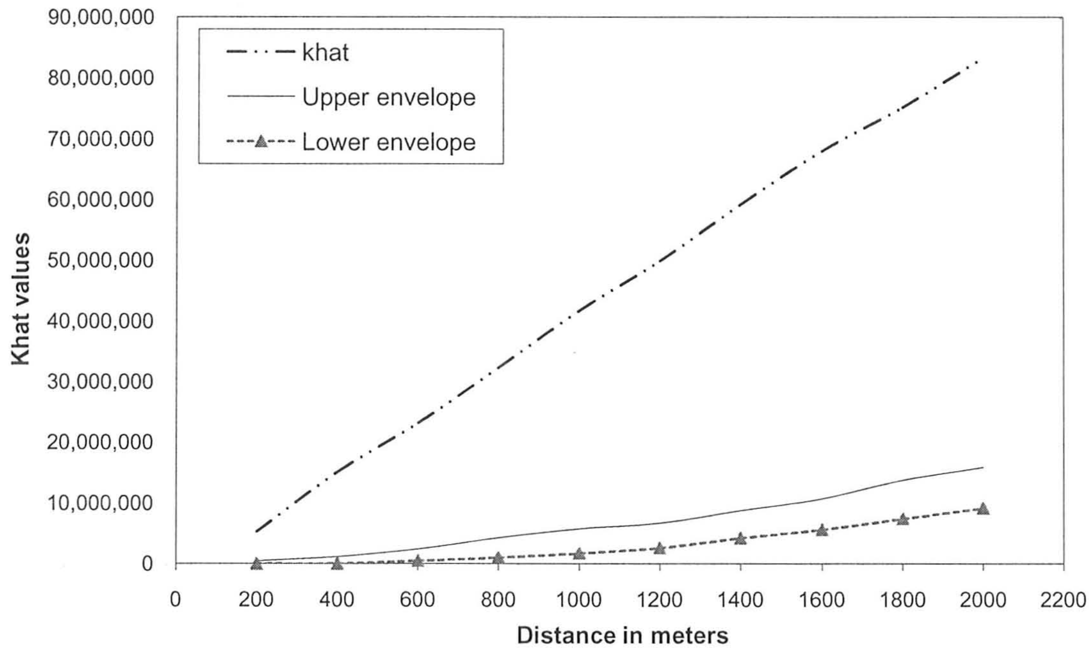


Figure A.10: Commercial (1961 - 1970) versus Residential (1961-1970) Development

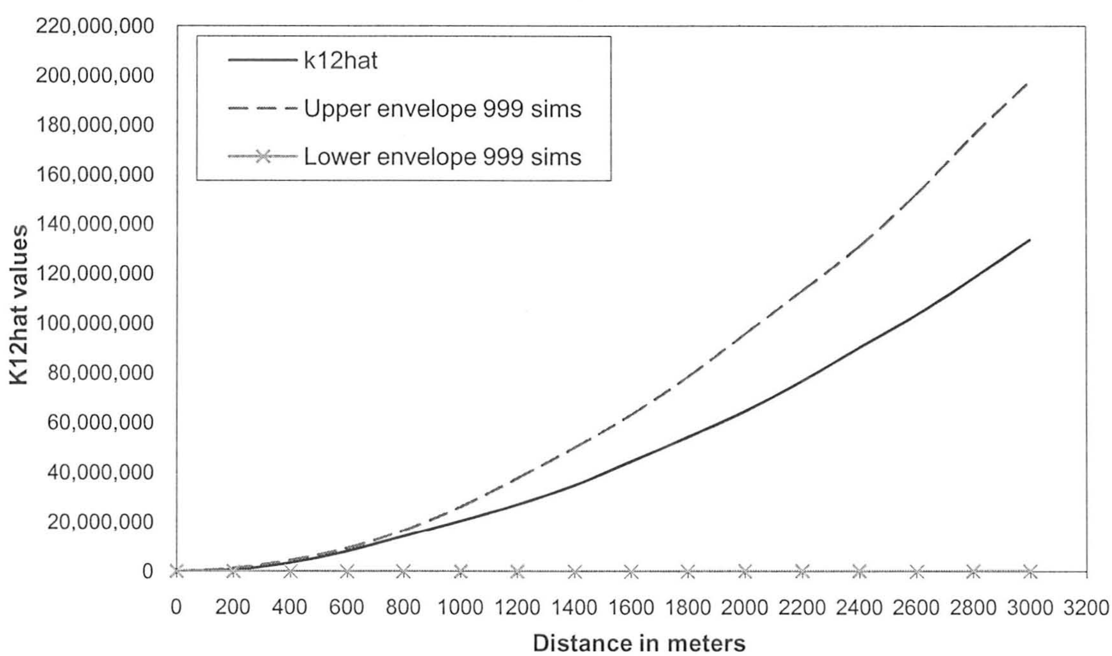


Figure A.11: Commercial (1971 - 1980) versus Residential (1971-1980) Development

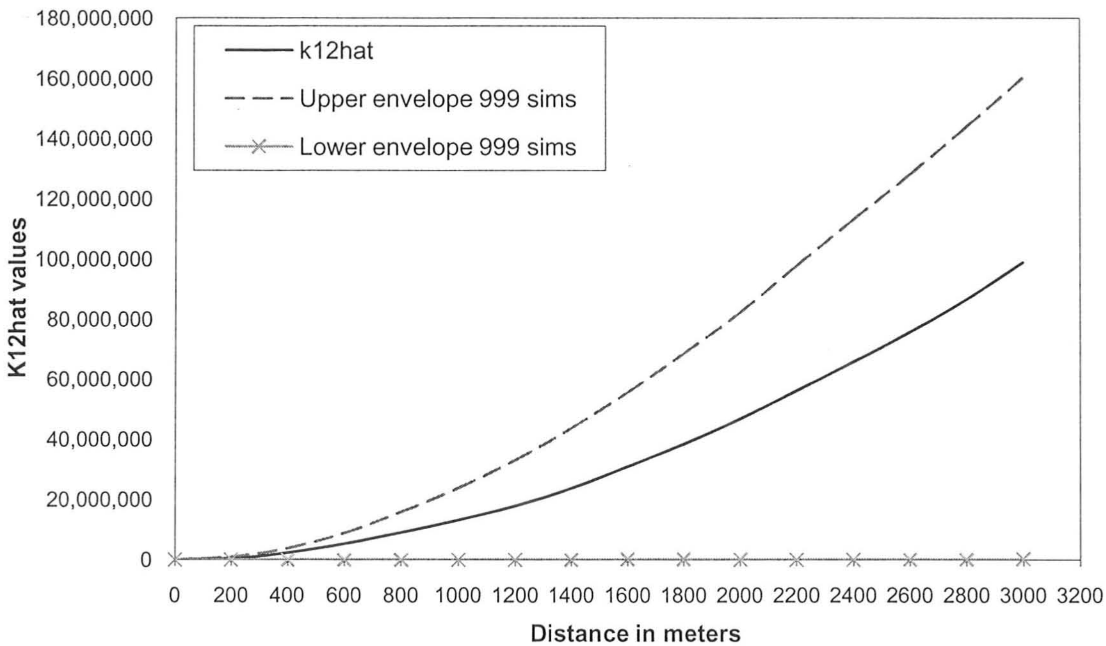


Figure A.12: Commercial (1981 - 1990) versus Residential (1981-1990) Development

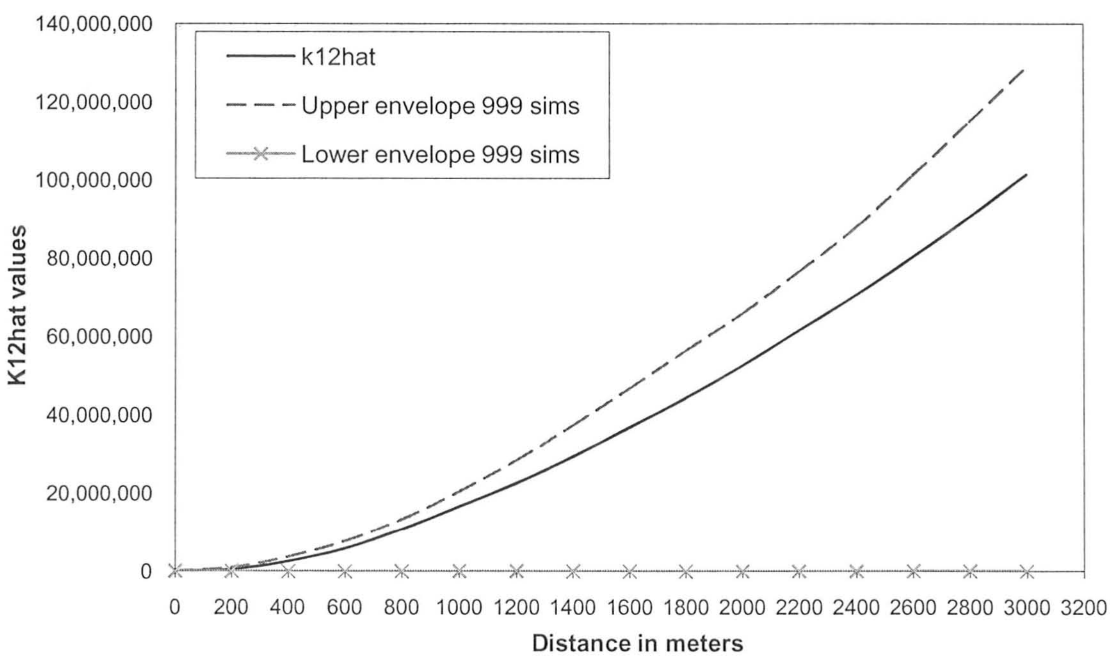


Figure A.13: Clustering of Commercial Land Development (1990-1991) Around Existing Residential Land Development (1986 - 1990)

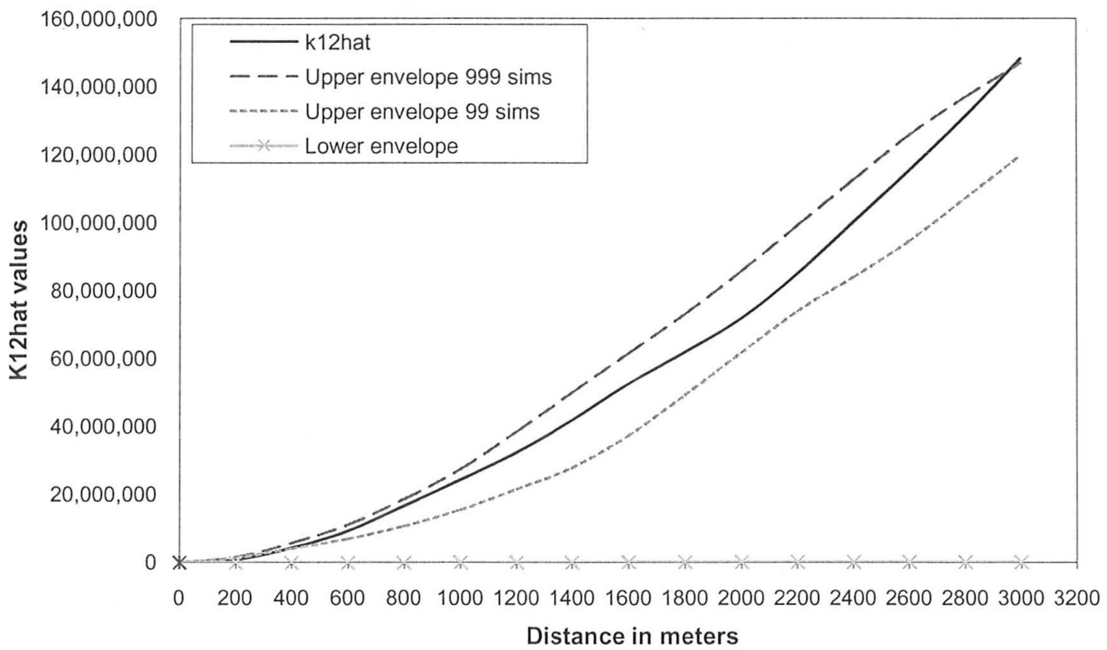


Figure A.14: Clustering of Commercial Land Development (1990-1992) Around Existing Residential Land Development (1986 - 1990)

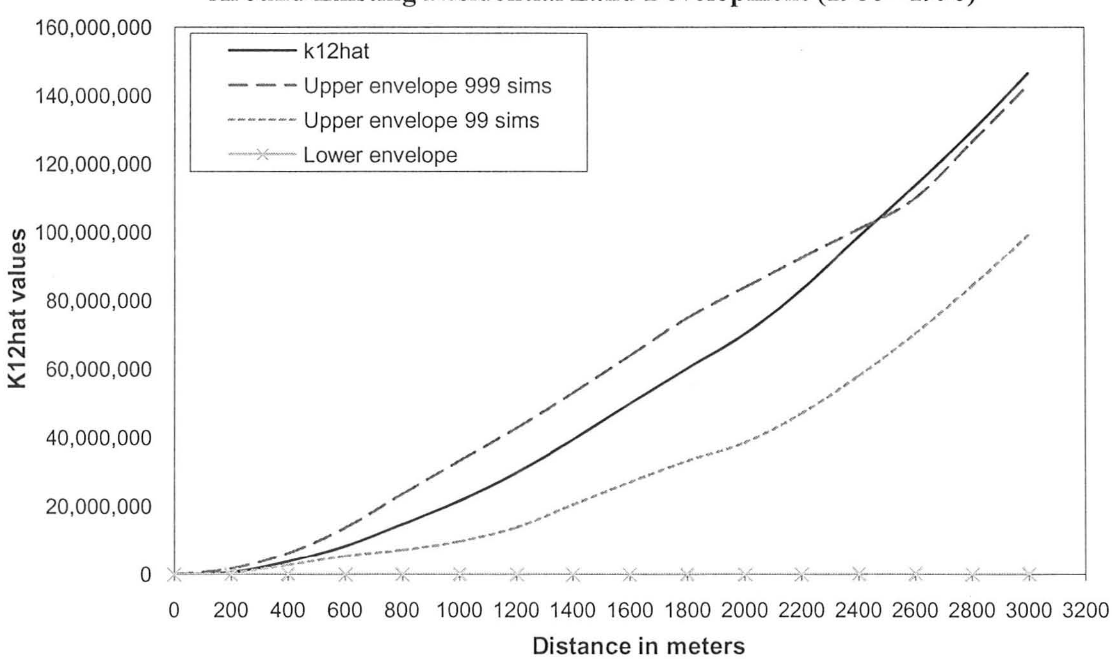


Figure A.15: Clustering of Commercial Land Development (1990-1993) Around Existing Residential Land Development (1986 - 1990)

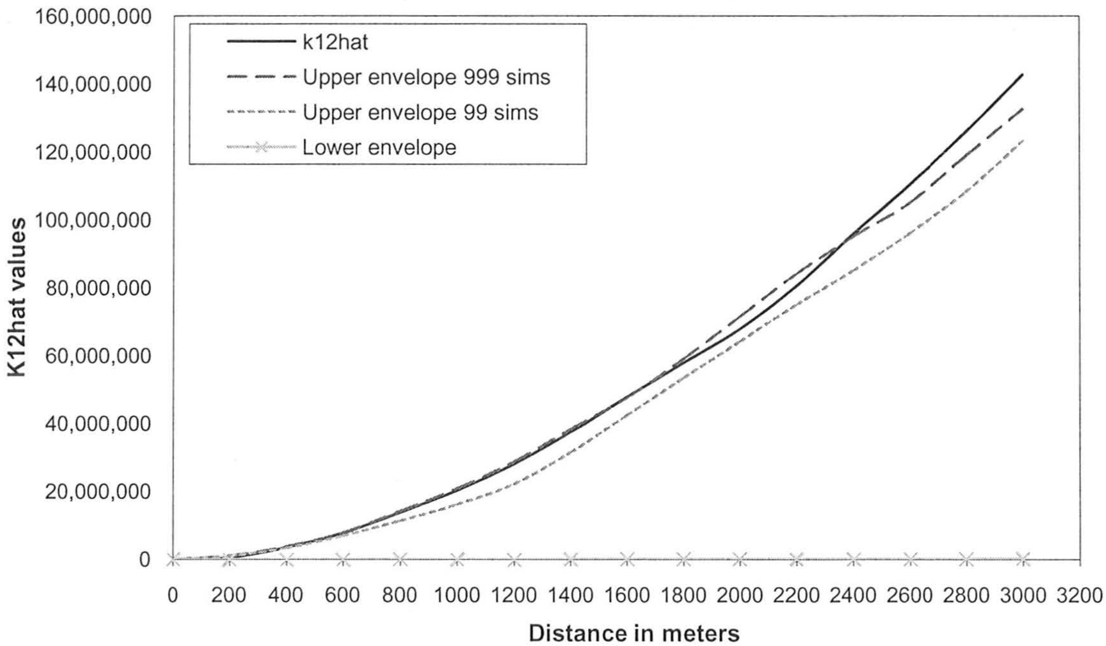


Figure A.16: Clustering of Commercial Land Development (1990-1994) Around Existing Residential Land Development (1986 - 1990)

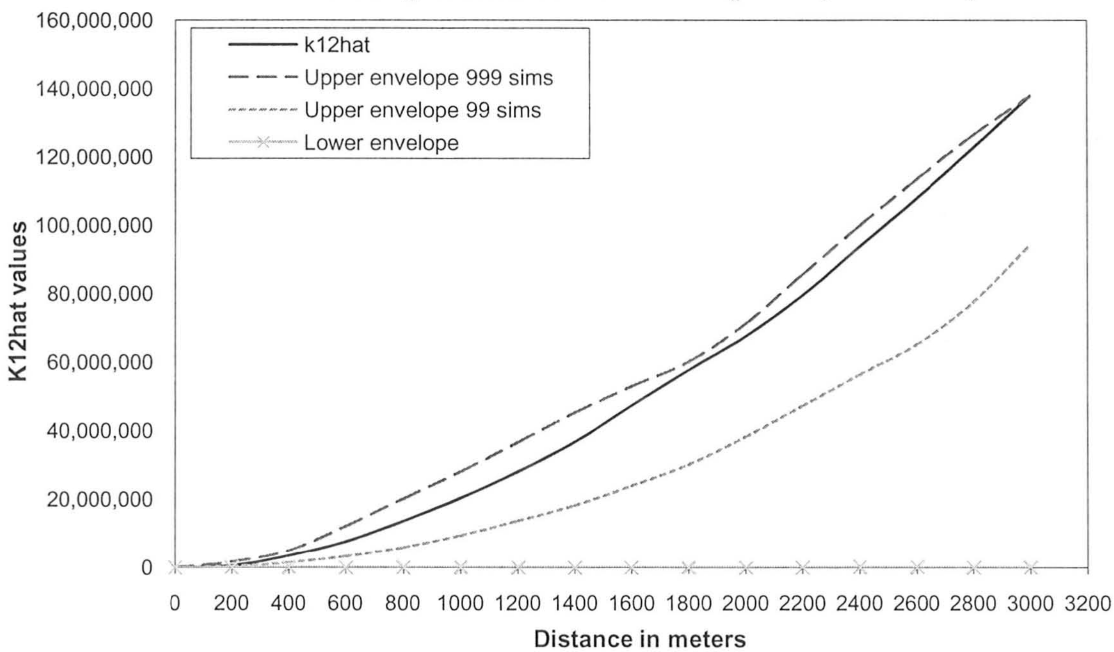


Figure A.17: Clustering of Commercial Land Development (1990-1995) Around Existing Residential Land Development (1986 - 1990)

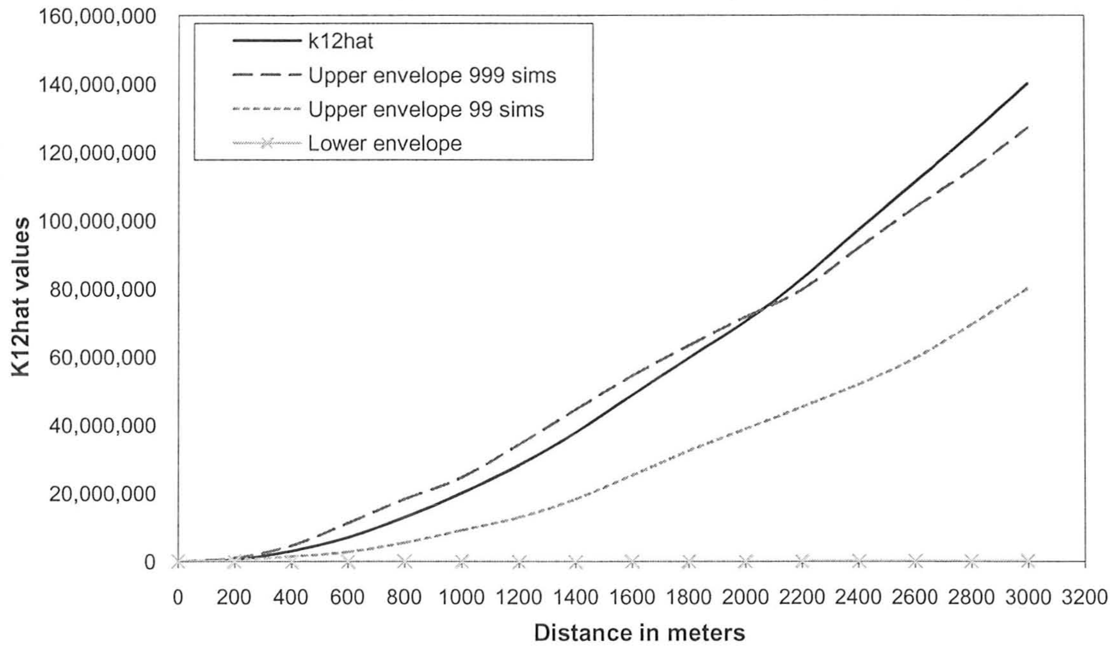


Figure A.18: Clustering of Commercial Land Development (1990-1996) Around Existing Residential Land Development (1986 - 1990)

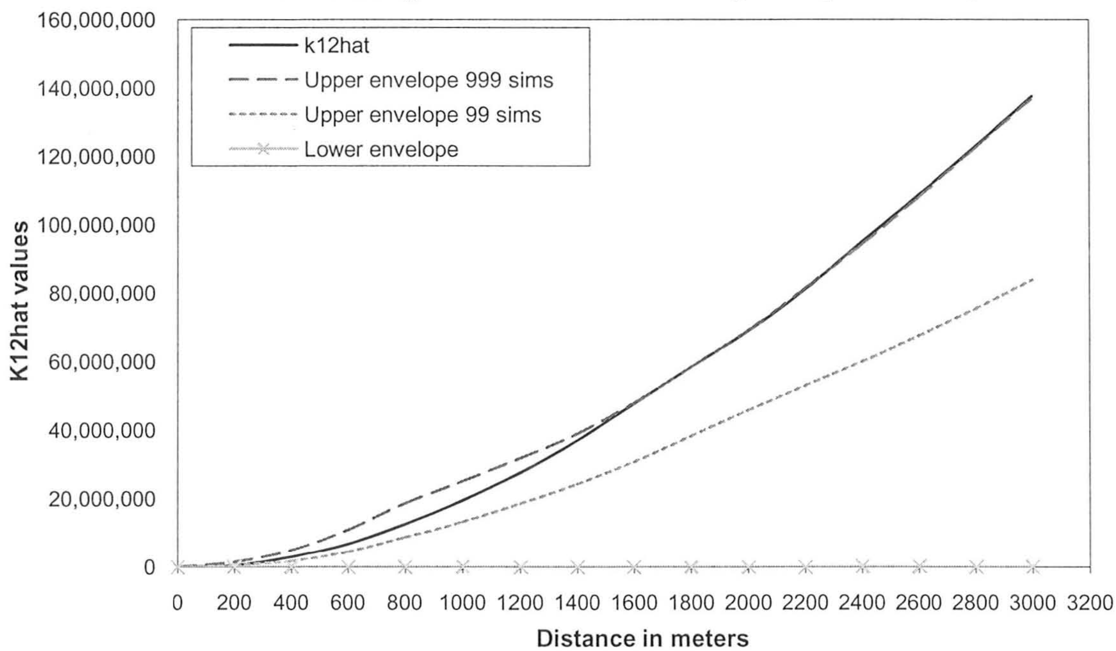


Figure A.19: Clustering of Commercial Land Development (1990-1997) Around Existing Residential Land Development (1986 - 1990)

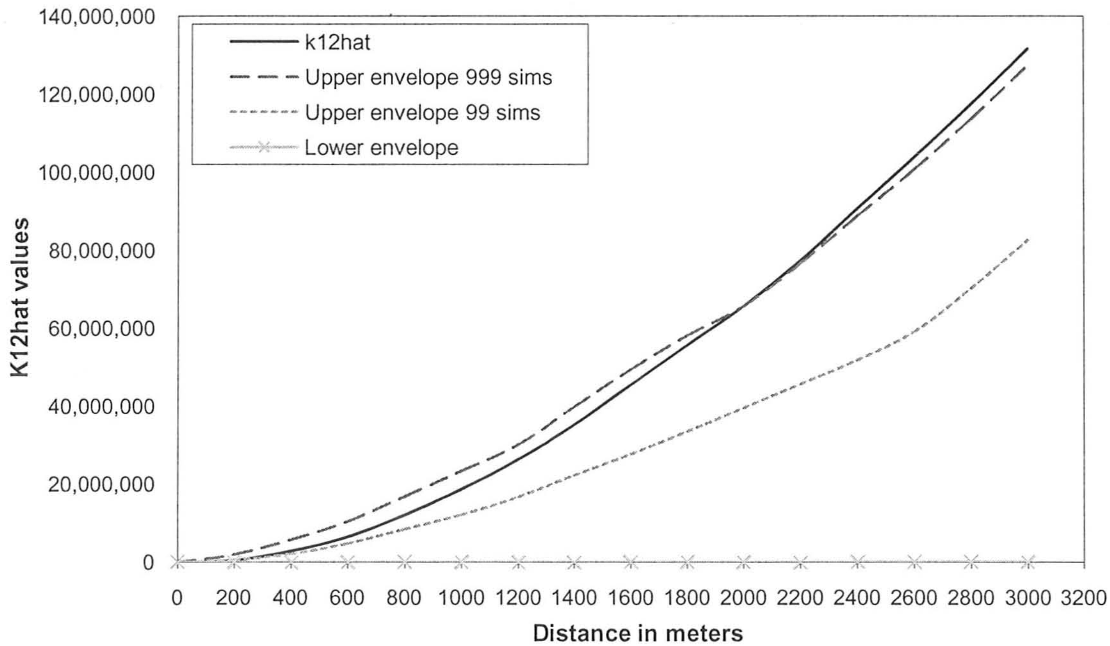


Figure A.20: Clustering of Commercial Land Development (1990-1998) Around Existing Residential Land Development (1986 - 1990)

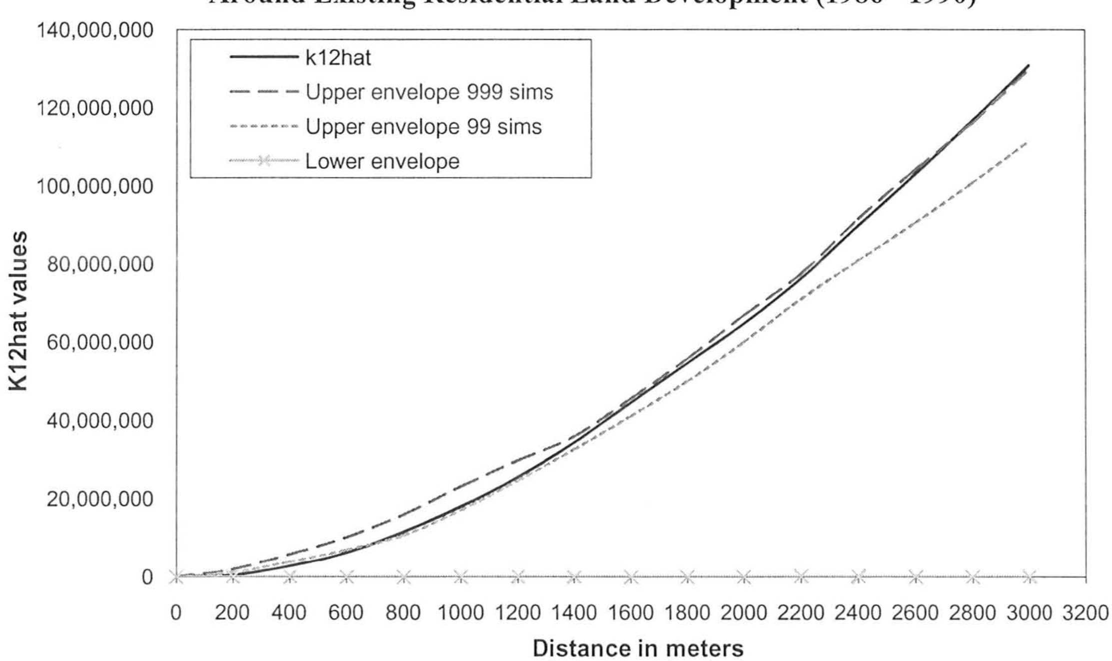


Figure A.21: Clustering of Commercial Land Development (1990-1999) Around Existing Residential Land Development (1986 - 1990)

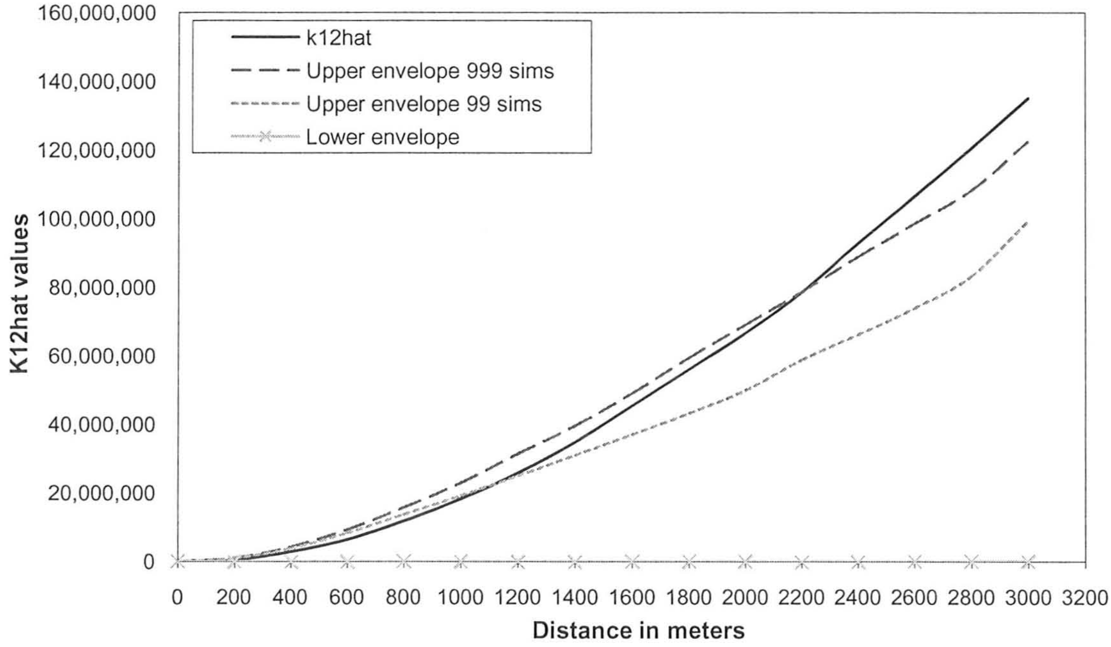


Figure A.22: Clustering of Residential Land Development (1995-1996) Around Existing Commercial Land Development (1991 - 1995)

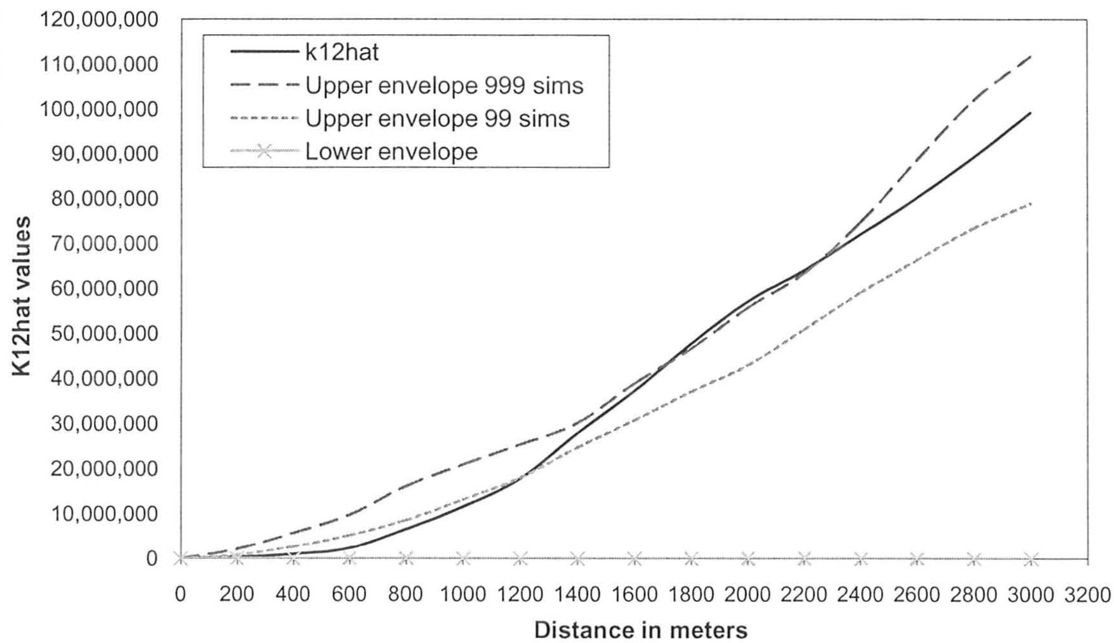


Figure A.23: Clustering of Residential Land Development (1995-1997) Around Existing Commercial Land Development (1991 - 1995)

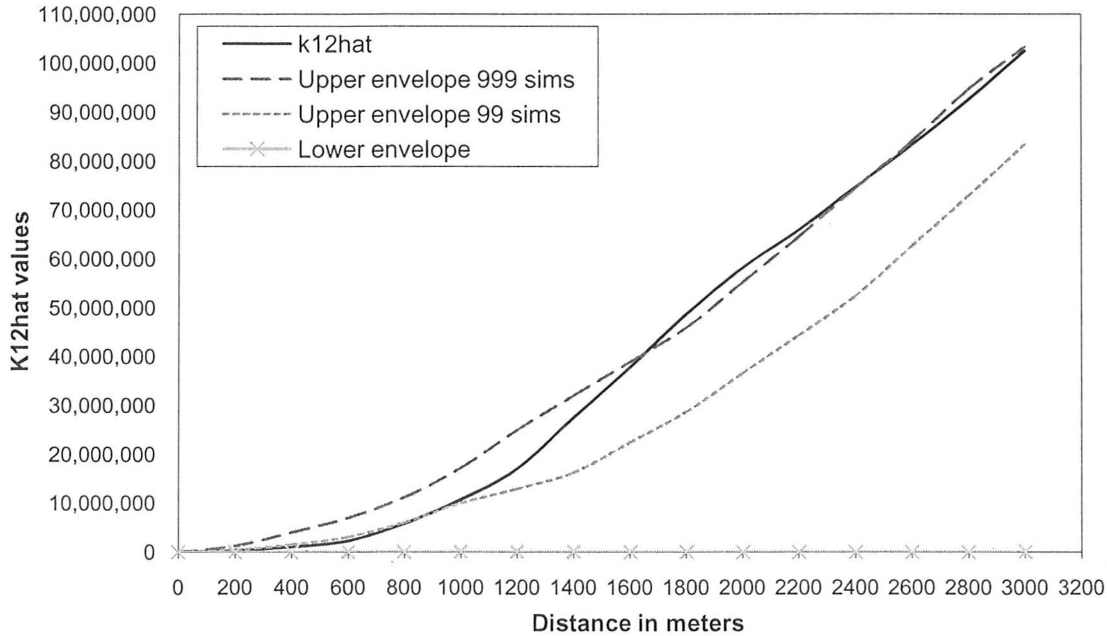


Figure A.24: Clustering of Residential Land Development (1995-1998) Around Existing Commercial Land Development (1991 - 1995)

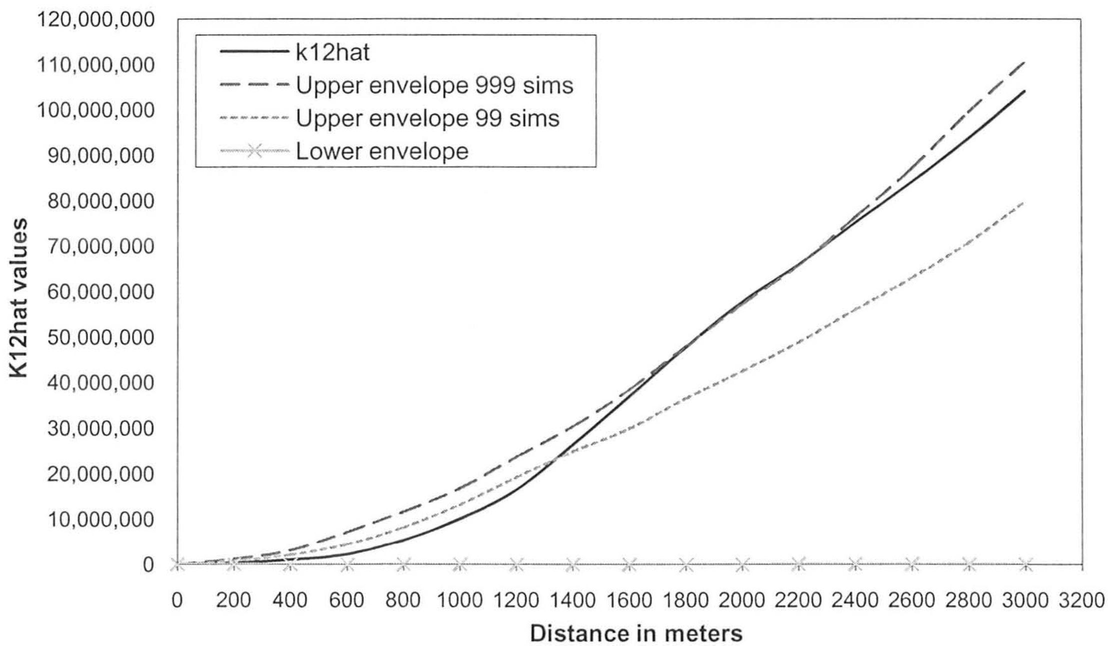


Figure A.25: Clustering of Residential Land Development (1995-1999) Around Existing Commercial Land Development (1991 - 1995)

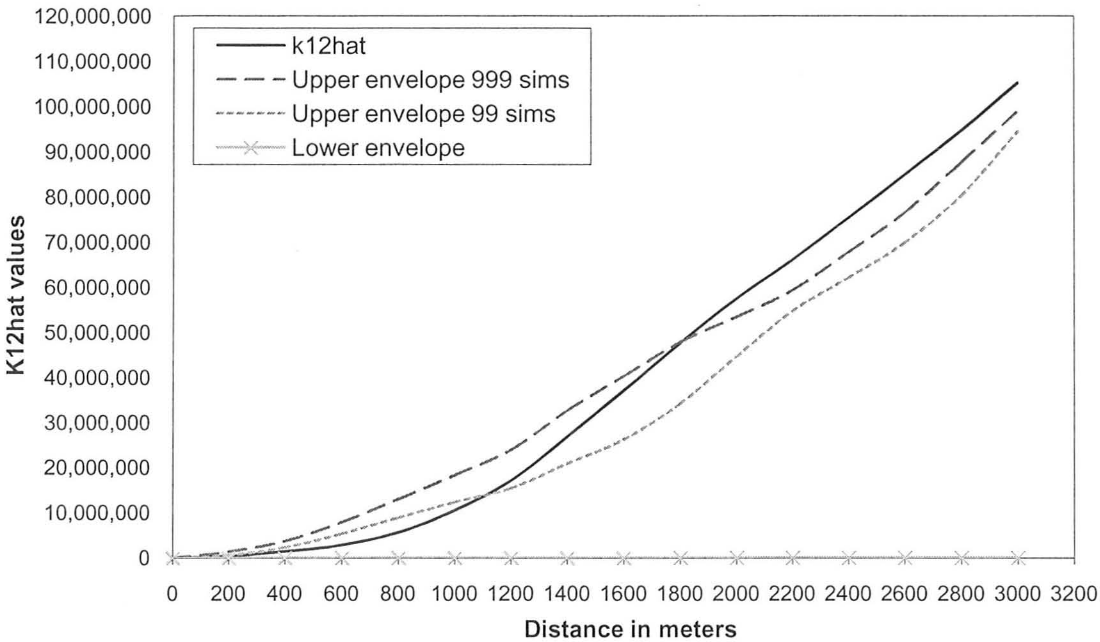


Figure A.26: Clustering of Residential Land Development (1995-2000) Around Existing Commercial Land Development (1991 - 1995)

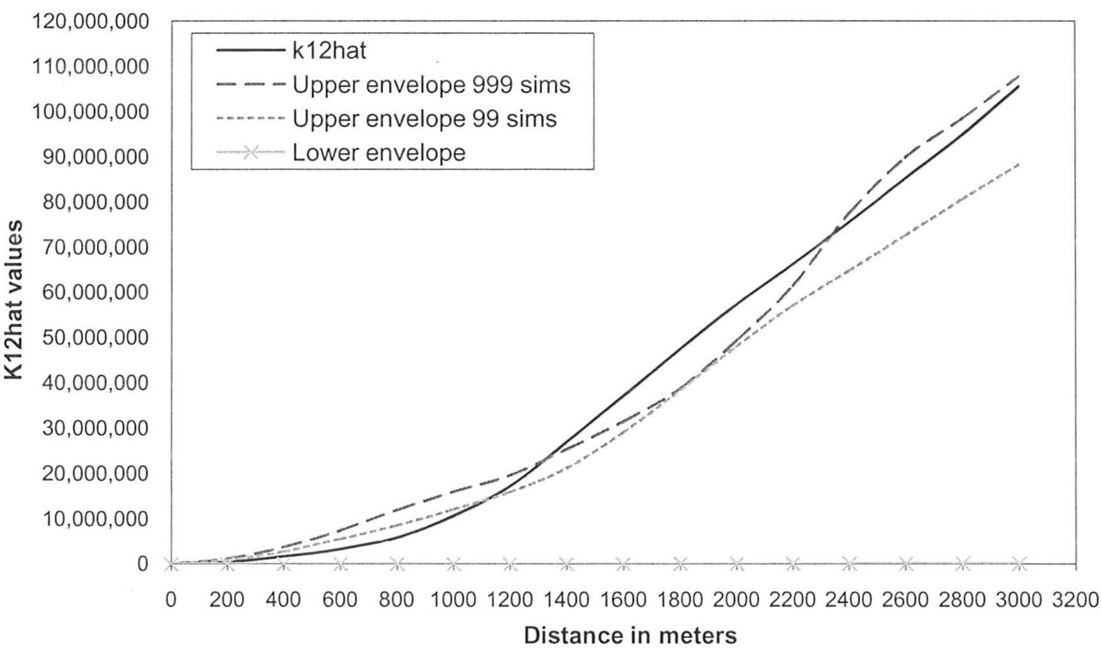


Figure A.27: Clustering of Residential Land Development (1995-2001) Around Existing Commercial Land Development (1991 - 1995)

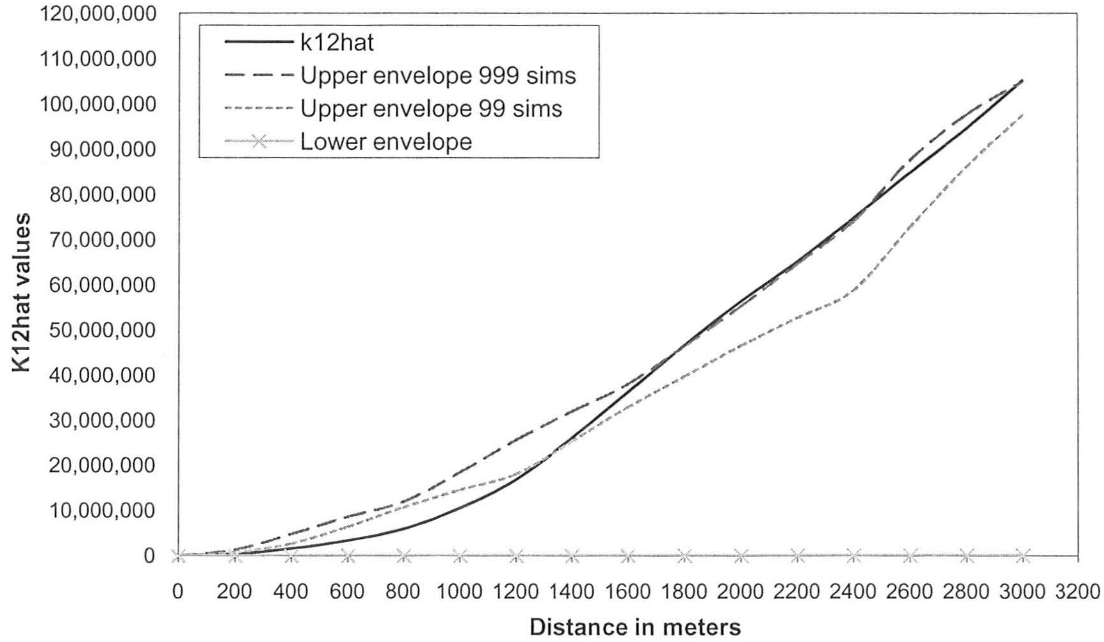
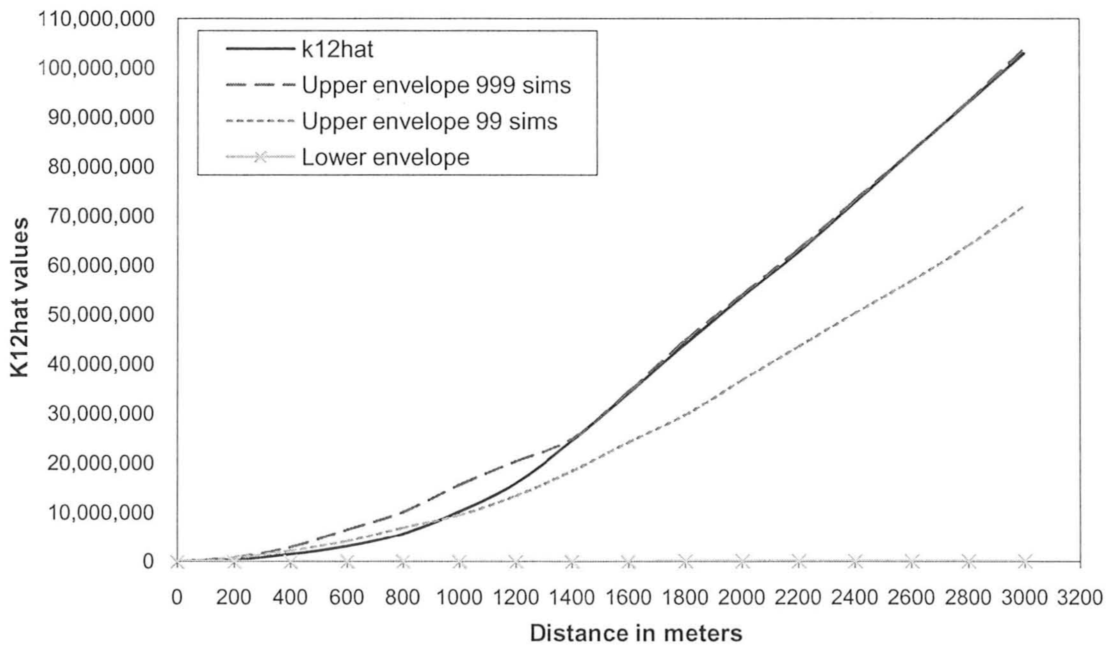


Figure A.28: Clustering of Residential Land Development (1995-2002) Around Existing Commercial Land Development (1991 - 1995)



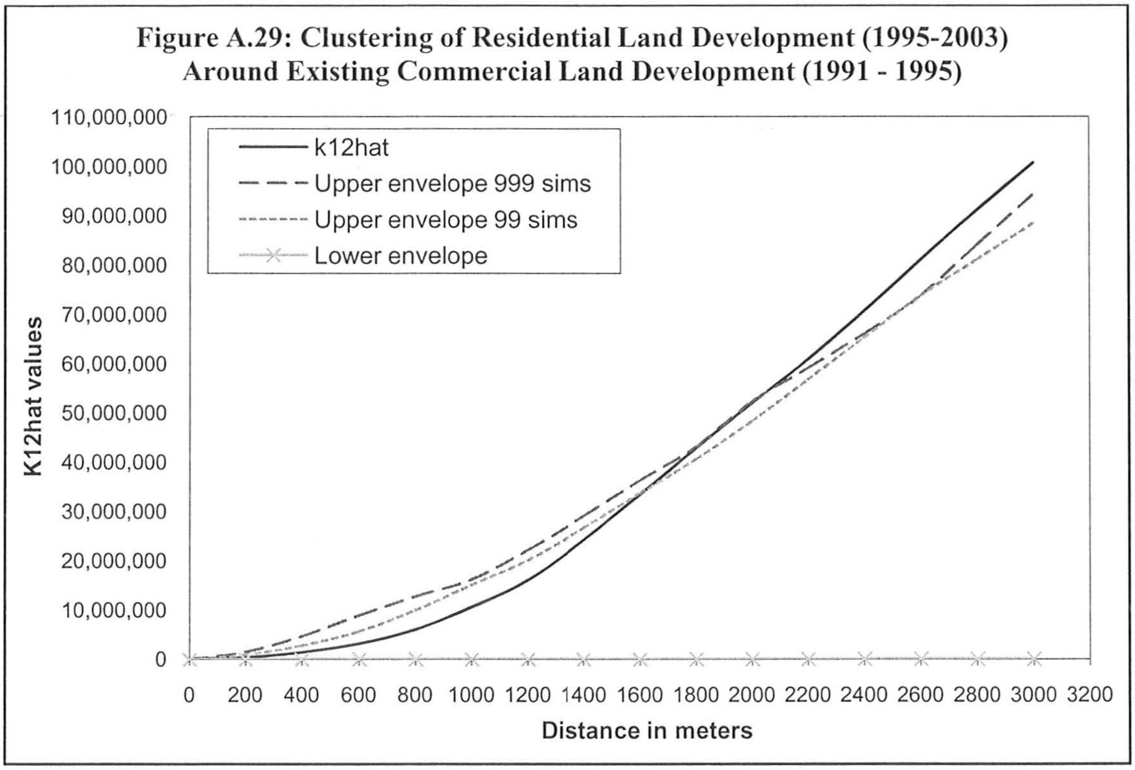


Figure A.29: Clustering of Residential Land Development (1995-2003)
Around Existing Commercial Land Development (1991 - 1995)
110,000,000
100,000,000
90,000,000
80,000,000
70,000,000
60,000,000
50,000,000
40,000,000
30,000,000
20,000,000
10,000,000
0
K12hat values
k12hat
Upper envelope 999 sims
Upper envelope 99 sims
Lower envelope
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200
Distance in meters