THE SIMULATION OF URBAN SYSTEM DYNAMICS IN ATLANTIC CANADA 1951-1991

JUN REN

THE SIMULATION OF URBAN SYSTEM DYNAMICS IN ATLANTIC CANADA 1951-1991

By

©Jun Ren

B. Eng., Shanghai University of Technology, China

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS

DEPARTMENT OF GEOGRAPHY

MEMORIAL UNIVERSITY OF NEWFOUNDLAND

MAY 1993

ST. JOHN'S NEWFOUNDLAND

ISBN 0-315-86655-1

Abstract

A dynamic urban model is used to study the post-war evolution of the Atlantic Canada urban system. The computer based simulation model is calibrated for the period 1951-1986 and then employed to predict the 1991 population of each CMA and CA within the system. The simulation results show that to a large extent, the evolution of the system can be understood in terms of endogenous system dynamics rather than exogenous events. Specifically, competition among the cities of the region is a significant factor in the urban system evolution. The high degree of abstraction of the model means that data requirements for application are minimal, and the calibration procedure is relatively simple. The successful predictions show that the model can yield useful results in spite of its simplicity.

Table of Contents

List of Tables

List of Figures

Acknowledgements

It is a great pleasure to thank all those who contributed to this thesis. I wish to thank my thesis supervisor, Dr. Roger White, for his knowledgeable and skillful direction of my research, preparation of an interesting research programme, and very helpful assistance in completing this thesis. I also thank him for his supervision in educating my ability to carry out research independently.

I gratefully acknowledge the financial assistance provided by the School of Graduate Studies in the form of graduate fellowships, and of the Women's Association of Memorial University Graduate Scholarship, as well as by Department of Geography in the form of research assistant.

I am very grateful to the faculty and staff members of the Department of Geography for sharing their knowledge and helping in many ways during my stay in Memorial University, especially, Drs. Joyce and Alan Macpherson, Dr. Christopher Sharpe, Dr. Norm Catto, Dr. John Jacobs, Dr. Bill Allderdice, Dr. Alven Simms, Dr. Keith Storey, Dr. Jo Shawer, and Mr. Gary McManus. Also the secretaries, Mrs. Carole Anne Coffey, Mrs. Linda Corbett, and Mrs. Christine Burke for their sincere friendships and concerns, which will remain in my memories.

I am indebted to Dr. Mark Whitmore, Mrs. Josephine Berron, and Dr. John Whitehead for providing me a work opportunity as a graduate assistant in Department of Physics, and for the excellent chance I obtained to use advanced computer facilities. This thesis would not have been completed in time had it not been for their support.

I thank the librarians and computer consultants at Memorial University as well as the Maine State Library in United States for their enthusiasm, patient, and effective help during the period of my research, particularly, Mr. John Read. His help, based on a comprehensive knowledge of computer software, in solving problems in a prompt and effective way, provided the basis for me to carry out my research successfully.

I appreciate the friendships of fellow graduate students: Ngiap-Puoy Koh, Lisa Spellacy, Sheila Vardy, Xiaohong Chen, Deborah Butler, Hong Wang, Ralph House, Sharon Scott, Catriona Mackenzie, Mandy Munro, Rebecca Boger, Doug Ramsey, Anne Collins, Colin Taylor. The time we share leaves an enjoyable memory to me.

I extend sincere thanks to my relatives and friends for their interest, help, and encouragement.

Last but not least, I owe a debt to my husband Bojiong for his special consideration, understanding, and support throughout the years this research has been under way. Thank you, Bojiong.

Chapter 1

Introduction

The economic development of a region is closely related to the growth of the urban system within the region. The existence of an urban system implies that the cities in the region form an integrated unity [1], which facilitates the transmission of economic impulses, the diffusion of technical innovations, and the migration of population. Increasingly, economic growth is articulated in the system of cities, and this system in turn determines the direction of growth in terms of the flow of information and innovations in the region. Thus it can be seen that the growth of an urban system plays a significant role in the economic development of a region.

The importance of an urban system is reflected in the large amount of research carried out in recent decades and in the evolution of research methodology. Urban systems have long been studied using a descriptive, historical approach [2, 3, 4, 5]. More recently, since central place theory [6, 7, 8] was established, the favoured methodology in urban system research has shifted from a historical approach to a systems approach. However, central place theory suffers from such disadvantages as overly restrictive assumptions and formulation as a static model. These limitations have restricted the usefulness of the theory for exploring and explaining the behaviour of real urban systems. Consequently, much recent research is aimed at modifying central place theory by introducing time to the static models. In fact, this effort represents nothing less than the application of a dynamic systems approach to the study of urban systems. Most of this research in dynamic urban modeling has been devoted to creating the models and investigating them theoretically. However, tests of the applicability of such models are relatively recent and scarce [9]. Only in the past decade has some research focused on the application of dynamic urban models to actual urban systems.

Most dynamic urban models are spatial interaction based models. Examples of this kind of model are the various dynamic central place models of Allen, White, Tellier, and others, [10, 11, 12, 13] and the production-constrained spatial interaction models of Wilson, Harris, and Clarke [14, 15, 16]. These models explore the dynamic mechanism responsible for the evolution of an urban system. The nonlinearity of these models, a reflection of the complexity of the systems, usually yields a bifurcation in the evolution of the system described by the model. Thus bifurcation theory may be applied to the study of these systems. Bifurcation theory concerns changes in the nature of solution properties of nonlinear equations when the values of parameters in the equations are changed.

Pumain et. al. applied a complex dynamic central place model based on bifurcation theory to the French urban agglomeration of Rouen in 1984 [17], and to the agglomerations of Bordeaux, Nantes, Rouen, and Strasbourg in 1987 [9]. Straussfogel applied the same dynamic urban model to the American metropolitan area of Philadelphia in 1991 [18].

The disadvantages of the complex dynamic urban models can be seen in the experimental research of Pumain et. al. and Straussfogel. Pumain et. al pointed out:

> The difficulties encountered in calibration show that the general methodology, required for application of such complex models to real-world situations, has to be seriously improved. They also underline the insufficient state of our empirical knowledge about intra-urban processes and regularities: we use many important concepts but we do not always know how to measure them how to find the values for the parameters of the model.

And in evaluating the ease and accuracy of operationalizing the model for a practical application, Straussfogel concluded that the difficulty involved in the model's calibration may make it too costly and time consuming to be used for practical purposes.

Lombardo and Rabino applied a catastrophe theory based model to the Rome metropolitan area in 1984 [19], and in 1986 they applied the same model to an enlarged urban area centred on Rome and including a number of neighbouring towns and villages significantly linked to the core [20]. Unfortunately, however, the ideas of catastrophe theory the model is based on limit the model's applicability. This kind of model is appropriate for a simple system with a small number of variables. It is usually difficult to apply a model based on catastrophe theory to a large scale, hierarchical urban system [21, 22].

It would be advantageous to have a model without the disadvantages seen in these approaches, ideally a model with a relatively simple calibration procedure as well as modest data requirements.

White [11] has developed a generalized dynamic urban model which possesses such features. This model is based on an integration of spatial interaction theory and the theory of the firm. Bifurcation theory is used to reduce both the number of equations and the number of parameters, thus in principle, minimizing the data required for empirical applications and simplifying the calibration procedure.

The primary task of the present thesis is to investigate the applicability of this model, to see whether such a model can, in fact, give a useful representation of the evolution of a real urban system, and to provide an insight into the dynamic mechanism involved in the evolution of the urban system, in terms of endogenous system dynamics rather than exogenous events. In the present research, the model is applied to the urban system of the Atlantic region of Canada, for the period 1951-1991. This system, which includes eighteen Census Metropolitan Areas and Census Agglomerations, not only is a hierarchical urban system but also possesses a relatively large geographical scale.

The major contents of the task are as follows:

- describing three kinds of dynamic urban models, comparing the features those models, and discussing other relevant research;

- describing the details of the urban model to be used, providing operational definitions for some variables used in the model, and simplifying the procedure for calibrating some parameters;
- illustrating the definition of an urban system and presenting a brief description of the economic development of the Atlantic urban system;
- examining problems in data sources, and establishing and applying procedures for dealing with those problems;
- calibrating the dynamic urban model to replicate the historical evolution of the urban system over the period 1951-1986, and using the calibrated model to predict the 1991 population of each CMA and CA within the system;
- evaluating the calibration results and their significance.

The following chapters will show how these tasks are accomplished, in order to evaluate the model's applicability and usefullness in the Atlantic region.

Chapter 2

Related Research

In this chapter, section 2.1 presents the classical central place theory put forward in the 1930's. Section 2.2 briefly reviews the modern dynamic central place theory established in the 1970's, and section 2.3 discusses a recent application of that theory. Finally, section 2.4 briefly discusses traditional economic base theory as it is related to the present research.

2.1 The Classical Theory of Central Place Systems

Five decades ago two German scholars, Walter Christaller and August Lösch, established the bases of central place theory [6, 7]. This theory focuses on a system of market centers and the relationships among the centers' location, size, and retail and services characteristics. The work of those two scholars remains an important landmark in the history of urban geography and regional economics. It provided a necessary foundation for further work in the analyses of central place systems. However, two major weaknesses constrain its range of application. First, all assumptions underlying this theory are very simplified, and are not consistent with the situations encountered in reality, so that the central place patterns described by them can not be found in the real world, except in special situations. Second, the classical models of Christaller and Lösch are static in conception and say little about how the systems behave if major changes of underlying conditions occur. In other words, the central place systems described by these models are in an equilibrium state, and the models do not illustrate the process of change and adjustment by which the equilibrium is attained. In spite of these weaknesses, the theories of Christaller and Lösch have inspired a great deal of research in urban systems. In recent decades this research has extended to the dynamics of central place systems.

2.2 Modern Dynamic Urban Models

The modern central place theory originated in the 1970's, and was aimed at explaining and predicting growth and change in central place systems by means of dynamic mechanisms inherent in the system itself. The three most representative models are the retail center model put forward by White [10] in 1977; Harris and Wilson's model [15] proposed in 1978 and Allen and Sanglier's central place model [12] published in 1979. The common feature of these models is a competitive mechanism based on spatial interaction among centers in a central place system. This mechanism, describing the evolutionary nature of the system, drives the central place system to a final equilibrium or a steady state corresponding to a given initial state and boundary conditions. The evolutionary process of the system is usually reproduced by computer simulation. However, the suggested dynamical mechanism varies from one model to another and thus the theories and the results differ from each other substantively.

2.2.1 White's Dynamic Model of a Central Place System

Considering the differences in spatial organization among actual central place systems, the complexity of the economic activities in various centers of the system, and the impossibility of solving a set of non-linear differential equations analytically, White [10] established a dynamic central place theory formulated as a simulation model. He described a retail system [10, 23, 24] in the original model, and then developed the model to represent an urban system [11]. In White's original model, the interaction between retail activities and consumers generates a central place system in which the behavior of consumers is described by spatial interaction equations, the characteristics of the retail activities are represented by cost equations, and the behavior of retailers is described by a growth function.

White's dynamic model of a central place system is composed of a set of equations expressed as follows:

$$I_{ij} = \frac{S_j / D_{ij}^n}{\sum_j S_j / D_{ij}^n} \tag{2.1}$$

where I_{ij} is the relative flow from i to j, S_j is the size of jth center in the system which may be characterised as the floor space of the jth commercial center in a retailing system or the population of the jth city in an urban system, D_{ij} is the distance from the ith residential area or ith commercial center to the jth commercial center in the retailing system or, in an urban system, from the ith rural region or ith city to the jth city. The value of the distance between i and j denoted by matrix element D_{ij} depends on the transportation network, and the exponent n represents the "friction" when people move from site i to site j. It can be seen that this expression of distance dependence is a form of the *Gravity Equation* defined by Lakshmanan-Hansen [25], and is a representation of competition among centers in the model. The *Revenue* R_j in center j is then given as

$$R_j = \sum_i Q_i I_{ij} \tag{2.2}$$

where Q_i is the total volume of expenditures in area i. The *Cost* incurred in generating the revenue R_j is assumed as

$$C_j = a + b_j S_j^E \tag{2.3}$$

where a is the threshold cost for a commercial center, b_j is a scaling constant and E represents economies of scale ($E < 1$) or diseconomies of scale ($E > 1$). The *Profit* P_j received by center j is the difference of reve ue and cost:

$$P_j = R_j - C_j \tag{2.4}$$

Eq.(2.1) to (2.4) specify a spatial competition relation among the centers in the system, and a temporal relation reflecting the process of evolution of the central place system is introduced as

$${}^{t+1}S_j = {}^{t}S_j + g\,P_j \tag{2.5}$$

where $g > 0$ is the economic response, denoting the size increment per unit profit.

Using computer simulation, an extensive sensitivity analysis [10, 23, 24] was carried out on this simple dynamic model. The main focus of the sensitivity analysis was on the final spatial pattern of the central place system in a steady state. The results show the dominant types of patterns that may be given by the model as well as the relation between the final pattern and the initial condition of the system. This process may be seen as a theoretical investigation of the model, and the parameter values contained in the model can be chosen quite freely, within limits, during this sensitivity analysis. Of course, in order to simulate an actual central place pattern, the values of the parameters must be calibrated to make the simulation results capture the real pattern. This procedure tests the applicability of the model.

(i) Bifurcation Phenomena

The simulation results cited in the previous paragraph show that the initial pattern of the central place system, which is the input data in the simulation, has a weak relation with the final pattern of the system, which is the output of the simulation. Either a regular or random initial pattern of distribution of centers in the system can yield a central place system with a centralized pattern (one or a few centers are extremely large) or a decentralized pattern (all the centers have a similar size), depending upon the value of certain parameters. This, at a preliminary level, indicates that the centralized pattern and the decentralized pattern are qualitatively independent of the initial state (although they are affected quantitatively by the initial state).

Furthermore, whether the pattern in the steady state of the system is dominantly centralized or decentralized is determined by the distance exponent n in Eq.(2.1). The simulation results show that there is always a decentralized pattern for high values of n, e.g. $n = 2$, and a centralized pattern for low values of n, e.g. $n = 1$. Also the simulations reveal the transition range of values, $1.2 < n < 1.7$, which separates the two different evolutionary regimes of the central place system.

Behind this phenomenon is bifurcation theory [26] (See Fig.2.1). It states that a deterministic equation does not necessarily give a unique value for the variable defined by the equation, such as ${}^{t}S_j$ in (2.5). Therefore, corresponding to the various sets of parameter values in the equation, there will be different evolutionary processes and qualitatively different final steady state patterns for the system.

A more detailed interpretation is that the form of a deterministic equation such as (2.5) defines a short term relation between ${}^{t+1}S_j$ and ${}^{t}S_j$, which tells the variable S_j how to go across each short interval. The value of a parameter such as the exponent n determines the long term possibilities for the evolution of ${}^{t}S_j$. Therefore, a final steady state is determined by both the short term behavior, which gives a particular size, or a point on an evolutionary trajectory at every time, and the long term behavior, which specifies the whole shape and position of the trajectory. With the non-linearity and inter- dependency existing in a set of coupled equations, bifurcation theory tells us that a continuous change of the value of the parameter will lead to a sudden shift in the whole

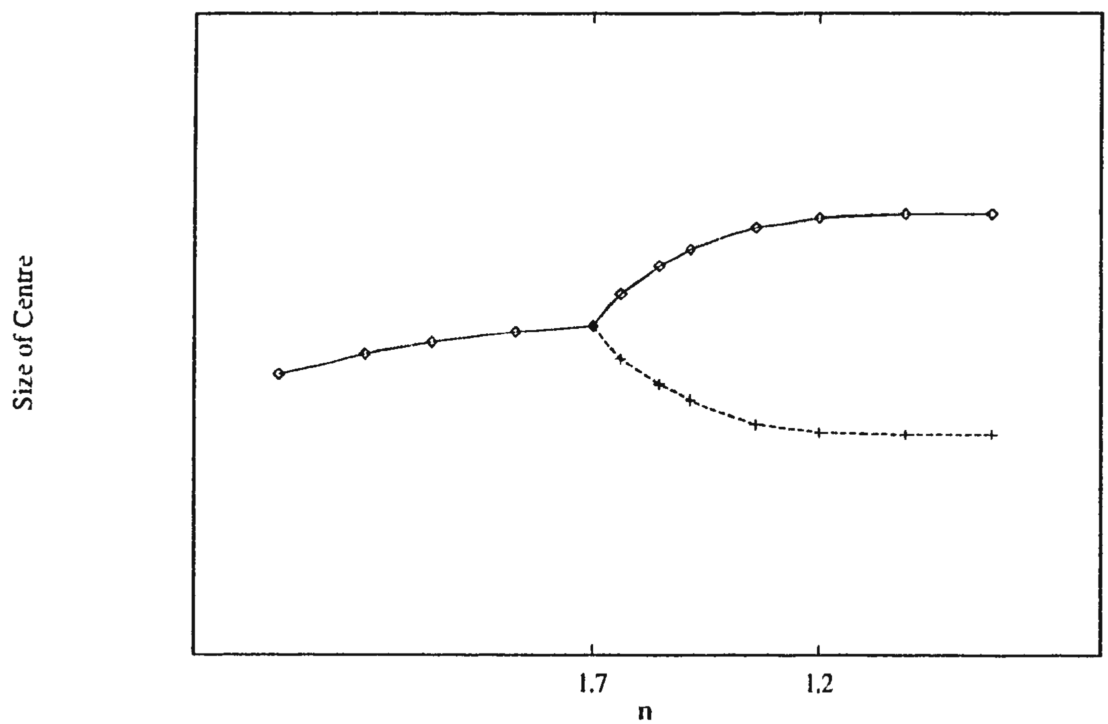


Figure 2.1: Bifurcation in Retail Centre Size. For $n > 1.7$, there is only one stable size. For $n < 1.7$, there are two stable sizes, and the system must choose one branch or the other. In an actual system, behaviour in the transition zone $1.7 > n > 1.2$ may appear unstable.

evolutionary trajectory. Hence, the range of values $1.2 < n < 1.7$ is a transition zone separating two qualitatively different evolutionary processes of the central place system.

Since the bifurcation was the most important feature of the simulation results, a further test of the robustness of the bifurcation phenomenon was carried out by substituting the negative exponential equation for the gravity equation such that

$$I_{ij} = \frac{S_j e^{-nD_{ij}}}{\sum_i S_j e^{-nD_{ij}}} \tag{2.6}$$

The simulation results [10] show that the bifurcation still exists; however, the transition range of values of the parameter n is $0.1 < n_c < 0.2$.

Relating the bifurcation phenomenon to the economic activities in a retail system, the author [24] pointed out that the decentralized pattern describes the distribution of retail stores providing low order goods whereas the centralized pattern represents the distribution of retail stores selling the high order goods.

Aside from the distance exponent n, White's [23, 24] research suggested that the parameter E may also yield a bifurcation that would be responsible for centralized and decentralized patterns. It was shown that the major effect on the central place pattern of increasing the diseconomies of scale (increasing E, where $E > 1$) is to decrease the range of centre sizes. This effect is similar to that of lowering the order of goods (increasing n). And the effect of increasing the economies of scale (decreasing E, where $E < 1$) is to increase the range of sizes, which is like raising the order of goods (decreasing n). However, due to the transportation network dependence, a high(low) value of n is not equivalent to a high(low) value of E. It is readily seen that a large E will suppress the increase of a big center in the system directly by raising the cost non linearly and has little impact on the location of this center in the system. In contrast, the effect of large n on suppressing the increase of a big center, acting mainly through the spatial interaction of consumers with centers, depends largely on the location of the centre relative to other centers. Similarly, a small E will favour the growth of a big center in the system directly by decreasing the cost, regardless of the center's location. However, the effect of small n in favoring the growth of a big center through increased spatial interaction at longer distance, depends largely on the position of the center on the transportation network of the central place system: for growth to be favoured, the centre must be centrally located in the network.

Since the E value may introduce the bifurcation, White also analyzed the role of b_j. What he found is that it is difficult to distinguish the roles of parameters b_j and E in applying the model to a real case. However, in present research, this uncertainty will be ruled out because the value of b_j will be fixed by certain conditions imposed on the urban system. The details will be presented in next chapter.

Generally speaking, bifurcation phenomena may appear in all sufficiently non-linear urban dynamic models. As for White's model, bifurcation produced two types of behaviour, each qualitatively distinct, corresponding to specific ranges of values of key parameters. According to the theoretical investigation of the model [10, 11, 23, 24], these two types of behaviour correspond to the high order sector and the low order sector respectively. In general as the number of sectors created in a model is increased, the model becomes more complex, and the calibration of a complex model needs much more time to complete than that of the model with two sectors. Yet the bifurcation analysis shows that there is little qualitative difference between a model with two sectors and a model with more than two sectors, as long as both types of sectors are present. This is why White establishes his dynamic urban model based on only two sectors.

(ii) Two-Sector System

White made an immediate generalization of the model to a two sector central place system [23] and analysed the simulation results in comparison with the *Rank-Size Rule* that has been found to characterize many urban systems.

The model consists of the following set of equations:

$$ {}^tS_j = \sum_{m=1}^{2} p_m \, {}^tW_{j,m} \tag{2.7} $$

where ${}^tW_{j,m}$ is the size of sector m in center j and the p_m are the parameters specifying the relationship of sector size to the total size ${}^tS_j$ of center j. The cost equation for sector m in center j is similar to that in the single-sector model, and is given by

$$ {}^tC_{j,m} = a_j + b_j \, {}^tW_{j,m}^{E_m} \tag{2.8} $$

The revenue for sector m in center j is expressed as

$$ {}^tR_{j,m} = \sum_i {}^tS_i \left({}^tW_{j,m} \, D_{ij}^{n_m} \right) \Big/ \left(\sum_l {}^tW_{l,m} \, D_{il}^{n_m} \right) \tag{2.9} $$

Finally, the temporal evolution is given by

$$ {}^{t+1}W_{j,m} = {}^tW_{j,m} + g_{j,m}({}^tR_{j,m} - {}^tC_{j,m}) \tag{2.10} $$

While this two-sector model is very similar to the previous single-sector model, an important difference is that there are two friction exponents, eg. $n_1 = 3$ and $n_2 = 1$, respectively, which means that both low- and high-order sectors are present in each center. The bifurcation phenomenon, which is explicit in the results of the single sector model, when the pattern is either centralized or decentralized (see Fig. 2.2), now is hidden in the simulation results, since the size S_j of each center is measured by a weighted sum of the two sectors (see Fig. 2.3). Furthermore, the behaviour of each sector affects that of the other, since the growth of either sector will lead to the growth of the other one. The interaction of the two sectors may even produce a linear rank-size distribution with a slope approximately equal to minus one, a result that is never observed in the single sector model.

However, the bifurcation still manifests itself in the rank-size distribution obtained from the simulation. Starting with the same initial sizes fo· both sectors, most systems evolve to a steady state, with a small number of high-rank centers containing two sectors together with a large number of low-rank single-sector centers. This result indicates that the appearance of high-rank centers is mainly determined by the centralizing process dominated by the high-order sector with $n_2 = 1$, while low rank centers result from a loss of the high-order sector and reflect the decentralization process governed by $n_1 = 3$.

The other parameters introduced in the model also play important roles in the sense that a quantitative change in the size and location of a center may be determined by varying these parameters; nevertheless, the qualitative behavior of the rank-size distribution of the central place system is indeed dominated by the value of the exponents n_i, due to the bifurcation.

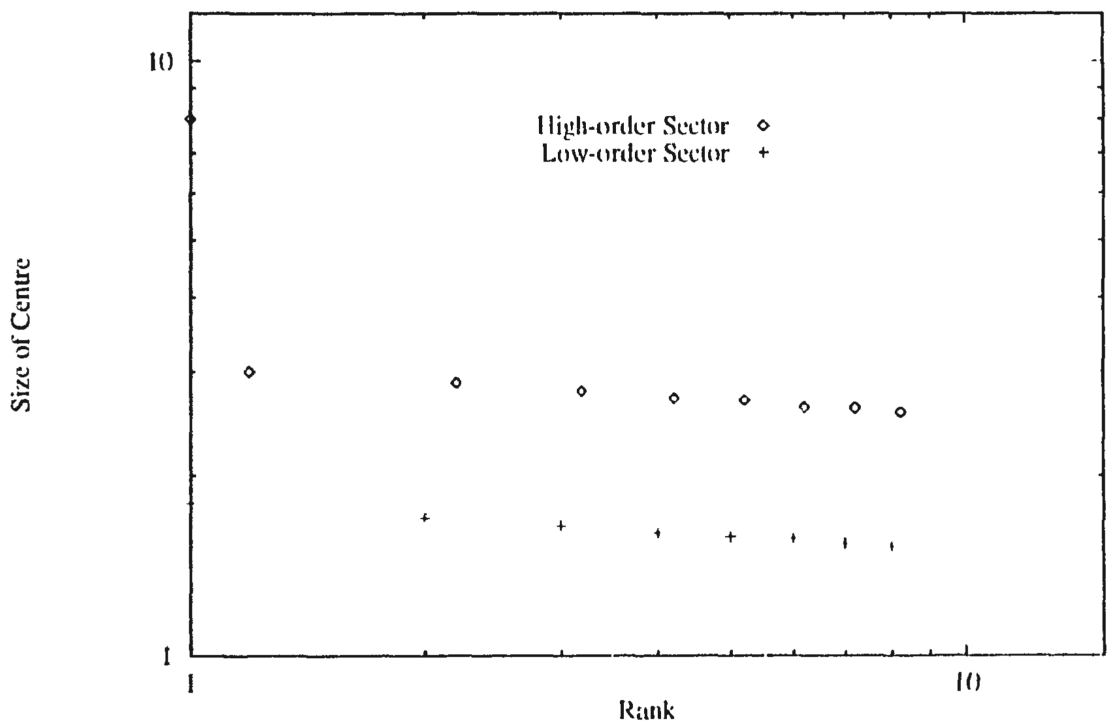


Figure 2.2: Rank-Size Relationship for One Sector Systems. One system contains only a high-order sector, and shows centralization of activity in a single large (primate) centre. The other system contains only a low-order sector, and shows dispersal of activity among similar-sized centres.

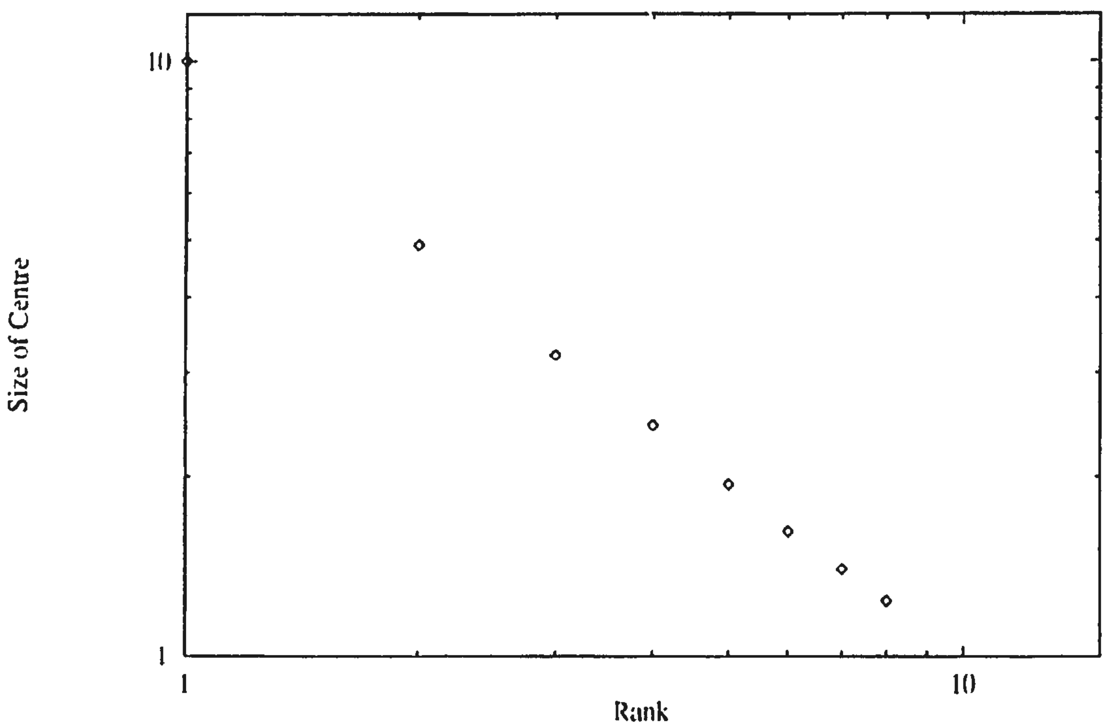


Figure 2.3: Rank-size Relationship for a Two Sector System. The bifurcation phenomenon is hidden in the composite relationship.

(iii) Comments on White's Model

Based on revenue and cost functions for centers competing spatially, the model is conceptually simple and empirically reliable. The development of the model from a simple version with one sector to a somewhat more complicated two-sector version enables us to understand the variety of behaviour appearing in the evolution of a complex system. Moreover, the wide variety in the spatial organization of the central place systems generated by the model indicates the strength and utility of the simulation technique. Thus the model should be applicable to any real central place system, whether a local retail system or a regional urban system.

However, as Christaller's theory pointed out, a model aimed at describing a real central place system should be able to deal with the hierarchical structure in the system. From the point of view of dynamic central place theory, this requirement takes two forms. The first is that a hierarchical structure must naturally and gradually appear in the evolution process of the system [10, 23, 24], and the second is that the creation of a new center at a certain hierarchical level must be possible. But the creation of a new center level raises basic methodological difficulties. Research aimed at incorporating this new mechanism in a model has been carried out since the 1970's by a number of researchers, including White himself [27], Wilson [14, 15, 16] and Allen [12]. Wilson's and Allen's models will be reviewed in sections to follow.

2.2.2 Wilson's Model

Wilson's approach [14, 15, 16] is somewhat similar to White's, although the dynamics of centre size are expressed in differential equation form:

$$\frac{d}{dt}W_j = \epsilon\,(R_j - k_j W_j)\,f(W_j) \tag{2.11}$$

where W_j is the size of center j, R_j is the revenue received by center j, and k_j is cost per unit of commercial area. The function $f(W_j)$ may be taken to be simply W_j, and in that case the equation represents a logistic growth process.

From this equation, an equilibrium condition for the size W_j is seen to be

$$R_j = k_j W_j \tag{2.12}$$

at which $\frac{d}{dt}W_j = 0$. However, this equilibrium condition is not as simple as it looks due to the non-linear dependence of R_j on W_j as well as the interdependence of all the $\{W_k : \forall k \neq j\}$. The explicit expression for R_j is

$$R_j = \sum_i I_{ij} \tag{2.13}$$

where the I_{ij} constitute a flows matrix, with

$$I_{ij} = A_i\, e_i\, P_i\, W_j^{\alpha}\, e^{-\beta c_{ik}} \tag{2.14}$$

and

$$A_i = 1 \Big/ \sum_k W_k^{\alpha}\, e^{-\beta c_{ij}} \tag{2.15}$$

Wilson paid particular attention to the analytical properties of the equilibrium condition. A detailed discussion and summary may be found in [16], however, certain important results will be discussed here.

The similarity of Wilson's model to White's implies the existence of a bifurcation phenomenon dependent on the value of β (equivalent to n in White's model). However, Wilson also shows that the parameter α (analogous to E in White's model) has a major effect on the final pattern of the system. A large value of α raises the cost per unit area to maintain a large center and a small value of α reduces the cost. Therefore, the bifurcation point of the evolution process of the system will be determined by the values of both α and β.

More interestingly, the detailed study [15] of the dependence of the revenue R_j on the k_j (equivalent to the b_j in White's model) yields useful results concerning the system's equilibria. The existence of an equilibrium state of a center with size W_j is determined by the values of both α and k_j, i.e. the equilibrium state of a center j is defined by two equations

$$R_j = k_j W_j \qquad \text{and} \qquad \frac{\partial R_j}{\partial W_j} \propto \alpha W_j^{\alpha-1} \tag{2.16}$$

The second condition brings about the nonlinear dependence of the revenue R_j on size W_j.

Wilson found that, for $\alpha < 1$, there is always a non-zero stable equilibrium state for any finite value of k_j; for $\alpha = 1$, the equilibrium state may be found only when $k_j < k_j^c$, with k_j^c being a critical value; and no equilibrium state can be found if $k_j > k_j^c$. For $\alpha > 1$, however, there are several possibilities: there may be two non-zero equilibrium states, one stable and the other unstable, for the case $k_j < k_j^c$, or there may be one equilibrium state for $k_j = k_j^c$, or finally there may be no equilibrium state, for the case $k_j > k_j^c$. This means that for $\alpha \geq 1$, for a particular center j, if k_j increases and passes smoothly through k_j^c, then the size W_j will jump from a finite value to zero. Conversely, for $\alpha \geq 1$, when k_j decreases until $k_j = k_j^c$, W_j will jump back from zero to a finite value. If Wilson's model, Eq.(2.11), can be changed to make the zero equilibrium, in the case $\alpha > 1$, become a non-zero equilibrium, then an interesting phenomenon can be observed. When k_j decreases through $k_j = k_j^c$, this process can not generate a definite finite value for the size W_j due to the existence of two possibilities. A decision has to be made between them. This phenomenon, which implies the possibility of a sudden change in the size W_j of a center as the parameter k_j varies continuously, may provide the basis for a dynamic mechanism for creating a new center at a certain hierarchical level of the system. However, a plausible reason for k_j varying continuously has to be found. This means, of course, that the coefficient k_j has to be a well defined variable describing a relevant aspect of economic activity.

2.2.3 Allen's Model

Allen and Sanglier [13, 28, 29, 30, 31] have developed a very general model of the evolution of an urban system, one with maximum accommodation for various possible dynamic mechanisms. Their approach is based on the theory of self-organizing systems established by Prigogine et al. [32], and involves such concepts as "memory", "irreversibility", "learning", "induction" and "dissipation".

A typical model [28] that represents Allen's theory is described as follows. The model is based on a logistic equation for the evolution of the population S_i at center i, expressed as

$$\begin{aligned} \frac{d}{dt}S_i &= bS_i\left(J_i^0 + \sum_k J_i^k - S_i\right) - mS_i \\ &+ \tau\left[\sum_{j\neq i} S_j^2 \exp(-\beta\, d_{ij}) - S_i^2 \sum_{j\neq i} \exp(-\beta\, d_{ij})\right] \end{aligned} \tag{2.17}$$

where b and m are the birth and death rate, respectively, k is the index denoting sector, J_i^0 is the basic 'carrying capacity' at i derived from the basic sector of employment, and J_i^k denotes the job opportunities offered by sector k induced by the basic sector at center i. The first term in the square bracket denotes the crowding taking place in centers $j \neq i$ which drives population flowing into center i from all j and the second term, with minus sign, represents the possible flow of the population from i to all j due to the crowding at

i.

The second equation in the model is the logistic growth of job opportunities given by

$$\frac{d}{dt} J_i^k = \alpha\, J_i^k \left(M_i^k - J_i^k \right) \tag{2.18}$$

where M_i^k is the employment at i originating from the production of sector k and α is the rate measuring the response of entrepreneurs to demand for their goods. So, employment is proportional to demand and the relation is given by

$$M_i^k = \eta_i^k\, D_i^k \tag{2.19}$$

where η_i^k is the number of jobs per unit of production, and D_i^k denotes the potential demand defined as

$$D_i^k = \sum_j \frac{S_j\, c^k}{(P_i^k + \phi^k\, d_{ij})^e}\, \frac{A_{ij}^k}{\sum_{i'} A_{i'j}^k} \tag{2.20}$$

where c^k is the quantity of goods produced by sector k per individual at unit price, P_i^k is the price at i, ϕ^k the transportation cost per unit distance, d_{ij} the distance between centers i and j, e is related to the elasticity of demand for k, and A_{ij}^k is the attractivity of the center i to center j. We see immediately that Allen specifies here a relationship between demand and supply which forms the basis of the numerical simulations. Moreover, the attractivity term $A_{ij}^k / \sum_{i'} A_{i'j}^k$ appearing in the demand equation introduces spatial competition among the centers, which is the common feature of modern dynamic models of central place systems.

In order to complete the simulation model, the dependence of the attraction A_{ij}^k on S_i and d_{ij} must be represented. Allen's choice for the relationship is a complicated one given by

$$A_{ij}^k = \left[\gamma - \frac{1}{\delta + \rho(S_i - S_i^{th})} \right]^l \Big/ (P_i^k + \phi^k d_{ij})^l \tag{2.21}$$

The denominator represents the falling off of the attractivity of center i with increasing delivered price $(P_i^k + \phi^k d_{ij})$ at center j. The numerator takes into account the attractivity of i as well as a saturation effect. The difference denoted by $(S_i - S_i^{th})$ implies the possibility of creating a function at level k in center i.

The above set of equations constitutes a well defined simulation model for a complex urban system. Essentially all economic activities are included, not just the retail and service sectors of traditional central place models. The model provides a dynamic mechanism for representing such phenomena as the creation and decay of centers, the appearance of a hierarchical structure through self-organization, and the exercise of decision-making control procedures.

It is obvious that Allen's model is more general than any of the others treated so far within the framework of modern central place theory. Due to the presence of a large set of adjustable parameters, the model should be capable of giving a good representation of a wide range of real urban systems. However, the large number of parameters, which gives the model its generality, reduces the reliability of the simulation results unless the value of most parameters can be more or less determined exogenously. While this difficulty of unspecified parameters exists in most simulation models, it is extremely severe in Allen's model. Pumain et. al. [17] used Allen's model to investigate the development of Rouen, France. They found that it is very difficult to calibrate the parameters in the simulation, though finally they were able to replicate the spatial organization of the central place system in the region.

2.2.4 Comment on the Three Models

We have briefly reviewed three representative dynamical models of central place systems. The models of White and Wilson are very similar to each other; however, the focus of the research of the two authors is somewhat different. White looks for insights into the behaviour of the system through extensive simulation experiments and application to a real system. This approach leads to the discovery of a bifurcation phenomenon and the determination of the parameter values which yield the bifurcation. Moreover, White's model is developed incrementally by including new variables, parameters and mechanisms. The advantage of building a model in this manner is that the knowledge of the role of the parameters in the previous model is always helpful in testing the new model. This leads to the calibration being relatively simple at each stage. Nevertheless, care has to be taken in designing a new model such that the newly included variables and parameters are consistent with those already in the model. Therefore, the approach relies on the experience, intuition and technical proficiency ot the researcher.

Wilson studies his model using analytical techniques. Using this approach, he discovered a bifurcation similar to that found by White. Further analysis leads him to introduce catastrophe theory as a dynamical mechanism for discontinuous change. Wilson's analysis provides a deeper understanding of the qualitative behaviour of the deterministic equations used in his model. However, it is quite difficult to construct a general model dealing with the evolution of a complex system on the basis of analytical mathematics.

Rather than the approach White took in building a model (from simple to complex), Allen established his model directly in its most general form. However, the price paid for the generality is the great complexity of the model. If the model is really general, it has to be applicable to every sector and every region for any kind of hierarchical structure found around the world. It should be able to tell explicitly that what is the difference between one class of structure and another by recognizing certain characteristic values of certain parameters. In this sense, Allen's model at the present stage may be considered as a *formally* general model, and a tremendous amount of work for specifying the details needs to be carried out.

2.3 Koh's research

In 1991 Koh [33] applied White's dynamic retail model to the major retail centers in the St.John's metropolitan area for the period 1960-1980. During that period the system included one very large centre (Downtown), two intermediate sized centers (Topsail and Kenmount), and five small centers (Churchill square, Torbay Road. Wedgewood, Elizabeth East , and Elizabeth West).

According to the theory on which this model is based, the development of a center depends upon its profitability: "when the revenue attracted by a central place significantly exceeds the cost of providing the goods and services, the center will grow, whereas if costs exceed revenue, the centre must in the long run decline [10]." The original dynamic retail model derived from the theory may not adequately describe the action of entrepreneurs in the St. John's metropolitan system. Therefore, when testing the model, Koh modified the growth function in order to make the model reflect the real situation properly. The modifications were of two kinds. First, Koh considered that there should be an upper limit on centre size, "a Maximum Centre Size", which she took to be the maximum size of each centre in its own business history. The limits on centre size mainly reflect two factors, planning regulations and competition for land use. For example, at some specific sites the relevant law effectively limits the development of retail activity by limiting the amount of avaliable land. Second, the growth of a retail centre usually occurs in what Koh referred to as stepped growth, because retailers usually do not respond immediately to every change of profit or loss; but when the profit or loss is large enough, and sustained over a sufficient period, the retailers may decide to expand the centre or reduce the retail space. In other words, the growth or decline of retail centers is discontinuous rather than continuous. To capture this phenomenon, she introduced the parameters u.

the threshold sensitivity level of expansion; d, the threshold sensitivity level of reduction; and y, the time lag of the growth. These parameters were used in constraint conditions on the development of retail centers.

The success of the calibration can be observed in a comparison between the actual history of the system given in Fig.2.4 and "best" model result in Fig.2.5. Koh's results can be described as follows. First, Koh's research focused mainly on qualitative characteristics rather than quantitative features. Although most absolute sizes were under-estimated, the relevant patterns were captured accurately: the results showed one very large center (Downtown), two intermediate sized centers (Topsail and Kenmount), and five small centers (Churchill Square, Torbay Road, Wedgewood, Elizabeth East , and Elizabeth West). Second, it was emphasized that, in the calibration, a simple model and a single set of parameter values, unchanged throughout the study period, were enough to replicate the pattern of relative sizes. The fact that the evolution of both Kenmount and Topsail from small centers into intermediate sized centers was captured by the model means that the location of these shopping centers is consistent with the location of high-order centers established by the dynamic mechanism of the system. Third, the zero value of the threshold parameters appearing in the simulation results indicates that the growth of retail centres depends mainly upon the inherent dynamics of the system rather than the individual behaviour of retailers.

Koh's research proves that although the retail model is not comprehensive, it can be employed to replicate qualitatively actual system development and to make reasonable predictions of the behaviour of the retail system. The pattern of relative centre sizes from the simulation results indicates that the data and methods employed for estimating centre size and retail expenditures are sufficient to carry out the qualitative analysis of the retail system. The results of her research support the argument that it is not always necessary to describe all details of a spatial process in establishing a model which can be employed to predict the structure of retail systems.

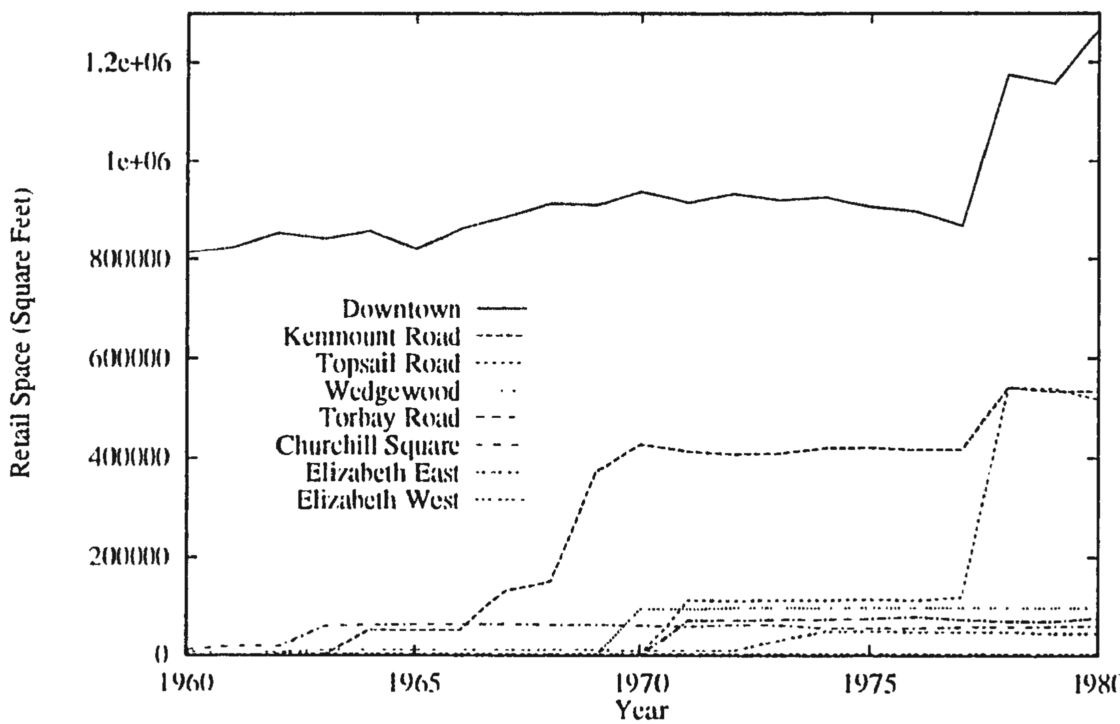


Figure 2.4: High Order Retail Space by Major Retail Centers for the St. John's Metropolitan Area 1960-1980 (after [33]).

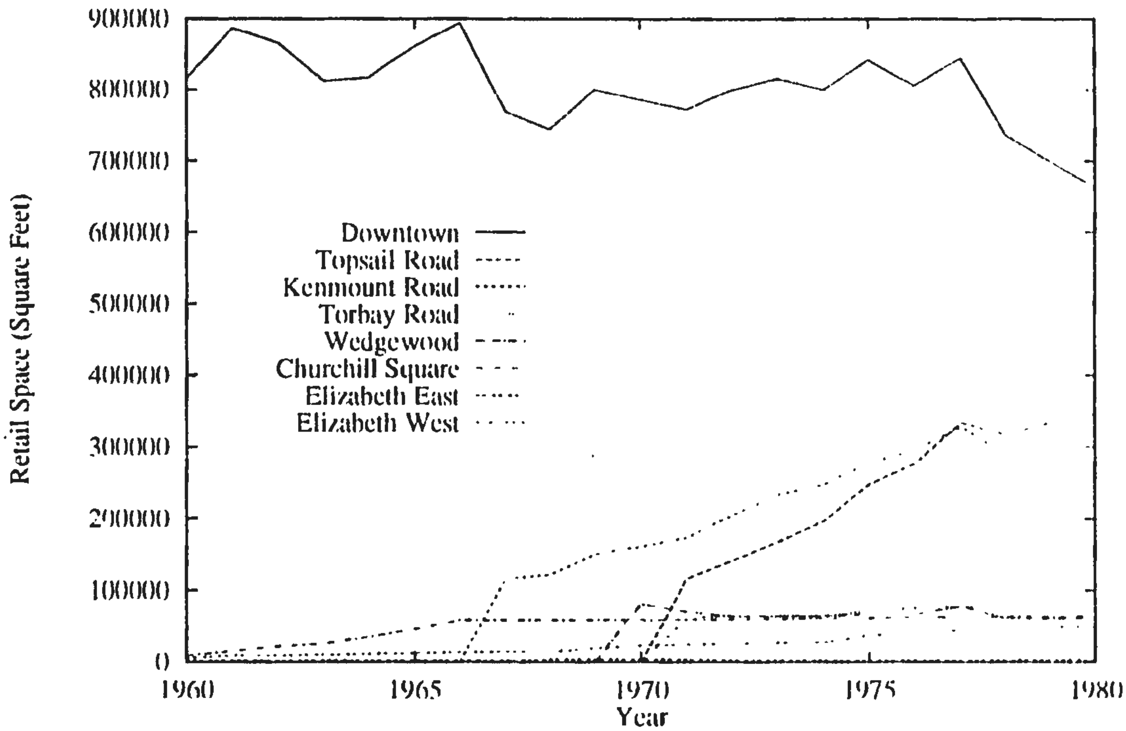


Figure 2.5: The Simulated High Order Retail Space by Major Retail Centers for the St. John's Metropolitan Area 1960-1980 (after [33]).

2.4 Economic Base theory

In the last section of this chapter it will be useful to discuss briefly some aspects of economic base theory, since that theory is linked to some extent with the present research. The concepts of the economic base theory were first specified in quantitative form in the late 1930's by Hoyt [34], who developed the idea of a "basic-service ratio", and attempted to measure the basic and service components of individual cities and regions [35].

The economic base theory concerns the relationship between the different economic sectors and the role played by those sectors in the total economic activity of the region. The theory [36] is usually applied in the context of studies of urban and regional economic development. Some concepts for the theory have also been used in dynamic urban modeling. For instance, Allen's model described the export activities and service activities in terms of the economic base principle [12].

In the economic base theory all economic activity of an urban area is divided into two components: basic (or export) activity and non-basic (or local service) activity. The goods and services produced by the basic activity in the local area are sold beyond this area; that is, the market for the products of the basic sector may be regional, national or international. The more an area can produce for export, the more income the area will obtain. In contrast with this, the nonbasic activity supplies the goods and services only for the area itself. Beyond the classification of basic and nonbasic activity, the economic base theory emphasizes the basic activity's importance in urban economic growth. Any impulse of growth in the basic sector spreads to the non-basic sector and results in the development of the latter.

Based on the discussion above some simple formulas can be employed for understanding the theory and the relationship among total economic activity, basic activity, and nonbasic activity of an urban area.

The total economic activity can be represented as

$$T = B + N \tag{2.22}$$

where T is total activity, B is basic activity, and N is non-basic activity. If the non-basic activity is assumed to be a proportion of total activity, then

$$N = kT \tag{2.23}$$

where k is a constant. Then Eq.(2.22) can be rewritten

$$T = \frac{1}{1-k}B \tag{2.24}$$

or

$$T = mB \tag{2.25}$$

where m is the economic multiplier relating total activity to basic activity.

Formulas from (2.22) to (2.25) describe only qualitatively the economic base theory. In order to quantify economic activity, the employment of an area is usually utilized as a measurement. For example, if employment of in basic and nonbasic activity in an urban area is 4000 and 6000, respectively, then the ratio of basic activity to nonbasic activity is 2 : 3 and the economic multiplier will be 2.5 in terms of the formula 2.23. This means that the employment increment of total activity will be 2.5 times as big as that of basic activity. Thus if changes in the basic sector can be forecast, and if the multiplier can be assumed to remain constant, then it is possible to forecast changes in total activity. The critical role of the basic activity and the operation of the economic mutiplier are the two characteristics which are usually seen as constituting the core of economic base theory.

Computationally, economic base theory seems very simple. In spite of this, there are two main limitations to the theory. First, it is difficult to determine whether the function of a sector is basic or non-basic, because most economic sectors involve both basic and non-basic functions. Second, the economic multiplier is an average value. The multiplier of an urban area may change with the different sectors because of the variety of the growth potential in different sectors.

In the present research, while economic base theory as such is not utilized, the economic sectors in the urban model are established by modifying the concepts of basic and non-basic activity, and the size of the sectors is defined in terms of employment. These points will be discussed in more detail in the following chapters.

Chapter 3

White's Model of Urban System Dynamics

This chapter presents a detailed discussion of the generalization of White's two-sector retail center model to a dynamic model of an urban system. Section 3.1 presents the nature of urban dynamics. Section 3.2 describes the generalized dynamic urban model and the treatment of exogenous versus endogenous effects in the system dynamics. Section 3.3 comments on the influence of choosing a transportation network appropriate to the urban model.

3.1 The Nature of Urban Dynamics

The development process of an urban area is a complex one, and includes many events which may be the stimuli forcing the growth of the area. Nader [3] considered that this process normally involves five main stages through which an urban centre usually passes before achieving metropolitan status.

A single economic activity, performed by most towns, is a mark of the first stage. In the second stage, after functions such as distributing, wholesaling and marketing are developed, a town becomes a service centre. In the third stage the town becomes a primary manufacturing centre by processing products originating within its region before they are sent to their ultimate markets. The fourth stage, in which the town functions as a secondary manufacturing centre, is achieved by expansion of the town's industrial activities, including the manufacturing and processing of products. In the fifth stage, the urban centre becomes a regional metropolis that acquires the control functions for the regional economy. The achievement of national metropolitan status, the final stage, is reached only by a few cities.

These five stages describe a dynamic process of urban area evolution. How to model this process in order to show the dynamic mechanism has been an interesting research topic in urban modelling. Generally speaking two kinds of model may be employed to describe the mechanism. One is a detailed and complex model that may include many factors impacting on the growth of an urban area. The other is a generalized and abstract model that only involves a few principal rules which are common to most urban areas. Comparing the former with the latter, one obvious difference is that there are many variables and parameters in the detailed model, and consequently the general behaviour of the model is not well understood, even when the model is successfully calibrated for specific situations [11]. In contrast, the variables and parameters in a generalized model usually are much less numerous than those in a detailed model. This difference is important. First, in the calibration process of the detailed model, the large number of parameters will make the calibration difficult and time consuming. Moreover when the calibration is achieved, the value of many parameters often can not be easily explained. By contrast, a generalized model is quite easy to calibrate, and the limited number of parameters can frequently be interpreted.

White's model is of the second kind: it is generalized and abstract. The urban dynamics described by the model " treats population distribution as primarily a consequence of the location of economic activity, but also recognizes that the distribution of population is an important determinant of the location of the economic activity [11]." Population is thus selected as the basic variable of the model due to its importance with respect to the location of economic activity. The mechanisms embodied in this model can be summarized as follows. An urban area with various economic sectors tends to capture the market of its surrounding region, which consists of other urban centres as well as rural areas. However, whether the urban area is able to capture the market successfully will depend in part on its operating efficiency in producing or supplying the required goods and services. Generally speaking, a large urban area, or a relatively large one with a good location, may possess more advantages [37], because economies of scale and agglomeration are more pronounced in these metropolitan centres. The advantages will allow certain economic sectors in these urban centres to enlarge more rapidly than the growth of the economy as a whole. This phenomenon does not imply that the size of an urban area can increase indefinitely because of the appearance of diseconomies scale and agglomeration. These arise due to such facts as urban congestion, decline of the environmental quality, and so on. Even though on a short term a large urban centre may possesses competitive advantages compared with smaller urban areas, over a longer term the urban dynamics may drive the urban system towards a new configuration in which the size of the largest centre in self-limiting.

For such an abstract model of urban dynamics, it is useful to recall the relationship between an individual event (or micro event) and the abstraction of the model (or macro event). For example, many people start businesses in Moncton, for a variety of reasons. Some of these businesses succeed while others fail and disappear. Companies move in and out of Moncton. The appearance or disappearance of each business is an individual event. But in general, people do business in Moncton because it has a relatively large population and a good location; it is a transportation node with good links to other places. Compared with a city with a smaller population and a worse location, like Edmondston, more people prefer to open businesses in Moncton, and more businesses are successful. Therefore, the population of Moncton will increase, and Moncton will develop faster than Edmondston. The growth of Moncton relative to Edmondston due to its better location illustrates a basic macro-level property of the model: the dynamic competition mechanism facilitated by the transportation network.

One further issue at the macro level concerns the bounds of the model: the area of application of the model has to have a geographical limit. But once the geographical limit (or research area) is determined, another issue appears – how to handle the connections between the urban system being modelled and the rest of the world. Links with cities and regions beyond the study area obviously affect the dynamics of the local urban system. In the model used in this research, it is assumed that the net effect of these links is to determine the growth rate of the urban system as a whole; this growth rate is treated as exogenous to the model. In other words, the model does not predict the growth rate of the system. It takes that as given. The model servers to distribute the over-all system growth to the individual urban centres that make up the system. The mechanism will be discussed in the following section.

3.2 White's Generalized Model

After introducing a general description of urban dynamics in the last section, we will discuss here White's generalized model in detail. In the most general terms, the model shows how a system develops under the assumption that all centres are competing for the economic activity generated in the system. All changes in the overall level of economic activity in the system are assumed to be exogenous. If there is growth in the system, the model will show how to allocate the total increment of growth to the various centres within the system. The model does not itself generate growth or decline for the system as a whole.

The competitive mechanism in the model is developed using concepts such as revenue, cost, profit, and sector size. However, the highly abstract nature of the model gives these common words a somewhat different meaning from their usual definition. Revenue measures the competitive success of a city in capturing a market, cost describes the competitive ability of a city in producing or supplying goods and services, and profit represents the synthesis of the two competitive abilities. The sector size is measured by a kind of index, rather than by output or employment. These concepts will be described in more detail below.

As White describes it," the model starts with a definition of the general suitability of an urban center as a location for activity in a given economic sector. This suitability may be thought of as an aggregate level of profitability for the sector in that particular city. It depends first of all on the degree of accessibility to the entire urban system, since that system constitutes the market and thus provides revenue [11]." White's generalized model of an urban system consisting of n cities and $m-n$ rural areas may be described by a set of equations as follows. The first is the total market potential defined as

$$ {}^tV_{j,k} = \sum_{j=1}^{n} \frac{{}^tS_j}{D_{ij}^{N_k}}, \quad i = 1,\cdots,m,\ j = 1,\cdots,n. \tag{3.1} $$

where ${}^tS_j$ denotes the population of city j at time t, D_{ij} denotes the distance between city (or rural region) i and city j, and N_k is the exponent of distance with $k = 1,2$ denoting the non-basic and basic sectors discussed in chapter 2. From the definition, it is seen that ${}^tV_{j,k}$ is the total attraction exerted on the population in city or rural area i by sector k in all cities in the system.

The revenue received by sector k of city j from all cities and rural areas is given as

$$ {}^tR_{j,k} = \sum_{i=1}^{m} {}^tS_i \frac{{}^tS_j / D_{ij}^{N_k}}{{}^tV_{j,k}} = {}^tS_j \sum_{i=1}^{m} \frac{{}^tS_i / D_{ij}^{N_k}}{{}^tV_{i,k}} \tag{3.2} $$

where ${}^tS_i$ denotes the population of either city or rural area i at time t.

In order to capture the revenue, the urban area, considered as an economic entity, must incur the cost of providing the goods and services. The cost at time t for sector k

in city j is expressed as

$$ {}^{t}C_{j,k} = C_0 + {}^{t}B_k \left({}^{t}W_{j,k}^{E_k} \right) \tag{3.3} $$

where constant C_0 is the threshold level of cost (for simplicity, we assume the threshold level of cost $C_0 = 0$), ${}^{t}B_k$ is a conversion or scaling parameter, the parameter E_k determines whether we are dealing with a case of diseconomies of scale ($E_k > 1$) or economies of scale ($E_k < 1$), and ${}^{t}W_{j,k}$ is a measure of sector size.

The notional profit ${}^{t}P_{j,k}$ obtained by sector k in city j at time t is then simply the difference of revenue and cost

$$ {}^{t}P_{j,k} = {}^{t}R_{j,k} - {}^{t}C_{j,k} \tag{3.4} $$

The evolution of the size of sector k in city j, ${}^{t}W_{j,k}$, is given by the following difference equation

$$ {}^{t+1}W_{j,k} = {}^{t}W_{j,k} + G\left({}^{t}P_{j,k}\right) + \frac{{}^{t}\Delta S}{{}^{t}S}\left({}^{t}W_k\right)\left(\frac{{}^{t}V_{j,k}}{\sum_{j=1}^{n} {}^{t}V_{j,k}}\right). \tag{3.5} $$

The right hand side of the Eq. (3.5) consists of three terms. The first term is the initial size of sector k. The second term indicates that the size of sector k will increase or decrease in response to positive or negative profit, respectively; the response rate G denotes the size increment per unit profit. However, the size increment of sector k in city j is determined not only by the profit it earns, but also by the total increase of the population in the system. The effect of the latter is given by the third term. If the total increase in the size of sector k due to an exogenous increase of the system population is ${}^{t}W_k({}^{t}\Delta S)/{}^{t}S$, with ${}^{t}S = \sum_j^n {}^{t}S_j$ and ${}^{t}W = \sum_j^n {}^{t}W_{j,k}$, then this amount of population will be allocated to each sector k in every city j according to its relative attraction ${}^{t}V_{j,k}/\sum_{j=1}^{n} {}^{t}V_{j,k}$.

It is interesting to compare this latter term with the "crowding" term in Eq. (2.17) of Allen's model [12]. In Allen's model, the "crowding" term plays a role in population redistribution within an urban system with a parameter τ determining the strength of this term. However, it is difficult to give an interpretation to the value of the parameter τ. This parameter is usually calibrated together with other parameters in a simulation and its value is unexplained. In White's generalized model, the term responsible for population distribution is self-consistently defined, through ${}^tW_k$ and the relative attraction that expresses the distance effect as seen in Eq. (3.1). The strength of the term is determined by the percentage increase of the total population in the urban system. The value of the parameter representing the net growth rate of the system, $\gamma = {}^t(\Delta S)/{}^tS$, reflects the net effect of the birth, death, and migration rates. This parameter will also play a role in determining the value of the parameter ${}^tB_k$ in the cost equation (Eq.3.3).

The new size ${}^{t+1}W_{j,k}$ of sector k is used to estimate the new population of each city by the following equation:

$$ {}^{t+1}S_j = \sum_{k=1}^{2}(p_k)\left({}^{t+1}W_{j,k} \right) \tag{3.6} $$

where p_k is a parameter describing the composition of a city in terms of the two sectors.

According to the economic base theory, all economic activities found in the cities of the system may be represented by two categories: export sectors and local service sectors. However, in reality it is quite difficult to separate all economic sectors as conventionally defined into these two groups, because each of those sectors contains both export and local service activity. For some sectors the proportion of sales in the external market is greater than that in local market, but for others, the proportion of sales in the local market is greater than that in the external market.

The difference is in the sensitivity of their sales to distance or in their relative ability to export. Moreover, even though the sector size in a city is intuitively related to the employment classified by sectors in that city, it is difficult to find a standard which allows us to divide the employment in each of the sectors into two components, "export" and "local service". Hence, actual employment data will not be used. Instead, size for the two sectors will be estimated using a method discussed in chapter 6, in the context of calibration.

We go back now to the cost equation and show that the conversion parameter ${}^{t}B_k$ must be calculated instead of being calibrated with the other parameters. The model treats growth in the region as comprised of two parts, redistribution within the region itself and net regional growth, treated as exogenous whether internally generated or caused by influences from outside the region. This treatment of all net growth in the region as exogenous is ensured by the condition that total profit for each sector k in the system be zero:

$$\sum_{j=1}^{n} {}^{t}P_{j,k} = 0, \qquad \text{for} \quad k = 1,2. \tag{3.7}$$

From this condition and Eqs.(3.5)-(3.6), we may derive the following expression:

$$\begin{aligned} {}^{t+1}S &= \sum_{j=1}^{n} {}^{t+1}S_j = \sum_{j=1}^{n}\sum_{k=1}^{2} p_k\, {}^{t+1}W_{j,k} = \sum_{k=1}^{2} p_k \sum_{j=1}^{n} {}^{t+1}W_{j,k} \\ &= \sum_{k=1}^{2} p_k \left[\sum_{j=1}^{n} {}^{t}W_{j,k} + G\sum_{j=1}^{n} {}^{t}P_{j,k}\right] + \sum_{k=1}^{2} p_k \left[\frac{{}^{t}\Delta S}{{}^{t}S}\, {}^{t}W_k \sum_{j}^{n} \frac{{}^{t}V_{j,k}}{\sum_j^n {}^{t}V_{j,k}}\right] \end{aligned} \tag{3.8}$$

The first term of Eq.(3.8) allows us to look at redistributive changes within the region in the absence of net regional growth. The second term illustrates the effect of the net increase of the system population. This net increase is treated as exogenous data, and one important function of the model is to allocate the net increase of system population to centres within the region.

The calibration process can be simplified by means of the constraints imposed by the condition (3.7) that total system profit be zero. Condition (3.7) may be rewritten in terms of the revenue and cost:

$$\sum_{j=1}^{n} {}^{t}R_{j,k} - \sum_{j=1}^{n} {}^{t}C_{j,k} = 0. \qquad (3.9)$$

A substitution of Eqs. (3.2) and (3.3) into the above condition yields

$$\sum_{j=1}^{n} {}^{t}S_j \sum_{i=1}^{m} \frac{{}^{t}S_i / D_{i,j}^{N_k}}{{}^{t}V_{i,k}} - \sum_{j=1}^{n} {}^{t}B_k \left({}^{t}W_{j,k}^{E_k} \right) = 0. \qquad (3.10)$$

Then the definition of the potential (3.1) can be used to simplify the above expression so that

$$\sum_{i=1}^{m} {}^{t}S_i \frac{{}^{t}V_{i,k}}{{}^{t}V_{i,k}} = {}^{t}B_k \left(\sum_{j=1}^{n} {}^{t}W_{j,k}^{E_k} \right) \qquad (3.11)$$

which yields

$${}^{t}B_k = \left[\sum_{k=1}^{2} p_k \sum_{i=1}^{m} {}^{t}W_{i,k} \right] \Big/ \sum_{j=1}^{n} {}^{t}W_{j,k}^{E_k} \qquad (3.12)$$

This relation not only simplifies the calibration procedure for a simulation by eliminating two parameters ${}^{t}B_k$ for $k = 1, 2$, but also ensures that the condition $\sum_{j=1}^{n} {}^{t}P_{j,k} = 0$ imposed on the system is satisfied.

3.3 Transportation Network

A significant issue concerning the transportation network arises in generalizing White's retail center model to deal with a regional urban system. Usually a single transportation mode is used in the retail center model for a city. However, the large geographical scale and the historical development of transportation technology yield a multi-mode network. Therefore, it is necessary to choose a most likely mode, taking into consideration transportation costs and the popularity of the transportation mode. On this basis, a single effective transportation network can be defined.

For the Atlantic region, the effective transportation network is constructed as follows. First, highway transportation is chosen as the most popular transportation mode and the shortest distance between two cities i and j by highway is taken as the effective distance D^e_{ij}. Second, for those effective distances containing water barriers, the ferry distance is converted into the highway distance by introducing a conversion factor F_D, which denotes a speed ratio (speed on highway/speed on ferry). Since highway speed is greater than ferry speed, the effective distance D^e_{ij} will be increased by this conversion:

$$D^e_{ij} = D^h_{ij} + F_D \cdot D^f_{ij} \tag{3.13}$$

where D^h_{ij} denotes the highway distance and D^f_{ij} denotes the ferry distance. For certain very isolated cities in the region, such as Labrador City, air transportation is the mode of choice; a conversion factor A_D, expressing a cost ratio (cost of airline/cost of highway), is introduced for converting the air distance into the the equivalent highway distance, which yields

$$D^e_{ij} = D^h_{ij} + A_D \cdot D^a_{ij} \tag{3.14}$$

For rural regions including CMAs or CAs, it may be desirable to make an adjustment to the distance measure between the point chosen to represent the location of the city and that representing the rural region. In order to truly reflect the attraction of a CMA or CA to its surrounding rural region, a separation coefficient S_D is introduced for obtaining an effective distance between the city point and the rural region point in a particular census division, this yields

$$D^e_{ij} = S_D \cdot D^h_{ij} \tag{3.15}$$

where the selection of S_D values will be discussed in the calibration chapter. The details of the effective transportation network D^e_{ij} is given in Appendix A.

In most previous research concerning urban systems, the influence of the choice of transportation network on the simulation results is seldom discussed [10, 16, 17, 23, 27, 30, 31]. In order to understand the importance of the transportation network, a trial simulation, using a transportation network defined in terms of Euclidian distance, will be also carried out; this simulation will use the parameters as calibrated for the model employing the effective transportation network. A comparison between the two simulation results should show explicitly the role of the transportation network in the dynamic urban model.

Chapter 4

The Atlantic Urban System, 1951-1986

The study area chosen for application of the dynamic urban model is the Atlantic region (Fig.4.1). The evolution of the urban system in this region is closely associated with the economic development of the area. Therefore, this chapter will focus on both the defining characteristics of the urban system and the economic development of the study area.

The research covers the period from 1951 to 1986. Some consideration was given to using a longer period, beginning in 1931. However, such a time frame, including such different historical periods as the depression, the Second World War, and the long peaceful period following, would be quite complicated to calibrate.

Section 4.1 discusses the definition of an urban system in the context of the Atlantic region. Section 4.2 outlines the economic structure of the Atlantic region, and section 4.3 briefly describes the economic history of each province in the region as well as the history of major urban areas. Finally, section 4.4 deals with technical issues arising from the definition of the study area boundary.

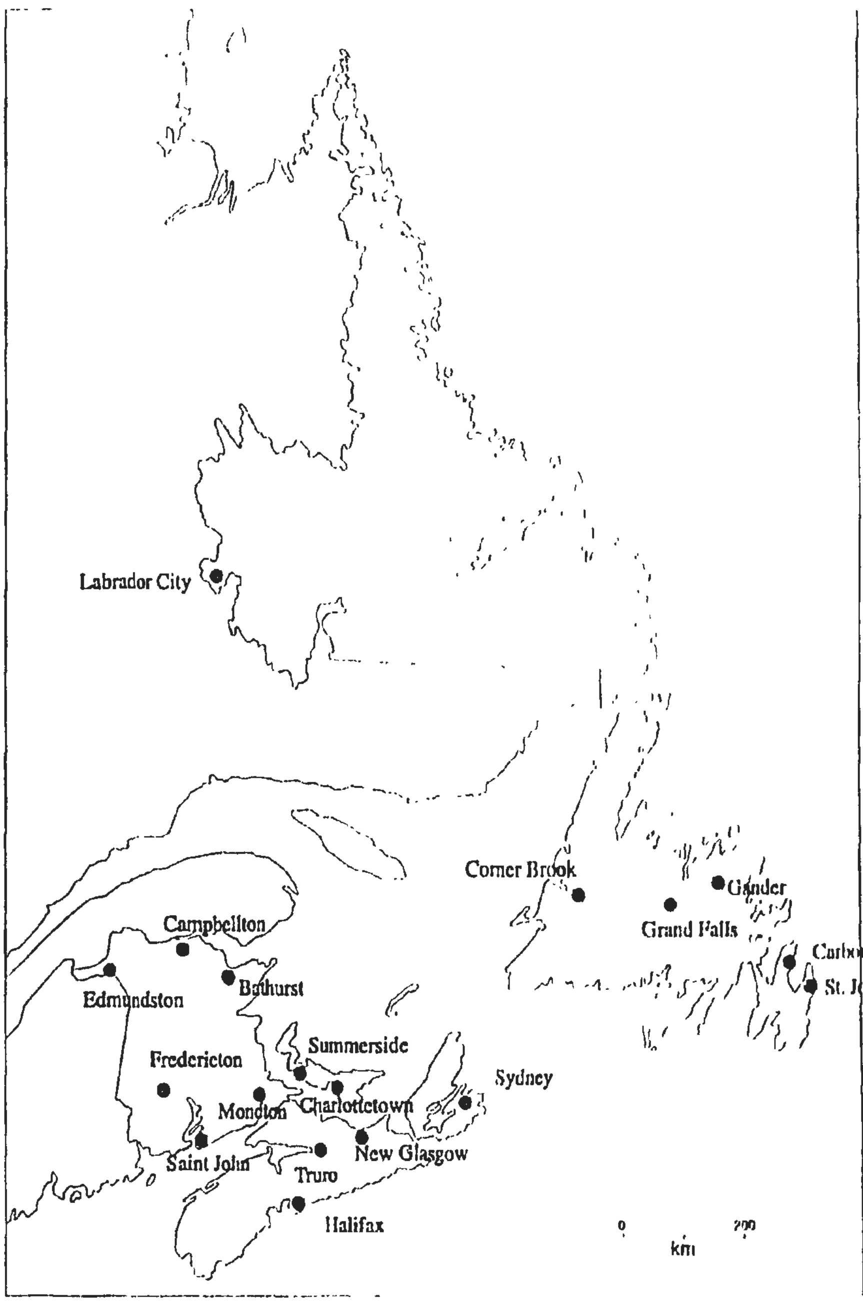


Figure 4.1: Study Area, Showing the Location of the Eighteen Census Metropolitan Areas and Census Agglomerations. (Base map supplied by Memorial University of Newfoundland Cartographic Laboratory)

4.1 Definition of the System

Before selecting an urban system it is necessary to have criteria for defining such a system. Bourne [1] has established a useful scheme for classifying urban systems.

> We do know that economic growth in any given country is increasingly articulated through the nation's set of cities [38, 39, 40]. This articulation has led, in advanced western economies at least, to a particular type of urban system organization. This organization may be summarized as consisting of at least three levels:
>
> (1) *a national system* dominated by metropolitan centres and characterized by a step-like size hierarchy, with the number of centres in each level increasing with decreasing population size in a regular fashion;
>
> (2) nested within the national system are *regional sub-systems* of cities displaying a similar but less clearly differentiated hierarchical arrangement, usually organized about a single metropolitan centre, and in which city sizes are smaller over all and drop off more quickly than in (1) above as one moves down the hierarchy;
>
> (3) contained within these subsystems are local or *daily urban systems* representing the life space of urban residents and which develop as the influence of each centre reaches our, absorbs, and reorganizes the adjacent territory. In a small country levels (2) and (3) may be difficult to differentiate, whereas in larger countries both of these levels may show further subdivision (see Fig.4.2).

It may be recognized that in actuality there are more than three types of urban systems according to Bourne's definitions. In contrast to Bourne's regional sub-system including a metropolitan center, the Atlantic urban system seems to be a combination of Bourne's levels (1) and (2), sharing characteristics of both a national urban system and a regional sub-system. In other words, this system is a collection of several regional sub-systems. A few metropolitan centers - Halifax, St.John's, Saint John, and Moncton, and Charlottetown play a leading role in the economic activity of each province. However, as the economy of the Atlantic region has developed, an economic core area has formed. Within this core, metropolitan Halifax has its greatest strength in the service sectors – education, trade, transportation, and the provincial and federal governments. Its role as a distribution centre in the whole Atlantic region is growing. Halifax, to a certain extent, exerts a leading role in economic activity within the region. Burke and Ireland [11] have

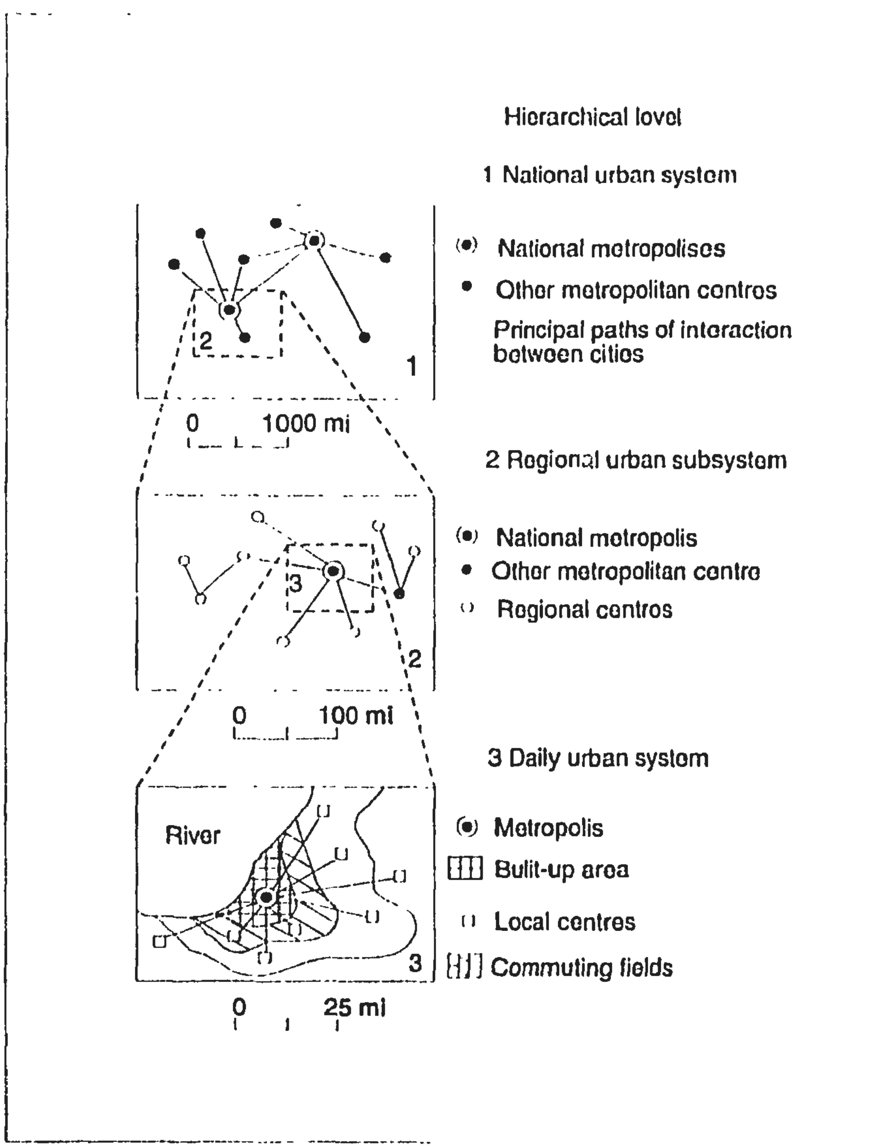


Figure 4.2: Hierarchical and Spatial Organization of the Urban System (after [1]).

argued that " in the early 1970s for the first time the core area began to play a major role in the economic leadership of the region." This core area includes Halifax, Moncton, and Saint John (see Fig. 4.3).

Moreover, although there are connections between the Atlantic region and places outside of the region, the area is relatively isolated, both by ocean and by the distance from the major national and international markets. Also, Canada's westward spread over the last 100 years has increased the eccentricity of the Atlantic region [4]. If we regard the Atlantic region as a whole in terms of its relative isolation and the emergence of metropolitan Halifax as a regional or sub-national metropolis, the urban system is then quite similar to Bourne's regional sub-system. Thus, the urban system in the Atlantic region would seem to provide a reasonable test case for the simulation model that forms the basis of this research.

4.2 Overview of the Study Area

Before 1949 the Atlantic region was not a politically or economically integrated area, not least because Newfoundland was not a part of Canada. The region was comparatively isolated, and the resource based economy relatively open. In spite of connections between the cities within the region, many of the cities had an independent export relationship with other areas such as mainland Canada, the United States or Europe, which tended to minimize the economic relationship among the region's cities. When in 1949 Newfoundland joined Canada as a province, many of the political and administrative barriers to the economic integration of the region were removed. More recently, as the tertiary sector has developed, the resource based structure of the economy has gradually

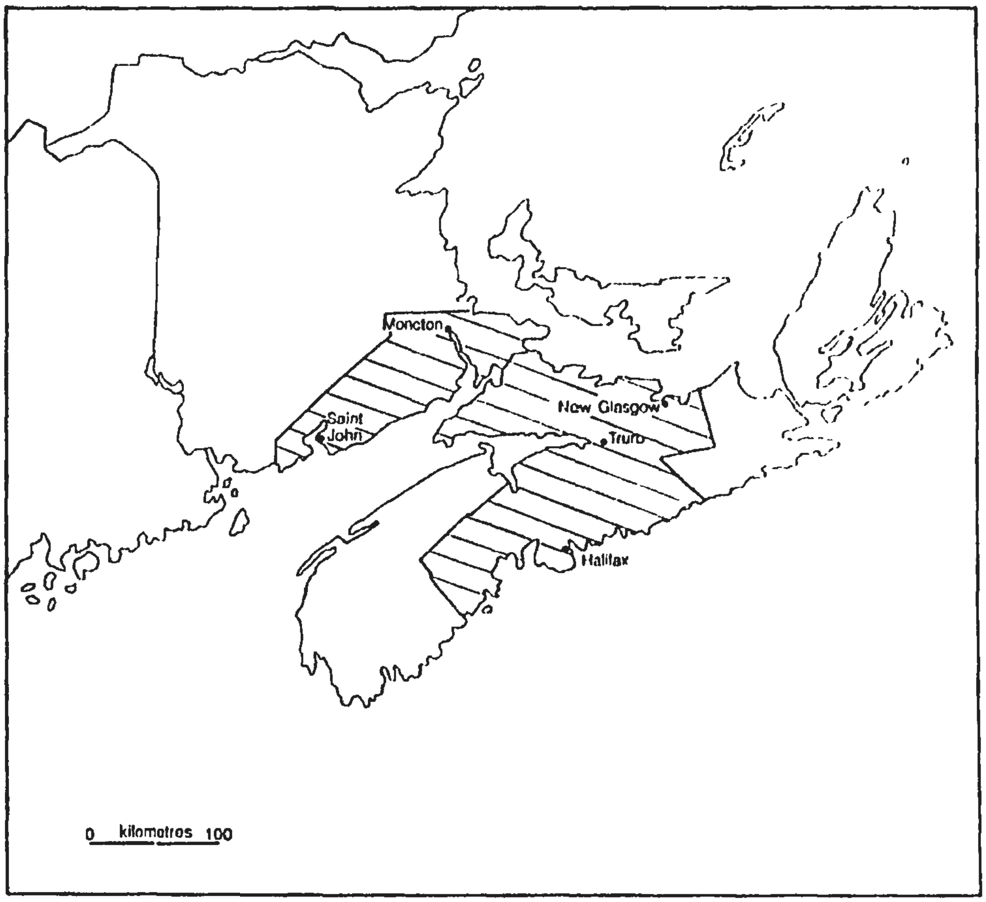


Figure 4.3: Burke and Ireland's Atlantic Core Region. (Base map supplied by Memorial University of Newfoundland Cartographic Laboratory)

shifted toward a service based structure. This shift underlies an important trend – relatively independent cities are gradually becoming integrated into a system of interdependent relationships. Nevertheless, fishing, farming, mining, and forest industries continue to be major economic activities, producing largely for export from the region.

Today, metropolitan Halifax is becoming the dominant centre in the Atlantic region for service sectors like finance and public administration. Moncton, due to its strategic transport location, is a major wholesaling and distribution point for the Maritime provinces. Saint John is an industrial city. In contrast with these three cities, St.John's and Fredericton are both centers of government and educational services. Compared with the more diversified economic structures of these cities, many smaller cities in the region are dominated by a single industry. For instance, there are pulp and paper mills in Grand Falls, Corner Brook, Bathurst, Campbellton and Edmundston, and iron mines in Labrador City.

4.3 Economic Growth and Change in the Atlantic Region

4.3.1 Newfoundland

The economy of Newfoundland [42, 43] is heavily dependent on natural resources. For some 400 years the Island depended almost entirely on the fishery, until during the past century the forest and mineral resources began to be exploited. After confederation with Canada in 1949, the economy of Newfoundland experienced dramatic and substantial changes. A number of fresh-fish processing plants were established and they gradually replaced the old method of processing the fish. A large proportion of the provincial forest output comes from the pulp and paper operations in Corner Brook, Grand Falls, and, (during the latter part of the study period) Stephenville. Since the 1950s most of the exported mineral product has come from Wabush and Labrador City in western Labrador. Agriculture is of minor importance in Newfoundland. New manufacturing industries were established with government support, but only a few succeeded.

St John's, the provincial capital, is the largest city in Newfoundland. After 1919, cheaper Canadian manufactured goods entering Newfoundland caused the city's industries to collapse and reduced commercial activity at the port. St John's became more dependent on public-sector employment and lost its traditional role as the fish-exporting centre of Newfoundland. The growth of a large civil service expanded the city's labour force and stabilized the economy. This growth supports a sizable retail, service and business sector. The completion of a paved highway across the Island (1965) further stimulated the city's economy. The other city in eastern Newfoundland included in this study, Carbonear, was an important centre for commerce, fishing, trading, shipbuilding and sealing in the 19th century. Carbonear's importance as a shipbuilding centre and as a port of trade declined because the seal hunt and both the Labrador and the inshore fishery declined. By the 1970's Carbonear, in addition to providing goods and services to its own population, was a distribution and service centre for the adjacent area. The Fishery provided employment in the primary sector, but most other employment was related to the distribution of goods and services.

In central Newfoundland Grand Falls was established with the opening of the pulp and paper mill in 1909. Although it was the mill that employed the majority of workers in Grand Falls, secondary and service industries grew quickly. During the period 1965-1970, the company's production increased by fifty per cent. The mill remains the largest single employer in Grand Falls. Gander was established in the late 1930's with the construction of the airport, and the town remains an important service centre for trans-atlantic flights and is important as a distribution centre. The town's central location on the island makes it a significant transportation point, and by the early 1980s, in addition to other carriers, there were seven trucking firms in Gander. Gander's central location and variety of transportation methods have also made it an important convention centre.

Corner Brook, in the western part of the province, is Newfoundland's second largest city. Because of its size and location, Corner Brook is a distribution, transportation and service centre for western Newfoundland and Labrador. It is the location of the western regional government offices and the regional centre for medical facilities, distribution, education, transportation and industrial and commercial resources. While the economy greatly diversified after the 1950s, the pulp and paper mill remains the base of the economy. The mill was once the largest integrated pulp and paper mill in the world and was still among the top twelve in 1976.

In Labrador, Labrador City began as a mining town in the late 1950s. Within a decade, it became the largest community in Labrador, and the fourth largest city in the Province. In order to attract a more stable work force, the mining company, in the early 1960s, sponsored or intiated a shopping centre, medical care and recreation facilities, and a school complex. Labrador City continued to grow through the 1970s, reaching a population around 12,000 by 1980. Slumping world demand for iron led to the first layoffs at Labrador City in 1981 and the population declined as further layoffs and occasional shut-downs occurred throughout the 1980s. Air transportation provided the only links between this city and the rest of the province.

4.3.2 Prince Edward Island

The economic structure of Prince Edward Island was relatively stable throughout the first half of the 20th century [44]. Agriculture was the most important activity: close to half of the Island's land is highly productive. Fishing was the other important resource based industry. In contrast with the rest of the Atlantic region, the forest and mineral resources were not commercially important. Since 1945 tourism has emerged as a major industry. And by the mid-1960s, the number of farmers and fishermen was declining.

Charlottetown is the capital city of the province [45]. At one time the city was a major port, but in recent years the number of vessels entering has declined significantly. First encouraged by the erection of a major railway hotel in 1931, the tourist trade was further developed by motel construction in the 1950s and 1960s, and was enhanced by the completion of an extensive network of paved roads expanding from Charlottetown. In 1984 the Federal Department of Veterans Affairs was moved to the city, resulting in development of the administrative sector.

The next largest urban centre is Summerside in the western part of the Island [44]. Summerside was launched as a shipbuilding centre. After the collapse of shipbuilding in the late 19th century , trade with the county's farming community sustained Summerside's economy. Summerside's principal economic activities are agricultural service industries, government offices and the nearby Canadian Forces Base.

4.3.3 Nova Scotia

Nova Scotia has limited natural resources. Even so, they are vital to the provincial economy [46]. Since the 1950s economic development has been the primary concern of provincial government. In the early 1960s the coal and steel industries had serious difficulties. The Cape Breton Development Corporation, established in 1967, was aimed at developing alternatives for miners as the coal industry declined. Most of the manufacturing plants in Nova Scotia are based on primary products and are relatively small. Only a limited number of the industries have been established since the 1960s. At least half of the manufactured products are exported, most of them to the United States.

Halifax [47] is the capital of Nova Scotia and the largest city in the Atlantic region. In the middle of 19th century the growth of Halifax's economy was based on trade with the West Indies. The internatic l shipping at this time brought a prosperity that led to a spurt of industrial growth in the city. Unfortunately, however, this industrial boom was short-lived because of distance from markets, lack of local resources, and central Canadian competition. During the study period Halifax has experienced steady development based on wholesale distribution, transportation, and government services. The strength of the metropolitan area economy depends on the defence and port functions, and the service sector.

Sydney is the second-largest city in Nova Scotia. A steel mill, based on local coal resources, limestone from nearby quarries, and iron ore from Bell Island, Newfoundland, formed the core of the city's economy. This industry has declined since the end of WWII as the coal mines became less productive and the steel mill became obsolete and less competitive with central Canadian producers.

In the central part of the province, New Glasgow is the centre of an urban community of 4 towns – Trenton, New Glasgow, Stellarton, and Westville – and the trading centre for the farming, lumber and fishing counties of Pictou, Antigonish and Guysborough. The establishment of coal mining resulted in the development of this area. The Nova Scotia Steel Company, the first steelmaking plant in Canada, was opened in this area, and supplied steel for central Canadian manufacturers of farm implements and for railway construction. Although the coal-mining industry has declined substantially, the economy of this area has been assisted by a relatively new paper plant and a tire-manufacturing facility. Truro, the other city in central Nova Scotia, is a major railway centre. The city has a relatively diversified economic base, with such manufacturing activities as metal foundries, machinery, printing and lumber milling. The textile mill established in 1868 still operates, and a dairy company located here since 1920 is a major employer.

4.3.4 New Brunswick

The forest is the province's greatest natural resource [4, 48], supporting various industries, and by the 1930s pulp and paper mills were more important than lumber. Second in importance are mineral deposits, which include the mines near Bathurst and Sussex. Agriculture and fisheries are of lesser, and declining, importance in this province, but they support a substantial food-processing industry. In the first half of this century, the industrial towns in the province stagnated as their industries failed to compete with central Canadian industries. Government support for economic development since the 1960s has stimulated the expansion of forest industries, the establishment of a new and important mining industry, the modernization of fisheries and farming, and increased manufacturing based on local resources.

Saint John, in the southern part of the province, is New Brunswick's chief metropolitan area. Timber trade, shipping, and shipbuilding were historically the important economic activities of this city because it has an ice-free port. After WWII, shipping and the shipbuilding industry continued to develop, and the pulp and paper mills also expanded. In recent decades Saint John has continued to develop industrially, with the addition of an oil refinery, a nuclear power plant, dry dock facilities and a major container port. Fredericton is the seat of the provincial government and university. In the 1960s and 1970s the civil service and university both grew rapidly. The lumber industry, agriculture, and its role as a transshipment point between the lower and upper Saint John River have also been important to the city's economy. Moncton started as a shipbuilding centre. The economy was transformed, however, in the post-Confederation period when

Moncton became the headquarters of the shops for the Intercolonial Railway and a railway centre. Until very recently, the railway remained one of most important activities in the city. The city owes its importance to transportation and distribution facilities, because most railway lines in and out of the Maritimes pass through it.

In the northern part of the province, Bathurst is the administrative centre of Gloucester County. Lumbering, shipbuilding (begun here in the 1820s) and sawmills dominated the economy until a pulp mill opened in 1914; it was expanded to make paper in 1923 and underwent major renovation in 1983 and 1987. The discovery of sizable base-metal deposits in 1953 in the surrounding region stimulated the city's development. In Edmundston the forest industries have expanded in this century from a sawmill operation to pulp and paper manufacture, and Edmundston has emerged as essentially a single-industry town. Campbellton is the administrative centre of Restigouche County. Its early industries were fishing, shipbuilding and trapping. Lumbering became most important in the late 19th century and remained so until a pulp mill was built in 1928. Its present major industry is tourism.

4.4 Study Area Boundary Modifications

In defining the study area, Edmundston and Campbellton, both in New Brunswick, cause special problems because of their particular location (see Fig.4.1). Edmundston lies on a narrow strip of territory squeezed between the province of Québec and the U.S. state of Maine. Thus the local trade area may in reality include territory which is not within the study area. But the fact that there is an international boundary between New Brunswick and Maine probably limits the influence of the population in the adjacent part of Maine. Thus the more important part of the Edmundston area population omitted from the simulation may come from Témiscouata county of Québec (see Appendix B The Rural Population Question for Edmundston).

For Campbellton the problem involves the definition of the CA boundary as well as the rural trade area population. In the present research the 1986 CA (or CMA)boundary is chosen as the standard boundary to be used throughout the study period. However, Campbellton is the only CA in the Atlantic region to include components within two different provinces in this area, New Brunswick and Québec, in the 1986 census. According to 1981 and 1976 census data, Campbelton CA includes components only within New Brunswick. This implies that there was very limited commuting from Québec in previous years, and therefore that economic integration across the provincial boundary was weak. Thus the 1981 CA boundary for Campbellton was chosen as the standard boundary within which to reorganize Campbellton CA data throughout the research period (see Appendix B Definition of the CA Boundary). Unfortunately the population of Bonaventure CSD, Québec, will be omitted from the simulations (see Appendix B Definition of the Rural Population of Compbellton).

According to the data analysis presented in Appendix B, excluding the rural population in Québec may have a small influence on the simulation results for Campbellton and Edmundston, and similarly for Maine on Edmundston. However, the effect on other cities would be negligible because once the distance become larger, these minor percentage errors become very small.

Chapter 5

Data Collection and Processing

In order to apply the dynamic urban model described in chapter 3 to the urban system in the Atlantic region, it is necessary to have actual data for the system, which provides a basis for calibrating the parameters and testing the model. For the Atlantic urban system, three sets of data are required:

- Population of the Census Metropolitan Areas (CMAs) and Census Agglomerations (CAs), as a measure of city size.
- Population of Census Divisions (CDs), to establish the size of rural regions.
- Distance between all city pairs and between all cities and counties or census divisions as measured on a transportation network.

Section 5.1 discusses boundary problems of CMA and CA data and suggests an approach to solving the problems. Section 5.2 describes data processing for different Census Divisions and methods of selecting the node to represent a census division in the transportation network. Finally, Section 5.3 presents two types of distance and points out an appropriate way of representing distance in the Atlantic transportation network.

5.1 Population Data for CMAs and CAs

Metropolitanism has become a common phenomenon in the twentieth-century. Its most distinctive characteristic is the ability of a city to dominate other cities and to extend its social, cultural and economic impact over a wide area [3]. According to the Census of Canada "Census metropolitan areas and census agglomerations are generally defined as large urbanized cores, together with adjacent urban and rural areas which have a high degree of economic and social integration with the core [49]."

In an earlier era, non-primary economic activities were usually confined to cities and towns that were well separated from each other. Long distance commuting was uncommon. With the development of transportation and rising levels of economic activity in the system, however, commuting became more common and the degree of economic integration between the urban core and adjacent urban and rural areas increased significantly in both frequency and scale. Therefore, metropolitan areas have become more appropriate than cities as spatial entities in defining the urban system [36].

In such an evolution, a metropolitan area develops through several stages: village → town → city → CA → CMA. Two problems arise in applying White's model to a system in which the urban centres have evolved in this way. First, all of the CAs in the system were first defined during the study period. Second, the boundary of a CMA or CA typically changes with time, which yields a sudden change of the CMA or CA population. Both problems relate to the definition of CMA and CA.

The definition of the Census Metropolitan Area in 1981 given by the Census of Canada

> refers to the main labour market area of an urbanized core (or continuously built-up area) having 100,000 or more population. CMAs are created by Statistics Canada and are usually known by the name of the urban area forming their urbanized core. They contain whole municipalities (or census subdivisions). CMAs are comprised of (1) municipalities completely or partly inside the urbanized core; and (2) other municipalities if (a) at least 40% of the employed labour force living in the municipality works in the urbanized core,

> or (b) at least 25% of the employed labour force working in the municipality lives in the urbanized core [50].

The Census Agglomeration in 1981

> refers to the main labour market area of an urbanized core (or continuously built-up area) having between 10,000 and 99,999 population. CAs are created by Statistics Canada and are usually known by the name of the urban area forming their urbanized core. They contain whole municipalities (or census subdivisions). CAs are comprised of (1) municipalities completely or partly inside the urb' 'zed core; and (2) other municipalities if (a) at least 40% of the employed labour force living in the municipality works in the urbanized core, or (b) at least 25% of the employed labour force working in the municipality lives in the urbanized core [50].

The above definition, however, was modified in the 1986 Census of Canada:

> While the CMA and CA concepts remain the same as in 1981, the use of place-of-work data from the 1981 Census as well as several modifications to the delineation criteria have resulted in new CMAs and CAs and many that are significantly different from those reported in the 1981 Census. To be included in a CMA or CA, a CSD[1] now requires a commuting flow of 50%, up from 40% in 1981. In addition the flow must be at least 100 persons. CAs composed of a single CSD are now permitted. Adjacent CMAs and CAs which are closely interrelated will now be combined into a single larger CMA or CA[49].

The change in definition of both the CMA and CA with time causes a problem in calibrating the parameters in the model. Here is an example, given to show the problem explicitly. According to the 1986 Census of Canada, New Glasgow is defined as a Census Agglomeration with population 38,737, which comes from an area consisting of 8 component census subdivisions: Fishers Grant 24, Merigomish Harbour 31, New Glasgow, Pictou subdivision B, Pictou subdivision C, Stellarton, Trenton and Westville [49]. The population of New Glasgow in 1976[2], however, was 23,513 coming from an area of only 4 components: New Glasgow, Stellarton, Trenton and Westville [51]. The population change (15,224=38,737-23,513) of New Glasgow in the period 1976-1986 was caused not only by the dynamics of the urban system such as are described by the model,

[1]Census Subdivision

[2]The definition of 1976 CMAs is the same as that of 1981, but the definition of 1976 CAs is different from that of 1981.

but also by the boundary change in redefining the Census Agglomeration to include four additional components. Moreover, from 1951-1971, the Census Agglomeration of New Glasgow was not defined at all.

The problem arising from the change in definition of the CMAs and CAs may be solved by a consistent construction of the urban system in the Atlantic region. The simulation in the present research covers the study period 1951-1986. So, for the entire period, the study uses as a standard boundary for each CMA or CA (with the exception of Campbellton), the boundary as defined by the Census of Canada in 1986. The geographic population distribution data in earlier years from the Census of Canada was then reorganized in terms of the standard boundary to construct for each CMA and CA a consistent set of population data for the period 1951-1981.

The example of New Glasgow shows this construction procedure. The eight components, according to 1986 Census of Canada, are taken as the census agglomeration for New Glasgow in the study period from 1951 to 1981; and the population of eight components are summed as the population of CA New Glasgow for each census year within this period. The result is shown in Table 5.1. The detail of reorganizing the population data for the New Glasgow CA is given in Appendix B. This procedure is applied to all eighteen urban centres (CMAs and CAs). Table 5.2 shows the results.

Census year	1951	1956	1961	1966	1971	1976	1981	1986
Reported	–	–	–	–	–	23,513	39,412	38,737
Calculated	34,689	34,948	34,476	35,409	36,693	38,508	39,412	38,737

Table 5.1: Census Agglomeration of New Glasgow. Data in row 1 is population as reported by Census of Canada. Data in row 2 is calculated from population of individual components as given in Census of Canada, 1986.

j	City Name	1951	1956	1961	1966	1971	1976	1981	1986
1	St.John's	77958	90489	104108	115890	133239	139946	152002	161901
2	Carbonear	10928	11801	11925	11549	11670	12452	12983	13082
3	Corner Brook	17256	24681	26773	28909	30111	34069	34735	33730
4	Gander	4780	5939	7207	7611	8426	9663	11056	10899
5	Grand Falls	16989	19663	22857	25487	25871	26917	26116	25612
6	Labrador City	2403*	3516*	5144*	7525	11009	15781	14693	11301
7	Charlottetown	31352	31386	34106	36026	41362	44842	48225	53868
8	Summerside	10144	10892	12929	14679	15077	15328	14950	15614
9	Halifax	151926	187363	215276	234637	250579	267990	277727	295990
10	New Glasgow	34689	34948	34476	35409	36693	38508	39412	38737
11	Sydney	117148	122018	127866	125749	125188	124069	122837	119470
12	Truro	27947	31058	31095	32554	34623	38394	39751	41516
13	Saint John	83950	91925	101474	107632	109367	117888	119950	121265
14	Bathurst	21501	24555	25181	28654	31123	33847	35011	34895
15	Campbellton	12984	14311	15470	15856	15802	15706	15508	14867
16	Edmundston	18224	19971	21915	21571	21161	21351	22420	22614
17	Fredericton	26155	30693	35968	37421	51746	58492	63048	65768
18	Moncton	58355	66483	75263	77684	85435	95647	98354	102084

Table 5.2: Population Data for Reorganized CMAs and CAs in the Atlantic Urban System Based on Geographic Population Distribution Data, Census of Canada, for 1951-1981. Data with "*" are estimated values by annual growth rate between 1966 and 1971.

In constructing this table, CA Campbellton is treated slightly differently from the other CMAs and CAs. Six components are within the boundary of Campbellton according to the 1986 Census of Canada: Addington, Atholville, Campbellton, Tide Head, Pointe-à-la-Croix and Restigouche. The first four components are in New Brunswick; however, the last two components, Pointe-à-la-Croix and Restigouche, are in Quebec and therefore out of the present study area. Thus, these two components are removed from the Census Agglomeration of Campbellton, and the boundary of Campbellton as defined by the 1981 Census of Canada is selected as standard boundary for whole study period (see Chapter 4).

The estimated value of the urban system's total population in each non-census year is obtained by use of the Akima cubic spline interpolation [52, 53], applied to the actual total population of the urban system in each census year. This method produces a smooth trend of population and the shape of the curve matches the shape of the census data points. It also minimizes oscillations within the interpolant. Using the interpolated data, the annual growth rate of the urban system, γ, ($\gamma = {}^t(\Delta S)/ {}^tS$) is calculated. These rates are then used as the growth rate of total size of both the local service and export sectors (${}^tW_k$) and treated as exogenous input. Fig. 5.1 shows the urban growth rate, γ, in the Atlantic region from 1951-1986.

5.2 Population and Location of Census Divisions

In this section, we discuss how to process the population data of a census division, and how to choose a node on the transportation network to represent a census division.

5.2.1 Population Data for Rural Regions

Populations for rural regions are based on Census Division data. According to Census Canada, Census Division (CD) is

> the general term applying to census divisions, counties, regional districts, regional municipalities and five other types of geographic areas made up of groups of census subdivisions. In Newfoundland, Manitoba, Saskatchewan and Alberta provincial law does not provide for geographic areas which are intermediate between the census subdivision and the province. Therefore, census divisions have been created by Statistics Canada in co-operation with the provinces. In all other provinces, the different types of census divisions and their limits are established by provincial law[54].

The census divisions in the Atlantic region should be divided into two groups: in one group are those census divisions containing CMAs, CAs, or both; in the other are those

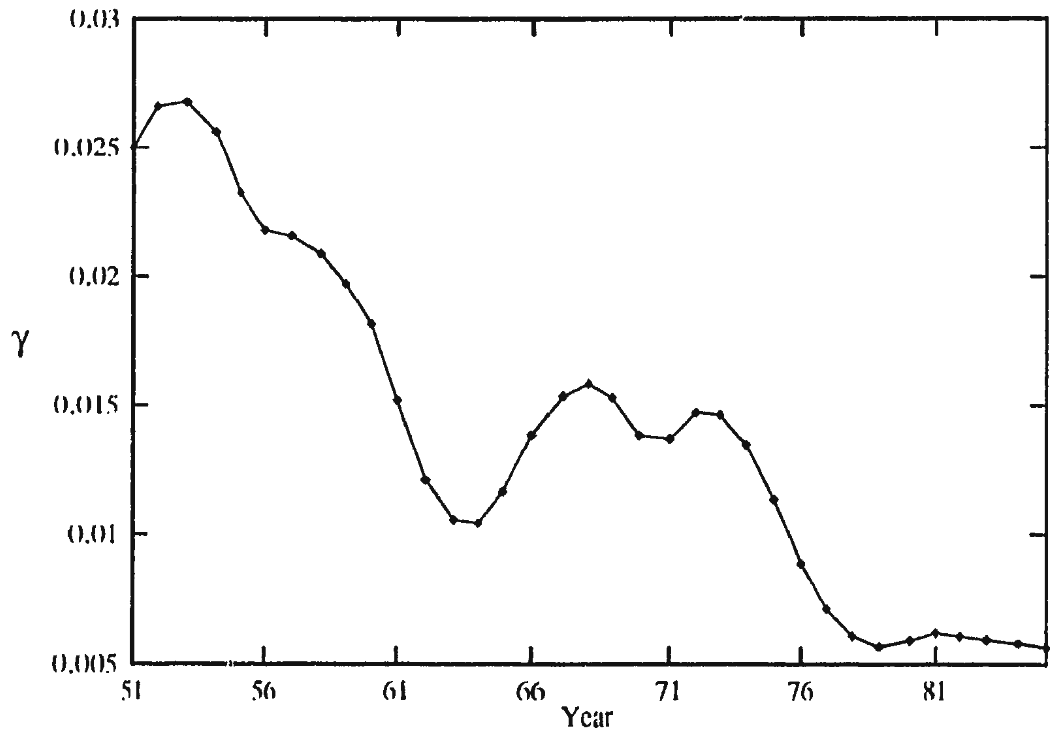


Figure 5.1: Annual Rate of Change, γ, of the Population in the Atlantic Urban System from 1951 to 1986.

which do not contain CMAs or CAs. A more complicated situation arises when a CMA or CA is located in two census divisions.

We will elucidate the data processing procedure through particular examples as in the [illegible] section. For census divisions containing a CMA or CA inside their boundary, we simply deduct the population of the CMA or CA and the remainder is used as the population of the rural region. The details of the rural region population data are given in Tables 5.3 and 5.4. The rural region name used here is composed as follows: the first letter denotes the province (F=N.F., P=P.E.I., S=N.S., and B=N.B.); the next two numbers denote the index of the Census Division according to the Census of Canada; and the last three letters are the abbreviation of the transportation node corresponding to the Rural Region. For example, F01HOL means Holyrood in Census Division one of Newfoundland.

In New Brunswick, Saint John (CMA), Fredericton (CA), and Moncton (CA) each lie in two census divisions (Saint John: CDs 6 and 11; Fredericton: CDs 12 and 15; Moncton: CDs 1 and 14). For the case of Saint John, the CMA core – the city of Saint John – is in Census Division 11. Most components (two of three), however, are in Census Division 6. In this case we sum the populations of census divisions 6 and 11 to create a composite rural region. The population of this new area is the total population of census divisions 6 and 11 less the population of CMA Saint John. The detail for census years 1951-1986 is shown in the Table 5.5.

For the case of Fredericton, the CA core – Fredericton – is in CD 15, and most CA components (four of five) are also in CD 15. So, instead of merging these two Census Divisions, we deduct the population of CA components within CD 15 from the population of the CD 15, and the population of CA components within CD 12 from the population of the CD 12. The remainders are used as the rural region population for CD 15 and CD 12 respectively. For the case of Moncton, the CA core – Moncton – is in CD 14 and most CA components (four of five) are also in CD 14. The same procedure as for CA Fredericton is applied to CA Moncton.

j	CD	1951	1956	1961	1966	1971	1976	1981	1986
19	F02MAR	22366	23980	24779	25672	27320	29627	30368	30285
20	F03MIL	20434	21675	23299	25530	24516	25836	26209	25737
21	F04STE	15982	19631	24185	25286	28350	30182	27749	27278
22	F07PBL	35294	38209	39652	39318	40576	43322	43438	43618
23	F08LEW	36799	40629	44659	49621	50690	53192	54542	54225
24	F09HBA	17051	19970	21710	23752	23140	24967	25738	25954
25	P01BRI	17943	17853	17893	18015	18424	18578	19215	19509
26	S01BRI	21747	21682	22649	21579	21842	23208	22522	23589
27	S02ANT	11971	13076	14360	14890	16814	17573	18110	18776
28	S05SPR	39655	39598	37767	35933	35160	35914	35231	34819
29	S06WEY	19989	19869	20216	19827	20349	20932	21689	21852
30	S07CHA	14245	13802	13274	12830	12864	12825	12752	12721
31	S09RAW	23357	24889	26144	26893	28935	32383	33121	36548
32	S10SMA	18390	18235	18718	18152	20375	21773	22337	21946
33	S11COL	33183	37816	41747	43249	44975	47977	49739	53275
34	S12MBA	33256	34207	34998	36114	38422	42388	45746	46483
35	S14MIE	12544	12774	13155	12807	12950	12947	13126	13125
36	S15SPE	10783	10961	11374	11218	12734	12447	12284	11841
37	S16SHE	14392	14604	15208	16284	16661	16970	17328	17516
38	S17BCO	8217	8185	8266	8001	7823	8417	8432	8704
39	S18YAR	22791	22392	23386	23552	24682	25210	26290	27073
40	B01RAL	3706	3525	3343	2828	5321	2906	2956	2991
41	B02HAR	22269	23073	23567	23356	24428	24561	24659	25429
42	B03BOC	25136	24497	23285	23543	24551	25423	26571	26525
43	B05BRI	26767	27492	26667	24736	24901	28987	30799	31496
44	B08NCA	42994	47223	50035	51711	51561	53894	54134	52981
45	B09YCO	13206	12838	11640	10940	12486	12720	12485	12487
46	B12MAU	7917	8580	20467	22275	17834	17429	16874	17881
47	B13PRO	18541	19020	19712	19694	19796	20932	20815	21504

Table 5.3: Population of Rural Regions Consisting of Census Divisions not Containing CMAs or CAs, 1951-1986.

j	CD	1951	1956	1961	1966	1971	1976	1981	1986
48	F01HOL	60657	68923	72871	71075	69469	75967	71425	71166
49	F05PAS	10833	10534	12313	13388	14768	12261	12166	11918
50	F06BAD	6199	8136	7981	9151	5792	6272	4836	4203
51	F10GBA	5487	7298	8390	13632	17157	17271	16625	17440
52	P02SHE	11399	12039	11736	11806	9773	11572	12245	9592
53	P03MPL	27591	27115	27965	28009	27005	27909	27871	28063
54	S03EBA	3158	3460	3641	3823	3887	4160	4198	4155
55	S04MAS	3589	3582	3212	3146	3112	3377	3173	3577
56	S08MHA	10291	10580	10447	10311	10882	10541	10399	10128
57	S13STE	9313	9618	9432	9081	9411	10568	10938	11035
58	B04PAQ	35985	39564	41162	41647	43629	47178	51145	52578
59	B07RVE	16105	17017	17068	15735	13815	13541	14012	14048
60	B10TID	23228	25409	25503	25265	25487	24914	25085	25054
61	B11BRI	13014	13734	13685	13842	16080	15803	17312	17793
62	B14MBR	27861	26349	27558	28613	24220	29331	29962	30726
63	B15ZST	17796	18357	19033	23785	15814	16700	15303	16156

Table 5.4: Population of Rural Regions Corresponding to Census Divisions Containing a CMA or CA, 1951-1986.

Census Year	CD 6	CD 11	Saint John	Joined Rural Region.
1951	22467	74497	83950	13014
1956	24267	81392	91925	13734
1961	25908	89251	101474	13685
1966	28548	92926	107632	13842
1971	33285	92162	109367	16080
1976	43588	90103	117888	15804
1981	51114	86148	119950	17312
1986	56598	82460	121265	17793

Table 5.5: Calculations for a Composite Rural Region at Saint John.

5.2.2 Locations of CMAs, CAs, and Rural Regions

The geographical location of each CMA or CA is represented in the model as a point. These points are used as nodes on a transportation network for the Atlantic region (see asterisk in Figs. 5.2, 5.3, 5.4, 5.5). For a rural region, choice of a representative point is more or less arbitrary due to the irregular shape of census divisions and the varying population density in rural areas. Nevertheless, points representing the location of rural regions in the present research are determined according to the following rules:

- If the geographic center of a rural region is close enough to the center of population, then the geographic center is taken as a node on the transportation network; e.g. Sherwood is selected as the transportation node for census division 2 in Prince Edward Island (see Fig.5.3).

- If in a rural region there is one area with higher population density, then this location is selected as the node on the transportation network; e.g. Riviere Verte is selected as the transportation node for census division 7 in New Brunswick (see Fig.5.5).

- When more than one possible location is found, the one closest to the main highway is selected as the node; e.g. Holyrood is selected as the transportation node for census division 1 in Newfoundland (see Fig.5.2).

The nodes thus determined to represent the location of rural regions are shown by the solid squares in Figs. 5.2, 5.3, 5.4, and 5.5.

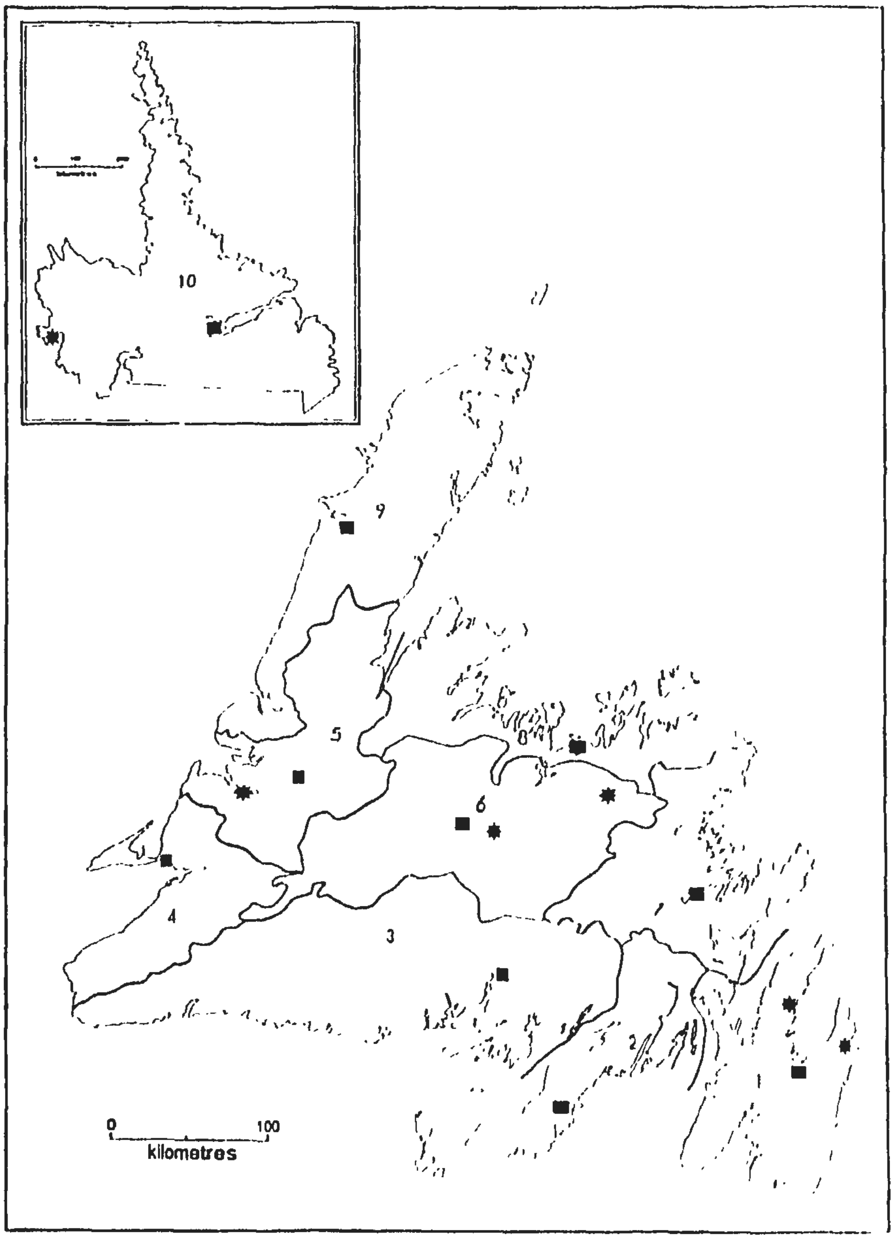


Figure 5.2: Census Map of Newfoundland, showing census divisions, with location points of CMAs and CAs (asterisk), and rural regions (solid square transportation distance).

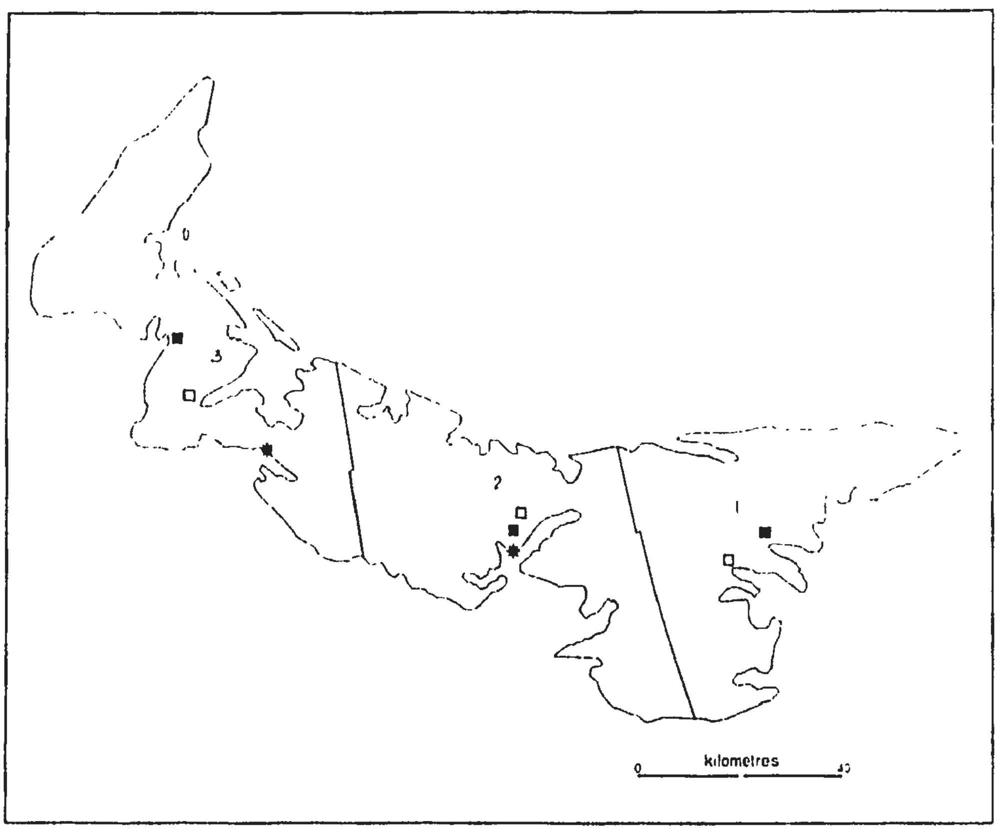


Figure 5.3: Census Map of Prince Edward Island, showing census divisions with location points of CAs (asterisk) and rural regions (solid square – transportation distance; open square – Euclidian distance).

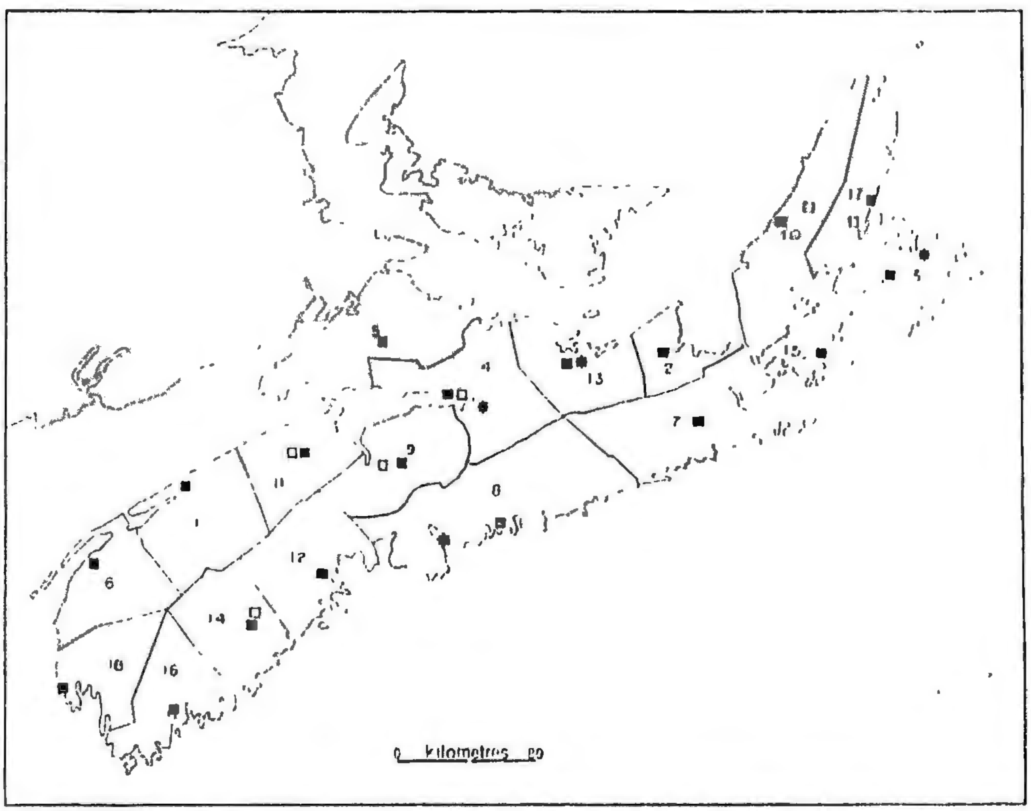


Figure 5.4: Census Map of Nova Scotia, showing census divisions with location points of CMAs and CAs (asterisk), and rural regions (solid square – transportation distance; open square -- Euclidian distance).

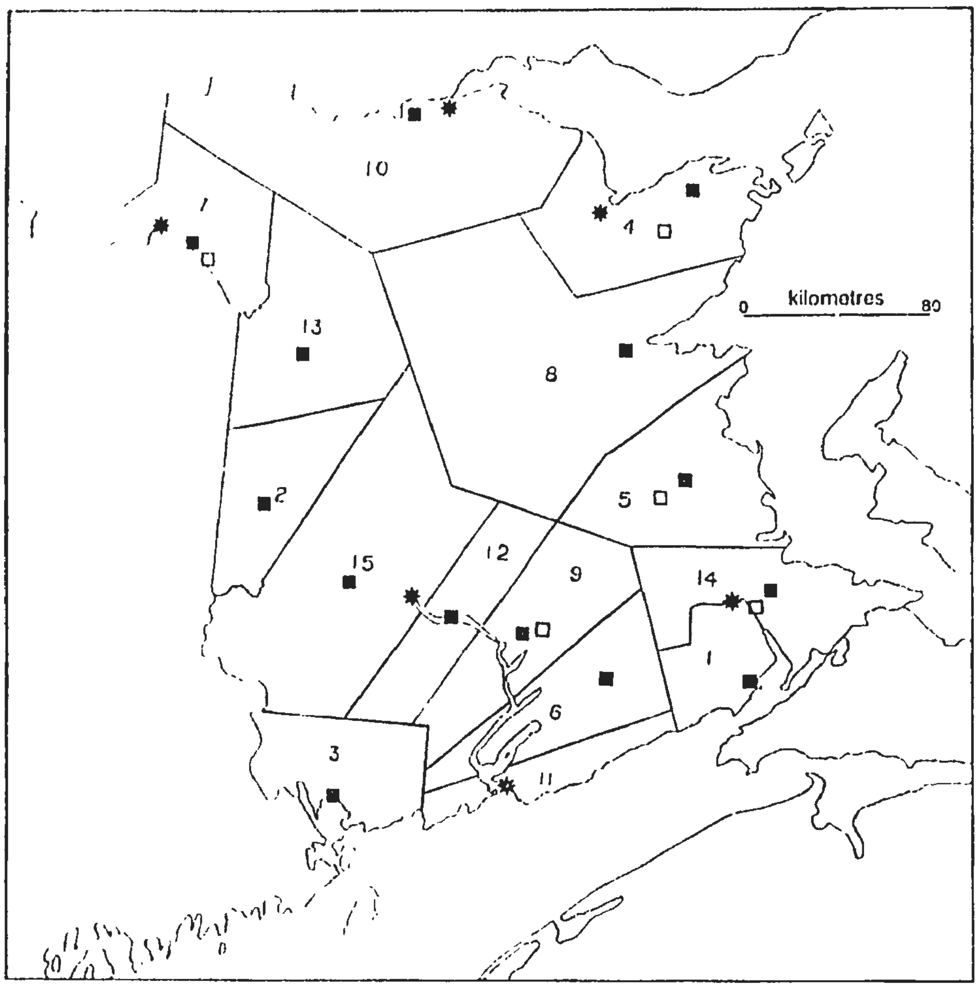


Figure 5.5: Census Map of New Brunswick, showing census divisions with location points of CMAs and CAs (asterisk), and rural regions (solid square transportation distance; open square Euclidian distance).

5.3 Transportation Distance

The transportation network expressed by distance matrix D_{ij} in the model can be represented by either the Euclidian distance (EUCD which can be obtained by digitizing the point locations shown in Figs.5.2-5.5) or the transportation distance (TRAPD). For the Atlantic region, because of the water barriers, the Euclidian distance is not an appropriate one to reflect the actual travelling distance. Therefore transportation distance is used to represent the transportation network in this research. However, a transportation network constructed from Euclidian distance will be also tested in order to see the sensitivity of the model to different distance representations in the transportation network. The calculation of the Euclidian distance was carried out using the coordinates of locations on a digitized map [55] which had fewer place locations than the road map [56, 57, 58, 59, 60] used for calculating transportation distances. As a result, a few locations in each of three provinces differ between the two kinds of maps. The locations which do not coincide can be seen from a comparison of the solid squares and the open squares in Figs.5.3-5.5.

The transportation distance between two points (cities or rural regions) was measured in kilometers using either the distance chart on the relevant provincial road maps, or by summing the distance segments shown on those maps. For some pairs of points the transportation distance includes the ferry distance (eg. Charlottetown – Halifax) or the airline distance (eg. Goose Bay – St.John's). Both ferry and airline distance are converted into highway distance through the F_D and A_D coefficients as discussed in the last chapter. The detail is given in Appendix A.

Chapter 6

Calibration

In this chapter Section 6.1 describes the calibration procedure. Section 6.2 discusses the empirical range of values of certain parameters. Section 6.3 presents the results of the numerical simulations and discusses the significance of the calibrated values of the parameters, and Section 6.4 examines the difference between simulation results using transportation distance and those based on Euclidian distance. Finally, Section 6.5 shows population predictions for 1991 made by using the calibrated model.

6.1 Calibration Procedure

Calibration of non-linear dynamical models has long been a difficult area in urban modelling, particularly for the models containing multiple parameters. Various procedures have been employed in the calibration of different urban dynamical models using data from different regions or cities. For instance Allen and Sanglier [28] considered that the only method available for the calibration of non-linear dynamic models is a systematic 'trial and error' approach. Pumain et al. employed a similar approach as they tested Allen's model [17]. Wilson proposed three statistical methods as he discussed the nature of the calibration and testing task [61].

In the present research, the calibration approach used is a fusion of an experimental method, which is similar to that used by Pumain et al., and a goodness-of-fit measure proposed by Wilson. The experimental method used by Pumain et al. could be described as changing the value of one parameter after another and comparing results obtained by simulation with actual values for each of the variables.

In the present research the objective of the calibration is to determine the set of parameter values that "best" simulates the pattern of cities in the urban system from 1951 to 1986. Achievement of the "best" simulation results is determined not only by the calibration approach to be used, but also by the initial set of parameter values.

Because of the large number of variables and the relatively long time period of 1951 1986, this empirical calibration approach has to be made efficient. Thus a standard error e, a relative error REE, and a match between simulation pattern and actual pattern, called a pattern match in this research, are all employed in carrying out the empirical approach. The standard error, a constructed auxiliary function, plays a preliminary role in the search, making the search for better simulation results faster. This function ensures that the parameter values are changed in a direction that gives better results. The error information representing the difference between actual data and simulation results for each variable in the system is integrated into this measure and calculated for each year in the whole period of research. As a result it can not unambiguously indicate which of two simulation results is better, because one simulation may be better for some years but not others. Therefore, in the first instance the number of error values is reduced to one: that for 1986. It is obvious that depending on one error value is convenient but not entirely appropriate. Furthermore, when e reaches its minimum and varies slowly with the small change of parameter values, it is difficult to assess which result is better. For those reasons, a more supple criterion, the relative error, will be used concurrently. The observation of the relative error is made not only for one particular year in the period, but also for the whole period through pattern match plotting. I show below the formulas I use along with some explanation.

More formally, if we have a set of real data S_j^a (population data for the eighteen cities in the Atlantic Region), and a set of simulation values, S_j, from the model, how do we compare the two? One possible measure is the sum of squares of the differences, proposed by Wilson [61]:

$$\hat{S} = \sum_j (S_j - S_j^a)^2 \tag{6.1}$$

Because the magnitude of the population variables will make the value of $\hat{S}$ very large, judgment of the simulation results will be quite inconvenient if $\hat{S}$ is used directly. Therefore, in the calibration procedure, the main measure used is the standard error, e:

$$e = \sqrt{\frac{\hat{S}}{n-1}} \tag{6.2}$$

where $e = 0$ indicates an exact fit and a minimum of e indicates a "best" fit. For each parameter we require a value that gives rise either to a minimum of e or a slowly varying e.

The relative error REE is defined as follow:

$$REE_j = \frac{S_j}{S_j^a} - 1 \tag{6.3}$$

where the S_j and S_j^a denote the simulated population and actual population, respectively, of city j.

Based on the discussion above it can be seen that the standard error and the relative error only help us to find the solution effectively and quickly, since the final solution we arrive at may also depend on the initial set of parameter values. Different initial sets determine various starting points for the search for the final solution. The initial set of parameter values in this research is determined by the theoretical evaluation of the present model [11].

In the process of calibration, the sector parameters w_k ($k = 1,2$) have a role which is different from that of other parameters. They are used to estimate the initial sizes for the two sectors. The basic equation for the calculation of the initial size of the "local service" sector ($k = 1$), mentioned in the model chapter, is expressed as

$$^0W_{j,1} = w_1 \times {}^0S_j^{w_2} \tag{6.4}$$

where w_1 is a scaling factor and w_2 reflects the power law of the dependence of sector size $^0W_{j,1}$ on initial city size ^0S_j. These two parameters are calibrated together with the other parameters in the model. Before the calibration is carried out, theoretical considerations give rise to the likely range of values for w_2: specifically $w_2 \approx 1$ due to its sensitivity. For simplicity, we mainly consider the case of $w_1 = 0.85$ and $w_2 = 1$ in this study, but during the calibration procedure the value of w_1 will be changed to a few other trial values.

The size of the other sector $^0W_{j,2}$ may be obtained directly from the size equation (Eq.3.6) in the model

$$^0W_{j,2} = \frac{^0S_j - p_1 \times {}^0W_{j,1}}{p_2} \tag{6.5}$$

Thus there is no need to calibrate.

6.2 Empirical Range of Parameters

In the present model, there is a set of parameters to be calibrated simultaneously. These parameters are as follows: the interaction parameters N_k, the economies of scale parameters, E_k, the fixed cost C_0, the response rate C, the population parameters p_k, the sector parameters w_k, the separation coefficient S_D, the conversion coefficient of airline distance A_D, and the conversion coefficient of ferry distance F_D. Hence, it is important to estimate a resonable range for each of the parameters, empirically or theoretically, based on earlier research work. Once the trial range of values for each parameter is determined, a large number of combinations of parameter values can be used in running the model and the optimum combination can be obtained by comparing the results from the simulation with the actual data for the period.

First, we have two distance exponents, usually called "friction", N_k ($k = 1,2$) appearing in Eq. (3.1). Empirical studies have shown [62] that they are in the range $0.5 < N_k < 4.0$, with N_1 and N_2 corresponding to the "nonbasic" and "basic" sectors respectively. Since the "nonbasic" sector is more sensitive to distance, N_1 should be greater than N_2. The empirical range of the two parameters is given [24, 62] as

$$1.8 < N_1 < 4.0 \qquad \text{and} \qquad 0.5 < N_2 < 1.3\,. \tag{6.6}$$

No single critical value of N_k can be found which distinguishes a centralized pattern, corresponding to the basic sector, from a non-centralized pattern, corresponding to the non-basic sector, as discussed in Chap. 2. However, there is a smooth transition from one kind of pattern to the other as N changes in the range $1.2 \le N \le 1.7$ [10].

Next are the parameters for economies or diseconomies of scale, E_k ($k = 1,2$) in Eq. (3.3). In terms of the simulation results in two-sector shopping center model [24], the empirical range is chosen as

$$0.95 < E_1 < 1.05 \qquad \text{and} \qquad 0.5 < E_2 < 0.75\,. \tag{6.7}$$

The fixed cost, C_0, in the same equation is taken as zero because it probably has no important effect on simulation [10].

The parameter G in Eq. (3.5) is a scaling factor, denoting the response rate of sector size to profits gained by a city [10]. If the value of G is too large, sector size will be unstable. In order to avoid the oscillation of sector size, the range of G is estimated as $0.008 < G < 0.012$.

The population parameters $p_k (k = 1, 2)$ in Eq.(3.6), according to the simulation results of the two-sector shopping center model [23], constitute something like local population multipliers for the city. Higher values for these parameters mean that the corresponding sectors will economically support more people in the city. Because the most important factor is the relationship between p_1 and p_2, the trial range for p_k is chosen to be relatively large:

$$0.5 < p_k < 2.5 \qquad \text{for} \qquad k = 1, 2 . \tag{6.8}$$

The range of the separation coefficient S_D introduced in chapter 3 is chosen as $0 \leq S_D \leq 9.0$. For $1 \leq S_D \leq 9.0$, the action of the coefficient is to enlarge the distance between a city and its rural region in order to avoid too much local rural expenditure power being attracted to the city, and the coefficient performs the opposite action when $0 \leq S_D \leq 1$.

The last two parameters, A_D and F_D, relating to construction of an effective transportation network, enter the simulation only through the distance D'_{ij} and thus the simulation result may be not sensitive to them. Trial values of $A_D = 5.0$ and $F_D = 4.5$ were chosen as the initial values at the beginning of the calibration. A_D was measured by dividing the average price of air transportation (38 dollars per 100 kilometers [63]) by the average price of highway transportation (8 dollars per 100 kilometers [64]) and F_D was measured by dividing average speed of highway transportation (90 kilometers per hour [64]) by average speed of ferry transportation (20.4 kilometers per hour [59, 56]).

The empirical values and ranges of the parameters merely serve as an initial guess in calibration. Based on the considerations above, the set of initial parameter values was chosen as follows (see Table 6.1):

Parameter	G	F_D	A_D	S_D	p_1	p_2	E_1	E_2	N_1	N_2	w_1
Initial Value	0.008	4.5	5.0	8.0	1.0	0.8	1.0	0.5	2.0	1.0	0.85

Table 6.1: Initial Parameter Values for Calibration. In addition, two parameters have fixed values that are not altered during calibration: $w_2 = 1, C_0 = 0$.

6.3 Calibration and Results

In this section the stages of calibration and the calibrated parameters will be discussed in detail.

6.3.1 Stages of Calibration

The calibration procedure consists of two stages. In the first stage, starting from the initial set of parameter values in Table 6.1, we vary one of the parameters within the trial range, and look for the "best" simulation results by searching for the minimum of e, and by comparing REE through pattern match. If the minimum of e is found at a particular value of the first parameter we replace the value in the original set by the calibrated one. Occasionally the minimum of e is not unique or it can not be found because of a slowly varying e; so we choose the better result by comparing REE through pattern match. Then keeping the first calibrated parameter and other parameters unchanged, we calibrate a second parameter by following the same steps. These steps are repeated until a preliminary calibration has been achieved for all parameters. Each parameter is calibrated for the period 1951-1986 in the first stage. Table 6.2 shows a preliminary combination of parameters obtained from this stage.

Parameter	G	F_D	A_D	S_D	p_1	p_2	E_1	E_2	N_1	N_2	w_1
Calibrated Value	0.009	8.0	9.0	1.0	0.95	1.01	0.99	0.64	1.9	1.1	0.85

Table 6.2: Parameters Values from the First Stage Calibration, $w_2 = 1, C_0 = 0$.

In the second stage the steps involved in the first stage are repeated in this stage until the "best" combination of parameters is again reached. Except for w_1, each parameter is calibrated around the value obtained in the first stage. The standard error e and relative error REE are still employed as the two criteria used in searching for the "best" solution. Table 6.3 shows the "best" result.

Parameter	G	F_D	A_D	S_D	p_1	p_2	E_1	E_2	N_1	N_2	w_1
Calibrated Value	0.011	3.7	2.0	0.35	0.9	1.9	1.03	0.65	1.8	1.4	0.85

Table 6.3: Calibrated Parameter Values, $w_2 = 1, C_0 = 0$.

With this set of parameter values, the simulation results qualitatively capture the population evolution of the system from 1951 to 1986. The following section will discuss the quality of the calibration in detail.

6.3.2 Evaluation of the calibration

The general quality of the simulation results can be seen in Table 6.4 and Fig. 6.1 The 1986 population of nine cities was underestimated: St. John's, Carbonear, Corner

Brook, Gander, Labrador City, Charlottetown, Truro, Saint John, and Fredericton. Nine were overestimated: Grand Falls, Summerside, Halifax, New Glasgow, Sydney, Bathurst, Campbellton, Edmundston, and Moncton.

CMAs and CAs	Actual Size	Simulated Size	Relative Error
St. John's	161901	141957	-0.12319
Carbonear	13082	12275	-0.06168
Corner Brook	33730	31837	-0.05612
Gander	10899	10878	-0.00195
Grand Falls	25612	40867	0.59562
Labrador City	11301	1767	-0.84362
Charlottetown	53868	39057	-0.27495
Summerside	15614	19810	0.26872
Halifax	295990	300316	0.01462
New Glasgow	38737	48295	0.24674
Sydney	119470	136044	0.13873
Truro	41516	33613	-0.19036
Saint John	121265	111774	-0.07827
Bathurst	34895	48292	0.38391
Campbellton	14867	23717	0.59527
Edmundston	22614	23982	0.06048
Fredericton	65768	48491	-0.26270
Moncton	102084	110242	0.07991

Table 6.4: Comparison of Actual and Simulated CMA and CA Sizes (Population) for 1986, Using Transportation Distance.

The cities with $REE < 15\%$ in 1986 are Halifax, St. John's, Sydney, Saint John, Moncton, Carbonear, Corner Brook, Gander, and Edmundston; they constitute half the cities in the system, and represent the successful part of the simulation results. The cities with $15\% < REE < 30\%$ are New Glasgow, Truro, Charlottetown, Summerside, and

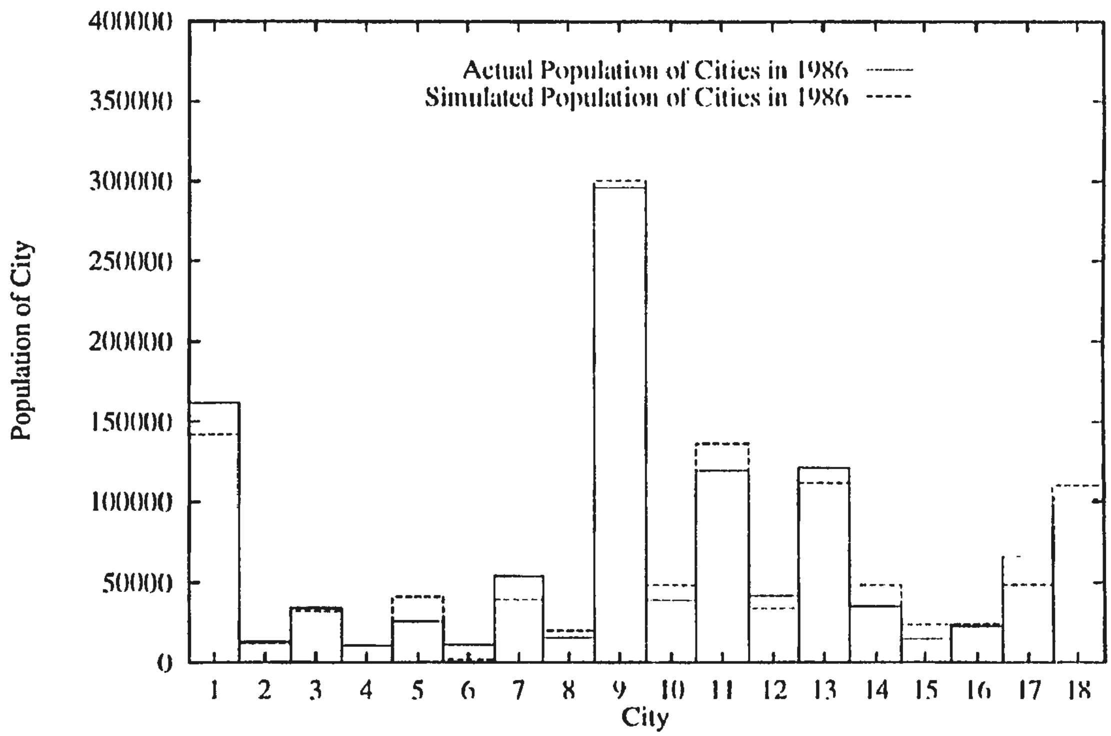


Figure 6.1: Actual and Simulated Population, 1986, for The Atlantic Region Urban System. Simulation is based on Transportation Distance; e=11179.

Fredericton, representing a third of the cities in the system. Cities with $REE > 30\%$ are Grand Falls, Labrador City, Bathurst, and Campbellton. The simulated population of these cities is the worst part of the results.

Aside from the relative errors for 1986 shown in Table 6.4, simulation results for the entire study period, shown in Fig. 6.2, also indicate that most cities are successfully estimated for the whole 35-year period. On the basis of these results, cities in the system may be classified into three major groups. The first group includes those cities for which the simulation was fully successful: Halifax, St. John's, Saint John, Moncton, Edmundston, Gander, and Carbonear. The simulated population of these cities is close to actual population for the whole period from 1951 to 1986. Cities in the second group have as a common characteristic that the population is well simulated within the period from 1951 to 1966; however, after 1966 these cities may be classified into two sub-groups. One sub-group includes those cities having a simulated population with slow changes and small percentage errors such as Sydney and Truro from 1966 to 1986. The other sub-group includes these cities having a simulated population with fast changes and large percentage errors from 1966 to 1986 -- specifically Grand Falls, Fredericton, Campbellton, Charlottetown, and Summerside. The third group includes Labrador City, New Glasgow, and Bathurst, which for most of the study period were not well simulated.

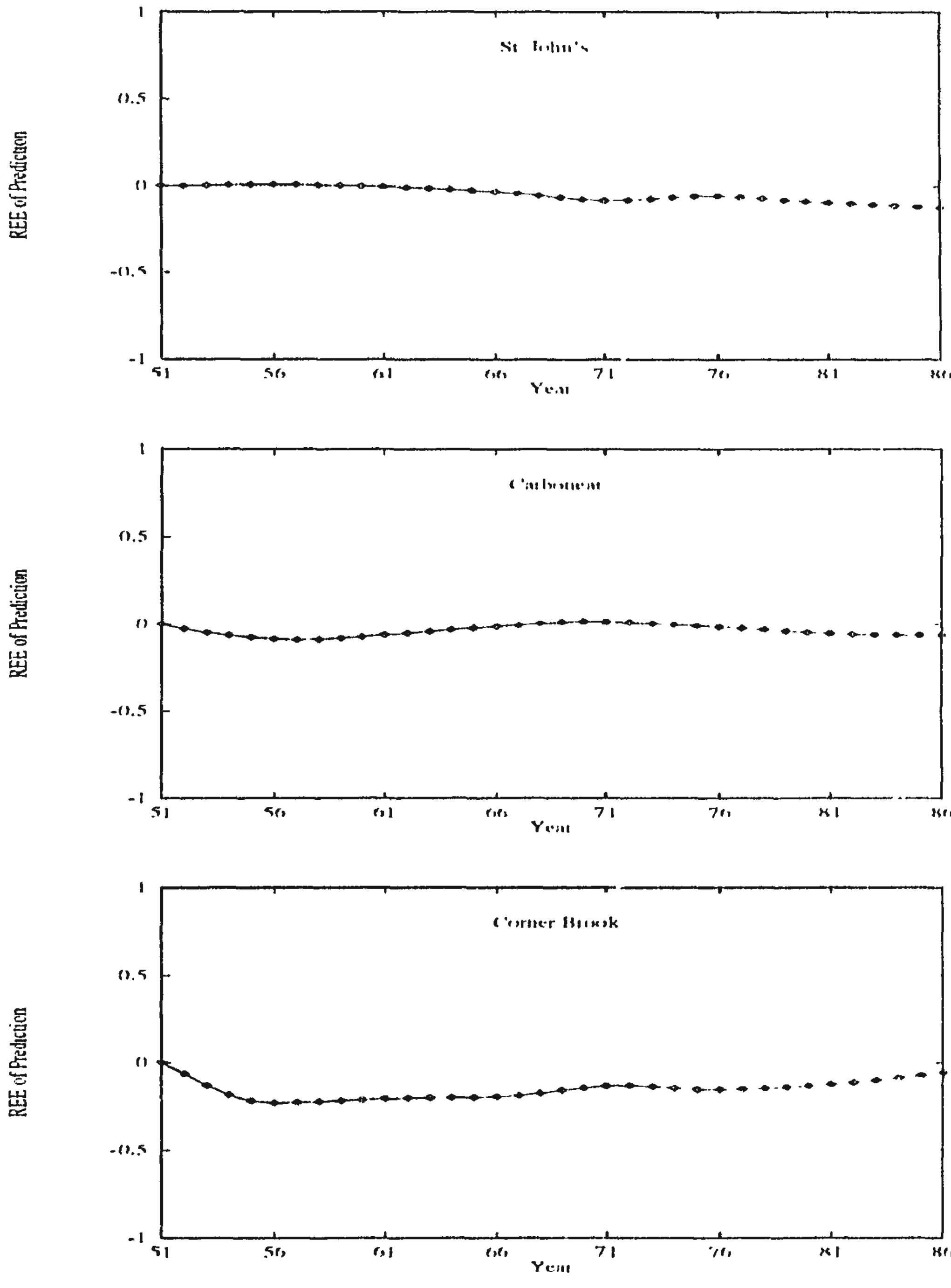


Figure 6.2: Relative Error of Simulated Populations for Atlantic Region CMAs and CAs, 1951-86. Simulations are based on Transportation Distance.

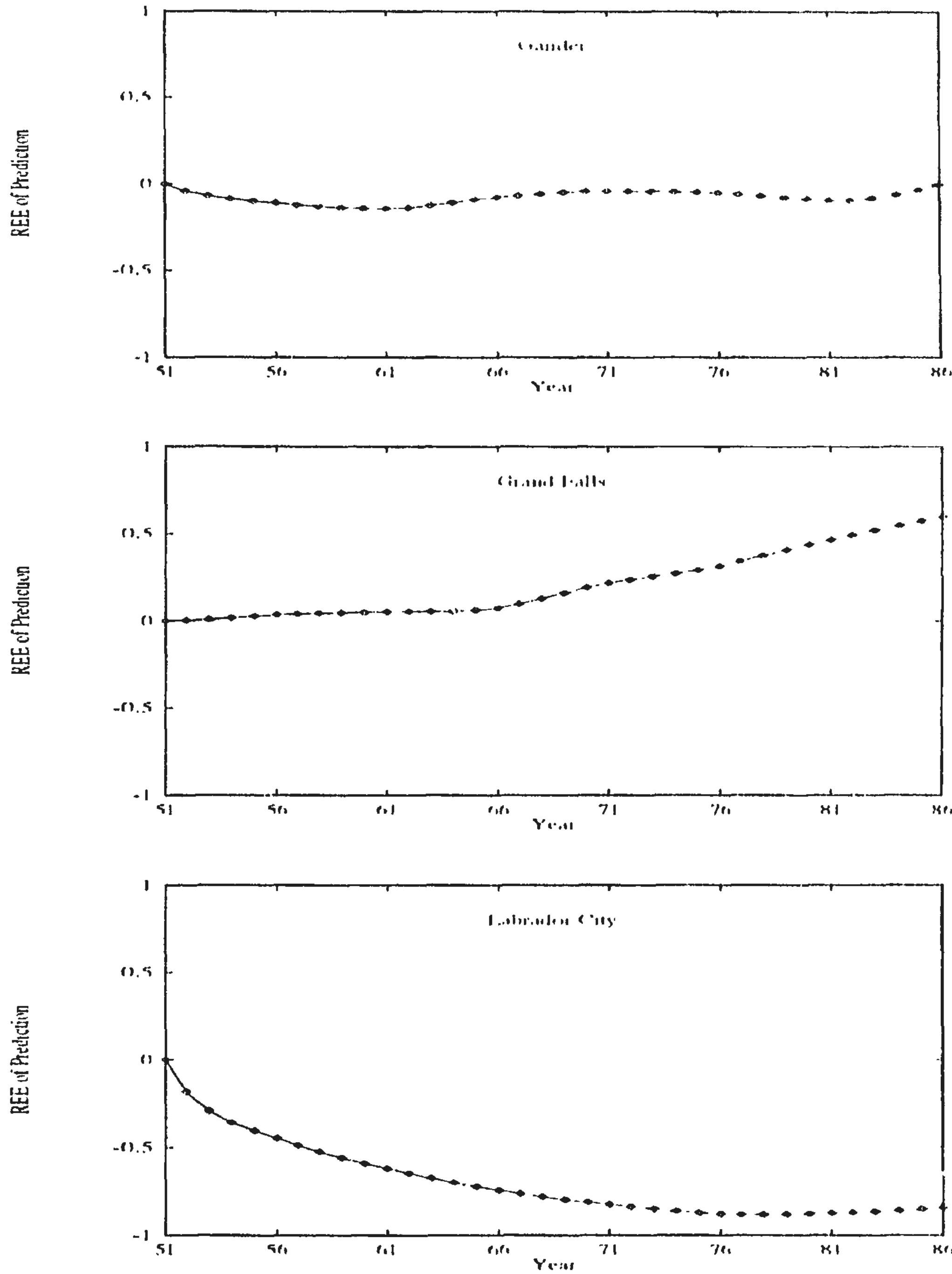


Figure 6.2: (cont.)

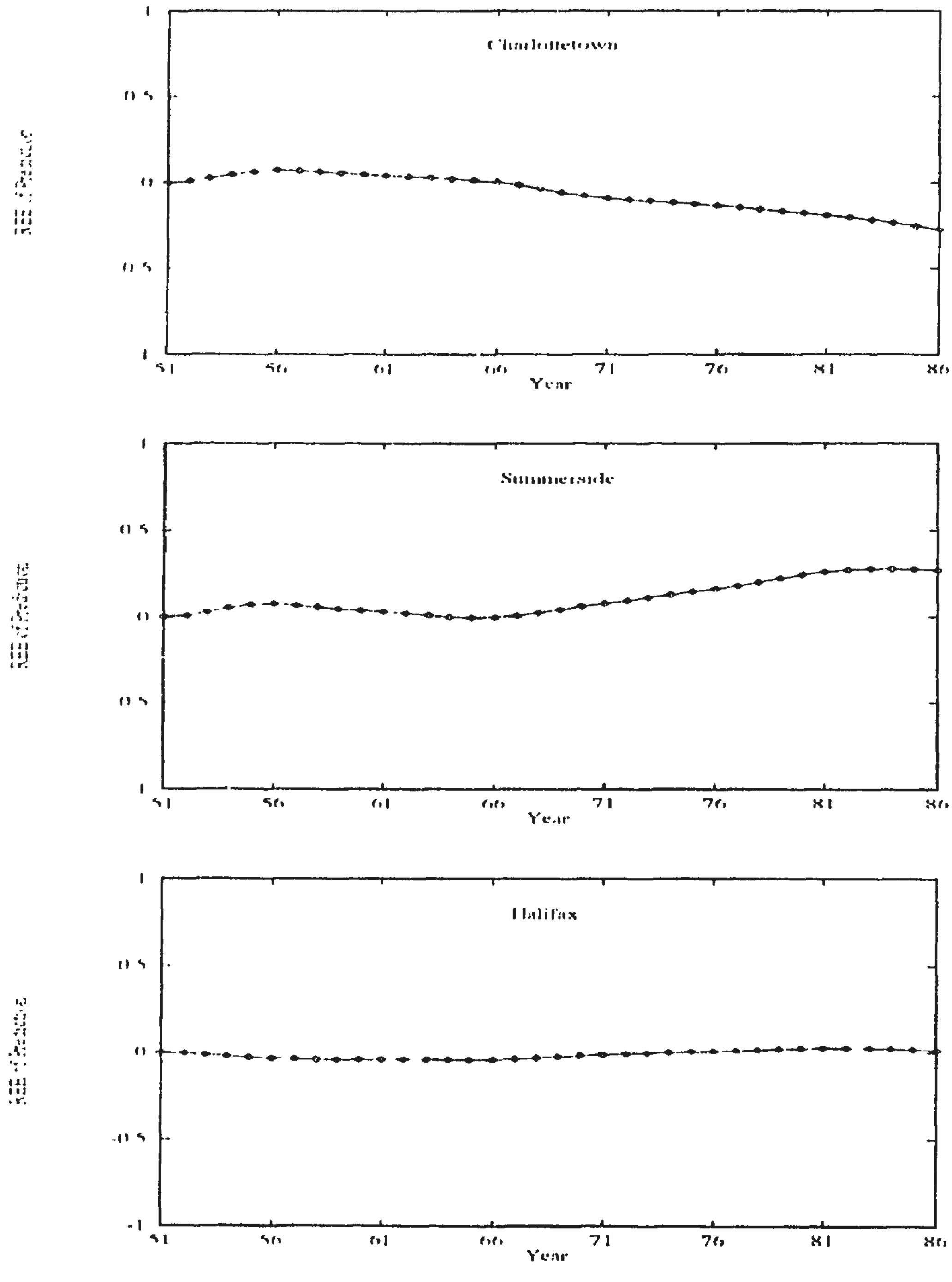


Figure 6.2: (cont.)

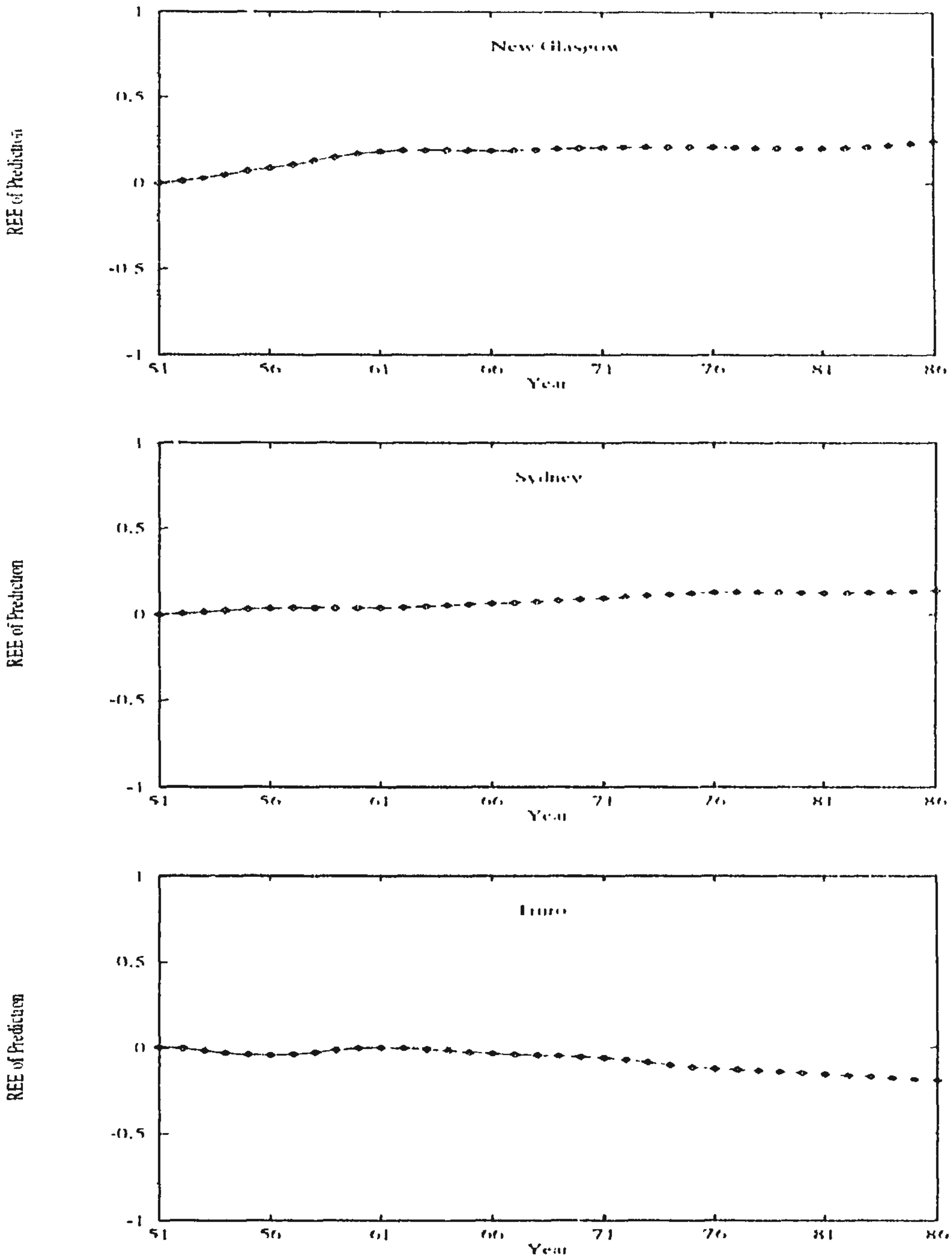


Figure 6.2: (cont.)

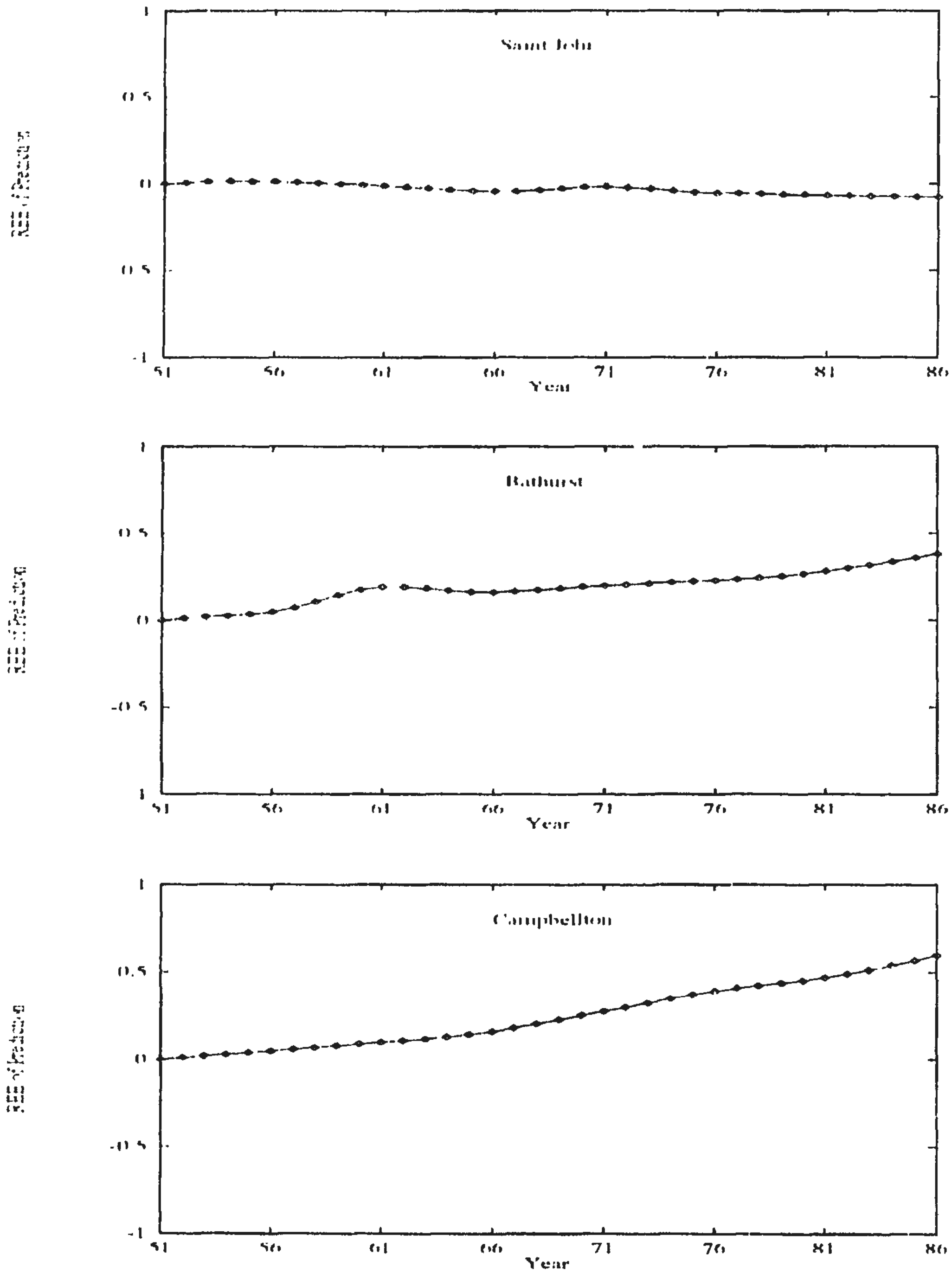


Figure 6.2: (cont.)

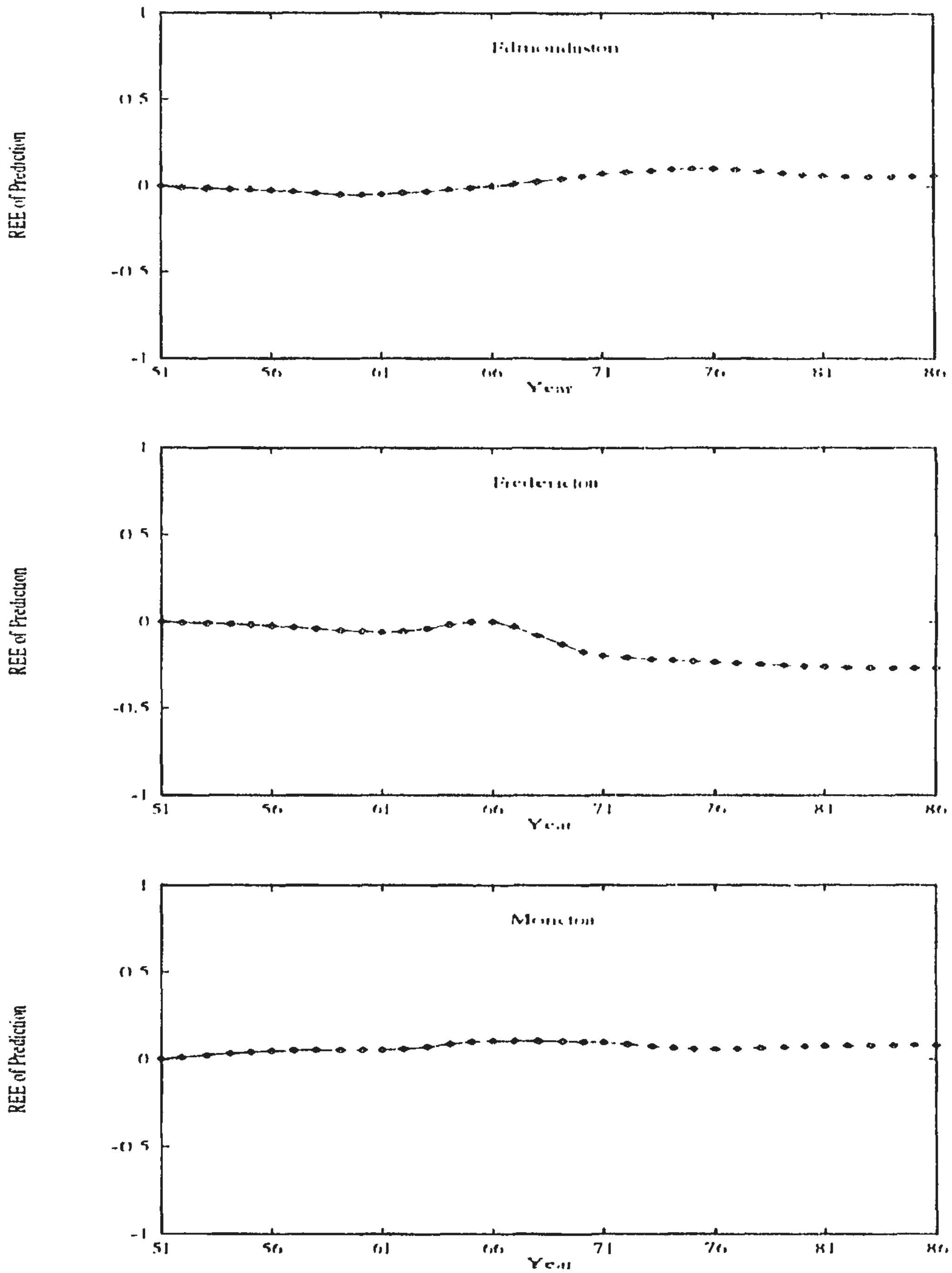


Figure 6.2: (cont.)

The total system growth rate data in chapter 5 shows that from 1951 to 1966 the growth rate decreased steadily, while from 1966 to 1986 it oscillated. Correspondingly, most cities show a better simulation result in the earlier period than in the later period. This suggests that the model can better handle population evolution of cities when population change is smooth rather than erratic. It also indicates that good simulation results can more easily be obtained for relatively short periods, as would be expected. A longer research period generally will make a successful simulation difficult, and simulation results are likely to be worse. Thirty-five years is a very long period for a simulation.

Tables 6.5 and 6.6 show the employment structure in terms of each of three major sectors for the Atlantic region CMAs and CAs, based on 1986 data in Census Canada [65]. Except for Labrador City, all cities have more than half of their employment in the tertiary sector. In other words, for the urban system, the resource based structure of the Atlantic economy has shifted toward a service based structure. If we take the sum of the secondary and tertiary rates for each city, the six highest values are for the cities of St. John's, Gander, Halifax, Saint John, Fredericton, and Moncton. Except for Gander, each of these cities has a relatively high value not only of the tertiary rate, but also of tertiary employment. Among these five Saint John and Moncton also have a relatively high proportion of employment in the secondary sector. Having a well developed tertiary sector alone or in combination with a well developed secondary sector is an indication that these five cities have relatively more economic links with other places in the system. Therefore they are more likely to be in competition with each other as well as with other centres. In addition, five cities — Gander, Halifax, Saint John, Fredericton, and Moncton — have a relatively good geographical location. Compared with these cities, the geographical location of St. John's is quite peripheral. Both economic and locational features of these cities are consistent with principles underlying of the present model. That is probably why these cities can be well simulated. In contrast, the three greatest values of the primary rate are for Labrador City, Sydney, and Bathurst. Two of these, Labrador City and Bathurst, have a relatively peripheral geographical location, and these two cities are not well simulated. On the basis of these observations, it would seem that cities possessing more economic links with other places within the Atlantic region, specifically, St. John's, Halifax, Sydney, Saint John, Moncton, Corner Brook, and Gander, are successfully estimated, while cities with resource based economies (Grand Falls, Labrador City, Bathurst, and Campbellton) are not.

CMAs and CAs	Primary	Secondary	Tertiary
St. John's	1800	13135	61430
Carbonear	190	1630	3245
Corner Brook	440	3395	10575
Gander	65	915	4475
Grand Falls	425	2695	7020
Labrador City	2165	420	2380
Charlottetown	1635	4755	20570
Summerside	410	1605	5785
Halifax	2225	28640	129270
New Glasgow	855	5300	9645
Sydney	4805	10150	31500
Truro	1495	5585	12480
Saint John	1070	14795	39295
Bathurst	1885	3105	9870
Campbellton	215	1160	4790
Edmundston	450	2985	6585
Fredericton	1170	5065	28505
Moncton	765	12440	35845

Table 6.5: Employment Data for Three Sectors for All CMAs and CAs, 1986.

CMAs and CAs	Primary Rate	Secondary Rate	Tertiary Rate
St. John's	0.023571	0.172003	0.804426
Carbonear	0.037512	0.321816	0.640671
Corner Brook	0.030534	0.235600	0.733865
Gander	0.011916	0.167736	0.820348
Grand Falls	0.041913	0.265779	0.692308
Labrador City	0.436052	0.084592	0.479355
Charlottetown	0.060645	0.176372	0.762982
Summerside	0.052564	0.205769	0.741667
Halifax	0.013895	0.178849	0.807256
New Glasgow	0.054114	0.335443	0.610443
Sydney	0.103433	0.218491	0.678076
Truro	0.076431	0.285532	0.638037
Saint John	0.019398	0.268220	0.712382
Bathurst	0.126851	0.208950	0.664199
Campbellton	0.034874	0.188159	0.776967
Edmundston	0.044910	0.297904	0.657186
Fredericton	0.033679	0.145797	0.820524
Moncton	0.015596	0.253619	0.730785

Table 6.6: Employment Rates of Three Sectors for All CMAs and CAs, 1986.

6.3.3 Discussion of Parameters

The relative values of E_1 and E_2 (Table 6.3) reflect an actual phenomenon in the urban system [66, 67, 68]. The major part of costs in many local service sectors consists of rent and wages. For instance, typical local services such as primary schools, restaurants, and shopping centres need space and labour to provide their service, but are not usually capital intensive, and do not rely heavily on highly specialized business services and facilities. Rents, and occasionally wages, are typically higher in large cities. Therefore, the average cost of operating local service sectors is likely to be higher in larger cities than in smaller ones. This means that the local service sectors experience diseconomies of urbanization when city population changes from small to large. In contrast with this, in export sectors such as manufacturing, rent and wages usually account for a smaller proportion of expenditures, while capital equipment and equipment maintenance, and services such as technical consulting and research are relatively more important. Usually the larger cities are home to a greater variety of technical and business services, because the larger cities provide a larger market for those services. Thus it is easier for export sectors in large cities to have access to these kinds of services, while the same sectors in small cities are at a disadvantage in terms of access to these services. Thus the export sector in small cities will frequently face higher costs for these services. As a result, export activities will typically have either lower diseconomies of urbanization than the local service sector, or actual economies of urbanization.

As mentioned in the previous chapter, each conventionally defined economic sector contains both local service and export activity. The important difference between sectors for our purposes is in the sensitivity of their sales to distance, or in other words, in their relative ability to export. The fact that $N_1 > N_2$ shows that sales of the non-basic sector are more sensitive to distance than those of the basic sector. The simulation results for those two parameters support the argument proposed by White in [24]

In the "best" combination (Table 6.3) the airline coefficient A_D, ferry coefficient F_D, and location-segregation coefficient S_D are equal to 2.0, 3.7, and 0.35 respectively. The value of F_D indicates that the ferry mode takes more time and costs more than the highway mode does for the same Euclidian distance. The value of A_D illustrates that although the airline mode requires much less time than the highway mode does, the cost of the airline mode is much higher than highway mode, so the net effect is that in most cases people would prefer the highway rather than the airline. The value of the coefficient S_D describes a phenomenon in which the rural population in those cen. is divisions including a city strongly prefer to purchase in the local city rather than in cities outside the local CD – a preference even stronger than the relative distances would imply.

In the combination of parameters from the second calibration stage G equals 0.011, a value that is close to the initial and first stage values of 0.008 and 0.009 respectively. This represents the value of G that is just small enough to avoid oscillation of sector size and is effective in obtaining the minimum value of e. The values of w_k and p_k provide a scaling action.

6.4 Euclidian Distance

As discussed in chapter 3, in order to understand the importance of the transportation network, a trial simulation was run using a transportation network defined in terms of Euclidian distance along with the parameters calibrated for the actual (modal) transportation network. One point that has to be emphasized is that one run of the model can only give a preliminary idea of the difference between using transportation distance and Euclidian distance. A comprehensive evaluation would require a complete recalibration of the model using Euclidian distances.

Table 6.7 represents the comparison of actual and simulated population for each city in the Atlantic urban system using Euclidian distance (1986). Table 6.8 illustrates the differences in relative error between using transportation distance and Euclidian distance. Fig. 6.3 shows the absolute error of city population using these two kinds of distance and the higher standard error from using the Euclidian distance. Compared with simulated populations using Euclidian distance, the simulated populations of seven cities - Halifax,

CMAs and CAs	Actual Size	Simulated Size	Relative Error
St. John's	161901	136676	-0.15580
Carbonear	13082	14129	0.08006
Corner Brook	33730	26474	-0.21512
Gander	10899	8719	-0.20006
Grand Falls	25612	35210	0.37476
Labrador City	11301	1797	-0.84095
Charlottetown	53868	43525	0.19201
Summerside	15614	15415	-0.01271
Halifax	295990	271176	-0.08383
New Glasgow	38737	46632	0.20381
Sydney	119470	149226	0.24907
Truro	41516	32846	-0.20883
Saint John	121265	147864	0.21885
Bathurst	34895	39629	0.13567
Campbellton	14867	23706	0.59455
Edmundston	22614	21379	-0.05462
Fredericton	65768	46222	-0.29720
Moncton	102084	122646	0.20142

Table 6.7: Comparison of Actual and Simulated CMA and CA Sizes (population) for 1986, Using Euclidian Distance.

Moncton, Saint John, Sydney, St.John's, Corner Brook, Gander — using transportation distance, has a smaller relative error (see Table 6.8). The transportation distance obviously favours large cities because most of these seven cities are large ones. The simulated populations of another seven cities — Carbonear, Labrador City, New Glasgow, Truro, Campbellton, Edmundston, Fredericton — show relative errors that are little changed by the use of Euclidian distances. Of these seven, the error of Carbonear, Truro, and Fredericton is smaller when using transportation distance, but the error of Labrador City,

CMAs and CAs	REE OF TRAPD	REE of EUCD
St. John's	-0.12319	-0.15580
Carbonear	-0.06168	0.08006
Corner Brook	-0.05612	-0.21512
Gander	-0.00195	-0.20006
Grand Falls	0.59562	0.37476
Labrador City	-0.84362	-0.84095
Charlottetown	-0.27495	-0.19201
Summerside	0.26872	-0.01271
Halifax	0.01462	-0.08383
New Glasgow	0.24674	0.20381
Sydney	0.13873	0.24907
Truro	-0.19036	-0.20883
Saint John	-0.07827	0.21885
Bathurst	0.38391	0.13567
Campbellton	0.59527	0.59455
Edmundston	0.06048	-0.05462
Fredericton	-0.26270	-0.29720
Moncton	0.07991	0.20142

Table 6.8: Comparison of 1986 REE for Two Treatments of Distance. TRAPD: Simulations based on transportation distance; EUCD: Simulations based on Euclidian distance.

New Glasgow, Campbellton, and Edmundston is larger. The simulated population of the remaining four cities, Grand Falls, Charlottetown, Summerside, and Bathurst - shows a smaller relative error when using Euclidian distance.

Besides the relative errors of simulated populations in 1986 shown in Tables 6.7-6.8, and absolute population differences illustrated in Fig. 6.3, the simulation for the whole research period, given in Fig. 6.4, also presents a pattern similar to that discussed in the last paragraph. Compared with simulated populations using Euclidian distance, the

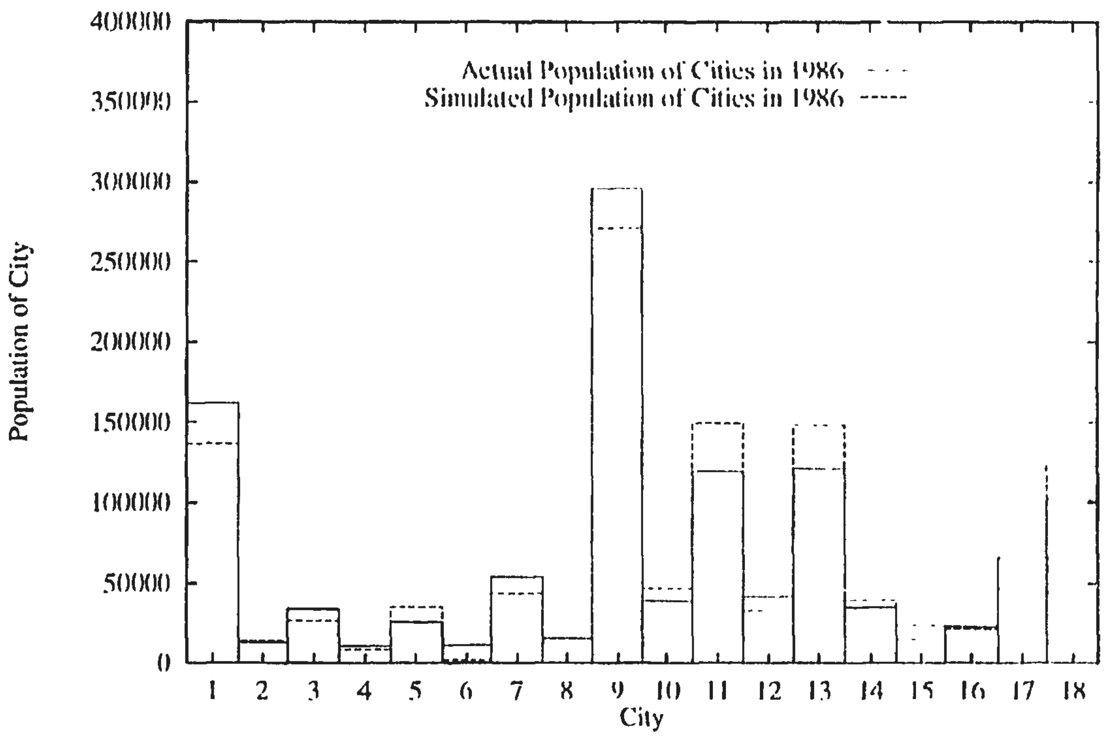


Figure 6.3: Actual and Simulated Population, 1986, for The Atlantic Region Urban System. Simulation is based on Euclidian Distance; e=15781.

simulated population of eight cities — Halifax, Moncton, Saint John, Sydney, St.John's, Corner Brook, Gander, and Fredericton — using transportation distance, has a smaller relative error in the study period; the simulated population of three cities, Grand Falls, New Glasgow, and Bathurst, has a larger relative error over the whole period. The relative error of Labrador City and Campbellton remains almost the same when using two kinds of distance. The relative errors of the remaining five cities change sign during the simulation period. After the 1960's, Carbonear and Truro have smaller relative errors using transportation distance. In contrast, before the middle years of the study period, Charlottetown, Summerside, and Edmundston have smaller relative errors using the transportation distance. One point that should be noticed is that the simulated population of each city, using the two kinds of distances, has the same population trend within the study period. In other words, the use of Euclidian distance alters the population trend only quantitatively. The qualitative nature of the trends is determined by the parameters in the model.

Two important results emerge from comparison of the simulations using transportation distance and Euclidian distance respectively. First, for the same set of parameters, the simulation results using transportation distance are marginally better than those based on Euclidian distance. Secondly, the difference between the two kinds of simulation results shows explicitly the role transportation distance plays in the urban system of the Atlantic region in which water barriers are so important.

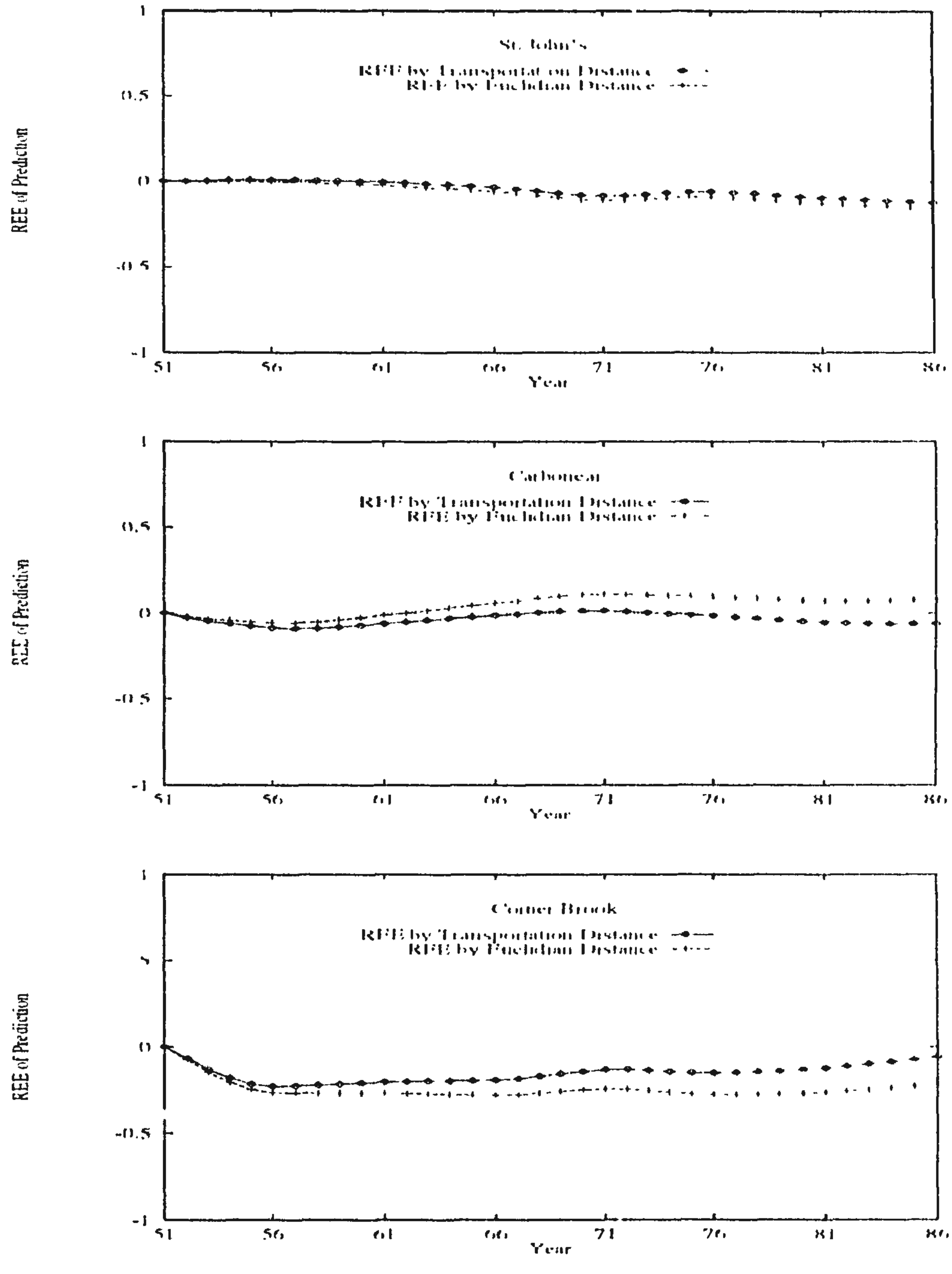


Figure 6.4: Relative Error of Simulated Populations for Atlantic Region CMAs and CAs, 1951-86: Comparison of Results Based on Transportation Distance and Euclidian Distance.

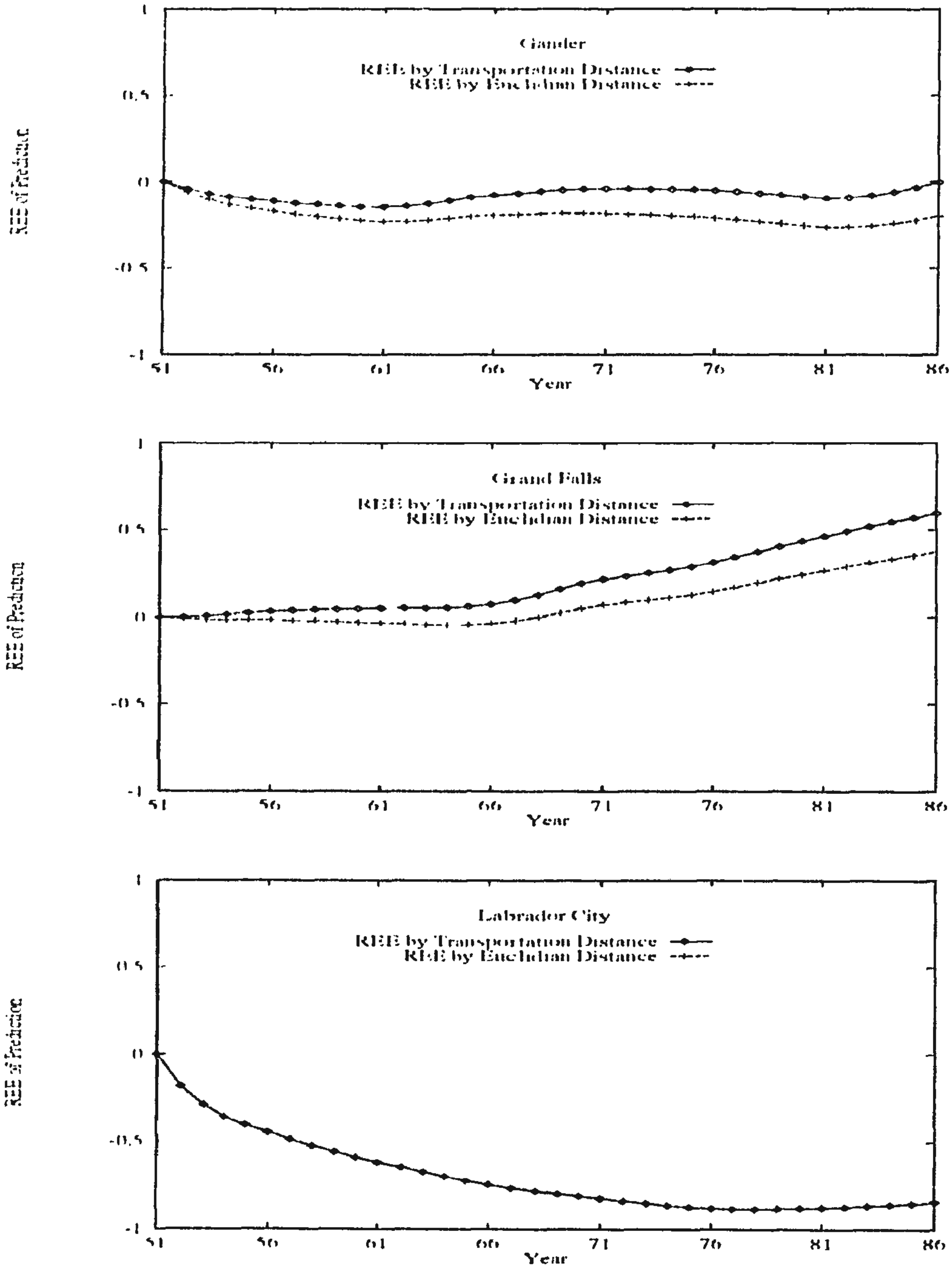


Figure 6.4: (cont.)

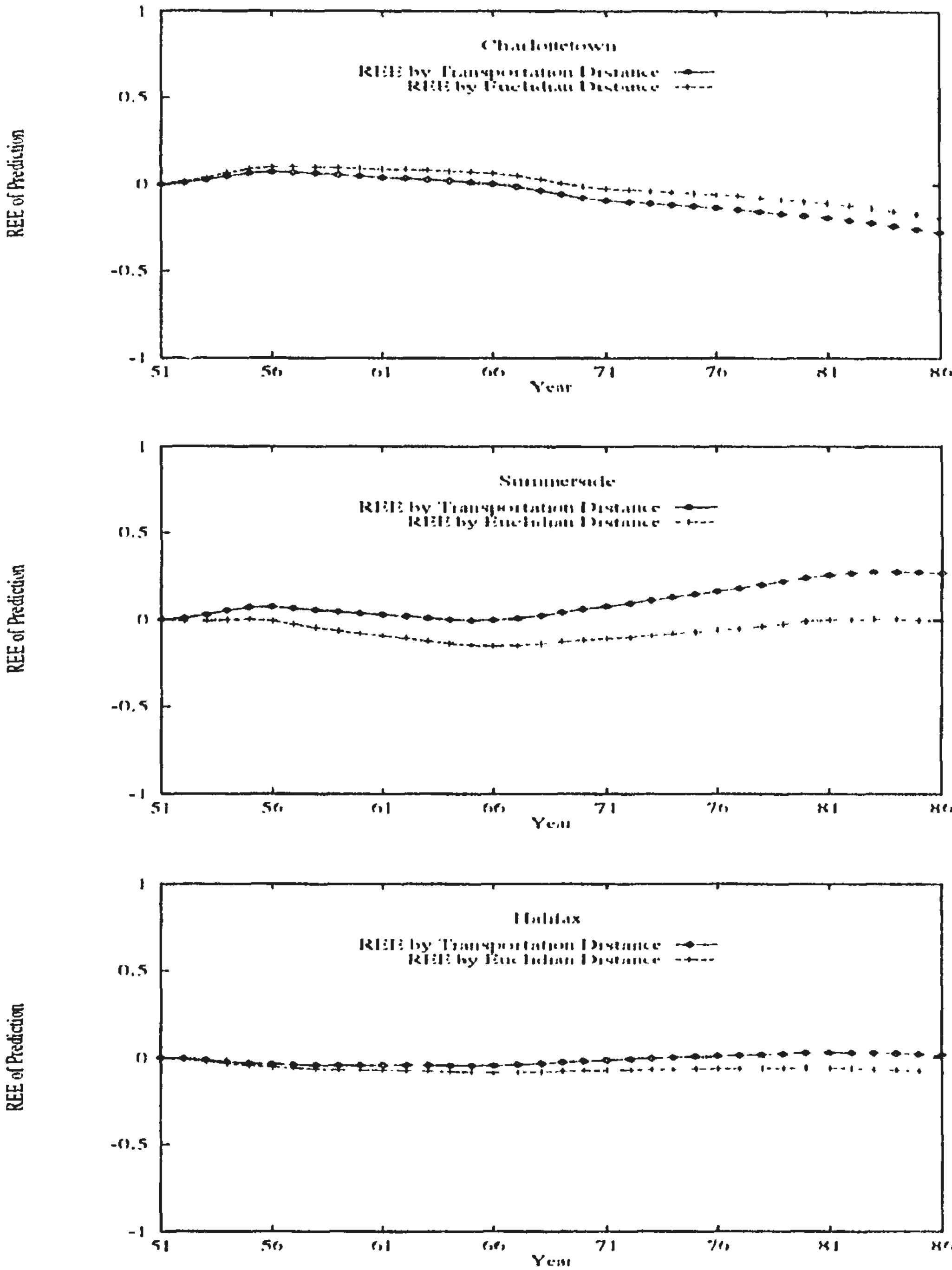


Figure 6.4: (cont.)

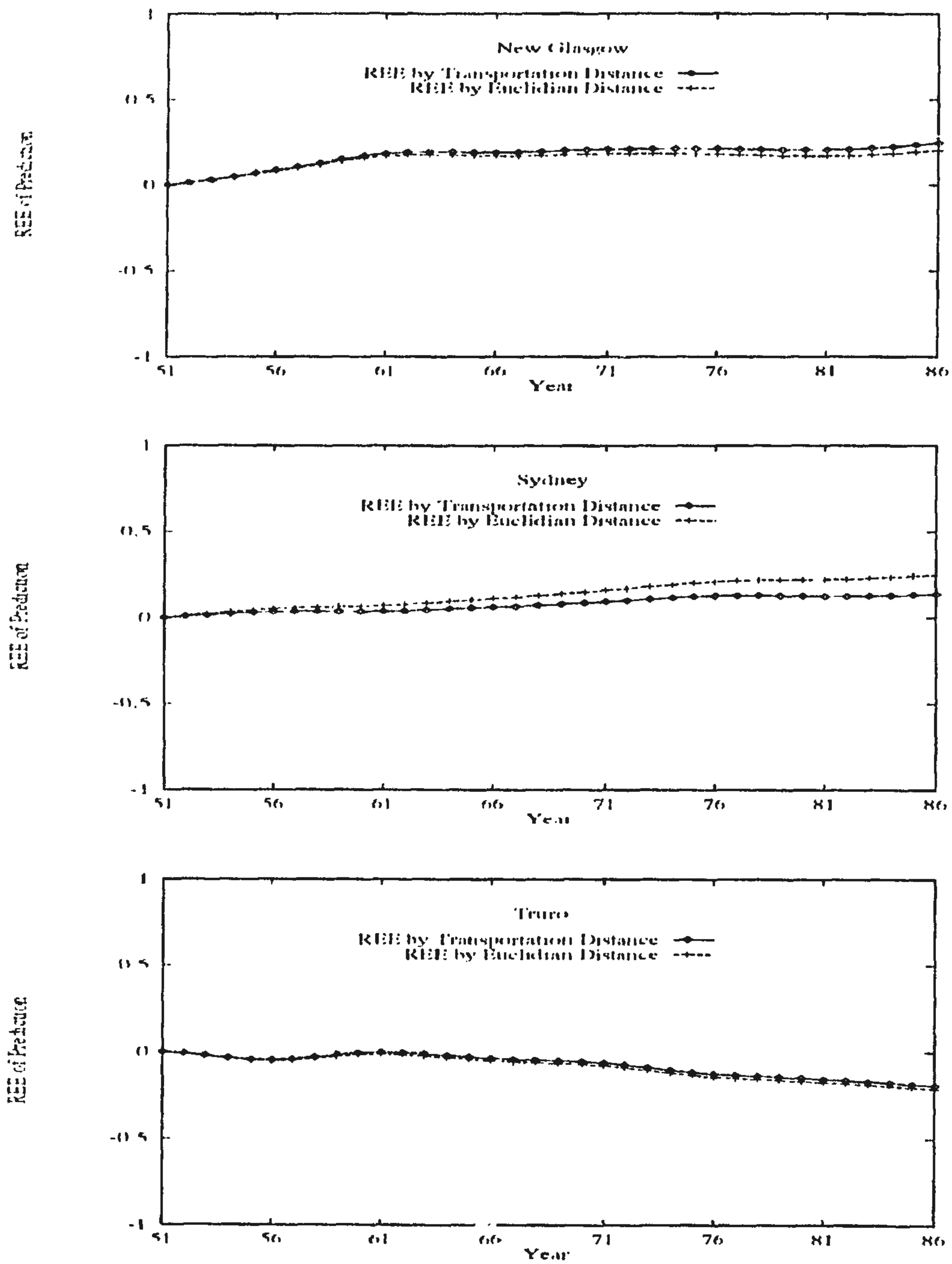
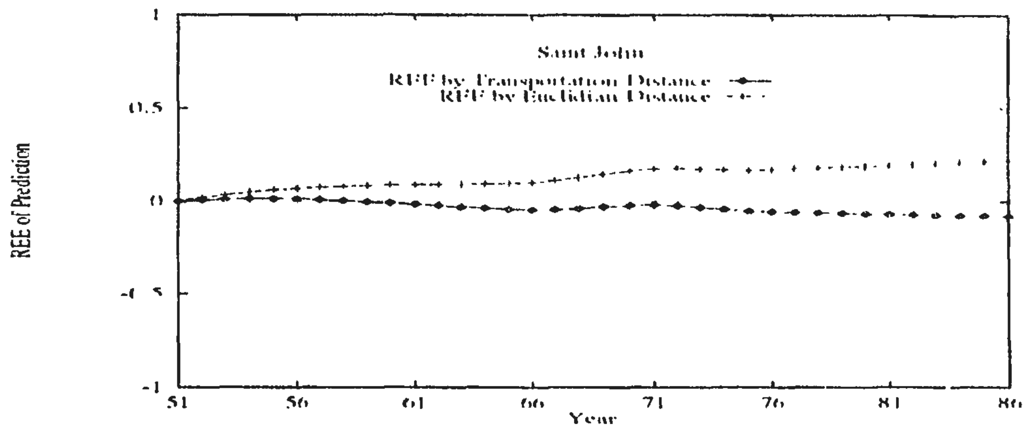
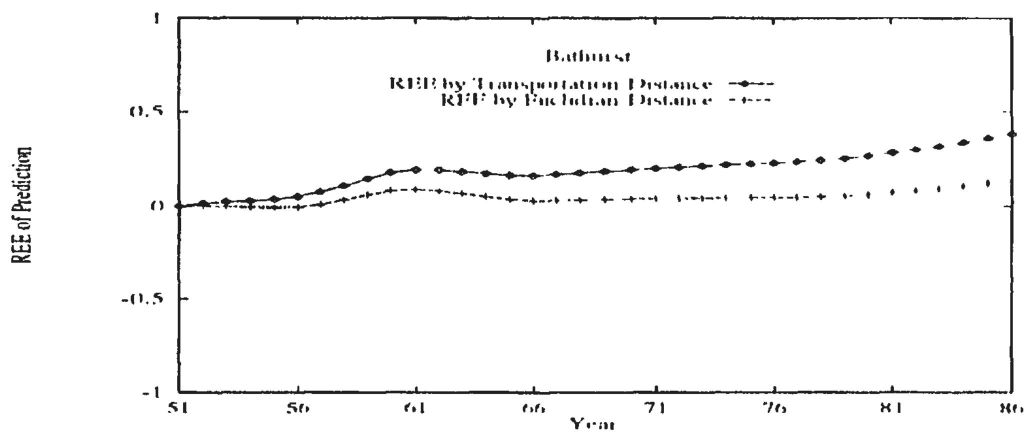


Figure 6.4: (cont.)





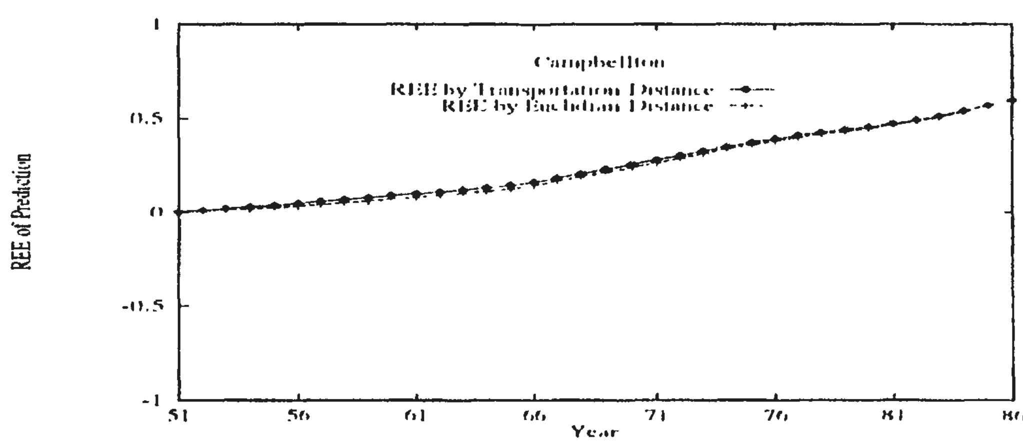


Figure 6.4: (cont.)

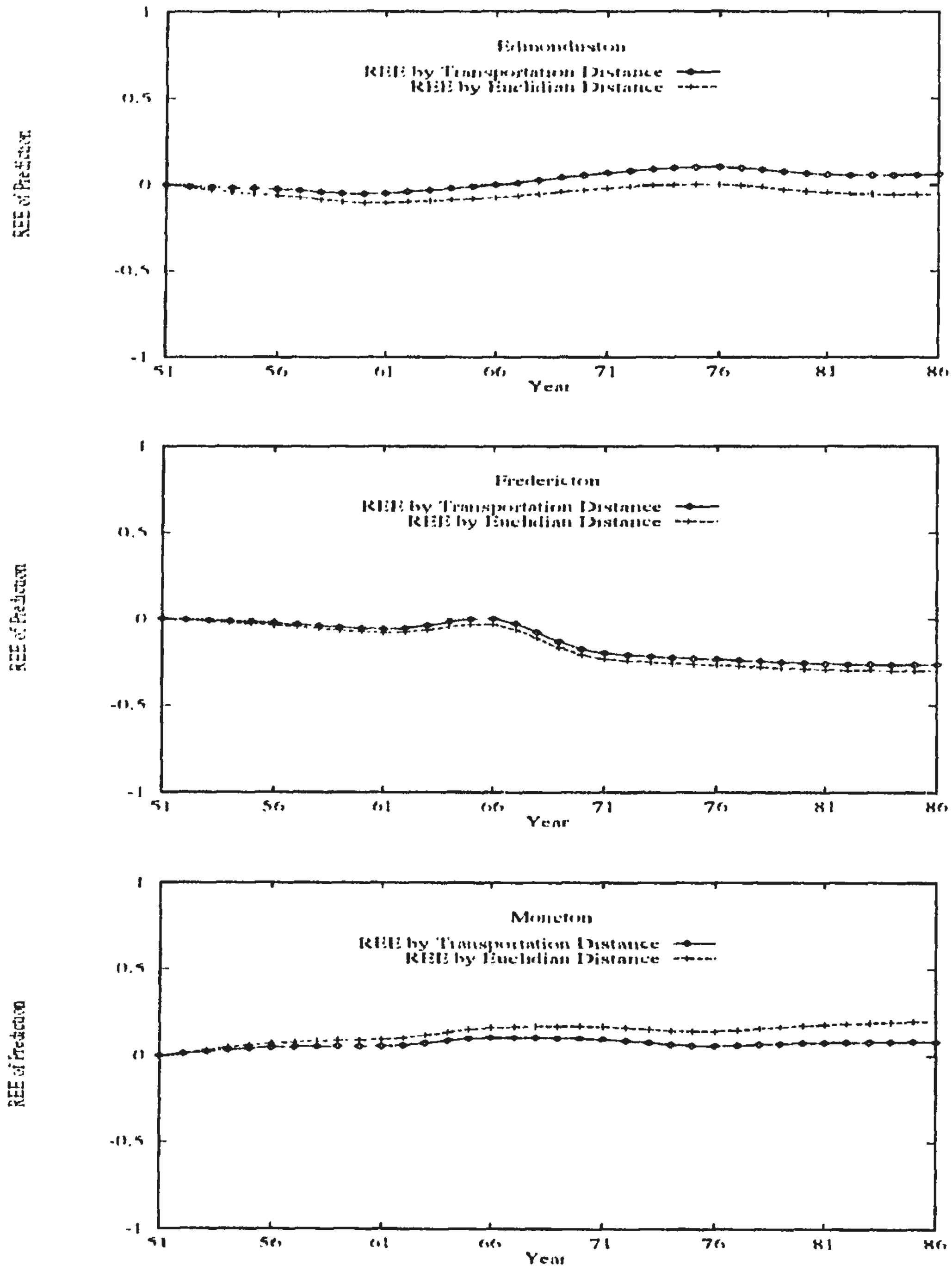


Figure 6.4: (cont.)

6.5 Prediction

The correspondence between the actual urban populations and the simulation results based on the calibration for the period 1951-1986 is one measure of the success of the dynamic urban model. This success reflects the degree to which the evolution of the system can be understood in terms of endogenous system dynamics, which the model represents, rather than exogenous events. Specifically, the results indicate that competition among the cities of the region is a significant factor in the urban system evolution. On the other hand, whether the calibrated model can successfully predict the future distribution of population in the urban system is another question, and would be another test of the model. Therefore, in order to investigate this point, the 1986 population data are used as input data and the calibrated model is employed to predict the 1991 population for each city in the system. The results in Table 6.9 and Fig.6.5 show a successful prediction. Except for Labrador City, the relative error of population in each city is less than 10%, with the error of twelve cities being less than 6%. a significant feature of the pattern of errors is that larger cities of Halifax, St. John's, Saint John, Moncton, and Sydney all have errors of less than 2.7%. This suggests that the competition mechanism represented by the model structure indeed plays an important role in the evolution of the urban system. It is also evidence in favour of the argument that relatively independent cities are gradually becoming integrated into a system of interdependent relationships as the resource based structure of the economy gradually shifts toward a service based structure.

I should be noticed that the prediction is made by using the growth rate of system population during 1985-86. We use the growth rate of 1985-86 instead of that of 1986-91 because we assume that we have only data available in 1986. Therefore the REE's of

CMAs and CAs	Actual Size	Simulated Size	Relative Error
St. John's	171859	169948	-0.01112
Corner Brook	33790	34133	0.01017
Gander	11053	11093	0.00362
Grand Falls	25282	26890	0.06360
Labrador City	11392	8982	-0.21157
Charlottetown	57472	52022	-0.09482
Summerside	15237	15577	0.02234
Halifax	320501	319886	-0.00192
New Glasgow	38676	38213	-0.01198
Sydney	116100	116780	0.00586
Truro	44003	39770	-0.09619
Saint John	124981	121708	-0.02619
Bathurst	36167	37881	0.04739
Campbellton	14508*	15388	0.06066
Edmundston	22478	21284	-0.05312
Fredericton	71869	67878	-0.05553
Moncton	106503	108045	0.01448

Table 6.9: A Comparison of Actual and Simulated CMA or CA Population for 1991. *14508 is population of CA Campbellton based on 1986 boundary.

the prediction using the regional growth rate of 1985-86 have two components: one due to the behaviour of the model and one due to the error in the assumed growth rate. In order to see how much of the REE is caused by the model, we eliminate the system growth rate error by modifying the 1991 simulated populations by the ratio of the sum of 1991 actual populations to the sum of 1991 simulated populations. Then we calculate a modified REE for each city using the modified simulated population (see Table 6.10). The modified REE can be seen as a measure of error caused only by the model. Compared with $REEs$ in Table 6.9, the adjusted $REEs$ are very similar. Except for Labrador City,

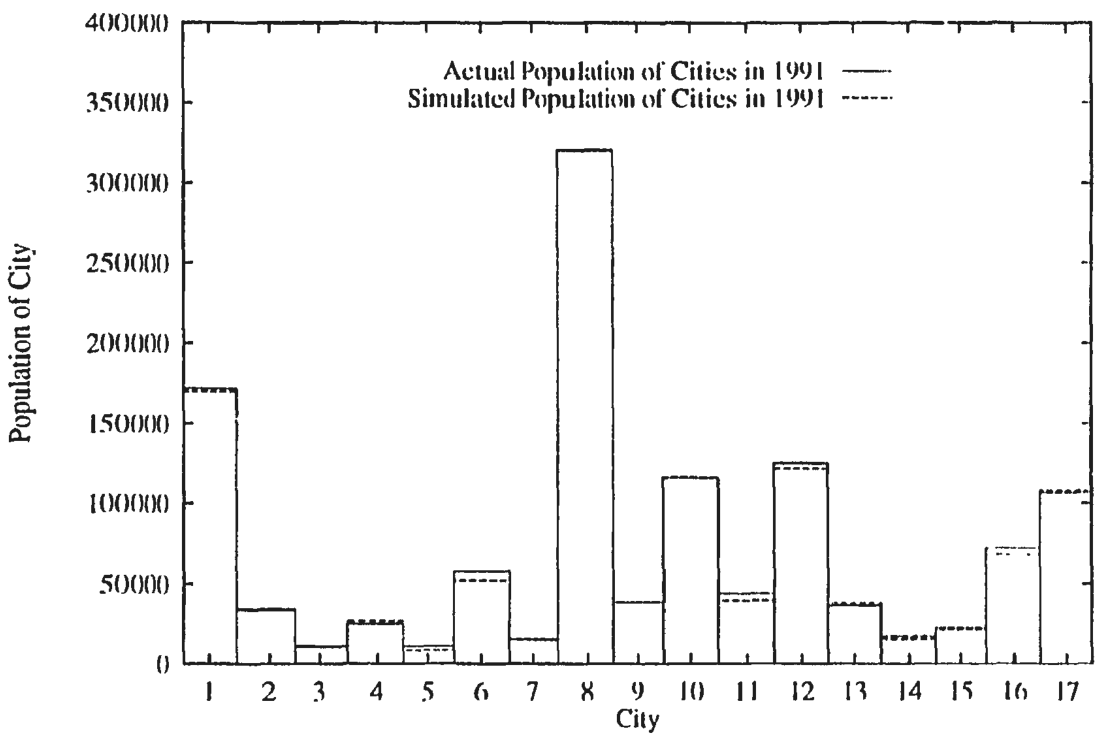


Figure 6.5: Actual and Simulated Population, 1991, for The Atlantic Region Urban System. Simulation is based on Transportation Distance.

CMAs and CAs	Actual Size	Adjusted Simulated Size	Adjusted Relative Error
St. John's	171859	172259	0.00233
Corner Brook	33790	34597	0.02388
Gander	11053	11244	0.01728
Grand Falls	25282	27256	0.07808
Labrador City	11392	9104	-0.20084
Charlottetown	57472	52729	-0.08253
Summerside	15237	15789	0.03623
Halifax	320501	324236	0.01165
New Glasgow	38676	38733	0.00147
Sydney	116100	118368	0.01953
Truro	44003	40311	-0.08390
Saint John	124981	123363	-0.01295
Bathurst	36167	38396	0.06163
Campbellton	14508*	15597	0.07506
Edmundston	22478	21573	-0.04026
Fredericton	71869	68801	-0.04269
Moncton	106503	109514	0.02827

Table 6.10: A Comparison of Actual and Adjusted Simulated CMA and CA Populations and REE's for 1991.

the adjusted relative error of population in each city is now less than 9%, with the error of eleven cities being less than 5%. Eight of the cities have a slightly better REE while the other nine have slightly worse $REEs$. The significant feature of the error-pattern evident in Table 6.9 can still be seen in Table 6.10: the larger cities of Halifax, St. John's, Saint John, Moncton, and Sydney all have a small error of predicted population – less than 2.9%. Therefore the conclusions drawn from the unadjusted simulation results (Table 6.9) remain valid.

Finally, in order to further investigate the model, the calibrated model is r n using

1986 data as initial conditions and with $\Delta S = 0$ so there is no exogenous input to the system (that is, no system growth). The model is run until equilibrium is approached in order to see what state the system would approach in the absence of exogenous changes like growth in the total regional population. The results of this experiment in Figs. 6.6 show that in spite of forty three iterations (equivalent to forty three years) being run, the system still does not reach an equilibrium. Even though some cities like Truro, New Glasgow, Summerside, and Fredericton have apparently approached an equilibrium, most cities still present a changing population. Some of these cities have a continuously increasing population, for example, Halifax, Bathurst, Moncton, Gander, and Grand Falls; and others, such as Sydney, Saint John, and Charlottetown, show a continuous decline. The population of St. John's increases for the first 15 years and then declines. The location of four of the cities with increasing population is in the central part of the local area transportation network. For example, Gander and Grand Falls are in central Newfoundland, and Halifax and Moncton are relatively centrally located in the Maritimes. The location of two cities with declining population, Sydney and St. John's, is at the periphery of the local area. Although Saint John lies on the central part of transportation network, compared with Moncton, its position is less central. Moreover the large population in Halifax has a relatively strong competitive effect on the surrounding area. Therefore the population of Saint John is suppressed by the competitive advantage of Halifax and Moncton, based on the population and the locational advantage of these two cities. The dominant role of location in the model can be also seen in the case of St. John's and Sydney. Even though they both are relatively large cities in their local areas, in the absence of exogenous influence, their population ultimately declines because of their peripheral location in the transportation network. In a word, when there are no exogenous influences, the evolution of the system is dominated by the location of large cities in the transportation network.

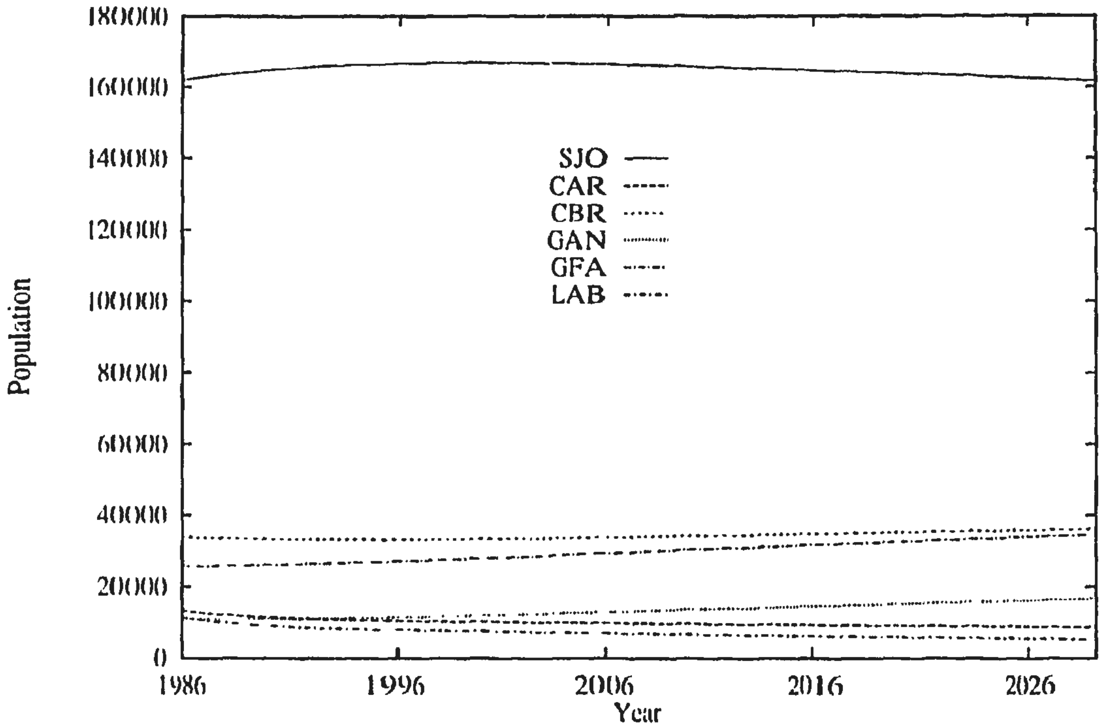


Figure 6.6: Forty-three Iterations of the Calibrated Model, With No Exogenous Changes in Regional Population ($\Delta S = 0$): Simulated Populations of Atlantic Urban Centres.

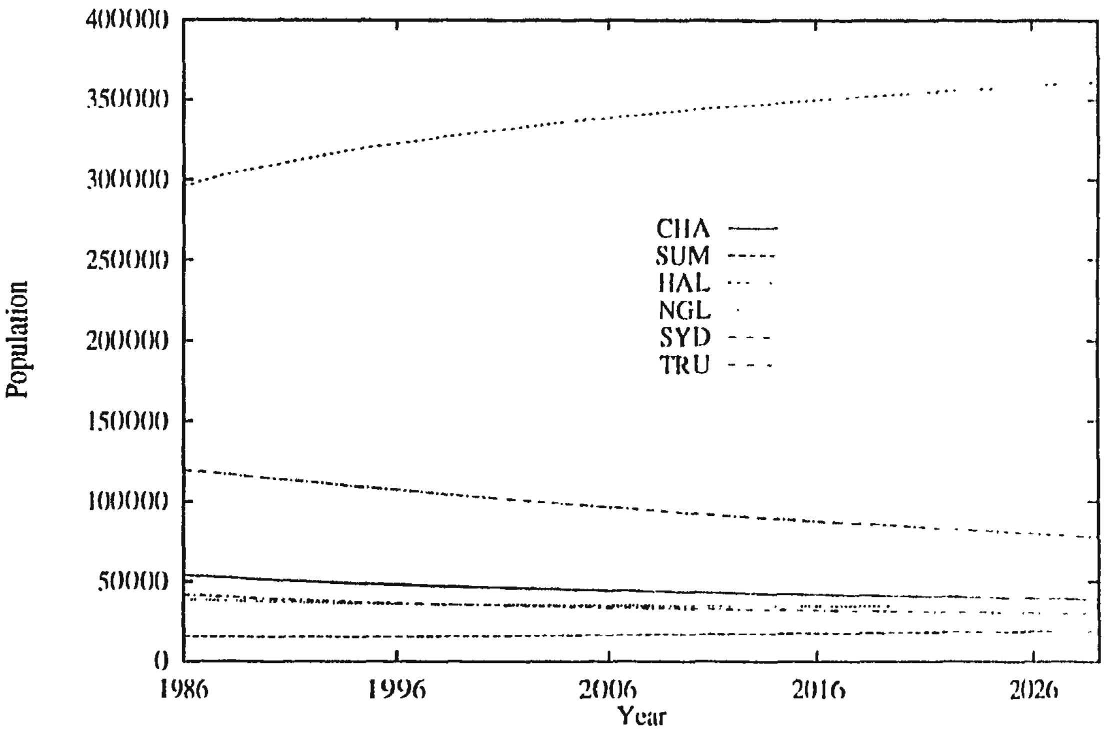


Figure 6.6: (cont.)

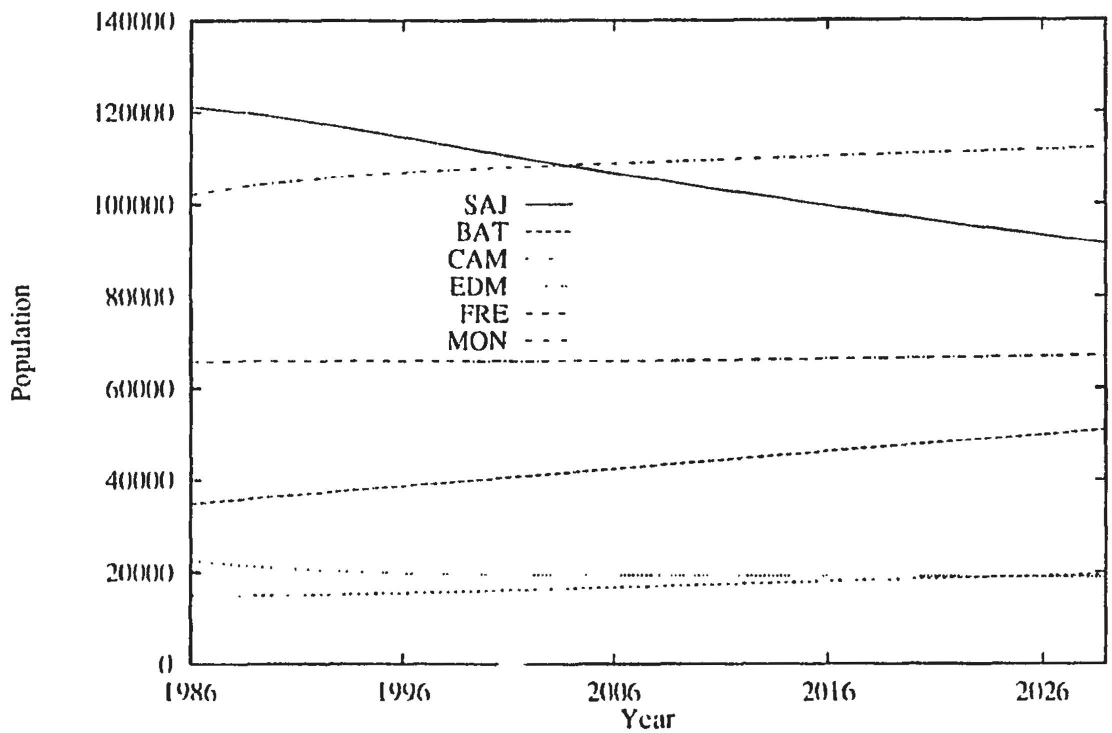


Figure 6.6: (cont.)

Chapter 7

Conclusions

This research constitutes the first application of a dynamic urban model to the Atlantic urban system. The results indicate the utility of studying the urban system through the lens of the dynamic system approach. Despite the simplicity of the model, it captures the actual pattern of the urban system for a relatively long time period. This chapter will evaluate the approach in light of the model used, the research area selected, the methodology of data reorganization and calibration, and other research in urban and regional development.

The most striking characteristic of the model is its simplicity and generality. Compared with the characteristics of some complex urban models, the simple model has such advantages as a limited number of parameters and less extensive data requirements, which make this model relatively easy to calibrate and apply. The model's intrinsic structure suitably reflects relationships of interdependence among the cities in the system. The calibration results suggest that the simple model can be used as a learning tool for understanding the endogenous system dynamics involved in the evolution of an urban system, especially insofar as they depend on the competition mechanism; while the successful prediction of populations in the urban system suggests the potential of a simple model for use in forecasting applications.

The simplicity of the model is reflected clearly in the small number of parameters. For example, only two, abstract, economic sectors are used, each described by just three parameters. There are no parameters that are specific to individual cities in the system. With a model designed in this way, the final values of the parameters show the general characteristics of the whole system. In comparison, a significant feature of Tellier's model [11], also highly generalized, is that each city has an independent parameter. This approach is effective for giving good prediction results. Nevertheless, to the extent that the results depend on these "fudge factor" parameters, the model can not provide a general insight into the behaviour of the system. These individual city parameters make every city a special case.

The advantage of low data requirements would be quite useful for calibrating the model in many countries and regions of the world. North America has relatively good data. Under such conditions many complex models can be calibrated in north America because many kinds of data are available for long periods. Unfortunately, however, many developing countries and regions do not have good data systems. It is impossible to calibrate a complicated model in those areas. Nevertheless, population data is common in both developed and developing countries. Only population data are needed to calibrate the present model. Therefore, the model used in this research could be calibrated in many developing countries as well.

Like all urban models, this model is applicable only within a certain range of circumstances. In some respects the urban system of the Atlantic region may not be an ideal area for testing the present model. For instance, the development of the urban system in the Atlantic area depends to a significant degree on factors like government subsidies and resource developments. Although these phenomena are not consistent with the process of inter-urban competition the structure of the model reflects, this is a problem which does not contradict the usefulness of the model, since spatial interaction and competition are universal phenomena in urban systems. The results of the present research show that inter-urban competition in the Atlantic urban system is significant and can not be ignored. In other words, this research provides insights for understanding the evolution of the Atlantic system in terms of endogenous system dynamics rather than the exogenous events, like resource developments, which have traditionally been the focus of attention in this region. Nevertheless, the model might be expected to perform better if applied to a region like central Canada in which exogenous events play a less important role.

The use of transportation distance has an impact on the simulation results. Even though a separate calibration of the model using Euclidian distance was not carried out, for a calibrated model the use of the two different distances gives two obviously different results. This means that the transportation system plays a key role in guiding the development of the urban system in an area which includes important water barriers. The demonstrated role of transportation distance suggests further considerations. Due to the importance of distance in population migration, retail centre growth, facilities allocation, and industrial location, the transportation distance should be taken into account when the research area is one where use of different transportation modes, especially water and air, is obligatory. Moreover, for the simulation of the Atlantic region urban dynamics, it is clear that keeping the transportation distance unchanged throughout the simulation is not appropriate. This treatment is not consistent with the actual situation. For example, compared with other parts of the Atlantic area, the economy of Burke and Ireland's Core region (see Chapter 4) developed relatively fast. In order to adapt to the economic growth, the transportation system had to be improved, for example by upgrading the highway system. Then the improved transportation facilities of the area, compared to other parts of the region, led to further growth in the core region. However, the static transportation network used in this research is not able to reflect this actual evolution of the transportation system. Therefore further research should consider the transportation system as changing with time in order to improve the simulation results.

The use of transportation distance helps ensure that the calibration of the model can be successfully performed. However, how to make the calibration more effective raises another issue. Calibrating across all combinations of parameter values is practically impossible even though the number of parameters in the model is not large. Thus before carrying out the calibration it is necessary to consider rationally the value range of all parameters and coefficients to be calibrated. Once the initial set of parameter values and their likely ranges is determined in terms of previous research or empirical work, how to make the calibration quickly and efficiently becomes quite important. In this research the standard error e and the relative error REE are employed to judge whether the simulation results improve as the value of an individual parameter is changed. However, a standard and general approach is still not available. Calibrating different dynamic urban models using actual data is usually carried out by different kinds of calibration approaches. The present research shows that the calibration technique used, a fusion of an experimental method and a goodness-of-fit measure, is an effective approach for this urban system.

Given the simplicity of the model and the relative ease of applying it, together with the demonstration of its success in simulating and predicting the development of the Atlantic urban system, it seems likely that the model has potential as a population forecast tool for urban systems. Also, in its original form, the model can be used to predict the development of the retail center system within an urban area. This point suggests that the model shows potential for applications in urban and regional planning. Within an urban system successful population predictions will provide a basis for the planning practise within each city on matters such as transportation network design, the allocation of service facilities, and housing construction.

In conclusion, this research demonstrates that the dynamic urban model is applicable to the Atlantic urban system. In spite of the simplicity of the model, qualitatively accurate simulation of actual system development was achieved, and the model proved to be capable of making reasonable predictions of the population of urban centres within the system. Thus, the model shows potential as a tool for analyzing and forecasting the development of an urban system.

Bibliography

[1] Bourne, L.S (1975) *Urban Systems: Strategies for Regulation*. Oxford: Clarendon Press.

[2] Acheson, T.W (1972) "The National Policy and the Industrialization of the Maritimes, 1880-1910" *Acadiensis*, Vol.1, No.2, 3-28.

[3] Nader, G. A. (1975) *Cities of Canada: Theoretical, Historical and Planning Perspectives*. Toronto: Macmillan of Canada.

[4] Walker, D.F. (1980) *Canada's Industrial Space-Economy*. Toronto: John Wiley and Sons Canada Limited.

[5] George, R.E. (1970) *A Leader and a Laggard: Manufacturing Industry in Nova Scotia, Quebec and Ontario*. Toronto and Buffalo: University of Toronto Press.

[6] Christaller, W. (1966) *The Central Places of Southern Germany*; translated by Baskin, C., from *Die zentralen Orte in Suddeutschland (1933)*. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

[7] Lösch, A. (1938) "The Nature of Economic Regions," *Southern economic Journal*, Vol.5, pp.71-78.

[8] Lösch, A. (1967) *The Economics of Location*; translated by Woglom, W.H., from *Die räumliche Ordnung der Wirtschaft (1940)*. New York: John Wiley and Sons, Inc.

[9] Pumain. D., Th. Saint-Julien, and L. Sanders (1987) "Application of a Dynamic Urban Model". *Geographical Analysis*, Vol. 19, No.2, PP152-166.

[10] White, R.W. (1977) "Dynamic Central Place Theory: Results of a Simulation Approach," *Geographical Analysis*, Vol.9, pp.226-243.

[11] Tellier, L. and R. White (1990) "Options for Forecasting Population and Activity Spatial Distributions," *Urbanization and Development* Discussion paper 5-90.

[12] Allen, P.M., and M. Sanglier (1979) "A Dynamic Model of Growth in a Central Place System," *Geographical Analysis*, Vol.11, pp.256-272.

[13] Allen, P. M., and M. Sanglier (1981) "A Dynamic Model of a Central Place System II," *Geographical Analysis*, Vol.13, No.2, pp.149-164.

[14] Wilson, A. G. (1976) "Retailers' Profits and Consumers' Welfare in a Spatial Interaction Shopping Model," pp.42-59, *London Papers in Regional Science 6. Theory and Practice in Regional Science*, I. Masser, ed., London: Pion.

[15] Harris. B., and A.G. Wilson (1978) "Equilibrium Values and Dynamics of Attractiveness Terms in Production-Constrained Spatial-Interaction models," *Environment and Planning A*, Vol.10, pp.371-388.

[16] Clarke, M., and A. G. Wilson (1983) "The Dynamics of Urban Spatial Structure: Progress and Problems." *Journal of Regional Science*, Vol.23, No 1, pp.1-18.

[17] Pumain, D., T. Saint Julien, and Sanders, L. (1984) "Dynamics of Spatial Structure in French Urban Agglomerations," *Papers of The Regional Science Association*, Vol.55, pp.71-82.

[18] Straussfogel, D. (1991) "Modeling Suburbanization as an Evolutionary System Dynamic." *Geographical Analysis*, Vol.23, pp.1-24.

[19] Lombardo, S. T., and G. A. Rabino (1984) "Nonlinear Dynamic Models for Spatial Interaction: The Results of Some Empirical Experiments." *Papers of the Regional Science Association*, Vol.55, pp.83-101.

[20] Lombardo, S. T., and G. A. Rabino (1986) "Calibration Procedures and Problems of Stability in Nonlinear Dynamic Spatial Interaction Modeling." *Environment and Planning A*, Vol.18, pp.341-350.

[21] Amson, J. C. (1974) "Equilibrium and Catastrophic Modes of Urban Growth." in E. L. Cripps (ed.), *Space Time Concepts in Urban and Regional Models*, London Papers in Regional Science, Vol.4. London: Pion.

[22] Berry, B.J.L. and J.B. Parr (1988) *Market Centers and Retail Location*. Englewood Cliffs: Prentice Hall.

[23] White, R.W. (1978) "The Simulation of Central Place Dynamics: Two-Sector Systems and the Rank-Size Distribution," *Geographical Analysis*, Vol.10, pp.201-208.

[24] White, R.W. (1984) "Principles of Simulation in Human Geography," In G. Gaile and C. Wilmott (ed.), *Spatial Statistics and Models*, pp. 384-416, Dordrecht: D. Reidel.

[25] Lakshmanan, T.R. and W.G. Hansen (1965) "A Retail Market Potential Model." *Journal of the American Institute of Planners*, Vol.31, pp.134-143.

[26] Wilson, A. G. (1981) *Catastrophe Theory and Bifurcation: Applications to Urban and Regional Systems*. London: Croom Helm.

[27] White, R.W. (1989) "Structural Evolution in Urban Systems," *Systems Research*, Vol.6, No.3, pp.245-253.

[28] Allen, P. M., and M. Sanglier (1981) "Urban Evolution, Self-Organization, and Decisionmaking," *Environment and Planning A*, Vol.13, pp.167-183.

[29] Allen, P. M. (1982) "Evolution, Modelling, and Design in A Complex World," *Environment and Planning B*, Vol.9, pp.95-111.

[30] Allen, P. M., M. Sanglier, G. Engelen, and Boon, F. (1984) "Evolutionary Spatial Models of Urban and Regional Systems," *Sistemi Urbani*, Vol.1, pp.3-36.

[31] Sanglier, M., and P. M. Allen (1989) "Evolutionary Models of Urban Systems: An Application to the Belgian Provinces," *Environment and Planning A*, Vol.21, pp.477-498.

[32] Prigogine, I., P. M. Allen, and R. Herman (1977) "the Laws of Nature and the Evolution of Complexity," In *Goals in a Global Community*, E. Laszlo and J. Bierman (eds.), New York: Pergamon.

[33] Koh, N. P. (1990) *Modelling Retail System Dynamics: An Application to the System of Major Retail Centres in the St.John's Metropolitan Area 1960-1980*. MA Thesis, Department of Geography, Memorial University of Newfoundland.

[34] Hoyt, H. (1949) *The Economic Base of the Brockton, Massachusetts Area*. Brockton Massachusetts.

[35] Isard, W. (1971) *Methods of Regional Analysis: an Introduction to Regional Science*. Cambridge, Massachusetts, The M.I.T. Press.

[36] Winger, A.R. (1977) *Urban Economics: An Introduction.* Columbus: Charles E. Merrill Publishing Company.

[37] Wheeler, J.O. and P.O. Muller (1986) *Economic Geography.* New York: John Wiley and Sons.

[38] Berry,B.J.L. (1964) "Cities as Systems within Systems of Cities", *Papers and Proceedings of the Regional Science Association*, Vol.13, pp.147-163.

[39] Berry,B.J.L. (1972) "Latent Structure of the American Urban System", in B.J.L.Berry, ed., *City Classification Handbook*, New York: Wiley Interscience.

[40] Berry,B.J.L. (1973) *Growth Centers in the American Urban System*, Vol.1, *Community Development and Regional Growth in the 60's and 70's*, Cambridge, Ballinger, Mass.

[41] Burke, C.D. and D.J. Ireland (1976) *An Urban/Economic Development Strategy for the Atlantic Region.* Ottawa: Ministry of State for Urban Affairs.

[42] Hiller,J.K. and P.Neary (1980), eds, *Newfoundland in the Nineteenth and Twentieth Centuries* Toronto: University of Toronto Press.

[43] Horwood,H (1969) *Newfoundland.* Toronto: Macmillan.

[44] Clark, A.H. (1969) *Three Centuries and the Island.* Toronto: University of Toronto Press.

[45] Rogers, I.L. (1983) *Charlottetown: The Life in Its Buildings.* Charlottetown, P.E.I.: The Prince Edward Island Museum and Heritage Foundation.

[46] Campbell, G.G.(1949) *The History of Nova Scotia.* Toronto: Ryerson.

[47] Raddall, T.H. (1948) *Halifax: Warden of the North.* Toronto: McClelland and Stewart.

[48] Daigle, J. (1982), ed., *The Acadians of the Maritimes: Thematic Studies.* Moncton, N.B.: Centre d'études acadiennes.

[49] Statistics Canada (1987) "Census Metropolitan Areas and Census Agglomerations." *Population,* Catalogue 92-104. Minister of Supply and Services Canada.

[50] Statistics Canada (1982) "Geographic Distributions." *Population,* Catalogue 93-903. Minister of Supply and Services Canada.

[51] Statistics Canada (1977) "Municipalities, Census Metropolitan Areas and Census Agglomerations." *Population: Geographic Distributions,* Catalogue 92-806. Minister of Supply and Services Canada.

[52] Akima, H. (1970) "A New Method of Interpolation and smooth curve fitting based on local procedures." *Journal of the ACM,* Vol.17, pp.589-602.

[53] (1987) *Math/Library: Fortran Subroutines for Mathematical Applications.* U.S.A, IMSL, Inc.

[54] Statistics Canada (1987) "Population and Dwelling Characteristics - Census Divisions and Subdivisions." *Newfoundland: Profiles, Part 1,* Catalogue 94-101. Minister of Supply and Services Canada.

[55] (1973) *Atlantic Provinces.* Ottawa: Surveys and Mapping Branch in Department of Energy, Mines and Resources.

[56] *Vacation Guide Map Atlantic Canada.* Maritime Resource Management Service Inc.

[57] (1985) *Newfoundland and Labrador Official Road Map.* St. John's: Department of Development and Tourism, Newfoundland and Labrador.

[58] (1982) *Prince Edward Island Visitors Map.* Canada: Prince Edward Island.

[59] (1980) *Nova Scotia Highway and Byways.* Published by Joint Authority: Department of Tourism and Department of Transportation.

[60] (1980) *New Brunswick* New Brunswick in Canada: Department of Tourism

[61] Wilson, A. G. (1974) *Urban and Regional Models in Geography and Planning.* New York: John Wiley and Sons.

[62] Olsson, G. (1965) *Distance and Human Interaction.* Philadelphia: Regional Science Research Institute.

[63] Personal communication with Air Canada, 1990.

[64] Personal communication with Canada National Road Service, 1990.

[65] Statistics Canada (1987) "Selected Characteristics for Census Metropolitan Areas and Census Agglomerations, 1986 Census." *Newfoundland: Profiles, Part 1.* Catalogue 94-128 Minister of Supply and Services Canada.

[66] White, R.W. (1979) "Firm Size and the Dispersal of Manufacturing in Canada" *The Canadian Journal of Regional Science,* Vol.II, No.2, 23-40.

[67] Gilmour, J. (1975) "External Economies of Scale, Inter-Industrial Linkages and Decision Making in Manufacturing", in F.E. Ian Hamilton (ed.), *Spatial Perspectives on Industrial Organization and Decision-Making.* London: John Wiley.

[68] Walker, D. (1975) "A Behavioural Approach to Industrial Location," in L. Collins and D. Walker (eds.). *Locational Dynamics of Manufacturing Activity*. London: John Wiley.

Appendix A

Transportation Network

A.1 Index of Nodes in the Transportation Network

(1) F01SJO	(2) F01CAR	(3) F05CBR	(4) F06GAN	(5) F06GFA	(6) F10LAB	(7) P02CHA
(8) P03SUM	(9) S08HAL	(10) S13NGL	(11) S03SYD	(12) S04TRU	(13) B11SAJ	(14) B04BAT
(15) B10CAM	(16) B07EDM	(17) B15FRE	(18) B14MON	(19) F02MAR	(20) F03MIL	(21) F04STE
(22) F07PBL	(23) F08LEW	(24) F09HBA	(25) P01BRI	(26) S01BRI	(27) S02ANT	(28) S05SPR
(29) S06WEY	(30) S07CHA	(31) S09RAW	(32) S10SMA	(33) S11COL	(34) S12MBA	(35) S14MID
(36) S15SPE	(37) S16SHE	(38) S17RCO	(39) S18YAR	(40) B01RAL	(41) B02HAR	(42) B03BOC
(43) B05BRI	(44) B08NCA	(45) B09YCO	(46) B12MAU	(47) B13PRO	(48) F01HOL	(49) F05PAS
(50) F06HAD	(51) F10GBA	(52) P02SHE	(53) P03HPL	(54) S03EBA	(55) S04MAS	(56) S08MHA
(57) S13STE	(58) B01PAQ	(59) B07RVE	(60) B10TID	(61) B11BRI	(62) B14MBR	(63) B15ZST

Table A.1: Index Number and Name for eighteen cities and forty-five census divisions (TRAPD), $j = 1, \ldots, 18$ denote eighteen cities (CMA and CA); $j = 19, \ldots, 47$ denote counties not containing cities; $j = 48, \ldots, 63$ denote counties containing cities. The name is given as follows: the first letter denotes the province (F=N.F., P=P.E.I., S=N.S., and B=N.B.), the next two numbers denote the census division according to Census Canada, and the last three letters are an abbreviation of the name for either city or census division.

A.2 Transportation Network of the Atlantic Region

A.2.1 Transportation Network for Eighteen Cities

1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	109	687	331	428	0	906	967	991	849	582	912	1235	1288	1341	1505	1229	1042
2	109	1	666	317	407	109	885	946	970	828	561	891	1214	1267	1320	1484	1208	1021
3	687	666	1	350	258	50	727	788	812	670	403	733	1056	1109	1162	1326	1050	863
4	331	317	350	1	91	0	1077	1138	1162	1020	753	1083	1406	1459	1512	1676	1400	1213
5	428	407	258	91	1	91	985	1046	1070	928	661	991	1314	1367	1420	1584	1308	1121
6	0	109	50	0	91	1	0	61	0	166	0	97	0	204	315	285	0	0
7	906	885	727	1077	985	0	1	61	252	112	329	173	356	409	462	626	350	163
8	967	946	788	1138	1046	61	61	1	313	173	390	234	417	470	523	687	411	224
9	991	970	812	1162	1070	0	252	313	1	166	432	97	309	499	610	701	418	295
10	849	828	670	1020	928	166	112	173	166	1	260	64	412	465	518	682	406	219
11	582	561	403	753	661	0	329	390	432	260	1	330	653	706	759	923	647	460
12	912	891	733	1083	991	97	173	234	97	64	330	1	357	399	510	591	381	195
13	1235	1214	1056	1406	1314	0	356	417	309	412	653	357	1	356	459	194	109	163
14	1288	1267	1109	1459	1367	204	409	470	490	465	706	399	356	1	111	119	246	204
15	1341	1320	1162	1512	1420	315	462	523	610	518	759	510	459	111	1	208	357	115
16	1505	1484	1326	1676	1584	285	626	687	703	682	923	591	194	119	208	1	285	472
17	1229	1208	1050	1400	1308	0	350	411	41.	406	647	381	109	246	357	285	1	187
18	1042	1021	863	1213	1121	0	163	224	295	219	460	195	163	204	115	472	187	1

Table A.2: Surface Distances Between Eighteen Cities. Self-Distance is unity. Where an air link is necessary, distance shown is the highway component only; where a ferry component is necessary, distance shown is ferry plus highway. Other distances are high way distances. These surface distances are shown for indicative purposes only, since the distance used in the simulation are highway distance, or highway distance plus the applicable ferry or air distance as modified by the relevant coefficients.

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0	0	0	0	0	1170*	448	448	426	426	426	426	426	426	426	426	426	426
2	0	0	0	0	0	1170*	448	448	426	426	426	426	426	426	426	426	426	426
3	0	0	0	0	0	783*	182	182	160	160	160	160	160	160	160	160	160	160
4	0	0	0	0	0	967*	182	182	160	160	160	160	160	160	160	160	160	160
5	0	0	0	0	0	967*	182	182	160	160	160	60	160	160	160	160	160	160
6	1170*	1170*	783*	967*	967*	0	794*	794*	953*	953*	897*	953*	856*	776*	776*	776*	776*	776*
7	448	448	182	182	182	794*	0	0	22	22	22	22	14	14	14	14	14	14
8	448	448	182	182	182	794*	0	0	22	22	22	22	14	14	14	14	14	14
9	426	426	160	160	160	953*	22	22	0	0	0	0	72	0	0	72	72	0
10	426	426	160	160	160	953*	22	22	0	0	0	0	0	0	0	0	0	0
11	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
12	426	426	160	160	160	953*	22	22	0	0	0	0	0	0	0	0	0	0
13	426	426	160	160	160	856*	14	14	72	0	0	0	0	0	0	0	0	0
14	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
15	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
16	426	426	160	160	160	776*	14	14	72	0	0	0	0	0	0	0	0	0
17	426	426	160	160	160	776*	14	14	72	0	0	0	0	0	0	0	0	0
18	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0

Table A.3: Ferry and (*) Air Component of Distance between Eighteen Cities.

A.2.2 Transportation Network between Eighteen Cities and Forty-Five Rural Regions

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19	306	285	669	313	410	313	1048	1109	1102	912	717	1000	1336	1377	1488	1645	1360	1173
20	574	552	449	236	191	236	1183	1244	1237	1067	852	1135	1471	1512	1623	1780	1495	1308
21	796	774	77	457	335	127	682	743	736	566	351	634	970	1011	1122	1279	994	807
22	221	200	466	117	208	117	1200	1261	1254	1084	869	1152	1488	1529	1640	1797	1512	1325
23	390	369	321	52	62	52	1055	1116	1109	939	724	1007	1343	1384	1495	1652	1367	1180
24	850	833	263	519	420	213	997	1058	1051	881	666	949	1285	1326	1437	1594	1309	1122
25	900	879	721	1071	979	66	66	127	248	100	362	146	378	407	520	711	415	229
26	1138	1117	959	1309	1217	177	380	441	177	290	556	221	130	486	589	524	239	293
27	793	772	614	964	872	211	158	219	219	49	211	117	474	516	627	708	498	312
28	1007	986	828	1178	1086	87	191	130	193	160	425	96	250	292	403	559	274	87
29	1219	1198	1040	1390	1298	260	482	543	260	373	637	304	112	468	571	506	221	275
30	840	819	661	1011	919	258	205	256	260	96	258	164	521	563	674	755	545	159
31	991	970	812	1162	1070	52	252	313	52	143	409	79	276	632	735	670	385	439
32	701	680	522	872	780	119	336	397	397	227	119	295	652	694	805	886	676	490
33	1070	1049	891	1241	1149	110	332	393	110	223	488	154	201	559	662	597	117	306
34	1091	1070	912	1262	1170	79	352	413	79	243	509	174	263	619	722	657	372	426
35	1144	1123	965	1315	1223	135	406	467	135	297	562	228	201	557	660	595	110	164
36	687	666	508	858	766	105	263	324	324	154	105	222	579	621	712	811	603	417
37	1218	1197	1039	1380	1297	209	480	541	209	371	636	302	294	650	753	688	401	457
38	719	698	540	890	798	137	354	415	415	245	137	313	670	712	823	904	694	508
39	1290	1269	1111	1461	1369	321	553	614	321	444	708	376	183	539	642	577	292	146
40	1096	1075	917	1267	1175	54	217	278	349	273	514	249	159	258	369	496	205	54
41	1351	1330	1172	1522	1430	309	472	533	604	528	769	504	241	310	280	161	122	109
42	1346	1325	1167	1517	1425	141	467	528	599	523	764	499	141	197	495	378	153	104
43	1105	1084	926	1276	1184	63	226	287	358	282	523	258	226	154	265	147	147	63
44	1182	1161	1003	1353	1261	140	303	364	435	359	600	335	279	79	190	387	167	140
45	1150	1129	971	1321	1229	108	271	312	403	327	568	303	114	312	424	164	79	108
46	1208	1187	1029	1379	1287	166	329	390	461	385	626	361	88	267	378	306	21	166
47	1456	1435	1277	1627	1535	414	577	638	709	633	874	609	316	241	258	141	227	414

Table A.4: Surface Distances Between Cities and Rural Regions Not Containing A City.

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
48	48	60	649	293	390	48	875	936	929	759	544	827	1163	1204	1315	1472	1187	1000
49	659	617	28	322	230	21	762	823	816	646	431	714	1050	1091	1202	1359	1074	887
50	456	440	231	118	28	180	965	1026	1019	849	634	917	1253	1294	1405	1562	1277	1090
51	0	109	50	0	91	0	0	61	0	166	0	97	0	246	357	285	0	0
52	912	891	733	1083	991	6	6	55	333	115	362	239	318	347	460	651	355	169
53	1001	980	822	1172	1080	95	95	34	422	204	451	328	407	436	549	740	444	258
54	602	581	423	773	681	20	349	410	412	240	26	310	667	709	820	901	691	505
55	933	912	754	1104	1012	118	194	255	118	85	351	21	336	378	489	645	360	173
56	991	970	812	1162	1070	47	252	313	47	143	409	79	357	713	816	751	466	520
57	849	828	670	1020	928	161	112	173	161	3	267	60	417	459	570	651	441	255
58	1288	1267	1109	1459	1367	246	409	470	541	465	706	441	389	57	168	376	288	246
59	1489	1468	1310	1660	1568	261	610	671	742	666	907	642	370	295	184	16	261	447
60	1349	1328	1170	1520	1428	307	470	531	602	526	767	502	507	119	8	200	398	307
61	1235	1214	1056	1406	1314	30	356	417	488	412	653	388	85	336	455	424	131	77
62	1025	1004	846	1196	1104	17	146	207	278	202	443	178	180	219	330	487	202	17
63	1267	1246	1088	1438	1346	38	388	449	520	444	685	420	147	284	358	241	38	225

Table A.5: Surface Distances Between Cities and Rural Regions Containing A City.

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
10	0	0	0	0	0	967*	448	448	426	426	426	426	426	426	426	426	426	426
20	0	0	0	0	0	967*	182	182	160	160	160	160	160	160	160	160	160	160
21	0	0	0	0	0	783*	182	182	160	160	160	160	160	160	160	160	160	160
22	0	0	0	0	0	967*	182	182	160	160	160	160	160	160	160	160	160	160
23	0	0	0	0	0	967*	182	182	160	160	160	160	160	160	160	160	160	160
24	0	0	0	0	0	783*	182	182	160	160	160	160	160	160	160	160	160	160
25	448	448	448	448	448	794*	0	0	22	22	22	22	14	14	14	14	14	14
26	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
27	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
28	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
29	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
30	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
31	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
32	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
33	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
34	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
35	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
36	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
37	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
38	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
39	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
40	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
41	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
42	426	426	160	160	160	856*	14	14	0	0	0	0	0	0	0	0	0	0
43	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
44	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
45	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
46	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
47	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0

Table A.6: Ferry and (*) Air Component of Distances Between Cities and Rural Regions Not Containing A City.

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
48	0	0	0	0	0	1170*	182	182	160	160	160	160	160	160	160	160	160	160
49	0	0	0	0	0	783*	182	182	160	160	160	160	160	160	160	160	160	160
50	0	0	0	0	0	783*	182	182	160	160	160	160	160	160	160	160	160	160
51	834*	834*	507*	627*	627*	452*	824*	824*	1004*	1004*	806*	1004*	998*	947*	947*	947*	947*	876*
52	448	448	448	448	448	794*	0	0	22	22	22	22	14	14	14	14	14	14
53	448	448	448	448	448	794*	0	0	22	22	22	22	14	14	14	14	14	14
54	426	426	160	160	160	897*	22	22	0	0	0	0	0	0	0	0	0	0
55	426	426	160	160	160	953*	14	14	0	0	0	0	0	0	0	0	0	0
56	426	426	160	160	160	953*	22	22	0	0	0	0	72	72	72	72	72	72
57	426	426	160	160	160	953*	22	22	0	0	0	0	0	0	0	0	0	0
58	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
59	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
60	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
61	426	426	160	160	160	856*	14	14	0	0	0	0	0	0	0	0	0	0
62	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0
63	426	426	160	160	160	776*	14	14	0	0	0	0	0	0	0	0	0	0

Table A.7: Ferry and (*) Air Component of Distances Between Cities and Rural Regions Containing A City.

A.3 Euclidian Distance Network for the Atlantic Region

A.3.1 Index of Nodes in Euclidian Distance Network

(1) F01SJO	(2) F01CAR	(3) F05CBR	(4) F06GAN	(5) F06GFA	(6) F10LAB	(7) F02CHA
(8) P03SUM	(9) S08HAL	(10) S13NGL	(11) S03SYD	(12) S04TRU	(13) B11SAI	(14) B01HAF
(15) B10CAM	(16) B07EDM	(17) B15FRE	(18) B14MON	(19) F02MAR	(20) F03MIL	(21) F01STE
(22) F07PBL	(23) F08LEW	(24) F09HBA	(25) P01CAR*	(26) S01BRI	(27) S02ANT	(28) S05[illegible]PR
(29) S06WEY	(30) S07CHA	(31) S09BRO*	(32) S10MAR*	(33) S11CAM*	(34) S12MBA	(35) S14GRE*
(36) S15SPE	(37) S16SHE	(38) S17NRB*	(39) S18YAR	(40) B01RAL	(41) B02HAR	(42) B03HOC
(43) B05HAR*	(44) B08NCA	(45) B09YCR*	(46) B12MAU	(47) B13PRO	(48) F04HOL	(49) F05PAS
(50) F06BAD	(51) F10GBA	(52) P02YOR*	(53) P03WEL*	(54) S03EHA	(55) S04BEL*	(56) S08MHA
(57) S13STE	(58) B04SSA*	(59) B07QUI*	(60) B10THD	(61) B11BRI	(62) B14FGR*	(63) B15ZST

Table A.8: Index Number and Name for Eighteen Cities and Forty-five Census Divisions (EUCD), see index of TRAPD. Names with "*" indicate different locations in the digitized map from those in road maps (see section 5.2.2).

A.3.2 Euclidian Distance Network of Eighteen Cities

i	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1	42	417	205	264	1160	807	853	907	796	590	850	1061	971	1044	1176	1080	937
2	42	1	374	166	222	1117	773	818	877	764	558	818	1027	932	1004	1136	1044	901
3	417	374	1	247	169	759	492	522	646	510	351	568	740	588	650	789	734	604
4	205	166	247	1	78	960	711	748	843	720	524	773	965	833	898	1036	969	833
5	264	222	169	78	1	895	638	674	776	651	460	704	891	755	819	957	893	758
6	1160	1117	759	960	895	1	790	758	951	873	891	880	851	594	546	624	772	773
7	807	773	492	711	638	790	1	55	182	82	229	98	255	248	335	419	276	130
8	853	818	522	748	674	758	55	1	196	128	281	122	218	197	283	364	226	84
9	907	877	646	843	776	951	182	196	1	127	321	84	209	369	444	478	282	187
10	706	764	510	720	651	873	82	128	127	1	206	53	272	326	411	482	315	177
11	590	558	351	524	460	891	229	281	321	206	1	260	474	450	535	640	504	359
12	850	818	568	773	704	880	98	122	84	53	260	1	222	312	394	451	273	144
13	1061	1027	740	965	891	851	255	218	209	272	474	222	1	263	307	292	89	136
14	971	932	588	833	755	594	248	197	369	326	450	312	263	1	87	204	199	183
15	1044	1004	650	898	819	546	335	283	444	411	535	394	307	87	1	143	226	256
16	1176	1136	789	1036	957	624	419	364	478	482	640	451	292	204	143	1	203	307
17	1080	1044	734	969	893	772	276	226	282	315	504	273	89	199	226	203	1	145
18	937	901	604	833	758	773	130	84	187	177	359	144	136	183	256	307	145	1

Table A.9: Euclidian Distances Between Urban Centres.

A.3.3 Euclidian Distance Network between Eighteen Cities and Forty-Five Rural Regions

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
19	188	158	287	202	200	1046	620	668	719	608	402	662	873	795	871	998	894	750
20	230	190	199	146	115	958	590	633	709	590	388	644	846	742	814	946	858	717
21	438	396	59	287	210	764	436	468	588	460	293	511	686	546	613	749	684	551
22	138	97	286	72	126	1021	718	759	817	719	516	772	973	859	928	1063	983	843
23	255	215	213	40	54	911	691	726	830	706	515	758	944	801	863	1002	943	810
24	465	425	191	260	213	709	655	676	821	694	541	740	890	699	745	888	870	754
25	770	736	462	677	605	802	38	91	195	75	190	111	291	278	365	455	314	168
26	1020	088	723	938	867	906	231	209	136	223	430	170	79	112	368	360	165	145
27	744	713	480	673	606	884	111	164	169	53	154	106	325	360	446	527	367	225
28	897	864	590	807	735	832	98	85	119	111	110	70	164	251	129	381	204	74
29	1092	1061	798	1013	942	948	306	282	194	296	502	242	97	160	404	378	181	211
30	752	722	506	691	626	923	143	194	155	68	167	110	312	391	477	551	382	245
31	919	887	637	843	774	903	153	155	52	123	329	70	166	318	391	426	213	115
32	643	609	366	561	493	843	167	218	283	159	65	212	418	384	470	575	443	297
33	962	930	668	881	810	889	176	162	34	166	372	112	117	297	164	186	188	116
34	973	943	705	906	838	061	224	224	66	186	386	136	165	370	436	450	248	188
35	1015	985	743	947	879	974	259	252	108	227	427	175	150	380	440	442	238	204
36	662	631	428	602	539	916	186	241	245	141	79	192	413	428	515	606	453	310
37	1075	1046	811	1012	945	1026	327	318	169	293	491	242	180	432	485	468	269	264
38	619	586	356	542	476	859	193	244	300	179	39	233	442	410	496	601	469	321
39	1130	1100	851	1059	990	1014	360	342	223	330	542	286	163	426	468	413	244	275
40	943	909	623	846	773	811	136	102	153	164	158	122	119	220	291	311	151	18
41	1136	1099	775	1015	938	735	341	288	361	389	570	349	162	203	198	131	78	213
42	1133	1099	805	1034	960	861	326	285	277	345	547	295	71	292	116	266	92	201
43	960	924	611	846	770	726	166	112	241	225	394	197	148	132	202	257	122	54
44	973	935	606	847	770	662	208	153	306	278	426	257	198	68	137	214	141	119
45	1021	985	682	914	838	778	214	167	230	253	443	212	77	187	237	248	62	84
46	1068	1032	725	959	883	781	262	214	265	309	490	257	74	202	235	219	17	112
47	1111	1073	737	981	90.	666	337	281	190	196	561	363	210	151	130	88	121	220

Table A.10: Euclidian Distances Between Cities and Rural Regions Not Containing A City.

j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
48	36	39	396	202	252	1146	774	821	871	762	556	815	1027	942	1016	1146	1047	904
49	194	152	29	220	141	774	520	550	673	545	374	595	768	617	679	818	763	633
50	292	249	139	108	30	868	613	648	754	629	440	681	866	726	789	928	865	731
51	832	794	510	627	583	427	808	803	990	875	792	906	980	729	732	862	928	859
52	803	768	484	704	671	781	11	54	103	92	227	109	261	243	330	418	279	134
53	867	831	531	760	685	747	72	17	205	144	298	134	209	181	266	347	212	73
54	609	578	472	545	482	897	215	269	300	187	21	240	457	443	529	630	490	344
55	855	823	569	776	706	870	92	112	89	59	265	11	213	301	382	440	263	113
56	867	837	611	804	738	944	161	186	39	95	282	64	239	371	450	496	305	194
57	796	764	519	720	651	872	82	128	127	0	206	53	272	326	411	482	315	177
58	944	905	565	809	731	608	220	171	348	209	420	288	259	29	116	231	203	165
59	1154	1115	771	1017	937	633	394	339	453	456	615	425	268	183	131	26	179	281
60	1052	1012	659	906	828	550	339	286	445	414	541	396	304	97	8	134	222	257
61	1040	1006	722	946	872	853	235	200	188	249	452	199	22	262	311	306	102	120
62	931	895	600	828	753	776	124	79	182	169	352	137	139	188	262	314	152	7
63	1100	1063	749	535	909	761	298	247	308	340	527	298	111	199	216	180	25	168

Table A.11: Euclidian Distances Between Cities and Rural Regions Containing A City.

Appendix B

Population Data for CMAs and CAs

B.1 Adjusted CA population for New Glasgow

Table B.1 shows the population data used to construct data for CA New Glasgow.

No.	Components (1986)	1951	1956	1961	1966	1971	1976	1981	1986
1	Fishers Grant 24	*	*	*	*	*	*	199	211
2	Merigomish Harb.31	*	*	*	*	*	*	*	
3	New Glasgow	9933	9998	9782	10489	10849	10672	10461	10022
4	Pictou Subd.B	4282	4245	4331	4494	4842	5788	6266	6147
5	Pictou Subd.C	7509	7773	7737	7859	8416	9207	9372	9111
6	Stellarton	5575	5445	5327	5191	5357	5366	5135	5259
7	Trenton	3089	3240	3140	3229	3331	3224	3154	3083
8	Westville	4301	4247	4159	4147	3898	4251	4522	4271
	Sum	34689	34948	34476	35409	36693	38508	39412	38737

Table B.1: Constructed CA Population of New Glasgow, Nova Scotia, based on 1986 boundary and on geographic population distribution in Census of Canada from 1951-1981. * — denotes that there is no Census Subdivision in this census year. – denotes that there is no data for this Census Subdivision in present census year. See Table 10.1 in Catalogue 92-111 Census Metropolitan Areas and Census Agglomerations (1986).

B.2 The Rural Population Question for Edmundston

From analyzing 1986 census data of Québec and 1986 projected data for the state of

Maine, an estimate can be made of the population not taken into account in the process of the simulation. In the state of Maine, the population of Fort Kent (4, 650), Frenchville (1, 400), Grand Isle (630), St. Agatha (930) was omitted. The ratio of the total omitted Maine population of 7,610 (1986 census) to the local population of 14, 048 in Madawaska county is 0.54. Taking Edmundston as the centre of a circle of $30km$ radius, within that radius the population of Dégelis (3,528) and of Saint-Jean-de-la-Lande (384) was omitted. The ratio of the total omitted population 3, 912 (1986 census) in Québec to the local population of 14,048 in Madawaska county (1986 census) is 0.28.

B.3 The Case of Campbellton

B.3.1 Definition of the CA Boundary

Choosing the 1986 population as an example, the population of the two CA components lying in Québec is 2,551: Pointe-á-la-Croix (1,655) and Restigouche 1 (896). The population of the four CA components in New Brunswick is 14,867: Addington (3,208), Atholville (1,501), Campbellton (9,073), and Tide Head (1,085). The percentage error due to the excluded Québec population is 0.17.

B.3.2 Definition of the Rural Popu' tion of Campbellton

Taking Campbellton as the centre of a circle of $30km$ radius, within the circle the population of Escuminac (659), Matapédia (818), Ristigouche (213), Ristigouche-Partie-Sud-Est (145), Saint-Alexis-de- Matapédia (851), and Saint-Francois-d'Assise (942) was omitted. The ratio of the total omitted population 3, 638 in Bonaventure CSD to local population 25,054 (1986 census) in Restigouche county, New Brunswick is 0.15.