A FRAMEWORK OF EVOLUTION AND OPTIMIZATION OF REGIONAL POPULATION DISTRIBUTION FOR SUSTAINABLE DEVELOPMENT IN CHINA

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A Framework of Evolution and Optimization of Regional Population Distribution for Sustainable Development in China

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Declaration

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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Abstract

Economic globalization promotes urbanization especially in developing countries. In China, regional economic integration has become a basic principle of social and economic development which could promote entire national economy. With the rapid development of urbanization, regional population distribution changes correspondingly. Excessive population agglomeration brings about problems like environmental disruption and resource waste, while too small population size is difficult to support economic development. In China, a big problem government is facing for years is population planning with sustainability considerations for social and economic development at regional level. Therefore, how to provide effective support for the regional population distribution is a necessary and significant research question.

As documented in literature, there are three major gaps in this research area. First, the studies on population density functions are mostly limited on the mathematical expression, whereas, innovation of population density model taking environmental factors into account at regional level is rare. Second, research about evolution and optimization of population distribution at regional level has yet to be developed. Third, an optimization model providing quantitative support to formulate policy control for sustainable regional planning is urgent to be investigated.

In order to fill these research gaps and answer the research question, this research develops a framework of evolution and optimization of regional population distribution for sustainable development. Five main objectives of this research are achieved and they are (1) to investigate the evolution mechanism of regional population distribution through qualitative and quantitative method from the perspective of sustainable development, (2) to identify the factors of population growth for sustainable development, (3) to set up an evolution model at regional level by

identifying the determinants of density gradient, then, (4) to develop an optimization model for sustainable regional population redistribution and (5) to validate the integrated framework of evolution and optimization for sustainable development.

In the process of achieving these objectives, four research methods are used in this research: document analysis, analysis and induction, modeling and case study. Document analysis, analysis and induction and modeling are used to achieve Objective 1 and Objective 2 – Evolution Mechanism; modeling are conducted to achieve Objective 3 – Evolution Model; analysis and induction and modeling are employed to achieve Objective 4 – Optimization Model; case study is used to achieve Objective 5 – Framework Validation. The research conclusions include major findings from the document analysis, analysis and induction, modeling and case study. Ultimately, the results of this validation process prove that the framework developed in the research can provide theoretical and technical support for regional planning about population distribution by facilitating planners to understand evolution mechanism and conduct optimization.

This research has contributed to the knowledge by investigating evolution mechanism and setting up optimization model of regional population distribution for sustainable development. Taking sustainability into account, it not only provides an improved research about how the regional population distribution evolves, but also provides effective solutions for unreasonable distribution. The main contributions of this research are: (1) it contributes to the research of regional population distribution from the perspective of sustainable development; (2) it reveals the driving force of urban population growth by identifying the influencing factors; (3) it improves the traditional population density model; (4) it develops an optimization model that helps reveal the proper population distribution for sustainable development.

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2. Lu, C., Wang, Y. W., Cui, X. Z. (2012). Urban population density and urban sustainable land use-a case study of Guangdong province. China Civil Engineering Journal, v 45, 231-235.
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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Research Background

With the establishment of a socialist market economy in the late 1970s, China entered a new era of social and economic development. In the report of the 11th Five-Year Plan (2006-2010), China's government pointed out that regional development pattern with specific features should be encouraged based on the resource and environment capacity and development potential. Proper region with huge cities should develop new urban agglomeration with reasonable population distribution, compact land-use pattern, abundant employment opportunities and high capability of factors cluster through overall planning. This is the new challenge and big breakthrough of China's regional development. Entire national economic boost based on the regional development has become a basic plan of China's social and economic development.

Regional integration could be regarded as the economic reflection to the globalization. It is a dynamic process of increasing the efficiency and profit of regional economy by rational division of labor and optimized allocation of the production factors. This pattern emphasizes the integrated advantages of the whole region. Plate development that takes population agglomeration as the major competitiveness is the first step of regional economic integration. These plates with developed traffic system and long history compose a huge urban agglomeration. Like the Pearl River Delta (PRD), Yangtze River Delta and Bohai region in China, they are the most important engines that improve the economic development of the whole country.

Population is the most active factor of production. Population movement, as a spatial distribution process of production factors, plays an important role of regional economic development. Since China's open up and reform policy, population movement has become a social phenomenon in the three decades from regulation restriction to political support. After 30-year development, the PRD, Yangtze River Delta and Bohai region become three main economic boost poles of southern and eastern China. From 1995 to 2000, migration of the three regions tripled compared with the previous five years. Population agglomeration and structural evolution of population distribution promoted regional polarization and economic development. At the same time, population distribution in regional level changed a lot and fast population agglomeration in some huge cities brought about serious resource, ecological and environmental problems, while, those cities with less population increase cannot meet the labor demand of industrial development (Lin & Ouyang, 2013). Population movement and migration that promote the transformation of population distribution has become the focus of regional development, since reasonable population distribution benefits development of entire region.

Sustainable development has become an eternal topic this world pay attention to (Mutisya & Yarime, 2014). To a developing country, especially in China, population, resources, environment and economy face severe challenge in most of the regions. Sustainable development is the problem of human survival and development in substance. Government in China just pursues economic growth and production increase but ignores the long-term profits and costs. This kind of rough economic growth pattern not only causes serious waste of resources but also environmental pollution (Liu et al., 2007). It is against to sustainability. In view of these serious problems, integration of economic and environmental policies in urban development is significant in the large population agglomeration region. Long-term strategies are supposed to be adopted to provide prior guidance and better protection for the development of metropolitan areas.

It is unchangeable that urbanization is fast in China. Although resource is limited and the labor demand of industrial development keeps increasing, the status of current regional development and the relevant environmental and ecological problems can be improved by optimizing the planning and management methods of regional population distribution. In-depth study of evolution mechanism of population distribution is the basic task of optimization. Furthermore, factors identification of urban growth can help promote entire regional development from the sustainable perspective. Therefore, in order to build up a sustainable development pattern according to the environmental capacity and resources situation, it is the time to re-plan the regional population distribution through adjusting factors of population concentration and decentralization. Even though high population density exists in big city like Beijing, Shanghai and Shenzhen for years, some effective strategies could also been used to promote the regional population distribution to a reasonable structure. Meanwhile, the air pollution and water shortage problems are serious for recent years in big cities because of the huge amount of people to a large extent. So how to make sure that not only the labor supply can fulfill the industrial demand but also total population does not exert great pressure on environment and ecological system is a crucial therapy to the symptom of the existing problems of high population density and environmental pollution in big cities by optimizing industrial distribution, transportation system, ecological protection, etc.

In order to promote urban growth and enhance the sustainability of regional development, it is urged to identify the factors of population concentration and decentralization and investigate the evolution mechanism of regional population distribution. A framework of analyzing and optimizing regional population distribution will be developed in this research. With the support of this framework, some socio-environmental problems related to population could be solved and practical methods in aid of regional planning could be formed for structural optimization of regional population distribution.

1.2 Research Aim and Objectives

Evolution mechanism of regional population distribution refers to relationship between every two factors in the structural system and the whole process of population concentration and decentralization. Specifically, from the perspective of sustainable development, planning of regional population distribution is a kind of regional planning paradigm which concerns about the sustainability of population distribution in the regional area. The purpose of this research is to deal with the concerns of regional sustainable development from the perspective of population distribution. In order to balance the regional development and enhance the sustainability of economic development, a framework about sustainable population planning is urged to create.

The overall aim of this research project is:

To develop an integrated framework for qualitatively and quantitatively investigating the spatial evolution mechanism and optimization model of regional population distribution and assisting regional development planning with a special focus on sustainability of regional development in China.

With the support of this potential framework, the spatial structure of population distribution could be optimized and some strategies could be formulated for regional sustainable development. It is an effective way to guide spatial structure of regional population distribution to evolve to a sustainable direction.

The specific objectives to be reached:

1.) To investigate the evolution mechanism of regional population distribution through qualitative and quantitative method from the perspective of sustainable development;

2.) To identify the factors of population growth for sustainable development;

3.) To set up an evolution model at regional level by identifying the determinants of density gradient;

4.) To develop an optimization model for sustainable regional population redistribution;

5.) To validate the integrated framework of evolution and optimization for sustainable development.

In order to achieve the overall aim, the five specific objectives need to be accomplished respectively. In detail, the evolution mechanism analysis of the regional population distribution is the foundation of the integrated framework, and the impact factors provides the regulations and conditions of building evolution model of regional population distribution. Based on the combination of accomplishment of the three objectives, the optimization model can be developed to improve the regional sustainability. Finally, case study will be conducted to validate this integrated framework.

1.3 Research Significance

Because of the rapid urbanization and urban sprawl, there are increasingly serious problems in terms of high population density, excessive land development and environmental pollution (Camagni, et al., 2002; Shen et al., 2009). For example, traffic congestion, reduction of arable land, air pollution, water shortage, etc. Urban population growth becomes a great challenge to economic development. In order to maintain an environment-friendly society and keep healthy development of urban population, a pattern of sustainable population distribution at regional level should be developed to benefit latter generations.

1.3.1 Practical Contributions

The 11th 5-Year Plan (2006-2010) put forward that reasonable development pattern at regional level should be conducted in five years. The 12th 5-Year Plan (2011-2015) specifically pointed out that China was supposed to optimize this regional development pattern to promote compatible development and healthy urbanization as well. Promoting the national economy through the development of regional economy has been an important and long-term planning strategy of this country. Meanwhile, the population is the primary issue that more and more people pay attention to. Correct handling the relationship among the population, resources, environment and social-economic development to a sustainable way has been advocated by the whole world. As an important element of the sustainable development, population distribution is of great significance in regional development. With the flexible economic planning strategies, regional population distribution will dramatically change. It is necessary to avoid the disadvantageous structure and guide the evolution of population distribution towards the sustainable development of society, economy and environment with sufficient consideration of the regional resources, ecological and environmental capacity. In all, analysis of intrinsic mechanism and evolution principles is a basic and significant work to get scientific and reasonable regional population distribution. Practical contributions are as follows:

1. To provide the scientific guidance for the regulation and planning of regional population. From the perspective of sustainable development, based on the analysis of influencing factors this research describes the whole evolution process of regional population distribution and develops evolution model. On the basis of the structural rationality evaluation results, this research identifies the existing problems, and then improves the planning of regional population distribution by multi-objective programming model. The aim of optimizing the regional population distribution is to guarantee the rationality of resource allocation, social stability and persistence of economic growth and to promote the coordinative development of population, society and environment under the restriction of ecological and natural resources.

2. To provide technical support on the scientific decision-making for governmental planning department. Based on measurement and calculation of the evolutionary model of regional population distribution and the sufficient recognition of intrinsic mechanism of structure revolution, this research clarifies the existing issues and obtains the optimal scheme of policy regulation according to the multi-objective programming model. Meanwhile, it provides reliable tool and method for scientifically forecasting the evolutionary direction and results of regional population distribution, which could be the guidance for planning procedure of the long-term sustainable development.

1.3.2 Academic Contributions

This research is to investigate evolution mechanism of regional population distribution and structural optimization based on the view of sustainable development. Studies in this field are still in the initial stage with problems such as lack of research method and weak theoretical foundation, which needs systematic and exhaustive analysis and discussion. This research has the following theoretical significance:

1. To establish a framework of evolution mechanism and structural optimization of regional population distribution for sustainable development. Based on the relevant definition of regional population distribution, analysis on evolutionary process, recognition of influential factors and solutions of structural optimization model, this research develops an integrated and systematic framework of evolution and optimization of regional population distribution which will support the following research.

2. To extend the qualitative and quantitative research of evolution and optimization of regional population distribution. Most previous research on evolution of population distribution was conducted just from social and economic perspective, paying less attention to resource and environment, while this research extends direction to sustainable development. Meanwhile, the optimization model this research developed for regional planning is a quantitative method to optimize regional population distribution.

This research aims to provide a framework for planning of sustainable population distribution at regional level. The framework is comprised of three major parts that are evolution mechanism, evolution model and optimization model of regional population distribution. In detail, evolution mechanism and optimization model of regional population distribution can be served as the research core of this research. With enough data resources, model validation can be conducted easily.

This framework can help to demonstrate the evolution process of regional population distribution from the sustainable perspective. It also identifies the factors of urban growth, sets up polycentric population density model and investigates which cities should be developed as development centers at regional level. The framework finally provides quantitative method to optimize the regional population distribution. It can be served as a supportive approach to sustainable regional development and planning.

1.4 Research Methodology and Process

1.4.1 Research Methodology

Using qualitative and quantitative methodologies, this framework is well-designed to achieve the five specific research objectives step by step. The entire research process is of solid logic.

1.4.1.1 Overview of Qualitative and Quantitative Methodologies

The research aim is to do qualitatively and quantitatively research of spatial evolution mechanism and develop quantitative optimization model of regional population distribution. Therefore, a mixed research methodology including both quantitative and qualitative methods is needed for this framework.

According to Cook and Reichardt (1979) (Table 1.1)' attribute summary of qualitative and quantitative method, qualitative research is a subjective, exploratory, process-oriented research methodology; meanwhile, quantitative research is objective, confirmatory, outcome-oriented measurement. Qualitative method was used in analyzing the evolution mechanism of regional population distribution and quantitative method was applied to develop mathematical models and assess the effectiveness of the proposed framework by conducting case study. Qualitative method is to answer the question of ‘what’ and quantitative method is to answer the question of ‘how’.

Table 1.1 Features of qualitative and quantitative method
(source: Cook and Reichardt, 1979)

Qualitative Method	**Quantitative Method**
Subjective	Objective
Inside perspective	Outside perspective
Process-oriented	Outcome-oriented
Holistic	Particularistic
Naturalistic and uncontrolled observation	Obtrusive and controlled measurement
concerned with understanding human behavior and viewpoint	Focus on the facts or reasons of social phenomena with objective evidence
discovery-oriented, exploratory, descriptive, and inductive	verification-oriented, confirmatory, inferential, and hypothetico-deductive

Both quantitative and qualitative methods are adopted in this research because either one of the two types of research methodologies cannot individually achieve the research aim. Qualitative research and quantitative research can be combined in different forms according to the different research objective. In qualitatively dominant research, quantitative methods are usually used to enrich and complement the qualitative descriptions with solid numeric data; in quantitatively dominant research, qualitative methods are often adopted to collect empirical data and explain the results of quantitative analysis; in equivalent/paralleled research, the two methods are equally and simultaneously employed to work out the mixed results.

In this research, evolution mechanism of regional population distribution is a qualitatively based analysis process. Regression approach is used to identify the factors of urban population growth in qualitative analysis process of evolution mechanism and quantitative method of population density function is the complement of qualitative analysis. Quantitative evaluation and multi-objective programming are the complement to facilitate and support the qualitatively oriented optimization process of regional population distribution.

1.4.1.2 Overview of Theoretical and Practical Methodologies

Research includes theoretical research and practical research based on different purpose of each research objective. Theoretical research involves the development and refinement of theories and is not concerned with practical applicability, while practical research concerns the application of theories to the analysis or solution of problems. Practical research can be divided into three types (Gay and Diehl, 1992):

1. Evaluation research, which is intended to support decision making regarding the relative worth of two or more alternative actions.

2. Research and development, which is not directed at formulating or testing theory but developing new products or processes. It involves meeting specific needs in accord with detailed specifications. Once completed, products or processes are field-tested and revised until a specified level of effectiveness is achieved.

3. Action research, which is concerned with immediate solutions to local problems. In other words, the primary goal of action research is the solution of a given problem, not a contribution to science. Since the flux of events and ideas which constitute the research situation will continue to evolve through time (i.e. 'not homogenous through time'), ending

an action research is ultimately an arbitrary act (Checkland and Holwell, 2007).

In fact, this research has the characteristics of above three categories of practical research. As a practical research, this study aims to develop a framework of evolution mechanism of regional population distribution and optimization model about planning for sustainable development. In this research, development of evolution model at regional level for sustainable development is evaluation research; Establishment of optimization model is development research; solutions to case study problems are action research.

1.4.1.3 **Research Methodology Adopted**

Based on the methodologies discussed above, to achieve the five research objectives in this project, four specific research methods are selected in the research which are document analysis, analysis and induction, modeling and case study.

Document Analysis

Document analysis is one kind of archival research, in which the data sources are various types of documentation like personal biographies, corporation/community yearbooks, and official documents which relate to some certain issues of society. Archival research is any research in which a public record is the unit of analysis (Dane, 1990). It is an important research method in social studies.

In this research, documents to be analyzed mainly referred to official documents issued in China including relevant policies on regional development planning and population distribution planning like Five-Year Plan of the entire nation and regional development planning of the PRD in Guangdong Province. Document analysis help reveal research question and find out existing problems in the planning practice. It mainly served as a qualitative research method here.

Analysis and Induction

Analysis and induction are the detailed methods of qualitative analysis which is a method of inquiry employed in many different academic disciplines, traditionally in the social sciences, but also in market research and further contexts. Qualitative researchers aim to gather an in-depth understanding of human behavior and the reasons that govern such behavior. The qualitative method investigates the why and how of decision making, not just what, where, when. Hence, smaller but focused samples are more often needed than large samples. Specifically, qualitative analysis contains the method of induction and deduction, analysis and synthesis, abstraction and generalization. In this research, analysis and induction are used to explore the relationship and interaction between the impact factors of regional population distribution and the division of evolution process of regional population distribution. It is the fundamental work before set up the integrated framework of the evolution mechanism and optimization model of regional population distribution.

Modeling

Model is quantitative description of objective phenomenon. It is used to analyze concepts, mathematical relations and logic relations of exist problem and performance system of algorithm. For managers, predictive models are more valuable, whilst auditing requires investigative modeling. The model that uses mathematical language to describe is called mathematical model. It could combine mathematical theory with practical problems. The practical problem is summarized as corresponding mathematics. Based on the mathematical thoughts, deep analysis and research is a method to describe practical problem from both the qualitative and quantitative perspective. Modeling is an effective approach to do abstract research work. Therefore, in this research, in order to give quantitative description of evolution process and quantitative approach of optimization, it is necessary to use mathematical method to do in-depth investigation of regional population distribution.

Case Study

Case study approaches facilitate in-depth investigation of particular instances of a phenomenon. It can serve for a research stage to validate proposed framework and also to show practical application. Stake (1994) categorized case study into three types with respect to study purpose:

a) Intrinsic case study: Study is undertaken because one wants better understanding of the particular case. It is not undertaken primarily because the case represents other cases or it illustrates a particular trait or problem; in other words, the case itself if of interest in all its particularity and ordinariness.

b) Instrumental case study: A particular case is examined to provide insight into an issue or refinement of theory. In this situation, the case is of secondary interest; it plays a supportive role, facilitating our understanding of something else.

c) Collective case study: A number of particular cases are studied, with less interest in one particular case, to inquire into the phenomenon, population, or general condition. It is not a collective case study but instrumental case study given several cases. Individual cases in the collection may or may not be known in advance to manifest the common characteristic.

The case study is designed at the beginning of this research and tailored within the whole research period to fit the goal of the research project. Based on the empirical analysis, strategies or policies will be recommended for reasonable region planning. It is an in-depth investigation or intensive study of a known area.

Different objective was realized by different research method which was shown in figure 1.1. A variety of research contents were conducted to reveal each research objective using research method of document analysis, analysis and induction, modeling and case study.

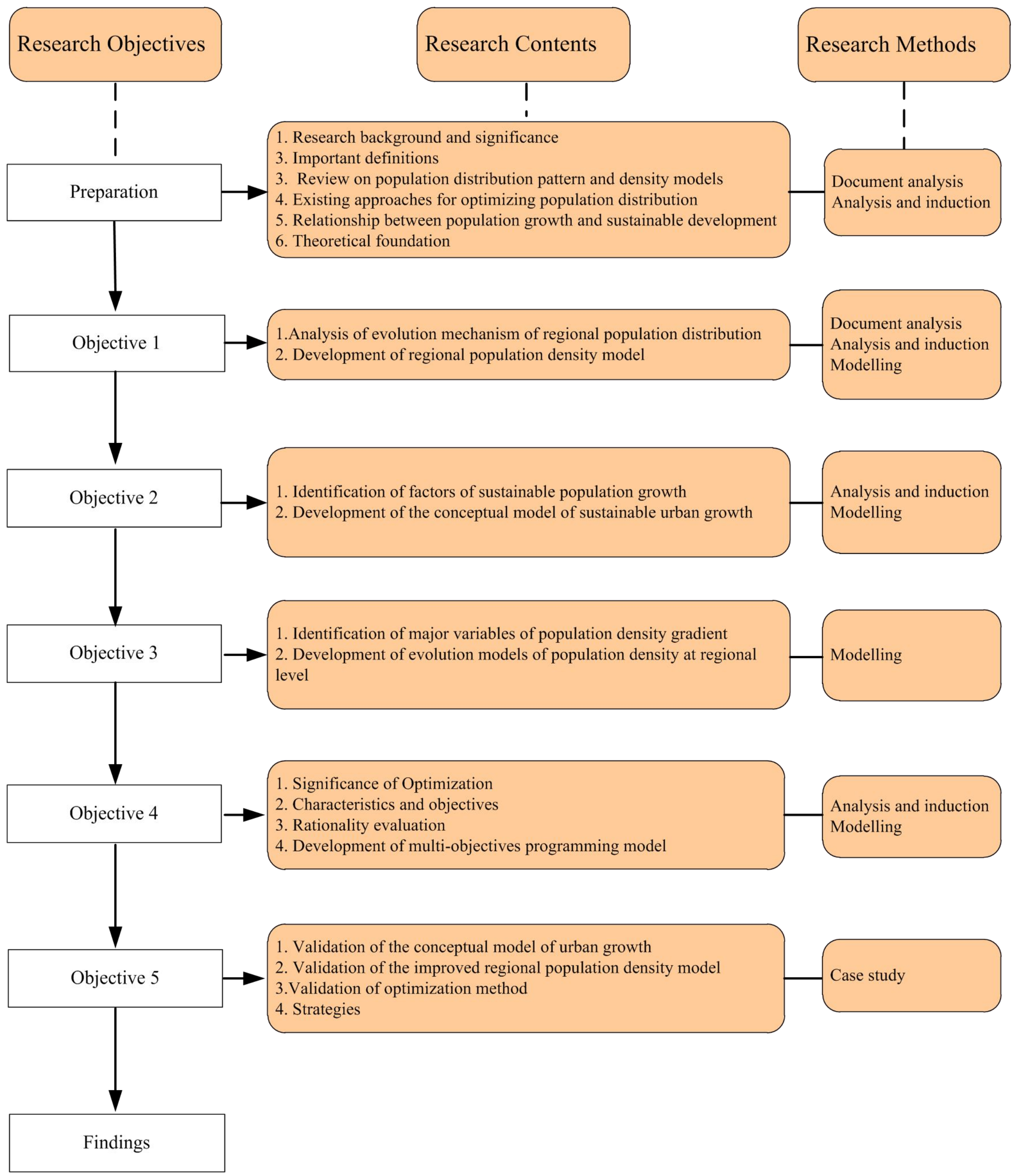

Figure 1.1 Research plan

1.4.2 Research Process

In order to identify an appropriate research problem and formulate a feasible research methodology, documents analysis and analysis and induction are conducted. A comprehensive literature review is carried out firstly to form an up-to-date understanding for spatial structure of population distribution and regional sustainable development, and then an in-depth literature review concerning the regional density functions is required to help establish a research niche and discover the research gaps. Proper theoretical foundations could help analyze the driving force of the evolution process of population distribution and identify the factors of urban growth from the perspective of sustainable development. Factors of population density gradient are explored based on the analysis and induction of literature. During the whole research process, analysis and induction of literature can be served as a powerful supporter in methods selection, data processing and model establishment.

In the stage of model validation, data from yearbooks in a certain area are used to fit the models. Results will give support to previous hypothesis. Regression analysis is employed to explore the relationship between theoretical factors and urban growth or population density gradient. It is a statistical technique for estimating the relationships among variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are held fixed. Two modules of urban growth modeling and polycentric population evolution modeling are the kernel of this framework for planning support. It can be completed based on the determinants and population-related information, regulations of regional development and standards of population planning.

To solve the practical problem, optimization model of population distribution which is the output from the two modules of evolution mechanism and evolution model in this framework need to be investigated to find the proper spatial structure. Strategies involve discovery of theory from data and results. Political implications are clear after systematic analysis and model development.

After the framework is integrated roughly, an empirical study is conducted as case study to apply and valid this proposed framework, and finally draw some conclusions regarding this research direction.

Based on the methodological strategy and specific research methods discussed above, a complete research process of this thesis is designed as Figure 1.2 shows. There are three phases in the research process: Research proposition, framework development, and framework validation. In Phase 1, research question and specific objectives are proposed based on comprehensive literature review and document analysis.

Phase 2 contains two parts of framework development: evolution and optimization. On the basis of in-depth analysis and induction of literature and document analysis, evolution mechanism of regional population distribution from the perspective of sustainable development had been investigated in both macro and micro way. Factors of urban population growth were identified in order to provide effective method to drive population agglomeration. In addition, regional population density model was improved, so that population distribution evolution process can be described quantitatively from the perspective of sustainable development. Optimization model provides quantitative approach to evaluate and optimize the existing regional population distribution. The entire framework of sustainable population distribution at regional level was developed after phase 2.

Phase 3 is the stage of research validation. A case study was conducted to valid the effectiveness of the proposed framework. The PRD region and Guangdong Province in China were selected to do evolution analysis and optimization. The details are discussed in Chapter 7.

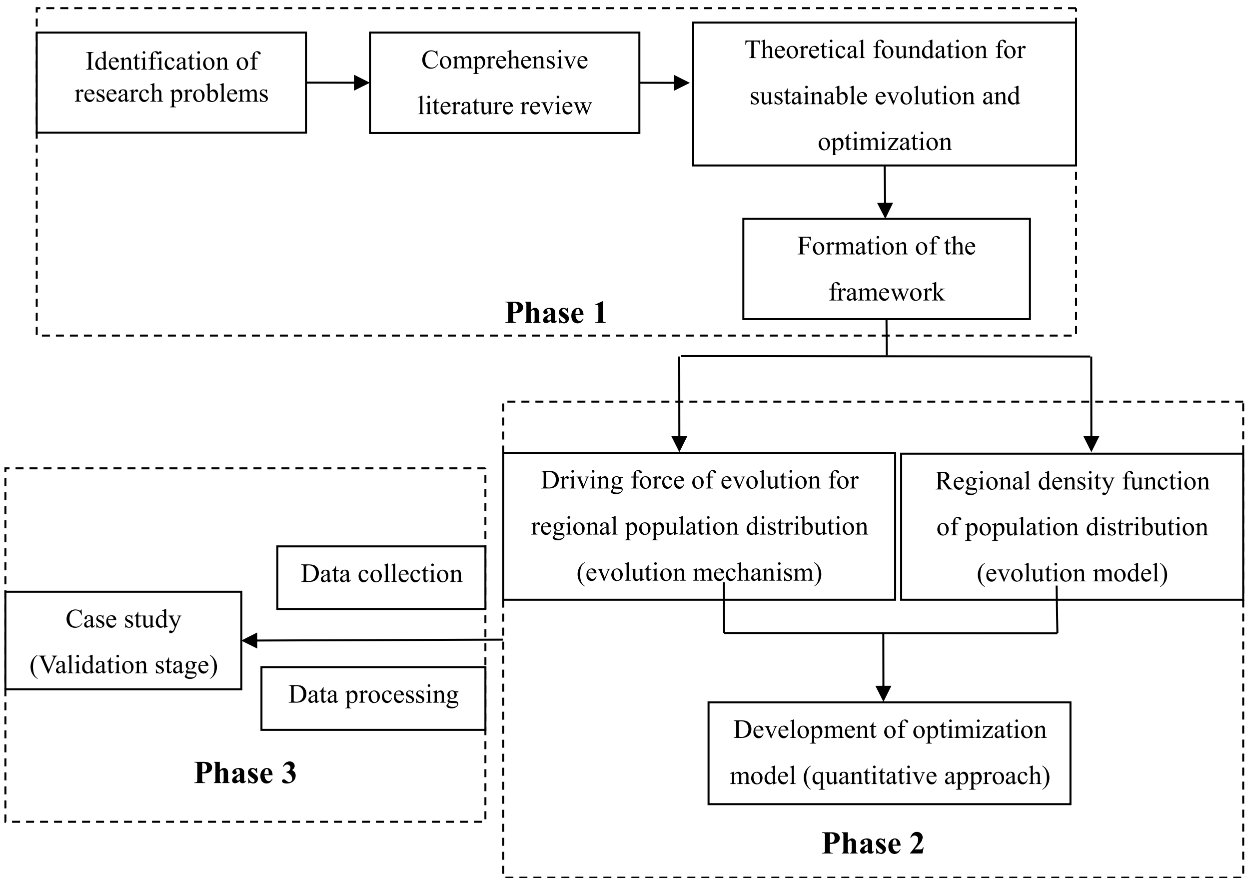

Figure 1.2 Research process

Specifically, in this framework, two major components that are evolution mechanism and optimization model development supporting sustainable regional population and economic development (Figure 1.3). In detail, evolution process and mechanism analysis provide the foundation required for the regional density model and optimization model, and mathematical support of government policy making.

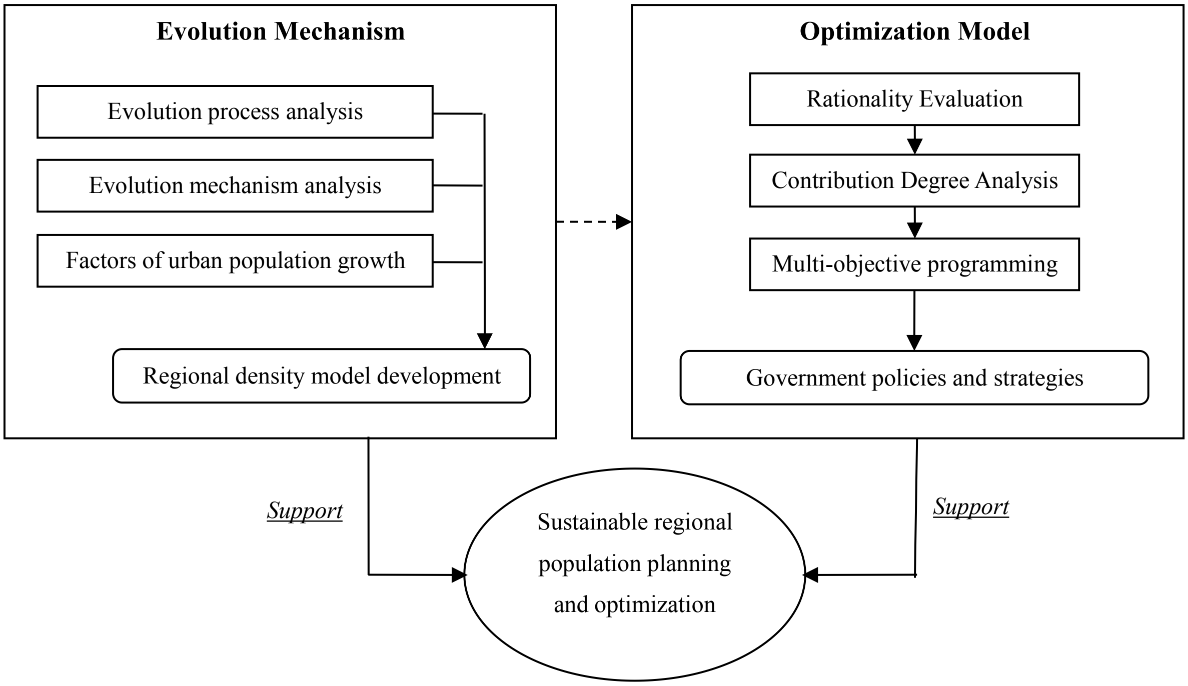

Figure 1.3 Detailed components in the framework

1.5 Structure of the Thesis

This dissertation is organized into eight chapters.

Chapter 1 introduces the research background and the research question to be investigated in this research, and addresses research aim, specific objectives, research design including methodology and thesis structure.

Chapter 2 provides a comprehensive review on the whole research picture – evolution mechanism and optimization of regional population distribution for sustainable development covering several keywords: Region', 'Spatial Distribution of Population' and 'Sustainable Development'. The review involves a mass of literature on population distribution studies from two perspectives: evolution mechanism and optimization. Based on the overview of existing literature related to the research topic, research gaps are discussed and identified.

Based on the theoretical foundation including agglomeration economics, spatial economics and the view of sustainable development, Chapter 3 proposes a conceptual framework of evolution and optimization of regional population distribution. It discusses sustainability issues from three dimensions. Factor analysis and systems analysis are conducted in detail, in order to explain the relationship and interactions from different perspective. Three modules of the framework including evolution mechanism analysis, development of evolution model and optimization model are introduced respectively.

Chapter 4 analyzes the evolution process and evolution stages of regional population distribution. The features of each evolution stage are discussed. It investigates evolution mechanism both from the macro-perspective and micro-perspective. Economic expansion demand, resource and environmental protection demand and social development demand are revealed as the driving force. It then identifies factors of urban population growth through and builds up a conceptual model.

Chapter 5 introduces spatial autocorrelation analysis method in order to reveal the center cites of one region and then identifies the factors affect the population density gradient. Based on the previous research work about density functions and the results of spatial autocorrelation analysis, it develops a regional population density model with poly-centers for sustainable development to describe the evolution process.

Chapter 6 investigates an optimization model of regional population distribution for sustainable development. It conducts rationality evaluation which is the primary work of optimization followed by contribution degree analysis that can provide technical support for policy making. Multi-objective programming approach is used to optimize the spatial structure of population distribution in order to provide quantitative methods for the government to plan for sustainable regional population development.

Chapter 7 validates the framework using a case study of China's Guangdong Province. There are three parts of the framework validation including driving force and factors of urban population growth, regional density function and optimization model. It tests the hypothesis of factors of urban population growth and population density gradient and uses multi-objective programming model to optimize population distribution in case study area.

Chapter 8 concludes the thesis and summarizes the major research findings. In this chapter, the contributions of the research are highlighted, and the limitations are explained. Finally, the recommendations for further research are also suggested.

The research logic and steps of entire thesis is show in figure 1.4.

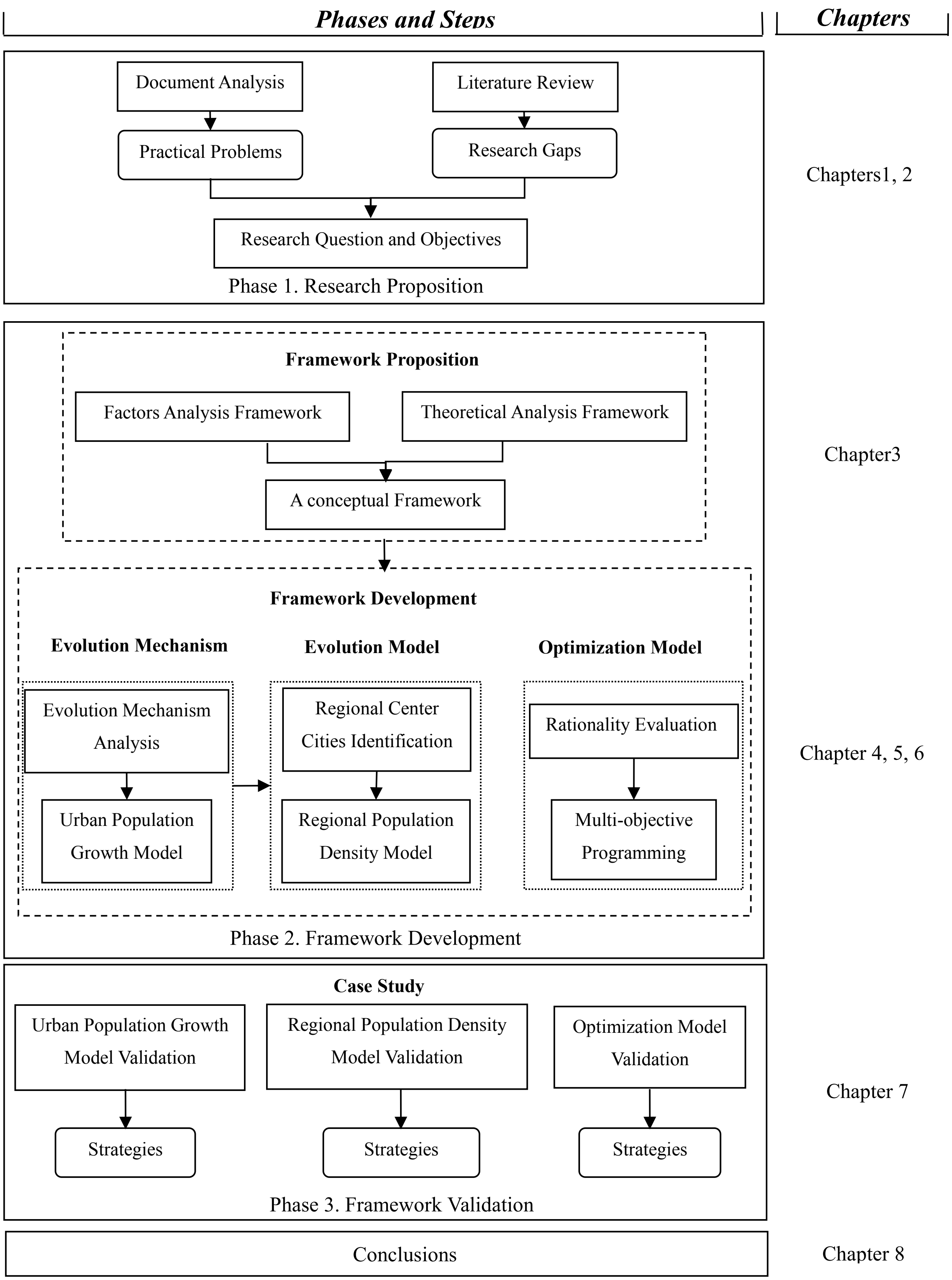

Figure 1.4 Research logic and steps

1.6 Summary of the Chapter

This chapter describes why and how to do this research. Research aim and objectives are presented, followed by specific method selection and research process. The structure of the thesis is also outlined.

Chapter 2 Literature Review

2.1 Introduction

This research plans to investigate the evolution mechanism and optimization model of regional population distribution for sustainable development. It is, therefore, necessary to have an insight into previous studies which have been conducted in the theme of evolution and optimization, such as spatial evolution patterns, models of population distribution and optimization strategies. This chapter presents a literature review of the research works so far on sustainable population distribution at regional level. For every research field, it is the first step to identify the fundamental definitions of research contents. This chapter identifies the meaning of 'Region', 'Spatial Distribution of Population' and 'Sustainable Development' followed by the previous research work of spatial evolution patterns, population density models, optimization strategies and population growth and sustainable development. Based on these, three research gaps are summarized.

2.2 Related Definitions

Regarding the regional population distribution, some key terms need to be defined. According to the related definitions given by others, the recognized definitions are summarized as follows.

2.2.1 Definition of Region

The concept of region normally used is derived from Geography. Region is most commonly found among the different sub-disciplines of geography, studied by regional geographers. Regions consist of sub-regions that contain clusters of like areas that are distinctive by their uniformity of description based on a range of statistical data, for example demographic, climatic, resources, energy, locales and so on. In Geography, regions can be broadly divided by physical characteristics (physical geography), human impact characteristics (human geography), and the interaction of Humanity and the environment (environmental geography). Take natural features like land type, climate, botany et al as standard, regions can be classified as natural regions; Take economic factors as standard, regions can be classified as economic regions; Take the culture like language and religion et al as standard, there comes different kinds of social and cultural regions (Kolb & Irving, 1972). When we integrate all these standards, we get complex regions. In China, government divides regions most according to institutional dimension like administrative division (Fernandez, 2012). A region can be sub-national, i.e., part of a country or it can be supra-national, a combination of countries. Quantitative distribution and structural distribution include attributes of education, sex ratio, age structure, etc (Meinig, 1986). Differentiation exists in inter-regions, while integrality and similarity exists in inner-regions. Most of the regional researchers, however, investigate the influence of population density distribution and growth rate.

2.2.2 Spatial Distribution of Population

The arrangement of population density in the space is the population distribution (Duncan, 1957). Spatial distribution of population provides basic information on population dynamics and evolution, and has the same meaning with spatial structure of population or geographic distribution of population (Doris, 1999). It describes geographic distribution of population in a certain region and at a certain time. It also represents the specific pattern of population movement in geographic space. Quantitative change of population always has phased features and belongs to certain geographic space. Characteristic diversity exits because of the combination of different population factors and geographic factors. Regional population development is a dynamic process. Changes of population spatial structure derive from many kinds of factors like climate, income, transportation, facility et al. Different development stage has different distribution features. Continuous spatial distribution of population at different time point constitutes the dynamic process of population distribution (White, 1986). Similarity of inner-region, differentiation of inter-region and evolution hysteresis are the features of regional population distribution. Urban economists and geologists have investigated the spatial distribution of population intensively like the work of Alonso (1964), Muth (1969) and Mills (1972).

2.2.3 Sustainable Development

In recent decades, ‘sustainable development’ has become one of the hottest topics in the world. The United Nations World Commission on Environment and Development (WCED) in its 1987 report Our Common Future defines sustainable development: ‘Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.' (Yaakup et al., 2005). Under the principles of the United Nations Charter the Millennium Declaration identified principles and treaties on sustainable development, including economic development, social development and environmental protection. As a result of the political agenda of sustainable development, the significance and approaches to sustainable development have been extensively discussed in international literature (Pearce, 1989; Morita, 1993; Reed, 1996; Murcott, 1997). Broadly defined, sustainable development is a systems approach to growth and development and to manage natural, produced, and social capital for the welfare of their own and future generations. Due to 'The Limits to Growth' (Meadows et al., 1972), i.e. the resource constraint to future development, a sustainable development mode is highlighted and under heated debates at present. Carrying capacity in an area is limited under a certain social and economic background. High population concentration in modern cities reflects urban economic prosperity, social and cultural development. On the contrary, it also brings about resources shortage, environmental pollution, traffic congestion, housing and employment problems. This phenomenon is called 'urban disease' which reduces urban function and effectiveness. In terms of urban development and management, the sustainable way of urban development has been intensively discussed by worldwide urban researchers. Mega (1994) developed the sustainability indicators for European cities based on the pressure-state-response model. Hills and Barron (1997) put forward the challenge to the sustainable development in Hong Kong mainly from the perspective of environmental issues.

2.3 Spatial Evolution Modes of Population Distribution

There are many vocabularies related to population concentration in urban area. England and many western countries use P. Geddes's 'conurbation', and in French people like to use 'urban agglomeration'. German calls it 'urban ballunsraune', but in United States and other American

States scholars prefer to use ‘metropolis’ or ‘metropolitan area’. Metropolitan area is an extended city or town area comprising the built-up area of a central place (usually a municipality) and any suburbs linked by continuous urban area. A large city and its surrounding communities constitute a metropolitan area. It is the area of a significant economic, political and cultural center for a country or region, and an important hub for regional or international connections and communications (Squires, 2002). During the past several decades, the spatial evolution modes of population distribution have been developed by urban scholars. However, there has been no unified system till now. Population movement is the standard to investigate these spatial evolution modes and the details are as followed.

2.3.1 Klaassen's (1981) Classic Spatial-Cycle Mode

Spatial-cycle mode of metropolitan area is put forward by Klaassen in 1981. From the perspective of central city, urban fringe area and dynamic change of population in metropolitan area, this mode regards that the spatial transformation of population distribution in metropolitan area as the circle process of 1) Urbanization, 2) Suburbanization, 3) Disurbanization, 4) Reurbanization, 5) Revived Centralization (Klaassen, Bourdrez & Volmuller, 1981).

This process has four stages (Figure 2.1). In the first stage of urbanization, the population of central city increases, the population of urban fringe area decreases, and the population of the whole metropolitan area increases. After that, the population of central city dramatically increases, the population of urban fringe area increases, and the population of the whole metropolitan area increases dramatically. In the second stage of suburbanization, the population of central city increases, the population of urban fringe area increases, and the population of the whole metropolitan area increases dramatically. Then, the population of central city decreases, the population of urban fringe area increases, and the population of the whole metropolitan area increases. In the third stage of disurbanization, the population of central city decreases, the population of urban fringe area increases, and the population of the whole metropolitan area decreases. Following this, the population of central city decreases, the population of urban fringe area decreases, and the population of the whole metropolitan area decreases dramatically. Finally, the population of central city increases, the population of urban fringe area decreases, and the population of the whole metropolitan area decreases. When the population increases in the whole metropolitan area, the new round of urbanization comes. In the fourth stage of urbanization, both population of central city and urban fringe area decreases, and the population of the whole metropolitan area increases. Finally, with the population increase of central city and decrease of urban fringe area, the population of the whole metropolitan area decreases. When the population increases in the whole metropolitan area, the new round of urbanization comes (Klaassen & Paelinck, 1979).

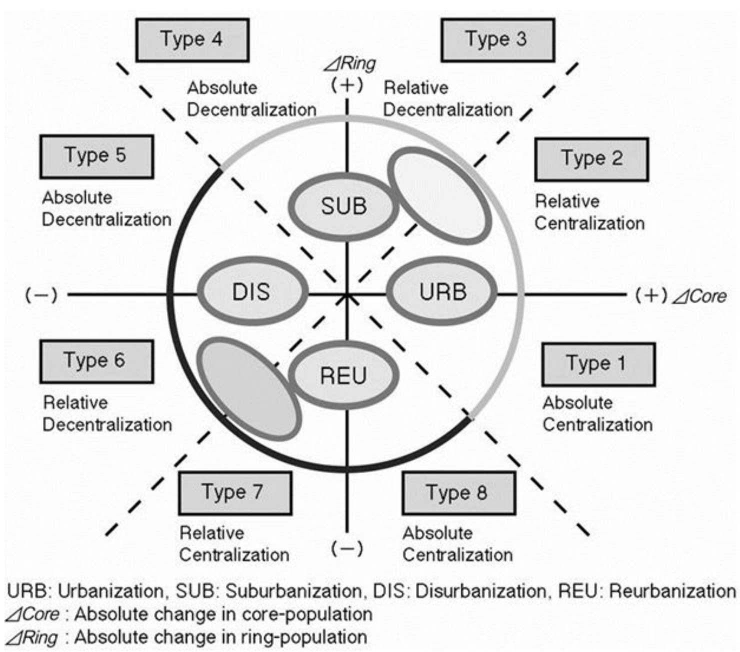

Figure 2.1 Spatial cycles within agglomerations: Klaassen's original framework
Sources: Transport and Reurbanization (1981)

2.3.2 Hall's (1984) Metropolitan Mode

This mode involves primacy city system, nonmetropolitan area, and the core and outskirts of metropolitan area. This mode can not only illustrate the inside of metropolitan area, but the dynamic change of the population in metropolitan area and other areas. This mode is also divided in the stages of urbanization, suburbanization and reurbanization (Hall, 1984).

In the first stage, the population of the central city in the primacy city agglomeration increases dramatically, the population of outskirts decreases, and the total population increases. The population of the central city in other city agglomerations increases, the population of outskirts decreases and the population of the nonmetropolitan area decreases dramatically. In the second stage, the population of the central city in the primacy city agglomeration increases dramatically, the population of outskirts increases, and the total population increases dramatically. The population of the central city in other city agglomerations increases, the population of outskirts decreases, the total population increases and the population of the nonmetropolitan area decreases dramatically. In the third stage, the population of the central city in the primacy city agglomeration increases, the population of outskirts increases dramatically, and the total population increases dramatically. The population of the central city in other city agglomerations increases dramatically, the population of outskirts increases, the total population in metropolitan areas increases and the population of the nonmetropolitan area decreases dramatically. In the fourth stage, the population of the central city in the primacy city agglomeration decreases, the population of outskirts increases and the total population increases dramatically. The population of the central city in other city agglomerations increases, the population of outskirts increases dramatically, the total population in metropolitan areas increases dramatically and the population of the nonmetropolitan area decreases. In the fifth stage, the population of the central city in the primacy city agglomeration decreases dramatically, the population of outskirts increases and the total population decreases. The population of the central city in other city agglomerations decreases, the population of outskirts increases, the total population in metropolitan areas increases and the population of the nonmetropolitan area increases.

2.3.3 Tomita's (1995) Expansion Mode

In this mode, the metropolitan area is divided into central city, inner circle area and outer circle area without consideration of the increase and decrease of population in the whole area. This mode uses the increase or decrease indicator of population ratio of the central city, inner circle area and outer circle area to determine the development stages. This mode is divided into 5 stages: centralization pattern, centralization extension pattern, prime centrifugal pattern, centrifugal pattern, and centrifugal expansion pattern. In this mode, the explanations of stages are similar to P. Hall's mode. In the centralization pattern, population ratio of central city increases, and the population ratio of inner circle area and outer circle area decreases; in the centralization extension pattern, the population ratio of central city and inner circle area increases and the population ratio of outer circle area decreases; in prime centrifugal pattern, the population ratio of central city and outer circle area decreases and the population ratio of inner circle area increases; in centrifugal pattern, the population ratio of the central city decreases and the population ratio of the inner and outer circle area increases; in centrifugal expansion pattern, the population ratio of the central city and inner circle area decreases and the population of the outer circle area increases (Tomita, 1995).

Taking Japan for example, this theoretical framework clearly describes the development stages and structural evolution process of metropolitan areas. It is helpful for scholars to make strategies for development from the perspective of population movement.

2.3.4 Tatsuhiko’ s (2001) Spatial-Cyclical Mode

This mode is developed based on Klaassen’ s mode, in which the metropolitan area is divided into the following five stages from the perspective of the size of population increase ratio in central city and the outskirts. In the stage of accelerated urbanization, the population increase ratio of the central city is greater than that of the outskirts and the ratio is in the state of increase. In the stage of decelerated urbanization, the population increase ratio of the central city is greater than that of the outskirts and the ratio is in the state of decrease. In the stage of accelerated suburbanization, the population increase ratio of the central city is less than that of the outskirts and the ratio is in the state of decrease. In the stage of decelerated suburbanization, the population increase ratio of the central city is less than that of the outskirts and the ratio is in the state of increase. In the stage of accelerated urbanization, the population increase ratio of the central city is greater than that of the outskirts and the ratio is in the state of increase (Tatsuhiko, 2003).

2.3.5 Summary

All these modes above are developed based on the description and summary of metropolitan’s history and current situation, and there are some features in common. First, all of the development patterns involve the urbanization, suburbanization and disurbanization, and use their own indicators to explain. Second, all the patterns divide the metropolitan area into at least two parts like central area and suburban.

The differences of these modes above are also obvious. Firstly, to the stages of structural evolution, Hall's and Tomita's modes only focus on the process of urbanization, suburbanization and disurbanization. However, Klaassen's and Tatsuhiko's modes extend to reurbanization. Therefore, these two modes not only give the description of current situation but also the expectation in the future. Second, Hall's mode investigates both the metropolitan city itself and other non-metropolitan area to explore the population dynamics at the regional level.

2.4 Population Density Models

As a recognized research frontier in urban studies, urban evolution has attracted most researchers' eyeballs since it comes out. The evolution model is a useful and advanced tool to tell people how is the process of urban development, and government can make effective strategies or specific control rules to balance or improve urban and regional growth in future.

There are several kinds of population density models/functions developed by urban scholars. Lots of empirical studies were conducted to find out the proper population density function that can describe the population distribution in a certain area. At different urban development stage, scholars got different kinds of density functions. The following paragraph will give detail information.

2.4.1 Population Density Function with Single Center

Urban population density function is a statistic model built up based on the average population density. It can reflect the factors for urban population density distribution using simple function expression and show the spatial distribution.

As early as 1951, this method was revealed. Research on the population density distribution has entered into a new era since the classic function was given by Clark (1951). It is a negative exponential function describing the relationship between population density and distance. The mathematical expression is as followed.

$$D(x) = D_0 \exp[-\gamma x] \tag{2-1}$$

Clark conducted statistical analysis based on the data from 20 cities. The density function describes how population density D changes with distance x from a central city regardless of direction. It is a negative exponential model. Where D is the population density at distance x from the center, D_0 is the density at distance 0 (the center of the metropolitan area, CBD), and γ is the gradient of the density function, representing the rate at which the logarithm of density decreases with distance. The value of γ is negative.

After Clark's negative exponential function, geography had come into a new era of metrology revolution. In the early stage of 1960s, Sherrett (1960) and Tanner (1961) supposed the normal model of density function. It can be expressed as follows.

$$D(r) = D_0 e^{-br^2} \tag{2-2}$$

The notation is the same as Clark's model. This Gauss function shows that urban population density far from the urban center decreases sharply compared with Clark's model.

Smeed (1961) developed the functions of negative power exponent model to describe population decrease in the area far from the Central Business District like urban fringe and hinderlands.

$$D(r) = D_0 e^{-b(\ln r)^2} \tag{2-3}$$

$$D(r) = Kr^{-a} \tag{2-4}$$

The notation is the same as Clark's model. Smeed did not explain the population density in the central area. However, this density function could not explain most of cases in the following studies. Parr (1989) pointed out the Clark's model was suitable to describe population distribution in central area, while Smeed's model was better to explain the population density in urban fringe and hinderlands.

At the end of 1960s, Newling et al (1969) used quadric curve instead of Clark's one variable and supposed quadric exponent function like

$$D(r) = D_0 e^{-br-cr^2} \tag{2-5}$$

Here *b* and *c* are all parameters. If *b* and *c* all get positive value, this function will increase then decrease. Newling's model can fit the real data better because it has polynomial in the exponent. Newling tried to integrate Clark's model and Sherratt's model. It can be easily seen that when *b* is equal to zero and *c* is more than zero, Newling's model becomes Sherratt's model; when *c* is equal to zero and *b* is less than zero, this model changes to Clark's model.

However, there is a more simple method to integrate Clark's and Sherratt's model and it is power exponent function like

$$D(r) = D_0 e^{-br^a} \tag{2-6}$$

When *a* equals to 1, this model goes back to Clark's model; when *a* equals to 2, this model is the same with Sherratt's. Integration of Clark's and Smeed's models can be unified in this following Gamma's function.

$$D(r) = Kr^{-a}e^{-br} \tag{2-7}$$

When *a* equals to 0, this function goes back to Clark's model; when *b* equals to 0, Gamma's model changes to Smeed's function. In addition, logarithmic normal distribution is also a good solution.

$$D(r) = D_0 e^{-b(\ln r)^2} \tag{2-8}$$

Mcdonald (1989) summarized the advantages and disadvantages of the population density functions employed from 1970s to the end of 1980s. Every model has its own application at different stages, but the most classic and famous one was still Clark's negative exponent function.

In China, research of density function started from late 1990s. Scholars used single center density functions to illustrate population density distribution features (Wang et al, 1999; Luo and Wei, 2006). Most of these research works were based on the data from census, and focused on finding out the optimal population density model with single center to illustrate the features and transformation process of urban spatial structure.

2.4.2 Population Density Function with Poly Centers

Accompanying with the complicate development of western cities' urbanization, density functions with poly centers developed day after day. Scholars' growing concern on urban development with several centers became a popular research direction in urban studies.

The study of density function attracted many researchers concerned with urban and regional development. After 1990s, scholars started to reformulate urban population density from the perspective of fractal and entropy theory (Batty and Kim, 1992; Chen, 2008; Chen, 2010). Batty and Longley (1994) used utility maximization model and principle of maximum entropy to prove that Clark's classic function was predominant. Griffith et al. (2007) employed a spatial regression approach which took into account the spatial autocorrelation latent in urban population density and furnished spatial autoregressive model for both monocentric and polycentric cities of 20 largest metropolitan areas in the US. In 1985, Parr (1985a) expanded the research area to the regional level and gave several kinds of improved population functions. A regional density function describes how population density changes with distance from a central city regardless of direction. Heikkila (1989) furnished polycentric density function by superposition principle under the hypothesis of substitutability. The precondition is that the different regional centers are of independence and there is no significant spatial interaction between those central cities (Heikkila, 1989). Mcdonald and Prather (1994) used polycentric model to test the influence from three employment centers to population density in Chicago. At the same year, Small and Song (1994) examined spatial patterns and changes in Los Angeles region, by estimation both monocentric and polycentric density functions for employment and population and found out polycentric models fit statistically better than monocentric models. After 1980s, polycentric models drew great attention from academia of different fields and as a result the development was promoted (Smith, 1997).

A polycentric density function can help to reveal population distribution and development trend under the influence and joint action of multi-centers. As such, a polycentric density function could be regarded as combination of several monocentric density functions in form. As pointed out by Heikkila et al. (1989), a polycentric density function could be postulated under three assumptions. If influences from different centers are perfectly substitutable, so that only the nearest center matters, then the polycentric function would be the upper envelope of functions applying to the various centers. If those influences are complementary, and access to every center is necessary, then the polycentric density might be the product of the function which has been specified by McDonald and Prather (1994). If the relationship among centers' influences is between these two extremes, then the sum of center-specific functions becomes a plausible specification. Based on this hypothesis, there came three different function patterns according to different combination mechanism. The centers in a certain area, however, in most cases are of independence and there is no significant spatial interaction. Centers are substitutable and complementary. The last assumption is the most realistic. The polycentric density function is additive (Griffith, 1981; Gordon et al, 1986). Take Clark's model as example, applying these ideas to the polycentric density functions, mathematical expression is as follows:

$$D_m(x) = \sum_{n=1}^{N} D_{0n} \exp(b_n x_{mn}) \tag{2-9}$$

Here *n* represents the number of centers, and *m* represents the number of spatial units. X_{mn} is the distance between spatial unit *m* and center *n*. D_m is the population density of the spatial unit *m*. The change of D_0 reflects the development trend of the central city's population density. The gradient *b* (absolute value) reflected the development trend of regional population density distribution. The bigger the absolute value of *b* is, the faster the population density decreases. The density gradient increase means there is concentration trend to the center, while the gradient decrease means diffusion outward. Therefore the variation of D_0 and *b* in different years shows the dynamic process of regional population concentration and diffusion. The first term on the right side of the equation is a vertical sum of the monocentric density functions, each reflecting the influence of one center on that location. Any area unit receives accumulative effects coming from different centers. Here the multiplicative density function does not have a separate intercept for each center, so there is no apparent way to take into account the variation in sizes of various centers. Furthermore, it implies that adding a new center at one side of an area lowers densities far away on the opposite side.

In China, most of the cities are still in the development stage with single center. So there was relatively less study using polycentric density model to investigate population distribution. The cases were only in Shenyang, Beijing, Shanghai and Nanjing that were metropolis. Wang and Meng (1999) took Shenyang as case and they were the first to study China's urban population distribution with polycentric density function. Feng and Zhou (2003) analyzed the population density function in Beijing from 1982-2000 on the assumption of poly centers. Wu and Ma (2007) studied the structural movement of population distribution with several centers in Shanghai from 1990 to 2000. He (2007) analyzed the population distribution movement in Nanjing from the perspective of poly-center.

2.4.3 Spatial Interpolation Model

In the mathematical field of numerical analysis, interpolation is a method of constructing new data points within the range of a discrete set of known data points. In real world, it is impossible to get exhaustive values of data at every desired point because of practical constraints. Thus, interpolation is important and fundamental to graphing, analyzing and understanding of 2D data.

Spatial interpolation is the procedure of estimating the value of properties at unsampled sites within the area covered by existing observations. In almost all cases the property must be interval or ratio scaled. Rationale behind spatial interpolation is the observation that points close together in space are more likely to have similar values than points far apart (Tobler's Law of Geography) Spatial interpolation model uses population density instead of population. The value of this method is that it puts irregular statistics into regular units, and this makes it possible to do integrated analysis of population distribution and other raster data like environmental factors. In the practical application, people can select different interpolation method and different size of unit. Interpolation can be divided into spot interpolation and area interpolation, like Thiessen polygon method and Kriging interpolation. The word 'kriging' is synonymous with 'optimal prediction' (Journel & Huijbregts, 1981). It is a method of interpolation which predicts unknown values from data observed at known locations. This method uses variogram to express the spatial variation, and it minimizes the error of predicted values which are estimated by spatial distribution of the predicted values. In 1979, Tober supposed Pycnophylatic interpolation and changed irregular area distribution to surface distribution (Tober, 1979). People can select unit size according to practical situation. In generally, the small the unit, the high accuracy the population density is. Units in urban areas are smaller than that in countryside.

Spatial interpolation is a very important feature of GIS, and it can be used to provide contours for displaying data graphically and calculate some property of the surface at a given point. Frequently is used as an aid in the spatial decision making process both in physical and human geography and in related disciplines such as mineral prospecting and hydrocarbon exploration. Many of the techniques of spatial interpolation are two- dimensional developments of the one dimensional methods originally developed for time series analysis.

2.4.4 Geographic Factors Model

Population is influenced by variable factors like natural, social and economic elements. Based on the correlation between population and geographic factors, many scholars build regression models that can reflect the real spatial distribution of population. With the rapid development of information technology like Geographic Information System and Remote Sensing Technology, it is easy to get surface data with big area and high resolution nowadays. People prefer to extract data resources of population distribution from Remote Sensing Technology. There are three methods according to selection of surface parameter and research methodology.

Spectrum estimation uses spectrum value or the results of different spectrums as independent variable to forecast spatial distribution of population density. Spectrum estimation can quickly establish the relationship between spectrum and population density, but the relationship of remote sensing spectrum and population density is lack of stability. The relationship varies a lot for different area. Although in the same region, correlation between images and population density is different at different time. Therefore it is hard to put it into practice. (Iisaka & Hegedus, 1982; Lo, 1995; Harvey, 2002)

The method of Land Use Density establishes the regression model of land use, related geographic factors and population data and then simulates regional population density. The technical procedures are as follows. 1) to classify the category of land use pattern based on the Remote Sensing Technic; 2) to establish the regression model of surface geographic factors and population density; 3) to solve model and analysis error; 4) to revise model. This method is widely used recently. In China, Tian et al (2004) used linear weighted model to simulate population density in countryside and power exponent function in urban area based on Land Use Density.

Impervious Surface Fractions (ISF) is the water proof surface and is usually in urban surface and residential buildings. It is the artificial transformation of the surface identity and people can get related information of population density distribution. Wu and Murray (2005) used ISF to classify the land cover patterns into two kinds of regions that are residential area and non-residential area. They combined Cokriging interpolation and built model according to the rate of ISF in residential area. Finally they found it was more effective to classify the land use pattern using ISF than traditional method. Traditional classification of land use pattern is discontinuous variable, but ISF is continuous variable which can build continuous function with population density (Ogrosky, 1975).

2.4.5 Summary

In general, there are four kinds of classic population density models which are widely used to describe the structural evolution process of urban development. Population density function with single center or poly centers is theoretical model. Using density functions, scholars could reveal the features of urban population distribution. Different cities at different development stage had different population density function which is a good method to explain the population and employment distribution in modern cities accurately. Spatial interpolation model and geographic factors model are the method using computer technic or other parameters to calculate population distribution. They are the application-oriented models.

2.5 Planning and Optimization of Population Distribution

Population distribution planning is the term used for an administrative and statutory activity which seeks to order and regulate the population density in an efficient and appropriate way, thus preventing excessive population concentration. Public policy objectives concerning urban population distribution are usually achieved through residential land use regulation. Various land use regulatory mechanisms are used to control the distribution of urban residential population. Control is necessary in order to maintain the efficient use of public facilities, to minimize the impact of environmental pollution, or to limit traffic congestion. Planning over population distribution also can be exerted indirectly through the selection of employment sites. If population policy goals can be expressed as a target for each zone of the urban area, then it is possible to determine that spatial distribution of employment for which population distribution comes as close as possible to these targets (Gerald, 1977).

In China, Dai (1996) put forward the theory using urban space displacement to improve the unreasonableness of population distribution. Urban space displacement could relieve the overpopulation issue and foster the reasonable redistribution of population. Urban space displacement is to update and recombine the key elements of urban space, optimize population spatial distribution and improve space utilization efficiency. Urban space displacement can redistribute industrial population and reduce the population density of central city. In the late 1990s, Wu (2010) and Ma (2009) suggested to establish a spatial structural system of multi-circle area, multi-axis, multi-pole and multi-core to optimize population distribution. In the early 1920s, Yang (2008) introduced the fractal theory and the central place theory to the study on urban spatial structure. He supposed self-organization evolution of the city system has the capacity of strengthening central area (Chen, 2008; Chen, 2010). The comprehensive urban system would be built up with central city, transportation system and economy corridor (Zhou & Zhang, 2003).

2.6 Population Growth and Sustainable Development

In recent 50 years, with the rapid economic development and population growth, problem between regional population and ecological environment has become a hot spot that the worldwide countries pay attention to. Rapid urban development accompanies with the serious contradiction of population, economy, environment and resource. Water abuse that exerts great pressure on ecological system causes river pollution and some rivers have already been dried up. Ecological system cannot effectively circulation. Some Africa countries confronted with draught and water shortage are influenced by population growth, urbanization and industrialization, and freshwater resource is in precarious situation (Olanike, 2003). Industralization and urbanization are the main reasons of metals soil pollution (Govil and Krishna, 2001). Most of Asia countries are experiencing rapid urbanization, and the huge number of rural to urban migration exerts grave pressure on inner city transportation system. Air and water pollution caused by industrial production is becoming more and serious (Sarath and Gregory, 2003). In recent 30 years, population and economic growth of Southeast Asia countries brings about massive energy consumption and shortage of environmental protection. Government cannot guarantee safe resource development (Shankar, 2005). People living in the city are not only the consumers of harmful air and water but also the producers of these pollutions. For the long run, this unsustainable development pattern is harmful to the entire economy and society. Therefore, urbanization and resource and environmental protection should be conducted together in order to achieve sustainable development. Coordination of population and economic, social and environmental factors has become an important aim of economic and social development in one country.

Carrying capacity of urban is limited. Under the circumstance of not destroying ecological system and rational resource utilization, the maximum population size that the urban environment can sustain indefinitely, given the food, habitat, water and other necessities available is the carrying capacity (Hui, 2006). Rapid urbanization brings about economic prosperity, while at the same time, problems of resources shortage, environmental disruption, intensive housing, traffic jam, employment difficulties will reduce entire urban function and even endanger long-term interests of human survival and development (Jiang, 2012). In recent years, some scholars in China proposed coordination development model of population and economy carrying capacity, population and resource and environmental carrying capacity from the perspective of sustainable development. Based on the sustainable thinking, Zhao et al (2003) did comprehensive research on resource, ecological, environmental, social and economic development system, put forward a comprehensive analysis model of population carrying capacity and built up the evaluation index system. They used case study to establish evaluation system of population development and carrying capacity analysis from the perspective of sustainable development. Wei (2008) investigated factors of economy, society, resource, environment and ecology from the perspective of development and their combined effect. Comprehensive evaluation model of population carrying capacity and regional dynamic population carrying capacity model were built up. Quantitative research about coordination development of population, resource, environment and social-economic system was developed by China' scholars who believed systematic coordination is the precondition of one country's stable and sustainable development. Population is one of the subsystems. This method is based on the system engineering theory which needs subsystems coordinate and cooperate with each other (Zhang et al, 2006).

2.7 Research Gaps

Evolution and optimization of regional population distribution affect sustainability of social and economic development. Research findings about this theme provide theoretical foundation and methodology to the research work of evolution mechanism and structural optimization of regional population distribution from the perspective of sustainable development. Because of the increasing demand of high living standard, sustainable development will still serve for a guideline for the relevant studies in the near future. Research works in related fields provide theoretical foundation and methods to investigate regional population distribution for sustainable development. Specifically, optimization draws a great attention in theoretical research with environmental concern in the coming years. In terms of evolution model research, density functions with single-center or poly-centers are still a powerful and useful tool for explaining the evolution process of urban population distribution. Besides, sustainability has drawn great attention of the entire society especially to the regional planning. By putting sustainable development theory into practice of regional population distribution planning, policies can be generated according to the framework, so as to assist urban planners to optimize the regional population distribution in the practical process of making strategies.

Based on the in-depth literature review and investigation on regional population distribution, however, there are mainly three research gaps in this area to be filled by this research project:

1) Lack of population density model innovation taking environmental factors into account

   Compared with the rough development pattern in the early stage of economic growth, sustainable thinking would be a significant objective in the coming years. Density function is a good tool to quantitatively describe the evolution process of urban population distribution, however, few scholars combine the population agglomeration and diffusion together with sustainable development, and most of them investigate only from the economic and social perspective. In view of the awareness of sustainable development, it is essential for the government to pay great attention to environmental protection when making policies to promote regional growth. Therefore, population density model taking environmental factors into account should be established in order to provide technical support to government and planners.

2) Lack of research of the evolution and optimization of population distribution at regional level

   The investigation about population distribution was initially developed at urban level, and then with the rapid development of urbanization, research scope was extended to metropolitan area with several population or employment centers. However, few studies were from the regional perspective. Specially, in the developing countries, it is a basic policy to develop regional plates as growth poles. Proper region with huge center cities is encouraged since it can help promote national economic development. Therefore, it is essential to do in-depth research at regional level. Regional plates with reasonable population distribution will accelerate regional economic growth.

3) Lack of a practical and sustainable optimization model to formulate policy control for regional planning

   Most of the previous research works about evaluation and optimization of regional population distribution focused on the qualitative explanation and description, while few of them were about the quantitative approach for policy control. Although there are some strategies to optimize population distribution at regional level, most of them are qualitative analysis and lack practical method. The policy control method is based on the results of optimization model. In fact, the formulation of this model is a process of conversion from qualitative description to quantitative description.

2.8 Summary of the Chapter

This chapter presents a picture of previous work related to regional population distribution including spatial evolution pattern of population distribution, density functions, optimization strategies, sustainable development. Sustainability has drawn great attention to citizens, government and scholars, so the new research trend about regional population planning is about sustainability. Finally, three research gaps in the scope of the existing literature on evolution and optimization of population distribution are indicated.

Chapter 3 A Conceptual Framework

3.1 Introduction

In this chapter, a proposed framework which can be treated as an analysis tool, in essence, and integrated approach to describe the evolution process and optimization is to enrich the research of regional population distribution. This framework is established from the perspective of sustainable development and it is systematically comprised of two main parts, the evolution mechanism and optimization model, which enable planners and organizers easily understand the rationale and encourages them to follow the framework as a guidance for sustainable planning of regional population distribution in developing countries.

Sustainable considerations in population distribution evolution and optimization at regional level are discussed in order to ensure the framework to work for regional sustainable development. Based on theoretical foundations and existing research on sustainable development and regional science, factors of sustainable evolution which is the important step before developing the framework are identified in this chapter. Factors analysis and system analysis can help understand interrelations of factors from the perspective of system engineering. With sustainable thinking, an evolution mechanism and optimization model framework will be built up then.

3.2 Theoretical Foundation

Population agglomeration and diffusion is the natural evolution process of regional development. In regional scale, it depends on the urbanization of center cities. At the beginning of development, center cities attract population from periphery to concentrate. While with the rapid expansion of urban size, suburbanization makes population move to hinterland and this process is called decentralization development. Centripetal force and centrifugal force were used to explore the theory that promotes the population and economic agglomeration and diffusion (Krugman & Elizondo, 1996). The dominant force of concentration is usually defined as centripetal force which leads to agglomeration economics or polarization of resources, land, labor and capital. In contrast, the decentralization forces which force the city to break apart mainly depend on better transportation and environment (Tabuchi, 1998). In fact, it is impossible to have urban evolution under either regime of extreme centralization or extreme decentralization and of course any mix in between (Baldwin & Martin, 2004). The following theories are the foundations to investigate the evolution and optimization of regional population distribution from the perspective of sustainability.

3.2.1 Agglomeration Economics

Regional development theories reveal the unbalanced growth and stresses that regional growth is an imbalanced evolutionary process. Regional economic growth always depends on one or several pole centers that promote the economic growth of neighboring cities (Viladecans-Marsal, 2004). This is called polarization which is the main idea of agglomeration economics. Polarization explains regional economic imbalance which is beneficial for the economic growth of entire region. Only a small number of very large cities could be the pole centers in a certain area, region or even country. Polarization is the explanation of regional economic imbalance. Industrial agglomeration at a certain location brings about concentrations of high employment and growth in center cities (De et al., 2012). Several industrial clusters may form growth poles that have a spillover effects on neighboring cities and lead to regional or national growth. Unbalanced development is significant and effective to stimulate economic growth especially for developing countries and it would take less time to develop regional economy. Thus the imbalanced expansion is good for the economic growth of entire region.

Population agglomeration is derived from economic agglomeration (Thomas, 2012). People move according to the economic factors like job opportunity, therefore sustainable growth of urban economies must take sufficient advantage of the agglomeration effect. People choose their residential and working location according to the employment opportunities. Rural to urban migration are attracted towards the economic level in cities (Jurajda & Terrell, 2009).

3.2.2 Spatial Economics

Spatial economics emphasizes the effect of transport costs on industrial locations in an imperfectly competitive market. In an economic geography model, it is essential to take into account the centripetal force and centrifugal force that promotes population and economic agglomeration (Krugman & Elizondo, 1996; Audirac, 2005; Cook et al. 2007). Centripetal force is derived from economies of scale, which also means industrial agglomeration, while centrifugal force is derived from transport costs, the effects of congestion, and the effects of pollution (Benguigui et al. 2001). 'Spatial economics' is developed by Japanese scholar Fujita (2002) and he uses an empirical study to analyze the relationship between industrial clusters and transport infrastructure based on the New Economic Geography research framework. Externalities and transport costs are essential interactions between different economic spaces (Armin, 1999). The falling cost of intra-urban transport following the construction of freeways significantly promotes the increase of urban area, decease of residential densities and allows metropolitan areas to develop in all directions at suburban location. Urban development requires adequate and effective transportation. Public transportation system from satellite cities to center cities makes population easy to diffuse (Mason & Nigmatullina, 2011). Cities with perfect transportation infrastructure facilities can expand spatial service scale. It is also attractive for the firms to select location of economic activities for the second time. Being a centrifugal force, transportation promotes suburbanization. Favorable traffic conditions promote regional industrial agglomeration. Cities that have an effective transportation infrastructure can expand spatially and are therefore attractive to firms as places to locate.

3.2.3 The View of Sustainable Development

Sustainable development is the organizing principle for sustaining finite resources necessary to provide for the needs of future generations of life. It is a process that envisions a desirable future state for human societies in which living conditions and resource-use continue to meet human needs without undermining the 'integrity, stability and beauty' of natural biotic systems (Hasna, 2007). Sustainable population development is a big issue to existing and future community environment. In global area, rapid urbanization and suburbanization have not only consumed and over developed the land resources, but also have resulted in the increased energy demands and environmental pollution (Yong et al., 2012).With the rapid increase of city populations, urban construction has accelerated and urban land-use has changed substantially in developing countries (Feng & Chen, 2010; Liang, 2011; Lu et al., 2011). Increasing use of land for industrial purposes has led to a decrease of arable land and wetland of entire regions. In addition, amenities would drive urban growth in the future because citizens in postindustrial cities increasingly select their own urban location according to the quality of life. Amenity consideration is a sustainable development pattern, and in the long run, regional planning should strive for sustainable economic growth, especially in developing countries with rapid urbanization (Terry et al., 2002). The major problems underlying regional development are extensive resource exploration, fast population growth, excessive land development, irrational industrial structure, and environmental pollution. Environmental problems lead affluent central city residents to migrate to the suburbs, which might cause a further deterioration of the quality of life of central areas, inducing further out-migration (Mieszkowski & mills, 1993). Sustainability has to be integrated into planning (Edward, 2001).

3.3 Three Dimensions of Sustainable Development

Sustainable development is based on the coordination of economy, society and environment. This development pattern emphasize that economic growth, resource and environmental protection and social equity should conduct together in order to achieve the comprehensive development of human beings. Sustainable development is related to environment protection but not the same. Social and economic development should be premised on environment protection. Combined with the environmental protection and social development, sustainable development can be treated as the guidance of national economic development on the strategic level. Three dimensions of sustainable development are identified in the following part.

3.3.1 Sustainability and Environmental Protection

'Environment' is one element of the three dimensions (Environment, Economy, and society) of sustainability as more and more people highlighted concerns about environmental protection after 1990s, such as air and water quality, chemical hazards, energy use, environmental justice, urban population and land growth, and global climate change. Carrying capacity of resources and environment should be consisted with social and economic development. In respect of urban development, environmental principles associated with sustainability include compact urban form, land use protection, transit-oriented development, close-loop resource cycles, environmental justice, pollution prevention, and the restoration of streams, coastlines, habitat, visual corridors, and other ecosystem components within cities (Wheeler, 2004). It is a constrained development pattern whose consumption is less than the carrying capacity of entire earth. The core content of sustainability at ecological level is environmental protection that supports normal social and economic development.

3.3.2 Sustainability and Economic Growth

It could be a sustainable development pattern if the economic system is market-oriented economy which can regulate market demand and supply, allocate all kinds of resources and provide incentives for entrepreneurship and innovation. However, along with the rapid development of market economy, some drawbacks appear, such as difficulties in valuation of public goods and examination of externalities which are highly related to social and environmental impacts of production and consumption, inflation, concentration of wealth and monopoly. Continuous expansion of resource consumption conflicts with the environmental notion of "limit" (Wheeler, 2004). Carrying capacity of resource and environment limits excessive economic growth. Sustainable development engages the economic growth which takes protection of resource and environment as precondition and puts a high value on qualitative growth but not quantitative growth. Production and consumption patterns with low input, low consumption and low pollution are the main characteristics of sustainable economic development. Economic growth is as important as resource and environmental protection.

3.3.3 Sustainability and Social Equity

Social equity is the farthest goal of sustainable development but it is the least well-developed compared with environment and economics (Wheeler, 2004). Unlike concerns laid on environmental or economic development, equity goals are often neglected and poorly understood by planners. Under this circumstance, equity concerns usually take a back seat in planning and administrative processes. Gap between the rich and poor leads imbalance in resource occupancy which is the root of social disparities. A prominent characteristic of inequity in poor communities is the shortage of social service, such as special service of vulnerable group, reparation of ageing infrastructure, affordable housing, and effective public transportation system. Another inequity during planning process is the ignorance of public participation at public decision-making stage. Policies should pay more attention to advance equity objectives in order to promote social equity. As the final objective of sustainable development, social equity will improve human being's living quality and build a sound social environment with equity, stability, security and good welfare system.

In consequence, sustainability of economy is foundation, sustainability of environment is precondition and sustainability of society is the final goal in the process of sustainable development.

3.4 How the Framework Works and Its Validation

After a comprehensive literature review, research gaps come out and research question is proposed. More important phases are to analyze research question and solve problems. Illustration of theoretical foundations and three dimensions of sustainable development is the precondition to propose a conceptual framework of evolution and optimization for regional population distribution. The framework development includes three parts. Firstly, evolution stages are divided based on the experience of representative metropolitan in global area. Driving force and evolution mechanism are deeply investigated from the perspective of sustainable development. Factors of urban population growth are also discussed in the end of this part. Secondly, evolution model is developed in order to provide a quantitative description of the evolution process of regional population distribution. Thirdly, rationality evaluation is the first step of structural optimization. Based on the results of rationality evaluation and contribution degree, multi-objective programming model is proposed. Using quantitative method to optimize regional population distribution is an effective way to promote the structural evolution to a sustainable direction.

If it is treated as a systematic problem, this research process can also be divided into three parts of system analysis, system evolution and system optimization which compose the framework this research proposed. System analysis including important definitions, theoretical foundations and conceptual framework establishment is the basic work before intensive investigation of system evolution and optimization. As the system analysis part, identification of important definition is the first step before in-deep investigation and framework establishment, and literature review helps to find out the research gap and objectives. With the theoretical foundations of agglomeration economics, spatial economics and the view of sustainable development, a conceptual framework is proposed. Evolution mechanism which is a clear explanation of system operation is included in the system evolution part. An improved population density model is developed in order to give quantitative method to describe evolution process. Framework would be completed with system optimization part. The follow-up rationality evaluation and multi-objective programming are conducted after system analysis and system evolution.

After the framework establishment, although it is built up based on the theory of agglomeration economics, spatial economics and the view of sustainable development, further testing is still essential in the validation process before it can be finalized. In evolution part and optimization part, some quantitative models are developed based on the existing theories. To some extent, these models are just hypothesis and surely need case study to valid. In the case study section, data in yearbook and documents are collected to verify and evaluate the proposed framework. Strategies could be put forward according to the results of case study validation. This proposed framework can, on the one hand, give government and planners both theoretical and technical support in making regional population strategies by providing qualitative and quantitative investigation; on the other hand, assist people in understanding population planning from the perspective of sustainable development.

3.5 Factors and Systems Analysis of the Framework

3.5.1 Factors Analysis

Structure of regional population distribution which is the long time accumulation of social and economic development means people's relative location and combining form in a certain area and it shows the scale and style of spatial population concentration. Population agglomeration and diffusion at regional level constitute the dynamic evolution process of regional population distribution (Henderson & Venables, 2009). Economic, social and environmental factors work together to drive evolution. Dynamic population agglomeration and diffusion at different time point constitutes different structure. Internal mechanism makes economic, social, environmental factors and population distribution as a complicated system, and dependence and restriction among them are the guarantee of continuation of sustainable development in the whole region.

In developing countries, rural-to-urban migration derives from industrialization that improves the capability of labor absorption in a given city (Kentor, 1981). Employment opportunities deriving from economic agglomeration promote population agglomeration and urbanization. Except for the economy growth and industrialization, policy factors have been found to be an important determinant in China's urbanization development (Zhu, Tian, & Zhou, 2007). An empirical study in the US showed that suburbanization mainly depended on social and economic variables such as income increase, transport cost decrease, fiscal differences, and development policies (Mieskowski & Mills, 1993; Palumbo, Sacks, & Wasylenko, 1990; Tan, Li, Lu, Luo, Kong, & Ma, 2008). However, scholars in China have pointed out that, because of its unique development pattern of a socialist market economy, suburbanization in China mainly derives from economic structural adjustment, land replacement and inner city renewal and reconstruction, investment in infrastructure, and land use policy (Zhou & Meng, 1998; Feng & Zhou, 2003; Zhou & Ma, 2000). Not only in developed countries but also in developing countries, environmental efficiency is the foundation of economic efficiency and social efficiency. A negative correlation has been found between environmental efficiency and population density which indicates that increased pollution cost deriving from high population density results in a decrease in environmental efficiency (Yong, Yu, & Hans, 2012). Based on the forgoing, it can be concluded that population agglomeration and diffusion (urbanization and suburbanization) is influenced by the economy, society, and the environment.

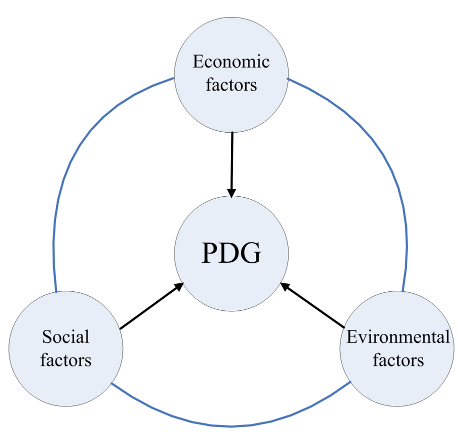

Figure 3.1 Factors of the framework

Figure 3.1 shows the interaction among different factors and population distribution structure which are connected by material flow, energy flow and information flow. It emphasizes the significance and importance of society, economy and environment, because it is established based on the view of sustainable development. Each factor has lots of elements that compose a complicated system. With the rapid development of industrialization and urbanization, economic, social and environmental factors have a profound effect on population distribution in a certain area. Adequate job opportunity, perfect social system and sound living environment are the main factors to promote population agglomeration. Government and planners could optimize population distribution structure through plan for all these factors in order to maintain sustainable development of the whole system.

3.5.2 Systems Analysis

In the process of regional population distribution evolution, different factor has different systematic aim. The most valuable aim of economic factor is to maximize profit and increase output. Environmental factor is to reduce pollution and ecological footprint, and social factor is to supply comprehensive infrastructure and promote living quality. There may be some contradiction when the factor conducts separately. For instance, nowadays, human beings damage environment and ecological resources in order to maximize manufacturers' profit. However, at the same time, excessive environmental protection will surely hinder rapid social and economic development. Therefore, when the three factors improve the structure of regional population distribution together, interactions of factors must be harmonious and uniform if the entire systematic goal is sustainable development. Based on the coordination of the three factors, the system can evolve to a sustainable direction. Agglomeration and diffusion at spatial dimension constitutes spatial structure of population distribution and at time dimension it becomes the evolution process of population distribution.

Based on the analysis above, it is concluded that evolution process of population distribution can be treated as a system operation, and sustainable evolution actually is a multi-objective coordination question. Therefore, the theoretical analysis framework is established from the perspective of systems engineering (Figure 3.2).

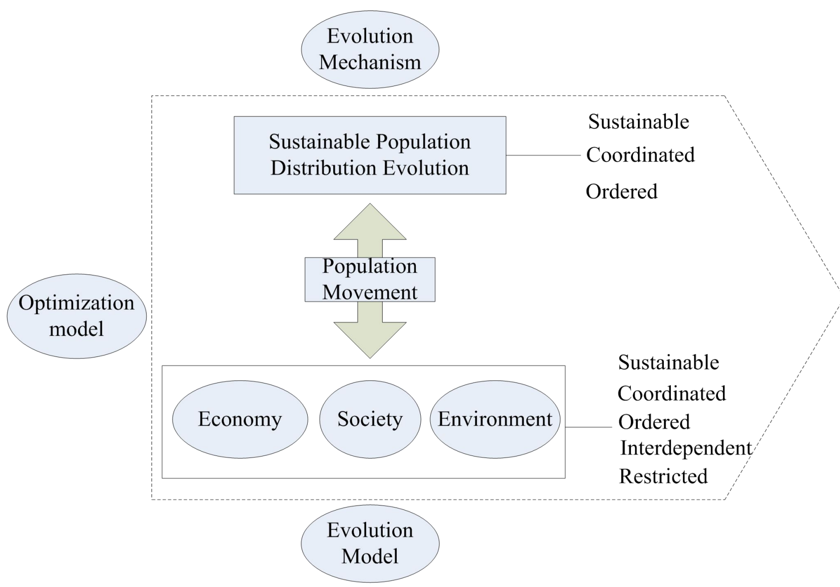

Figure 3.2 Process of systems analysis

As the aim of entire system, sustainable evolution of regional population distribution which depends on the coordination of the three factors is in the center of theoretical analysis framework and it is connected with the three factors by population movement. On one aspect, population movement in the region changes the structure of population distribution, and on the other hand, it is influenced by the comprehensive action of economic, social and environmental development. Coordination and restriction of three factors makes one region develop rapidly under the circumstance of adequate carrying capacity of resource and environment. Evolution mechanism could explain the reason why people move from one place to another place and it also could give a detailed description about the relationship between population movement and the three factors. As a quantitative tool, evolution model is proposed to describe population distribution in one region which is influenced by economy, society and environment. Rationality evaluation of population distribution structure at a certain time point is the preliminary work of structural optimization. In a word, the theoretical analysis framework which has three main research parts of evolution mechanism, evolution model and optimization model shows the entire system operation process from the perspective of system engineering.

3.6 Structure of the Conceptual Framework

This section aims to build a conceptual framework to analyze evolution mechanism and optimize spatial structure of regional population distribution from the perspective of sustainable development. An overview description of the research framework is provided in this part and the detail information will be investigated comprehensively in Chapter 4, 5, 6 separately. The conceptual framework includes three modules that are evolution mechanism, evolution model and optimization model is shown in Figure 3.3.

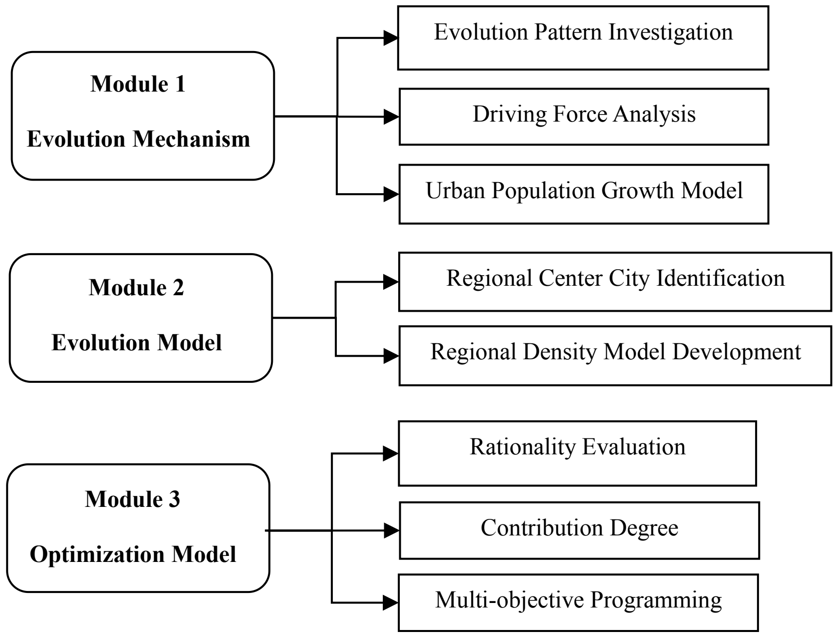

Figure 3.3 Conceptual framework

Evolution Mechanism Analysis

Research about evolution mechanism including evolution process analysis, driving force, evolution mechanism analysis both from micro-perspective and macro-perspective and a conceptual model of urban population growth from the perspective of sustainable development are conducted in this module. Evolution patterns of population distribution in metropolitan area which provide good lessons to analysis sustainable evolution process of regional population distribution are reviewed firstly. Then this module identifies driving force of sustainable evolution of regional population distribution and analyzes sustainable evolution mechanism from both macro and micro aspect. Factors of urban population growth which are the driving force of population distribution evolution are discussed, and based on this and the classic theories, this module finally develops a conceptual model to identify the factors of sustainable urban population growth.

Evolution Model Establishment

After comprehensive and systematic research of regional population distribution evolution, mathematical model is needed to provide quantitative support of previous analysis results. Population density model is a good tool to describe evolution law of population distribution and explain the relationship between population density at a certain spatial point and the distance from the point to the CBD which is usually Euclidean distance. Clark's negative exponential function is the representative model and it is widely used or improved. Transformation of Clark's negative exponential function by scholars fulfilled research contents. However, in the real world, the distance is the road travelling distance that could exactly describe the real situation between two special points but not Euclidean distance. The new model amends this definition of the distance. It will be better if the core cities in one region are identified by technical support but not government's opinion. Core cities should be confirmed before density functions examination. This module introduces a quantitative method of spatial autocorrelation to reveal the real regional center cities which maybe not the same with human's cognition. Factors of population density gradient that affected the ability of population agglomeration and diffusion were identified by Alperovich (1982a) initially. Taking sustainability into account, this model proposes environmental and ecological factors that affect population agglomeration and diffusion. it is an improvement compared with Alperovich (1982b)'s social and economic factors. Based on the above, a new improved regional population density model with multi-centers is developed.

Optimization Model Development

Thorough evolution mechanism analysis both from quantitative and qualitative perspective is the precondition of optimization model investigation. After problem analysis, effective method should be developed to solve problem. Optimization can be treated as the approach to the problem. Before mathematical model, overall optimization objectives are discussed firstly. Then, rationality evaluation method model as the previous work of optimization is proposed to examine whether the current situation of regional population distribution is sustainable or not. In order to provide technical support for the follow-up optimization strategies, contribution degree of three factors is analyzed. Taking economic, social, resource and environmental factors into account, optimization should be investigated from the perspective of sustainable development. Multi-objective programming model of regional population distribution is built up that could provide quantitative approach for the government to plan for sustainable region development.

This is a conceptual framework and also an overview introduction of the integrated framework of evolution and optimization for sustainable development. Details and content will be deeply investigated in Chapter 4, 5 and 6.

3.7 Summary of the Chapter

This chapter presents the theoretical foundations of framework development. Three dimensions of sustainability are also discussed in this part. It proposes the framework of evolution and optimization for regional population distribution from the perspective of sustainable development. Three modules, evolution mechanism analysis, establishment of population density model and optimization model are introduced respectively in short. Basically, the framework can serve as a guidance of regional population regulation and planning, and it also provides a theoretical and technique support for decision making of governmental planners.

Chapter 4 Evolution Mechanism

4.1 Introduction

Combined with the experience of representative metropolitan areas worldwide, this chapter analyzes the evolution process of regional population distribution and after identifying the driving force of structural evolution, evolution mechanism is investigated both from the macro-perspective and micro-perspective. Finally, factors of urban population growth are proposed by a conceptual model for sustainable development.

4.2 Evolution Process Analysis

In a certain area, living and manufacturing make people concentrate at different location with different size. According to their different property and spatial form, the cluster can be divided into city, town and village which actually are the resident clusters with different capacity and different population size. These clusters at spatial points compose regional population distribution structure. The external form of the spatial structure is agglomeration and diffusion which alternate over period in the evolution process of regional population distribution (Xu, 2010).

Evolution pattern of population distribution in metropolitan area provides good lessons to analysis sustainable evolution process of regional population distribution. Qualitative analysis and quantitative description are proposed to explain evolution process.

4.2.1 Evolution of Population Distribution in Representative Metropolitan Area

Several representative metropolitan cities in developed countries such as New York in North America, Tokyo in Asia and London in Europe are the economic development areas with powerful and comprehensive capacity. Metropolitan cities and areas are not only the economic poles of one country but also the population centers. In essence, metropolitan cities or areas are the spatial composition of population clusters with complicated structure. Small metropolitan city has the same meaning of big city, while, metropolitan area can be treated as an economic region. Spatial structure of the entire system reflects interactions among cities in the region. Therefore, from this point, although regional population distribution is not the same with population distribution of metropolitan city or area, it also could be taken as a good reference if we investigate the evolution process of regional population spatial structure. As representative experience of population distribution evolution for Metropolitan areas, New York, Tokyo and London's development process of the spatial pattern of population is discussed in the following part.

4.2.1.1 Experience of New York Metropolitan Area

The New York metropolitan area covers 33 thousand kilometers and includes the most populous city in the United States (New York City); counties comprising Long Island and the Mid-and Lower Hudson Valley in the state of New York; the six largest cities in New Jersey (Newark, Jersey City, Paterson, Elizabeth, Trenton, and Edison) and their vicinities; six of the seven largest cities in Connecticut (Bridgeport, New Haven, Stamford, Waterbury, Norwalk and Danbury) and their vicinities; and five counties in Northeast Pennsylvania. It is composed of core area, inner circle, outer circle and outskirt. This metropolitan area experienced urbanization process from 1870 to 1950. During 1870 to 1920, with the rapid development of industrialization of United States, regional city system emerged and urban population increased. People moved from rural to urban area and lots of people concentrated in downtown. In the next thirty years, urban industrialization of United States came to post-industrial era. Most of urban area had been built up, and population in city center kept increasing. However, when the city center could not hold population growth and economic growth, city boundary extended to suburban and the area extended to a metropolitan city gradually. After 1950s, suburbanization gradually showed up. Information technique, transportation and telecommunications the third industrial evolution brought us upgraded industrial structure, and this promoted the spatial sprawl of metropolitan area. At this moment, hub functions and morphology evolution of metropolitan area became mature. After 1970s, inner city diseases such as serious environmental pollution and traffic jam drove population to diffuse to the suburban area. Downtown developed slowly and this kind of recession resulted in counter-urbanization. New York metropolitan area went to the stage of re-urbanization from late 1990s to nowadays. It is a cyclic process that population of inner city or the city centers began to re-concentrate. At the end of 2010, the population of New York City has increased to 8,175,000. Figure 4.1 shows the evolution process of population distribution of New York Metropolitan area in the recent 160 years.

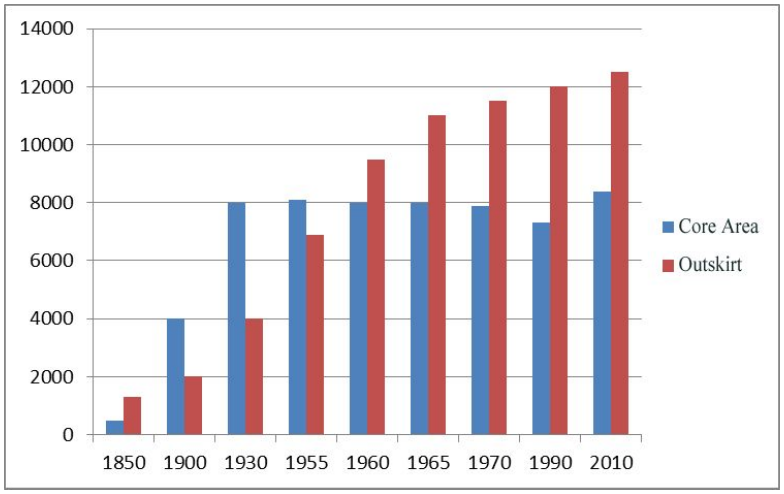

Figure 4.1 Evoluation of population distribution in Newyork Metropolitan

4.2.1.2 Experience of Tokyo Metropolitan Area

Tokyo Metropolitan area takes Tokyo as center and covers a 50 kilometers circle including Tokyo, Kanagawa Prefecture, Saitama Prefecture and Chiba prefecture. In 1950s after World War Two, population, industries and other related functions concentrated to Tokyo, Osaka and Nagoya rapidly which were the three big cities at Pacific Coast. After 1985, however, the structural pattern changed from three metropolitan cities to one pole metropolitan area taking Tokyo as development center. Suburbanization emerged in metropolitan area in 1955. Population in Tokyo center reduced and population of 23 districts of Tokyo and three prefectures including Kanagawa, Saitama and Chiba increased. After that, 23 districts of Tokyo decreased from 8.9 million in 1965 to 7.96 million in 1995. However, total population of Tokyo metropolitan area kept increasing and this phenomenon was absolutely dispersive suburbanization. The development of Tokyo metropolitan area did not undergo de-urbanization and re-urbanization, but went into new urbanization in 1995. Population of 23 districts of Tokyo came into next round population growth. Population in city center and inner city increased significantly. Population in suburb was basically flat, while population in the outskirt decreased significantly. In 2010 population in Tokyo rose to 8.95 million, and the population of the entire metropolitan area increased from 13.05 million in 1950 to 36.7 million in 2010 with around two times growth. Taking an overview of development history of Tokyo metropolitan area, population kept increasing. Figure 4.2 shows the whole evolution process of population distribution of Tokyo metropolitan area in the recent 160 years.

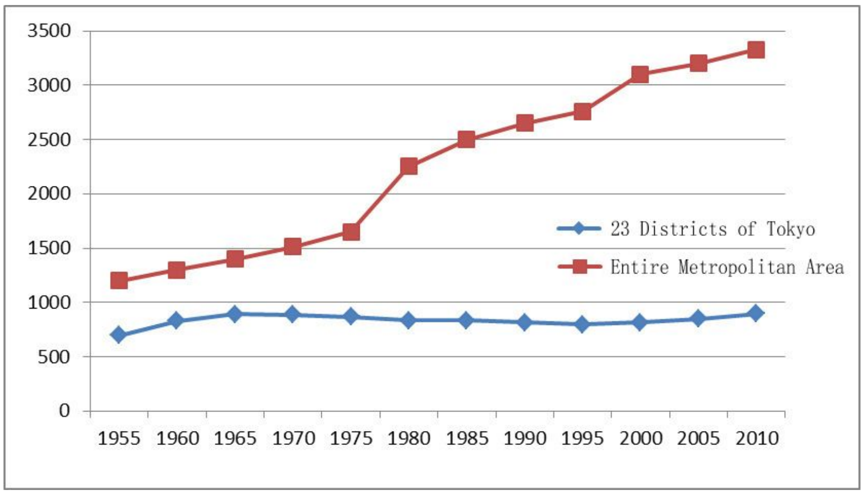

Figure 4.2 Evoluation of population distribution in Tokyo Metropolitan

4.2.1.3 Experience of London Metropolitan Area

London metropolitan area that is composed of London built-up area and suburban of London covers an area of 1.58 thousand square kilometers. From the second industrialization to the end of the nineteenth century, continuous urbanization of Great London promoted population growth of built-up area. During the following 40 years from 1901 to 1941, suburbanization emerged. Population in London built-up area reduced from 4.54 million to 4.01 million which was a significant drop of 11 percent. The population of suburban rapidly increased from 2.05 million to 4.72 million that was a two times growth in 40 years. At the same time, entire London metropolitan area’s population got an increase from 6.54 million to 8.73 million. In the next 40 years, the population of built-up area, suburban and the entire metropolitan area began to decrease and this was a de-urbanization process. The number reached the bottom in 1990 and then metropolitan area went into the re-urbanization process. After 1990s, built-up area, suburban and the entire metropolitan area's population kept increasing, and the number in built-up area was a 50 percent increase compared with that of 1991. Suburban and metropolitan area also got an increase like this. Figure 4.3 was the process of population distribution evolution in London metropolitan area in recent 160 years.

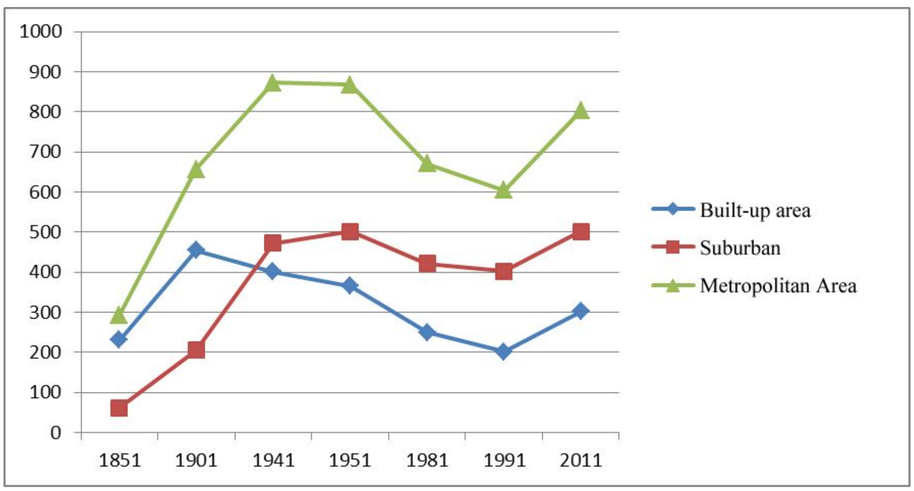

Figure 4.3 Evoluation of population distribution in London Metropolitan

Based on the population evolution features of the three representative metropolitan area and spatial evolution pattern of metropolitan cities discussed in Chapter one, we can conclude that it is a self-organization evolution process including urbanization, suburbanization, de-urbanization and re-urbanization.

4.2.2 Evolution Stages of Regional Population Distribution

Generally, different population distribution shows the change of population density in different area. According to the theory of new economic geography, population agglomeration and diffusion is the natural evolutionary process of regional development, which on a regional scale depends on the urbanization of center cities. At the beginning of the development process, the attraction of center cities causes a movement of population from suburb to center. However, the expansion of urban size results in suburbanization, where there is a movement of population to the hinterland in a process known as decentralization development. Centripetal force and centrifugal force are used to explore the theory that promotes the population and economic agglomeration and diffusion (Krugman & Elizondo, 1996). The dominant force of concentration is usually defined as centripetal force, which derives from agglomeration economics or polarization of resources, land, labor and capital. In contrast, the decentralization forces which force the city to break apart mainly depend on better transportation and environment (Tabuchi, 1998). In fact, it is impossible to have urban evolution under either regime of extreme centralization or extreme decentralization; or any mix in between (Baldwin & Martin, 2004). Population agglomeration and diffusion is a dynamic process that shows the features of centripetal and centrifugal force. Centripetal force normally includes economical level, resource and environment, social welfare and infrastructure. Centrifugal force is usually transportation. Population distribution evolution undergoes process of agglomeration and diffusion.

Based on the previous research work, evolution stages of urban or regional population distribution could be divided into urbanization, suburbanization, de-urbanization and re-urbanization. It was the conclusion of population data analysis, and it was also a summary of population movement in representative region of developed countries. Different researcher used different method to study the evolution pattern from different perspective, and metropolitan area was divided into central and periphery part. Klaassen and Paelinck (1979) extended study to re-urbanization compared with other researchers. This theoretical extension is not only the summary of history and current situation, and it also was a prediction of future. All these research constituted a comprehensive theoretical system of metropolitan development pattern.

When the urbanization level is high, inner land scarcity, population growth and economic expansion would promote urban land boundary to sprawl outward (Li et al., 2003; Yu & Ng, 2007). Some of citizens have to choose to settle in suburb in this process. Suburbanization accompanies urban and regional development. In the mid to late stage, de-urbanization emerges. Long term population agglomeration and high density brings about traffic jam, crime and environmental pollution of city center. Therefore, less people would choose to settle in downtown, and more and more citizens move out to suburban or even villages. Evolution pattern changes from urbanization to suburbanization or de-urbanization. This is because with the rapid development of telecommunication and transportation, people change their preference of residential environment. De-urbanization is not the opposite direction of suburbanization. If we enlarge the research scope, this kind of de-urbanization could be regarded as the population movement from big city to satellite cities. Therefore, to some extent, de-urbanization is the longitudinal extension of suburbanization. Suburbanization and de-urbanization resulte in the population distribution structure with multi centers. It would be a sustainable pattern if evolution of population distribution minimizes environmental pollution and resource waste that urbanization brings. Active immigration by sound living environment and attractive employment opportunities in satellite cities is better than passive emigration by inner pollution and traffic jam in center cities. To some extent, it is an artificial process to build up a satellite city and its urbanization.

The first stage shows the status of population increase in the city with one single center, holding population in peripheral cities constant or reduced, and the entire region population increases.

The second stage shows people continue to concentrate to city center, and peripheral cities' population starts to increase. The entire region's population increases significantly. Center city's population is stable in the third stage, and another one or two center cities emerge with a new round population agglomeration. Peripheral cities' and the original center city's population diffuse, but the population in the entire region is still in the rising trend. In 2014, China's government proposed a concept of New Urbanization which did not emphasize the core effect of the big city or urban, but the important role of small and medium-sized city. It means China is experiencing the third evolution stage. In the fourth stage, population in center cities diffuse and population in peripheral cities increase. The entire region's population keeps stable. When regional economic development goes a high level, both the center and peripheral cities' population tend to be stable. People can move freely in the region according to their preference. Agglomeration and diffusion exist at the same time. This kind of high level development pattern is usually called network system pattern with multi centers structure. It emphasizes division and cooperation between center cities and peripheral cities. Center cities' development level is the base of peripheral cities' development. Peripheral city's development is an active process. This kind of population distribution evolution pattern including urbanization, suburbanization, de-urbanization and re-urbanization is an evolution pattern good for sustainable region development. Center cities and peripheral cities develop together harmoniously with free population movement in metropolitan area. Employment opportunity is enough in this region. Government should make effective policies to make this regional development sustainable.

With the periodical regional development, the evolution speed of regional population distribution becomes faster and faster. Five development stages can be divided into accumulation stage, development stage, rapid development stage, stable development stage and stable stage (Figure

4.4). Before industrial revolution, regional economy mainly depends on agriculture. It is a low level development pattern with singer center and long duration. When the industrial revolution starts, manufactures always choose factory location that is the population agglomeration center with good economic foundation and transportation system. In this stage, population and economy concentrated rapidly to the center which is the growth pole of the whole region. In the third stage, several another center cities with different population size emerge. The new center cities are influenced by the original center city and if they arrive at the level of original center city, they will get into their own rapid development stage. These cities show their own agglomeration effect when they have enough power. After these two development stages, it comes to the stable stage, population in original center city continue to diffuse and the population size reduces. New center cities' population size however begins to increase because they have arrived at their own development stage. In the final stage, boundary of center cities and peripheral cities become less and less obvious. Differentiation of cities reduces, and people can move freely in the region according to their own preference. Regional economic development is in an advanced stage.

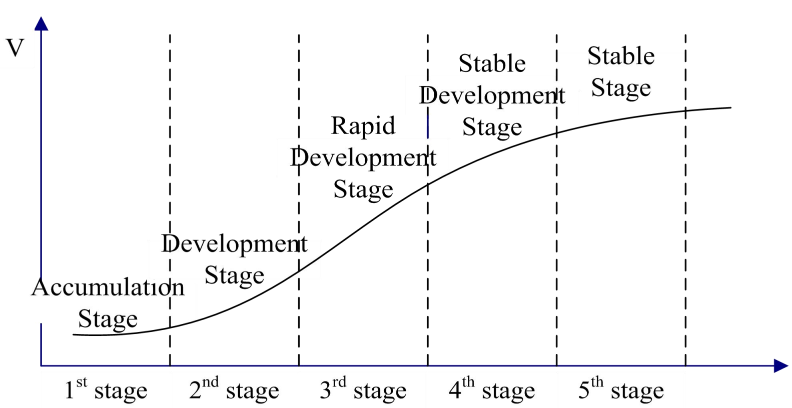

Figure 4.4 Evolution speed of different stages

Evolution stages and their features are shown in Table 4.1.

Table 4.1 Evolution stages and features

stage	Agglomeration and diffusion	Spatial form	Evolution features
1st stage	Population in center city increase Population in peripheral cities reduce	Single center	Center city is independent Infrastructure is at low level Peripheral cities' development capacities are poor
2nd stage	Population in center city increase significantly Population in periphery cities increase	Single center	Connection of center city and peripheral cities increases Infrastructure is gradually improved Peripheral cities' development capacities increase
3rd stage	population in the original center city is stable population in new center cities increase population in periphery cities reduce	Poly centers	New center cities with agglomeration capacity emerge Inter-city traffic trunk is built up Agglomeration and diffusion capacity of peripheral cities shows up
4th stage	Population in center cities reduce Population in peripheral cities increase	Poly centers	Division in center cities is prominent Inter-city traffic system starts to be built Functions of peripheral cities are strengthened, and capacity of agglomeration and diffusion increases
5th stage	People in center cities and peripheral cities can move freely	Poly centers and Network	Functions in center cities are diverse Regional transportation system is perfect Functions of peripheral cities are perfect

Different evolution stage has different features. In the accumulation stage, regional population distribution evolution is the simple single center agglomeration pattern. Industrialization is not obvious. Concentration in center city and diffusion in peripheral cities show the change of population distribution structure. Center city is relative independent but the population size is small. Its spatial occupation is small and economic development is slow. Both the infrastructure and development capacity of peripheral cities are poor.

In the development stage, regional pole structure forms. Industrialization which helps to perfect infrastructure and transportation develops rapidly in the center city. People concentrate in the pole city that is also the development pole of the entire region. Influenced by the center city, population in the peripheral cities grows slowly. The spatial structure of regional population distribution is single center agglomeration. Infrastructure of inner city and transportation of inter-city are improved. Peripheral cities' development capacity is strengthened.

In the rapid development stage, there are some other center cities with diffusion capacity. Population in the original center city tends to be stable or reduce. People concentrate in the new center cities and the peripheral cities' population begins to diffuse. The spatial structure of regional population distribution is poly center agglomeration. Inter-city traffic trunk is built up and agglomeration and diffusion capacity of peripheral cities shows up.

In the stable development stage, regional economic development has arrived at a high level and population in center cities diffuses but the population gravitates towards peripheral cities. The spatial structure of regional population distribution is stable poly-center pattern. Division in center cities is pronounced. Inter-city traffic system starts to build. Functions of peripheral cities are strengthened, and capacity of agglomeration and diffusion increases.

Stable stage is the high level development stage. Population agglomerates and diffuses freely among center cities and peripheral cities. Function diversity of center cities makes them full of agglomeration and diffusion capacity. Peripheral cities' functions are perfect. High income, telecommunication cover, transportation system combine all the cities. People can move freely in the region. This kind of multi-center network spatial pattern is the aim of sustainable development.

4.3 Evolution Mechanism Analysis

4.3.1 Driving Force

The formation and evolution of the regional population distribution depends on the driving force. Various demands under the effect of nonlinear coupling promote the evolution of regional population distribution to the next development stage. Overall, the main driving force derives from economic demand, social demand and resource and environmental demand.

4.3.1.1 Economic Expansion Demand

From the macro-perspective, with the rapid development of regional center cities, economic expansion demand drives the evolution of regional population distribution. Production specialization could reduce the unit cost because of scale economics effect. Various economic factors concentrate in the center cities in order to achieve scale economics and economic expansion. Being the basic factor of economic development, labor force continues to concentrate to the center cities. Population agglomeration and diffusion at node cities shows the structural change of population distribution (Tan, 2012). In some developing countries like China, after its reform and open up policy, population growth and GDP increase show that imbalanced economic development is the main factor that influences structural change of population distribution (Sun et al., 2012). Structural change, however, affects economic growth in turn. On one aspect, with the population growth in developed region, adequate labor input and technique innovation enlarge the productivity scale. On the other hand, population growth accelerates the infrastructure construction, and improvement of infrastructure, education and medical treatment will promote urbanization of center cities. Spatial concentration of population distribution accelerates regional economic development (Sun et al., 2009). Therefore, economic demand is a macro factor of population distribution change. On the contrary, structural change of population distribution will affect economic development. In addition, policies about economic layout will change population movement direction, like special economic zones which could attract lots of population immigration.

From the micro-perspective, according to development economics, population movement is the reflection of pursue for high income and good job opportunity (Klink, 2008). Krugman's New Economic Geography shows that centripetal force and centrifugal force together exist in economic development center. Centripetal force is the power attracting people to concentrate and under the circumstance of high salary and high profit, labor and enterprises concentrate to the regional center; centrifugal force is the power promoting population to move out, and none-economic factors like resource and environmental problems may drive regional center to break up. Generally, population movement in the region depends on the economic level especially in the economic developed area. People immigrate to the area with sound economic environment in order to pursue higher income, and this process promotes the change of regional population distribution.

4.3.1.2 Resource and Environmental Protection Demand

From the macro-perspective, resource and environmental protection demand drives structural evolution of population distribution. Urbanization which brings living convenience and comfort fulfills human beings' development demand. However, if the population density is too high in industrial developed area, environment will be polluted seriously. Most of these cases are in developed countries. Developing countries abuse natural resources and destroy ecological environment in order to obtain economic growth rapidly. This behavior results in the decrease of absolute area of natural ecological environment which actually is tend to be extinct and disappear. Environmental deterioration seriously affects the urban residents' living and producing. Air pollutants, solid waste and waste water from industrial enterprises and automobile exhaust emissions make urban environmental pollution more serious than none industrial area. Living pollutant in the area with high population density aggravates the pollution of the entire region (Zhao, 2010). For instance, too dense population and industrial distribution brings haze fogs which are bad for people's health in the city of Beijing and Shijiazhuang in China. In some fragile ecological zone region, if the population spatial pattern is too dense, it is easy to damage the ecological environment. Because population carrying capacity of these natural fragile ecological areas is very low and too sensitive to the changes in population density (Cai et al, 2012). If population is beyond the carrying capacity, it will not only bring about ecological crisis but also make economic poverty. Therefore, in order to achieve the objective of rational utilization of resources and ecological pressure dispersion, it is essential for population distribution evolution to a balanced direction.

From the micro-perspective, when regional economy develops to a certain level, negative factors like resource shortage, ecological damage, and environmental deterioration caused by excessive population agglomeration and excessive urbanization of the center cities all promote people to move out. In addition, transportation and housing pressure also will make the situation worse. In the post-industrialization era, when the economic difference like income and job opportunities among cities decreases, people prefer to resident in the area with high living standard. For instance in developed countries, after the golden age of industrialization, social distribution tends to be equitable and people prefer to live in sound environment with perfect transportation system. Many middle class families move out from city center and settle in the suburb or the satellite cities in order to enjoy the good natural environment. Therefore, environmental and resource factors become more and more important to the citizens with the equilibrium of economic development and social distribution.

4.3.1.3 Social Development Demand

From the macro-perspective, social development demand promotes the structural evolution of regional population distribution. With the rapid development of regional economy, single center pattern was broken up, and poly-center pattern emerged. The entire region has come into a new era of diversified development. Population agglomeration and difference of development pattern are the advantages of a country or region’s cultural diversification. Social development needs diversified economy and culture, and this kind of demand promotes regional population distribution structure to change from mono-center to poly-center and finally to the network development pattern. After entering into the development pattern of poly-centers, the change of transportation method and perfection of transportation system will all influence spatial distribution of regional population. From just walking to convenient transportation means and application like high-speed railway and airplane in modern society, regional population size and distribution changed a lot correspondingly. This kind of social development demand like infrastructure construction of transportation and telecommunication is promoting the spatial transformation of regional population distribution.

From the micro-perspective, in order to enjoy more social resource, people like to move from the area with relatively poor social resources to the area with rich resources. It is the feature of mono-center agglomeration stage of regional population distribution. When it comes into the high level evolution stage, it is easy for people to move from one place to another if the social resource is enough, infrastructure is perfect and transportation is convenient. This kind of movement not only promotes the cultural exchange between two areas, but also brings more diversified development of the social structure.

4.3.2 Evolution Mechanism

4.3.2.1 Macro-evolution Mechanism Analysis

From the macro-perspective, driving factors of evolution of regional population distribution are closely tied to each other. As the urban development foundation, natural system, resource and ecological environment restrict social and economic development. In order to pursue agglomeration economic effect, spatial concentration of enterprises helps to obtain shared location to save cost. Scale economy makes the production factors concentrate, and at the same time, labors continue moving to the economic center. As the endogenous variable and tensile force, economic effect is the main factor of enlargement for regional population and area size. When urban size arrives at a certain degree, its diffusion effect will radiate surrounding areas and boost their economic growth. This is a good development pattern for the entire region. However, with the long time and excessive development, inner city will also bring a lot of serious problems like resource shortage, traffic jam and environmental destroy which could promote urban population to diffuse to the suburb. Through technology transfer, product output and industrial space recombination, center cities make a part of production factors and economic activities diffuse outward. This diffusion guarantees the appropriateness of economic scale and optimization of entire region's industrial structure. At this moment, a complete set of perfect infrastructure and transportation system and other social resources should be built up to help spatial structure of regional population transform. Normally speaking, spatial diffusion and extension of population in center city is always along the construction of transportation corridors or circles and in this process, center city drives the economic growth of hinterland. People concentrate in the hinterland and form a subprime economic center. Therefore, population diffusion drives agglomeration in new space and the population cluster comes to be a satellite city. With population agglomeration and diffusion, economic, social and environmental factor work together to promote the evolution of regional population distribution. Evolution process is shown in figure 4.5.

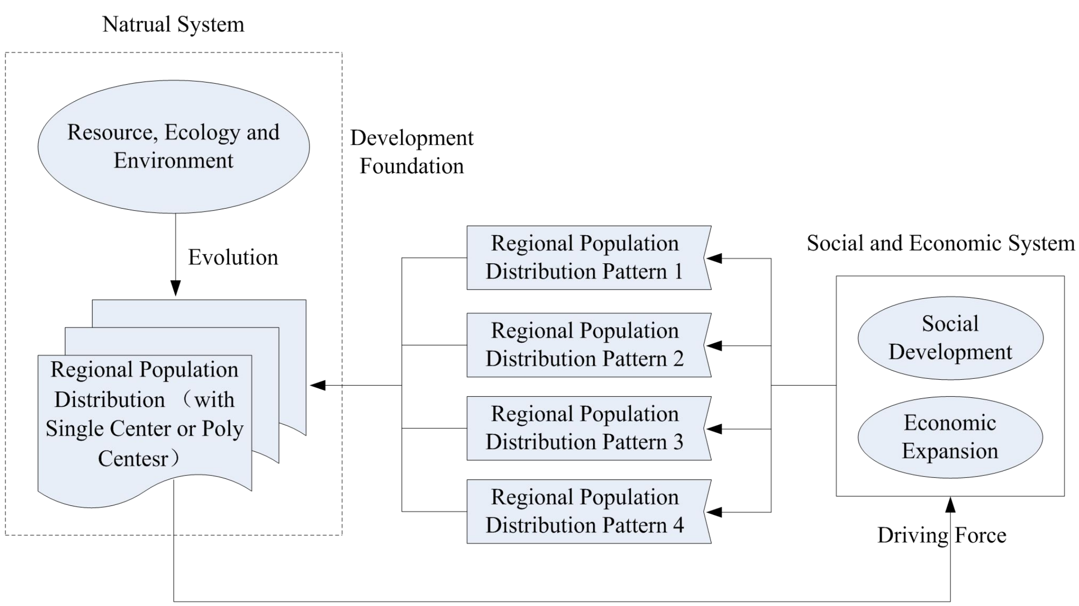

Figure 4.5 Macro-evolution mechanism

4.3.2.2 Micro-evolution Mechanism Analysis

Under the influence of economy, society and resource and environment, regional population distribution evolves continually to the direction which is good for human beings' development. Figure 4.6 shows the evolution mechanism from micro-perspective.

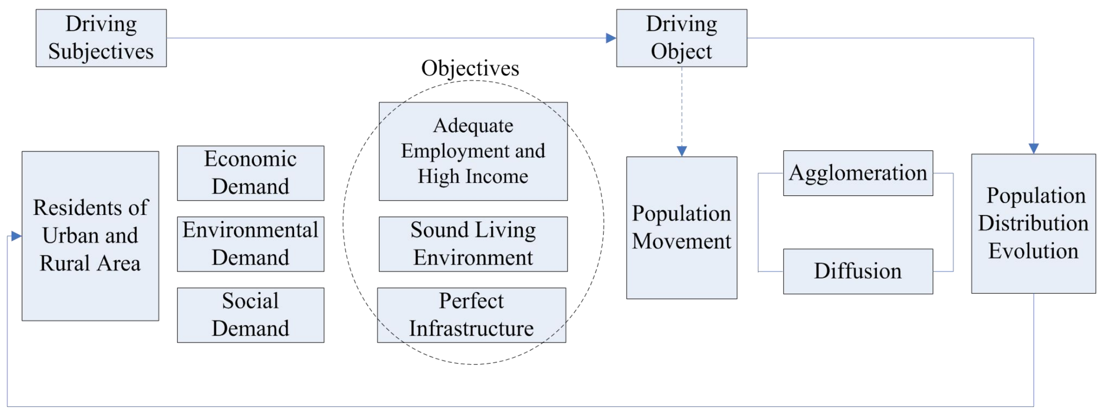

Figure 4.6 Micro-evolution mechanism

In the early stage of economic development, in order to make more money and obtain job opportunities, people don't care about the living environment and social resource and they move to the center cities with economic factors agglomeration. Economy is the driving force of population movement. While, when the income increases and economic condition is good, more people transfer their focus to enjoy high-quality life and other social resources. Problems like traffic jam and the bad living condition in inner cities push population to move out. Therefore, being the basic of social and environmental demand, economic demand is the main factor pulling population movement in the early stage of economic development from the micro-perspective. When the social and economic develops into the advanced stage, people change their focus from economy to society and environment, and at this moment, social demand, environmental demand together with the economic demand determine population movement direction. The three factors drive population agglomeration and diffusion, and promote the structural evolution of regional population distribution.

4.4 Factors Identification of Urban Population Growth

Urban population growth is the precondition of regional growth and industrial agglomeration. Relationship between growth and agglomeration depends on labor mobility among different regions. As a part of urban growth, urban population growth plays an important role to promote regional economic development. Conceptual model of urban population growth can help understand structural evolution of regional population distribution from the perspective of sustainable development.

4.4.1 Theoretical Foundation

Regional development theories, such as Williamson's (1965) Inverted - U Theory and Hirschman’s (1958) theory of unbalanced growth, unanimously stress that regional growth is an imbalanced evolution process. Regional economic growth always depends on one or several pole centers which could promote the economic growth of neighbor cities (Friedmann & Wolff, 1982). Krugman (1991) used Core-Periphery Model to describe spatial industrial agglomeration and unbalanced development. From the spatial perspective, the evolution of European economy focused on the differences of regional and national industrialization processes. Polarization explained regional economic imbalances in Europe (María, Fernando, & Vicente, 2006). It was also perceived reasonable to attempt the way of imbalanced development especially for the developing countries (Hirschman, 1958). Zhong (1997) conducted data analysis in Guangdong Province in China and pointed out that the imbalance expansion was beneficial for the entire regional economic growth. Several industrial clusters form the growth poles then promoted the entire regional growth. Attributable to the agglomeration economy, industrial agglomeration brought about employed population concentration. High growth in center cities would generate spillover effects on neighbor cities and led to high national growth (Chen & Wu, 2010). Xu's (2010) empirical study of China's cities showed that sustainable growth of urban economy must take advantages of agglomeration effects sufficiently.

Krugman (1991) emphasized the effect of transport cost on industrial location in the imperfectly competitive market. Krugman and Elizondo (1996) pointed out that it is essential to take the centripetal force and centrifugal force that promoted the population and economic agglomeration into account in the economic geography model. Centripetal force mainly derived from economies of scale which also means industrial agglomeration, and centrifugal force derives from transport cost, congestion effect and pollution effect (Tabuchi, 1998). Fujita (2002) used empirical study to analyze the relationship between industrial cluster and transport infrastructure based on the research framework of New Economic Geography. From the perspective of theoretical mechanism of regional spatial structure evolution, externalities and transport cost were the essentials of the interactions between different economic spaces (Armin, 1999). Favorable traffic conditions promoted the regional industrial agglomeration (Howard, 1970). Economic development required adequate and effective transportation. Cities with perfect transportation infrastructure facilities could expand spatial service scale. It was attractive for the firms to select location of economic activities for the second time (Wang & Jin, 2005).

With the rapid increase of city population (including the floating people), urban construction accelerated and urban land-use structure changed substantially. Increase of Industrial and residential land led to the decrease of arable land. In the view of urban planning, it was not a reasonable and sustainable land-use pattern (Tan et al., 2008). Kong (2012) emphasized that government should take important urban environments into account and strictly manage urban growth and development in terms of land use pattern. Terry (2002) and Knapp (1989) et al believed that amenities would drive urban growth in the future because citizens in the postindustrial city increasingly selected their own urban location according to the quality of life. The amenity consideration is a sustainable development pattern, and in the long run, regional planning should strive for sustainable economic growth especially in the developing countries with rapid urbanization. The major problems underlying in regional development are extensive resource exploration, fast population growth, irrational industrial structure and environmental pollution (Zheng & Dai, 2012). Shift-Share analysis has been used universally in planning, geography and regional science in recent years (Knudsen, 2000). Usually used to describe regional economic growth or examine the regional planning effect, shift-Share analytic approach divides growth of economic variable (such as income, output and employment) in a certain area into different parts.

4.4.2 Factors of Urban Population Growth

Population distribution evolution is accompanied with population movement. Except for the natural population increase, most of the growth derives from population immigration. People move out from one place and settle in another place and this process causes population growth. Normally speaking, population movement is the result of push and pull.（Figure 4.7）. The driving force of urban population growth is from production and living aspect. Natural geographic factor, resource and environmental factor, social and cultural factor, economic factor, transportation and telecommunication factor and other factors which are all the driving force of population movement promote the urban population growth and structural evolution of regional population distribution (Duncan & Vernon, 1999; Fallah et al., 2012).

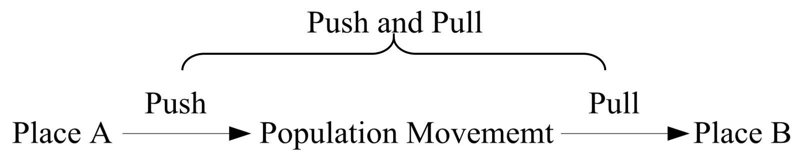

Figure 4.7 Centripetal force and centrifugal force of population movement

4.4.3 Conceptual Model Design

In the third world, the proximate determinants of urban growth lie in the natural increase of urban populations and migration, both intranational (rural-to-urban and urban-to-urban) and international (Kasarda & Crenshaw, 1991). Hence, it is hypothesized that population growth could be divided into natural increase part and mechanical increase part. Natural increase is related to the original population size and natural environment in addition to birth and death rate. Migration and immigration contribute to the mechanical increase. Most research has concentrated on the relative contributions of natural increase and migration (Chen, 1996; Mobrand, 2006; Klink, 2008). Rural-to-urban migration was the principal focus of investigations as it is easy to be modified by national policies (Fan & Stark, 2008). Government could put forward relevant policies to accelerate the speed of urbanization and promote urban growth. Migration shows the capability of labor absorption in a certain city while employment opportunities drive population agglomeration and economic agglomeration. The model framework for urban population growth (Figure 4.8) is developed based on the hypothesis of natural increase and mechanical increase.

Regression analysis is employed to explore the relationship between theoretical factors and urban growth in this paper. As independent variables, original urban population is used to reflect urban size while residential land share of constructive land represents living environmental factor in natural increase part. Alternatively, in the mechanical increase part, as adopted in the study of Hanson (1998; 2005), transportation distance instead of transport cost is used to estimate the spatial relationship between sample city and center city (Partridge, Dan, Kamar &, Olfert, 2009), while population number of the dominant industry is selected to show industrial agglomeration effect.

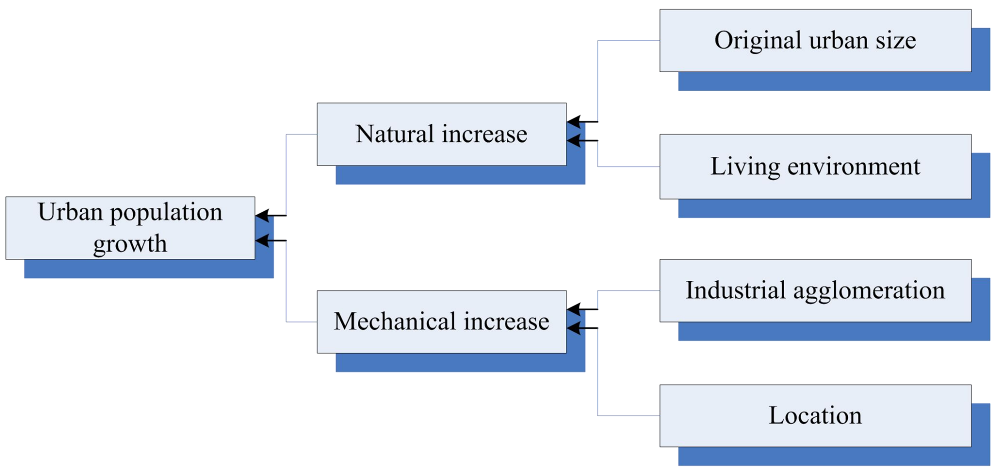

Figure 4.8 Conceptual model of urban population growth

This conceptual model identified the driving force of urban population growth from the perspective of sustainable development. Natural increase and mechanical increase explained the urban population growth process from the micro-perspective.

4.5 Summary of the chapter

This chapter analyzes the evolution process and evolution mechanism of regional population distribution from the perspective of sustainable development. The evolution process is divided into five stages which are introduced separately. Driving force of population distribution evolution is also discussed both from macro-perspective and micro-perspective. Based on the above, conceptual model has been proposed in order to provide quantitative support to identify the factors of urban growth from the perspective of sustainable development. These contents build the qualitative analysis part of evolution mechanism.

Chapter 5 Regional Population Density Model

5.1 Introduction

This chapter presents the development of regional population density model for describing the evolution process of regional population distribution by improving previous models and some statistical methods like regression analysis and spatial autocorrelation analysis. It starts with an overview description of representative functions and continues with the introduction of spatial autocorrelation analysis method which can help identify the center cities in one region. Economic factors, social factors and environmental factors affect the population density gradient. Regression model is established to reveal these indicators and with the regression results, regional population density model of poly-centers is developed from the perspective of sustainable development.

5.2 Theoretical Foundation of Model Development

5.2.1 Density Function with Single Center and Poly Centers

The population density function proposed by Clark (1951) has always been widely used to analyze the spatial structure of metropolitan areas (McDonald & Prather, 1994; Mcmillen & McDonald, 1998; Small & Song, 1994; Lin, 2001; Feng et al., 2009). Population or employment densities decline as the distance increases from the metropolitan area center, most of which is the central business district (CBD) of the entire region. The density gradient has often been used to measure the degree of spatial concentration and diffusion of population, while it can also reflect the trend of variation of the regional population distribution. It is expressed as the negative exponential function:

(5-1)

where *D(x)* is the population density at distance *x* from CBD. D_0 and *b* are the model parameters, which respectively represent the estimated population density in the center and density gradient. The higher value of the parameter *b* indicates the faster population density decline with the increasing distance from the CBD.

Along with regional development and structural movement, this kind of monocentric model has to be extended to fit a polycentric region pattern, with several identified sub-centers. Polycentric density function can help to reveal regional population distribution and variation trend under the mutual influence of different centers. Heikkila (1989) argued that a regional scale polycentric model can be described as a combination of several monocentric models:

(5-2)

Where D_0 is the slope that shows the estimated value of population density in center cities. The change of density gradient reflects agglomeration capacity increase and decrease. Therefore, estimated value of D_0 and *b* in different years can describe he dynamic process of population agglomeration and diffusion.

5.2.2 Improvement of Traditional Density Function with Poly-centers

A polycentric regional density function can help to reveal regional population distribution and development trend under the influence and joint action of poly centers. Parr (1985) used UK and North American Regional data to argue that the spatial structure of a metropolitan-area-based region can be described in terms of a population density function of the square-root negative exponential type which was called regional density function. Apart from Parr's, there are some other models which can be used in regional research. Most of them are an extension of the urban density functions. Many scholars found that a negative exponential function can be used to describe the urban population density distribution based on their case studies (Wang, et al 1999; Alperovich, et al 2000; Shen, et al 2000). Another representative regional density function is verified by Wang through a case study of major plains of China from 1982 to 1990 (Wang, 2001). The reverse-exponential function has the best fitting power for the regional density patterns in the study areas.

Table 5.1 shows the three regional population density models in detail, including the year(s) of application and location of the case area.

Table 5.1 Three representative models of regional population density

Form	Case	Time	Case Property
$D(x) = D_0 \exp(bx^{0.5})$	UK and North American Regions	1985	Metropolitan
$D(x) = D_0 \exp(bx)$	More than 20 cities in America and China	Since 1951	Normal urban
$D_x = a + b\ln(x)$	The Northeast, North and Hubei-Hunan Plains	2001	Plain area in China

Based on Heikkila's idea, polycentric regional density function can be described as a summation pattern.

$$D_m(x) = \sum_{n=1}^{N} D_{0n} \exp(b_n x_{mn}^{0.5}) \quad (5\text{-}3)$$

$$D_m(x) = \sum_{n=1}^{N} D_{0n} \exp(b_n x_{mn}) \quad (5\text{-}4)$$

$$D_m(x) = a + \sum_{n=1}^{N} b_n \ln(x_{mn}) \qquad (5\text{-}5)$$

Here n represents the number of centers, and m represents the number of spatial units. x_{mn} is the distance between spatial unit m and center n (Euclidean distance). D_m is the population density of the spatial unit m. The change of D_0 reflects the development trend of the center city's population density. The gradient b (absolute value) reflected the development trend of regional population density distribution. The bigger the absolute value of b is, the faster the population density decreases. The density gradient increase means there is concentration trend to the center, while the gradient decrease means diffusion outward. Therefore the variation of D_0 and b in different years shows the dynamic process of regional population concentration and diffusion. The first term on the right side of the equation is a vertical sum of the monocentric density functions, each reflecting the influence of one center on that location. Any area unit receives accumulative effects coming from different centers.

Here the multiplicative density function does not have a separate intercept for each center, so there is no apparent way to take into account the variation in sizes of various centers. Furthermore, it implies that adding a new center at one side of the region lowers densities far away on the opposite side.

Distance between two spatial units in traditional density function is the Euclidean distance which was based on the assumption of homogeneous topography and ring form. However actually in one region, there are geological properties of rivers and maintains but not only plains. This research plans to use another variable that is the shortest travelling distance which takes account of actual conditions in case study region instead of Euclidean distance. We assume that the shortest travelling distance has better results, and use Google Earth Software to get the shortest road travelling distance between two area units, and the validation of this hypothesis will be conducted in Chapter seven. The traditional polycentric density model would be improved.

5.2.3 Alperovich' s Density Gradient Model

Based on the regional density function with multi-centers, Johnson and Kau (1980) and Alperovich (1982a) put forward the Varying Parameter Model (VPM) to investigate the determinants of the population density gradient. They brought social and economic elements into density function as parameters, and revealed the influence of the determinants on population density gradient. They proposed the following five explanatory variables as the main factors: total population, city area, transportation cost, income, and city age. Alperovich suggested that a complete specification of an equilibrium model of urban population and its behavior across urban areas should include the following two additional relations:

The density functions vary as the values of the five parameters change across regional areas. These two functions are linear and this method has been used for empirical analysis (Alperovich, 1982b). They permit the estimation of the determinants of D_0 based on observations pertaining to the CBD of each urban area and the estimation of the gradient b based on all available data. Thus, the estimates of b under the selected function are more efficient and reliable than those derived from other methods that do not utilize all available data.

The available data for population gradient *b* was used to conduct multiple linear regression analysis for constructing the regression model:

(5-6)

where *b* is the population density gradient, is the constant term, is the random term, , , , represent regression coefficient, and are the determinants of population density gradient. They are Fix$_{ij}$, Share23$_{ij}$, Passenger$_{ij}$ and Environment$_{ij}$.

This study used multiple linear regression analysis to explore the relationship between theoretical factors x_i and population density gradient *b*. This method models and analyzes the relationship between one dependent variable and one or more independent variables. Stepwise regression method is employed to solve multicollinearity problems. It is an automatic procedure for statistical model selection with many potential explanatory variables.

5.3 Identification of Center Cities

5.3.1 Spatial Autocorrelation Analysis

Regionally center cities are identified by using spatial autocorrelation analysis. Spatial autocorrelation refers to the potential interdependence of some variables among observations in the same area. Spatial dependency is the co-variation of properties within geographic space. Characteristics at proximal locations appear to be correlated, either positively or negatively. Spatial dependency leads to the spatial autocorrelation problem in statistics since, like temporal autocorrelation, this violates standard statistical techniques that assume independence among observations (De Knegt et al, 2010). It is believed that the correlation between two neighbors located within a spatial geographical scope is stronger than that between those two far away each other (Dormann, 2007). Spatial autocorrelation method can reveal the spatial dependency among observations. In general, correlation is prevalent in the geographic data because the spatial data are affected by agglomeration and diffusion of population and economic activities to some extent.

Spatial autocorrelation refers to the correlation of the same variable in the neighboring location of the spatial domain, which aims to check if there is a similarity between attributes of a spatial unit and its neighboring one (Cliff, 1973). Socioeconomic variables are generally used to investigate the correlation between two neighboring area units. For any spatial attribute, it measures the similarity or dissimilarity degree of variable to its neighboring spatial value. The numerical relationship of the spatial variable can be divided into positive (aggregation of similarity values), negative (diffusion of similarity values) and zero correlation (random distribution of similarity values). The spatial autocorrelation can also be divided into global and local ones according to the research object (Cliff, 1981).

Global spatial autocorrelation is a measure of the overall clustering of the data. It is a description of attributive features in the whole regional space, which further determines whether there are spatial clustering features and calculates agglomeration intensity according to the distribution of a phenomenon, but the minor defect is it cannot obtain the spatial agglomeration location of the statistical variable and the correlation degree. Major parameters include Moran's *I* and Geary's *C* statistics. Here we use Moran's *I* to calculate the overall difference between regional population density and economic indicators. The calculation is as follows:

$$I=\frac{\sum_{i=1}^{n}\sum_{j\neq i}^{n}w_{ij}(x_i-\overline{x})(x_j-\overline{x})}{S^2\sum_{i=1}^{n}\sum_{j\neq i}^{n}w_{ij}}=\frac{n\sum_{i=1}^{n}\sum_{j\neq i}^{n}w_{ij}(x_i-\overline{x})(x_j-\overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n}w_{ij}\sum_{i=1}^{n}(x_i-\overline{x})^2}(\forall j\neq i) \quad (5\text{-}7)$$

where, n—the total number of samples;

x_i, x_j—observed values of the statistical indicator;

$\overline{x}$—the average of observed values of the entire region;

w_{ij}—the spatial weight between spatial units i and j.

The value of Moran's I ranges from -1 and 1. The result closer to 1 or -1 suggests a higher positive or negative spatial correlation of the statistical indicator in the research area. Moreover, significance test of the calculation result also should be conducted. When it meets test condition, there would be a statistically significant spatial correlation in this area. The statistic Z is calculated as follows:

$$Z(I_i)=\frac{I_i-E(I_i)}{\sqrt{VAR(I_i)}} \quad (5\text{-}8)$$

If there is no global autocorrelation or no clustering, we can still find clusters at a local level using local spatial autocorrelation. Local spatial autocorrelation depicts the same attribute correlation between each spatial position and the adjacent position in research area. Moran's significance map can intuitively reflect statistically significant local spatial autocorrelation and its type from the visual aspect, which divides the regional unit into four types: high-high, low-low, high-low and low-high. The high-high or low-low type refers to a unit with a relatively high or low observed value, which is consistent with the observed value in its adjacent area, implying local spatial agglomeration of high or low values. Conversely, high-low or low-high type reflects the local spatial difference of the statistical data. This research uses local Moran's *I* of LISA (Local indicators of spatial association) to perform analysis. It is calculated as follows:

$$I_i = \frac{(x_i - \bar{x})}{S^2} \sum_{j=1}^{n} w_{ij}(x_j - \bar{x}) = \frac{n(x_i - \bar{x}) \sum_{j=1}^{n} w_{ij}(x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (5\text{-}9)$$

Different from the significance test of global spatial autocorrelation, local Moran's *I* needs to conduct the significance test of the statistic Z in order to reveal the validity of the statistical indicator. The calculation of Z value is the same with that of global autocorrelation.

A spatial weight matrix is made to show the mutual adjacency relation between two spatial units and the incidence. It is a binary symmetric matrix in general:

$$\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix} \quad (5\text{-}10)$$

where, $W_{ii} = 0 (i = 1,2,\ldots\ldots, n)$ indicates no adjacency relation between *i* and itself. $W_{ij} = W_{ji}$ represents the same contribution degree between *i* and *j* each other. In the research of spatial autocorrelation, there are many definitions for the spatial weight matrix, the following two of which are widely used: binary adjacency matrix and distance-based binary spatial weight matrix.

When *i* is adjacent to *j*, $W_{ii} = 1$;

When *i* is not adjacent to *j* , $W_{ii} = 0$.

Or,

When the distance between regions i and j is less than a defined value, $W_{ij}=1$;

When the distance is more than or equal to the defined value, $W_{ij}=0$:

Traditional spatial weight matrices are defined by simple locational factors, and the value can only be 0 or 1, which may have some limitations to the description of the relation among different individual units. It can be analyzed from the above chapters that the traffic network is a major reference factor for changes in regional population distribution, a linkage between different areas, and even a foundation of regional economic development (Jeon et al., 2006). Therefore, in order to make the study much closer to reality, we modify the spatial weight matrix and use the value of individual unit located in the same microeconomic circle but not bordered on as the reciprocal of the distance of road network. This method reflects the inter-local cooperation in the background of regional economic integration compared with traditional spatial weight matrix. The expression of the spatial weight matrix based on the road network is:

$$W_{ij}=1/D_{ij} \quad (5\text{-}11)$$

where, D_{ij} is the shortest distance by vehicle between center i and j, which belong to the same but not adjacent microeconomic zone.

If i is adjacent to j, then $W_{ij}=1$;

And if i and j are not located in the same microeconomic circle, then $W_{ij}=0$.

Applying such modified spatial weight matrix, road network distances are put it into the matrix to work out which statistical unit has greater contribution to spatial agglomeration in the research area. Thus, the regional development pole of economy and population is found out and its impact on surrounding areas can be also revealed.

5.3.2 Data Processing and Result Analysis

In spatial autocorrelation analysis, two aspects of data preparations are needed: one part of distance data are obtained from the statistical yearbooks, and the other are from the related software calculation. The research area is divided into statistical units in county level according to the administrative divisions. GDP per capita and population density are selected as indicators to find out the population and economic agglomeration areas in a certain region. The shortest distance of road network between related cities is used as the spatial distance data (where the shortest distance of the road network between two spatial units is measured by Google Earth) to modify the spatial weight matrix.

The modified spatial weight matrix is constructed and the spatial autocorrelation analysis is performed by ArcGIS Toolbox software modules in the computational process. Custom spatial weight matrix is generated by early-stage preparations and is entered into the software. Then, global and local Moran's I are computed using the spatial autocorrelation (Moran's I) analysis tool and agglomeration and abnormity analysis tool provided by modules, by which analysis results can be visualized.

It can conclude as follows by computing global Moran's I of GDP per capita and population density, and its standard statistics Z, and P of significance test for Z.

If a 95% confidence interval is taken, there are spatial correlation characteristics in the population density and GDP per capita when the P value is less than 0.05. Areas with high economic development level and population density show the trend of agglomeration, and vice versa. Global autocorrelation result means whether the region has the ability of population and economic agglomeration, that is, whether there are population and economic clusters in that region. Strong global spatial correlation indicates that the population or economic activities with high element agglomeration have concentrated in the well-developed growth pole of the region.

Local spatial autocorrelation indicators of each spatial unit can be obtained using judge standard which is the same with global autocorrelation. If a 95% confidence interval is taken and the *P* value is less than 0.05, the city has significant agglomeration ability.

5.4 Model Development

Under the background of China's urbanization and industrialization, this research of spatial structure evolution of regional population distribution in this project pays attention to urban development process. The word 'city' or 'urban' here does not mean that we abandon all elements other than the urban geographical boundary, but place research emphasis on changes in spatial pattern of population caused by economy, resource, environment and society. Population density gradient is a parameter reflecting the population agglomeration ability of a city.

5.4.1 Indicator Selection

On the basis of the evolution mechanism analysis of regional population distribution, literature review and classic theories, this research develops model to identify the factors of population density gradient which are mainly from the aspect of macro-economy, social life, resources and environment. Adjusting these influencing factors of population density gradient could improve the ability of population agglomeration.

5.4.1.1 Economic Indicators

1) Macro-economic indicators

Urban economic growth, on the one hand, will improve the quality of life for city dwellers, on the other hand, will provide sufficient employment opportunities, manifesting as keen demand for labor force. Such increase in employment supply reflects in urban agglomeration ability, which is mainly embodied in the fact that sufficient employment opportunities and good living environment attract plenty of rural surplus labor forces to work and settle down in cities and thus change the original spatial pattern of regional population. Hence, economic indicator is the leading factor of the population agglomeration ability in a regional center city. Gross domestic product (GDP) can reflect the economic aggregate of a country or region, and is also the sum of the total output created by economic activities in a particular period (usually one year) and the labor market value, which is an aggregate performance of the economic development situation of the region (Oguz, 2012) and the final product of production activities of all resident units in a country (region) in a given period. Therefore, we select GDP as one of the alternative indicators reflecting the overall level of macroeconomic development of a city; on the other side, total investment in fixed assets is a pattern of manifestation of fixed asset acquisition and construction, and also reflects the ability to reproduce fixed assets of a city or region. This research considers the volume of investment in fixed assets as another alternative indicator reflecting the macroeconomic condition. Total retail sales of consumer goods include turnovers of consumer goods sold to the public or a variety of groups by such industries as catering, lodging, and wholesale and retail. It can measure the level and degree of social purchasing power in a designated area or region over a period of time and also reflect the marketing of such industries as wholesale and retail industry. This indicator also reflects the living standard and the situation of consumption ability of the public in the region. As a result, we consider total retail sales of consumer goods as the third alternative indicator reflecting the urban macroeconomic development.

2) Industrial structure indicators

In terms of a country or region, sizes and relative ratios of the output of the primary, secondary and tertiary industries are key indicators for measurement of its industrial development altitude, while orderly development of industrial structure is also an essential impetus in the urbanization process of a region. Compared with the primary industry, the secondary and tertiary industries will provide more employment opportunities, which are also the reason why the urban population is greater than that in rural area. Employment brings the population concentration. Therefore, industrial structure is an important indicator reflecting the economic development level and the changes in the spatial structure of population. With the continuous improvement of the level of economic development, output values of three industries in a region always present the following laws. The proportion of output value of the primary industry to the employed labor decreases, while that of the secondary and tertiary industries to the employed labor increases (Ashton, 2009). Most developing countries have transited from single development of the primary industry to the manufacturing-dominated economic structure gradually, and further to that dominated by service and high-tech industries slowly, which place even more emphasis on the important role in manufacturing, service and high-tech industries in the process of urban economic and social development. Such transition, either from the perspective of creating economic benefit or attracting employment and promoting technological progress, will be a process of industrial structure transiting from a lower to a higher level that accelerates the evolution of the regional population distribution. In this research, for industrial structure factors, proportions of the employed population in the primary, secondary and tertiary industries are selected as an alternative indicator.

5.4.1.2 Social Life Indicators

1) Social life indicators

Migration of population is to strive for better employment opportunities, higher economic incomes and good living standards. Regions with high residential living standard would attract the floating population to immigrate and enhance urban agglomeration ability; on the contrary, regions with poor living standards have relatively weak population agglomeration ability. Therefore, this research selects a representative indicator reflecting people's living standards to test how and where it acts with the ability of population agglomeration. Living standards can be considered as the consumption level of social products and labor services that meet people’s material and cultural needs in social economic activities, including real income, consumption level, social service, proportion of the recreation time, health care and education. Especially, per capita disposable income in urban residents is the most representative indicator reflecting people's living standards and also a representative of citizen’s income level, especially cash income level and actual wealth ownership, which are parts of earnings that the public use in arrangement of their daily life and daily consumption. Thus, this research selects the per capita disposable income reflecting people’s living and consumption levels in the process of urban development as the most representative indicator. Moreover, per capita consumption expenditure of urban households also represents another alternative indicator for social life, because it reflects consumptions used in daily life by citizens, including all expenses on purchasing goods and services, and represents their average consumption and expenditure levels.

2) Infrastructure indicators

Infrastructure can provide social production and residents' living with public service. As a public service system, it ensures human social and economic activities and it is a general material basis for urban development. Urban infrastructure is a supporting and basic element of municipal construction, which concerns every aspect of residents' living. ‘Infrastructure’ includes public utilities (road, railway, airport, communication, utilities) and social undertakings (education, science and technology, health care, sports and culture). It is generally acknowledged that improvement of medical and educational levels stimulates the population agglomeration, while regions with more well-developed transport system have stronger regional population diffusion ability (Ko et al, 2011). Bus passenger transportation volume refers to total passenger volume transported in a certain period, which is an indicator of service quantity that the public transport industry services people's life and work, reflecting the carrying capacity of bus and transportation system in a certain period. Therefore, this research selects highway and railway passenger transportation volume as an indicator reflecting the external urban accessibility and investigating the effect of transportation on population diffusion ability of a center city. In addition, traveling cost is also one of the factors considered by citizens. Reduction in transportation cost increases the possibility of population diffusion in a center city. This research considers the transportation cost as another alternative indicator reflecting the infrastructure level. Considering that urban infrastructure includes not only highway traffic but also social service facilities, such as education, health care and sanitation, per capita hospital bed is used to reflect the social service infrastructure level.

5.4.1.3 Resource and Environment Indicators

1) Natural resource indicators

Natural resources include land, water, forest, climate and mineral resources. This research mainly focuses on land and water resources when selecting natural resources as an indicator because it does not specialize in resource-based cities. Land, as a basic carrier of social activities, is a result of interference with and influence on natural ecosystems. The earliest land ecosystem formed cities in the process of human's exploitation and utilization. Continuous evolution and transformation of urban land-use provide a predominant foundation for population concentration, survival and development. The correlation between population and land can be reflected by such indicator like population density, land holdings per capita, per capita farmland, and arable land per capita. In view of the data availability, the proportion of residential land to construction land iss selected as an alternative indicator assessing the population density gradient in order to protect the urban land from being extensively occupied by industry. In addition, coastal plain regions attract a large population to immigrate because of good natural and ecological environment and pleasant climate. For example, in China, A large number of immigrants are attracted to the coastal regions of the Yangtze River Delta and the PRD, partly because of the predominant geological location and good natural conditions; inversely, few people would immigrate into some mountainous areas in Western China actively. Thus, this research considers the location of a city (coastal or mountainous) as another alternative indicator investigating the population density gradient.

2) Environmental indicators

Environmental comprehensive quality will affect the agglomeration ability of a city. It is not difficult to understand that cities with well-integrated environment are easier to attract the floating population because people increasingly recognize the significance of living environment. Waste gas, waste liquid and solid wastes caused by industrialization have seriously polluted urban air, fluvial, marine and terrestrial environments, which are the most primary pollution sources in the industrial age. In addition, air pollution caused by domestic sewage, garbage and automobile exhaust produced by a large urban population daily has negative effects on urban environmental quality. Moreover, most of the land in the city is used for housing development and industrial construction, which occupies parts of arable land and leads to soil and water loss. This will also destroy the urban ecological environment in the long term. As an urban respirator, virescence largely represents a city's external environmental quality and abilities to absorb the waste gas and purify air. The proportion of environmental protection investment to GDP reflects the input of environmental protection. All the above are representative indicators related to the urban environment. To simplify the research process, this research is to demonstrate the urban environmental level through the synthetic value of environmental quality and introduce a pressure-state-response (PSR) model from the perspective of sustainable development. Based on the PSR model, the following indicators will be entered into the research which are per capita construction land area, per capita urban wastewater discharge, sulfur dioxide emissions per square kilometer, per capita arable land, per capita green area, proportion of environmental protection investment to GDP, wastewater treatment rate, and harmless treatment rate of solid waste. The PSR model is a widely-used research method for urban environmental sustainability by scholars at present (Sekovski et al., 2012). Comprehensive environmental quality will be get through the PSR model.

Table 5.2 is a description of detail indicators.

Table 5.2 Indicators of population density gradient

Type	Indicator
Macro-economic factors	GDP, Fixed asset investigation, Retail sales of consumer goods
Industrial structure factors	Percentage of primary industrial employment, Percentage of the second and tertiary industrial employment
Living standard factors	Urban household disposable income per capita, Urban households consumption expenditure per capita
Public transportation factors	Distance to the center city, Passenger of highway and railway, Hospital beds per capita
Natural environmental factors	Percentage of residential land, Coastal or mountain
Comprehensive environmental factors	Comprehensive environmental quality

5.4.2 Framework of Pressure-state-response

The pressure-state-response (PSR) framework for the environment is used as a basis to develop the study of people's perceptions of the state of the urban environment (Ken et al., 2004; Wang et al., 2013; Carr et al., 2007). Indicators in the pressure-state-response (PSR) framework are used to assess the ecological and environmental quality in a certain area from the perspective of sustainable development. In a PSR framework, pressure indicators reflect the negative effects human activities bring to the ecological environment. State indicators reflect conditions of ecological and environmental quality, natural resource and ecological system. Response indicators reflect the strategies people take to solve ecological environment problems. This framework links pressure caused by human activities with changes of environmental condition variables (Kelly, 1998). Pressure, state, and response indicators form an integrated system of indicators that collectively address the problems that confront the overall environmental system (Zhen et al., 2009). Based on the three indicator selection principles and according to the PSR system and Walz's study (2000), a PRS framework of the overall environmental quality is built for urban areas of developing countries as shown in Table 5.3 below.

Table 5.3 Indicator system based on the PSR framework

PSR framework	Indicator
Pressure indicators	Construction land area per capita
	Urban waste water discharged per capita
	Each square kilometers SO_2 emissions
State indicators	Area of cultivated land per capita
	Green area per capita
Response indicators	Percentage of investment in environment protection in GDP
	Rate of sewage treatment Rate of consumption waste treatment

Being an objective method, the entropy weight method was used to calculate the comprehensive environment quality (Mi & Li, 2010). The steps taken to ascertain the weight for environment quality of a certain area were as follows.

(1) Data standardization

$$x_{ij}^{'} = (x_{ij} - \overline{x_j}) / \sigma_j \qquad (5\text{-}12)$$

Where $x_{ij}^{'}$ is the standardized indicator; $\overline{x_j}$ is the mean of indicator *j*; σ_j is the standard deviation of indicator *j*. In order to delete the negative value, translate the coordinate to make $x_{ij}^{''} = K + x_{ij}^{'}$, where *K* is the range of coordinate translation.

(2) Entropy calculation

Entropy is a measure that uses probability theory to measure the uncertainty of information. It shows that the more dispersive the data are, the bigger the uncertainty is. The entropy value of indicator j is defined as follows (Shannon & Weaver, 1947):

$$E_j = -k\sum_{i=1}^{m} f_{ij} \ln f_{ij}, \quad f_{ij} = \frac{x_{ij}^{''}}{\sum_{j=1}^{n} x_{ij}^{''}}, \quad k = 1/\ln m \tag{5-13}$$

Where E_j is the entropy of the indicator *j*; f_{ij} is the proportion of $x_{ij}^{''}$; m is the number of evaluation objects.

(3) Weight determination based on entropy value

The weight based on the entropy of *j* indicator is as follows:

$$w_j = \frac{1 - E_j}{\sum_{j=1}^{n} 1 - E_j} \tag{5-14}$$

Thus, the weight coefficients and the integrative level of ecological and environmental quality could be derived.

5.4.3 Model Development

Based on the analysis above, we build the multiple linear regression model of population density gradient in center cities. Stepwise regression method is employed to solve multicollinearity problems. It is an automatic procedure for statistical model selection with many potential explanatory variables.

The expression is:

$$b = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_n x_n + u \qquad (5\text{-}15)$$

Where b is the population density gradient; β_0 is constant; u is the stochastic term; $\beta_1, \beta_2, \beta_3, \cdots, \beta_n$ are the regression coefficient.

We use least square method to solve the parameter estimate of multivariate linear regression model. Take binary linear regression model for example, solution of the regression parameters of the standard equations is like:

$$\begin{cases} \sum y = nb_0 + b_1 \sum x_1 + b_2 \sum x_2 \\ \sum x_1 y = b_0 \sum x_1 + b_1 \sum x_1^2 + b_2 x_1 x_2 \\ \sum x_2 y = b_0 \sum x_2 + b_1 \sum x_1 x_2 + b_2 \sum x_2^2 \end{cases} \qquad (5\text{-}16)$$

Solve equations and get the value of b_0, b_1, b_2.

$$b == (x^{'} x)^{-1} \cdot (x^{'} y) \qquad (5\text{-}17)$$

That is

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} n & \sum x_1 & \sum x_2 \\ \sum x_1 & \sum x_1^2 & \sum x_1 x_2 \\ \sum x_2 & \sum x_1 x_2 & \sum x_2^2 \end{bmatrix}^{-1} \cdot \begin{bmatrix} \sum y \\ \sum x_1 y \\ \sum x_2 y \end{bmatrix} \tag{5-18}$$

Regression results reveal the factors of agglomeration and diffusion in center cities. Regression coefficient reflects impact and direction of variables. Bigger regression coefficient means the corresponding factor has a great influence on the city's agglomeration and diffusion capacity. Small change of these factors will cause great change of population density gradient. In addition, if the value of regression coefficient is positive, agglomeration capacity of center city will increase with the value increase of indicator. On the contrary, if the value of regression coefficient is negative, agglomeration capacity of center city will decrease with the value increase of indicator. In essence, regression coefficient shows the factors of population density gradient. This function would be an effective tool to analyze agglomeration and diffusion capacity of center cities.

Negative exponential function shows the population density evolution in a certain region and density gradient depends on the factors of economy, society and environment. Based on the analysis above, this paper develops a regional population distribution evolution model with poly-centers as followed.

$$\begin{gathered} D_m(x) = \sum_{n=1}^{N} D_{0n} \exp(-b_n x_{mn}) \\ D_{0n} = D(E, S, R) \\ bn = bn(E, S, R) \end{gathered} \tag{5-19}$$

Where $E = (e_1, e_2, e_3, \cdots, e_n)$, $S = (s_1, s_2, s_3, \cdots, s_n)$, $R = (r_1, r_2, r_3, \cdots, r_n)$ means slope and gradient depend on the factors of economy, society and environment. X is the shortest travelling distance between center city and other spatial unit, and other variables have the same meaning with the traditional one.

5.5 Summary of this Chapter

This chapter reviews the conceptual model of population density gradient and spatial autocorrelation analysis method which are the base of evolution model development. According to the factors of density gradient, indicators are selected from economic, social and environmental subsystem. Regression model help find factors of density gradient and finally regional population distribution model with poly-centers are built up.

Chapter 6 Optimization Model

6.1 Introduction

This chapter investigates the optimization model of regional population distribution. Overall optimization objectives are discussed firstly, following by the rationality evaluation of current situation. Contribution degree of economy, society, resources and environment is analyzed in order to support policy making from the macro-perspective. Multi-objective programming model is used to optimize regional population distribution, and it provides technical support for the government to plan for sustainable region development from the micro-perspective.

6.2 Significance of Optimization

Upon the contents in previous chapters, population problem is not only the important problem restricting comprehensive, balanced and sustainable development in the region, but also the key factor influencing regional economic and social development. Regional population distribution is the result accumulated from regional development in long term. The distribution of labor forces is the important configuration form of production factors. The pattern and state of labor force produces great influence in such aspects as economy, society, environment, resources and ecological benefits. Therefore, the optimization of regional population distribution is imperative as one important link in regional planning in order to achieve comprehensive and rapid sustainable development of regional economy rapidly.

From the perspective of sustainable development, the optimization of regional population distribution emphasizes the equity of spatial unit while utilizing limited resources. Firstly, it refers to intergenerational equity, namely the equity between contemporaries and descendants.

From the perspective of the optimization of regional population distribution, it indicates the problem between development of regional cities and sustainable use of resources and environment. When the population aggregation is large and the urban density is high, the rational adjustment of population distribution rather than the arbitrary growth is conductive to the rational use of land resources, the free mobility of economic factors, the reduce of urban construction cost and prevention of city disease; secondly, it is generational equity, namely the equity between contemporaries, thus everyone's basic requirements will be met. From the perspective of the optimization of regional population distribution, if the economic development of one city is not at the cost of damaging the economic benefits and development of other cities, it may achieve common and rapid development in the whole region through adjusting population spatial distribution as much as possible. Therefore, the sustainable development may be guaranteed when each regional unit achieves equity and harmonious coexistence. Regional population distribution for sustainable development is the advanced stage of evolution with an aim of perfect connection between time and space.

6.3 Characteristics and Objectives of Optimization

6.3.1 Characteristics

Spatial structure of regional population aims to optimize population distribution at regional nodes. The population size in each spatial unit shall be controlled in a reasonable range, which shall not be too small to hinder the scale effect population concentration brings or too large to cause aggregation diseconomy due to environmental and resource overdevelopment. Therefore, it has to harmonize population distribution and economic distribution. With the knowledge of evolution mode and development law of regional population distribution, taking sustainable development as guidance, comprehensive carrying capability of economy, society, resources and environment as constraint and the maximization of economic benefits, environment benefits and social benefits as the purposes, government or planner could drive the redistribution which makes regional population distribute rationally and promote regional economic growth expected in the long term.

Regional population distribution has a close connection with the economic, social, resource and environmental subsystem of regional development. Therefore, the development of factors related to the subsystems must be considered. Firstly, rationality of population distribution is the precondition of optimization. Secondly, regional population distribution should be coordinated with the level of regional economic growth. Finally, with the increasing destruction of ecological environment and the depletion of resources, scholars are looking for an effective way that is suitable for sustainable development so as to realize energy saving and emission reduction while trying to improve economic development.

6.3.2 Objectives

Based on the above chapters, the optimization objectives of regional population distribution mainly include three aspects as follows from the perspective of macroscopic analysis: to promote the core status of regional center cities and promote regional economic growth; to improve the regional competitiveness in order to radiate the national economy; to strengthen environmental protection, rationally utilize resources and improve the sustainability of regional economic and social development. The three optimization objectives are consistent with three factors of sustainable evolution of regional population distribution.

1) To promote the core status of regional center cities and promote regional economic growth

Center city is the core of regional development. Compared to general cities, center cities have significant characteristics. For example, the enormous agglomeration functions and innovation ability are the important factors of regional economic development, which may drive the harmonious development and prosperity of entire region and achieve the agglomeration of higher degree and larger scale. There are more advantages in the center cites than surrounding areas such as capital, technology, talents, information, infrastructures, market capacity, cultural activities and housing conditions. Various resources including labor force and production factors concentrate in the center cities and this brings about agglomeration economy and scale economy. Thus, with powerful functions and effect, the center cities become the growth poles, and play an important role in regional and national development. Therefore, the development of regional center cities is the core of development of the entire region.

People are the fundamental guarantee to accelerate the development of center cites. A certain population scale will promote economic development. Different development stage has different population size. Regional population distribution shall be adjusted according to the features of different development stage. In view of agglomeration and diffusion effect, the core status of center cities should always be emphasized no matter what stage it is in the economic development process. Therefore, optimization of the center city is the major objective because of center cities' powerful radiation effect.

2) To improve the regional competitiveness in order to radiate the national economy

Regional competitiveness is the capability that optimizes the resources allocation. It generally contains three aspects which are basic competitiveness, core competitiveness and dominant competitiveness. Natural resources, population size, capital, infrastructures, scientific and technical level determine basic competitiveness; regional core competitiveness generally refers to industrial competitiveness, and indicates the comprehensive development strength and potential of representative industry in one region; dominant competitiveness refers to the polarization and radiation capability which promotes the entire regional economic development under the circumstance of a certain market mechanism. The metropolitan area in American urbanization process is a successful case of regional development. As the core economic zones, metropolitan areas on the east coast of United States of whose urbanization rate has reached 90% promote the economic development of entire nation. Three economic zones in China (Yangtze River Delta, PRD and Beijing-Tianjin -Hebei Region) created nearly half GDP while the population size was less than 20% of national population in the past several decades. It is obvious that economic circle plays an important role in national development.

As a precondition, the basic competitiveness plays an important role in the process of regional development. Any industry will not develop without adequate supply of resource, population and capital. As the subject of spatial structure system, population distribution reflects agglomeration and diffusion capability which promotes regional economic growth. Therefore, the enhancement of regional competitiveness is the ultimate aim of optimization. In other words, the development of national economy will be radiated through structural optimization and powerful regional competitiveness.

3) To strengthen environmental protection, rationally utilize resources and improve the sustainability of regional economic and social development

Sustainable development is the aim humans pursue, which is achieved by effective environmental, resources and ecological protection. Environmental disruption and pollution caused by excessive economic development and population agglomeration is a big challenge for sustainable development. It is urgent and necessary to optimize regional population distribution due to the prominent contradictions between economy and nature, resources, ecology and environment. Sustainable development means sustainable utility of nature, resource, ecology and environment, thus, human survival and development shall meet the requirements in carrying capability. Rational utilization of natural resources, control of population growth, adjustment of economic structure, coordination of environmental protection and economic development and public participation policy are all the effective methods for sustainable development. Therefore, the coordination and unification of economic growth, social progress and ecological protection is the precondition to guarantee sustainable development.

The ultimate aim of sustainable development is not simple environmental and resource protection. Sustainable development not only just emphasizes resource, ecological and environmental protection but leaves enough development space for offspring while pursing economic growth, which is against the development pattern of maximizing economic benefits at the cost of damaging ecological environment and excessively exploring non-renewable resources. Sustainable development will gradually transfer resource-oriented economy to technology-oriented economy and improve the comprehensive benefits of society, economy and environment. Population distribution will be optimized and the resource and environmental pressure of cities caused by excessive population will reduce through industrial structure adjustment and rational distribution. The scientific and technical research and development will improve the utilization efficiency of resources and energy, reduce the emission of industrial waste gas, waste water and rubbish, purify urban air and create a comfortable production and living environment for the residents. These are all good methods to attract immigration.

6.4 Rationality Evaluation

6.4.1 Definition of Rationality Evaluation

The rationality of regional population distribution in this thesis mainly refers to the inter-coordination relationship between population distribution and its influential factors. Under certain social and economic background and resource and environmental conditions, the carrying capability of social economy, resource and environment is limited. Most previous studies only aim at the research work of just one aspect which either carrying capability of resource and environment or carrying capability of social economy (Lin et al, 2011; Liu, 2012). There are limitations without considering the mutual influence of three factors that are economy, society and environment. Sometimes, cities with abundant resources and sound environment are not always at the high level of local economic development. For example, compared to plain area, mountainous area has abundant resources and favorable ecological environment, however, economy is still at the low level due to the shortage of geographical advantage, and just high resource carrying capacity cannot promote regional population growth and urbanization. Therefore, resource and environment is the foundation, social economy is the condition and infrastructure is the guarantee. The study in rational population distribution is significant under the mutual effect of three factors. Sustainable development requests factors of the entire system to coordinate with each other, and the rational population distribution is the precondition of ordered system. Therefore, it is significant and important to judge and evaluate the rationality of population distribution. This chapter aims at investigating the rationality evaluation method of regional population distribution, laying foundations for the sustainable development of the whole nation's social economy.

6.4.2 Model Development of Rationality Evaluation

Regional population distribution is influenced by economic development, living standard, population size, resources, environment and infrastructures. The research is conducted from three aspects that are resource and environmental carrying capacity, economic carrying capacity and social carrying capacity. Where, the resource and environmental carrying capacity refers to the population size carried by certain natural environment per unit area; the economic carrying capacity refers to the population size carried by certain economic level per unit area; the social carrying capacity refers to the population size carried by certain social resources per unit area.

The standard indicator here refers to the average level of the reference region.

This research focuses on the comprehensive effect of resource and environment, economy and society on regional population distribution, thus explores the comprehensive carrying capacity of resource and environment, economy and society. For convenience, we suppose the research area is an independent closed system without transactions with other regions, namely the population size in different areas depends on the comprehensive carrying capacity determined by the natural environment and resources, social resources and economic development level.

The formulas of population capacity of resource and environment, economic level and social resources in spatial unit *i* based on the analysis above are as follows:

$$ {}_{R}P_{I} = \sum_{i=1}^{n} R_{i} f_{i} / \sum_{i=1}^{n} f_{i} \tag{6-1} $$

$$ {}_{E}P_{I} = \sum_{i=1}^{n} E_{i} f_{i} / \sum_{i=1}^{n} f_{i} \tag{6-2} $$

$$ {}_{T}P_{I} = \sum_{i=1}^{n} T_{i} f_{i} / \sum_{i=1}^{n} f_{i} \qquad (6\text{-}3) $$

Where, ${}_{E}P_{I}$ is the population capacity of economy； E_i is the ratio of gross index of economic development and standard per capita index in *i*; ${}_{R}P_{I}$ is the population capacity of resources; R_i is the ratio of gross index of natural resources and standard per capita index in *i*; ${}_{T}P_{I}$ is the population capacity of society; T_i is the ratio of gross index of social development and standard per capita index in *i*; f_i is the weight.

The carrying capacity of resources, economy and society are calculated as follows:

$$ {}_{E}D_{I} = {}_{E}P_{I} / S_{I} \qquad (6\text{-}4) $$

$$ {}_{R}D_{I} = {}_{R}P_{I} / S_{I} \qquad (6\text{-}5) $$

$$ {}_{T}D_{I} = {}_{T}P_{I} / S_{I} \qquad (6\text{-}6) $$

Where, S_I is the land area of spatial unit *i*.

Based on ${}_{R}D_{I}$, ${}_{E}D_{I}$ and ${}_{T}D_{I}$, population, natural resources, economic development level and social resources could be analyzed comprehensively, and the expression of comprehensive carrying capacity ${}_{ERT}D_{I}$ is like:

$$ {}_{ERT}D_{I} = {}_{Ra} \times {}_{R}D_{I} + {}_{Ea} \times {}_{E}D_{I} + {}_{Ta} \times {}_{T}D_{I} \qquad (6\text{-}7) $$

Where R_a，E_a，T_a are the model parameters, and suppose $R_a+E_a+T_a=1$.

Taking real population density D_I as dependent variables and ${}_{R}D_{I}$ 、 ${}_{E}D_{I}$ 和 ${}_{T}D_{I}$ as independent variables, a multiple linear regression model is developed as follows:

$$D_I = A + B({}_{Ra} \times {}_R D_I + {}_{Ea} \times {}_E D_I + {}_{Sa} \times {}_S D_I) \qquad (6\text{-}8)$$

Where, B is the model parameter.

We can get the regression model with maximum R^2 through adjusting the value of parameters R_a, E_a, T_a. Here, R_a, E_a, T_a are the parameters of ${}_{ERT}D$.

6.4.3 Result Analysis

The model judges whether the population in each spatial unit or city is coordinated with resource and environment conditions, economic development level, social resource foundation and the combined effects, thus gets the rationality evaluation results of population size in that spatial unit. The evaluation results could be interpreted from four aspects as follows:

When the resource and environmental carrying capacity exceeds the actual population density, namely ${}_R D_I > D_I$, it indicates that the population carried by resources and environment in unit area is surplus when compared to actual population density, in other words, the population pressure does not exist; when ${}_R D_I < D_I$, it indicates that the population carried by resources and environment in unit area is insufficient, namely there exists population pressure; when ${}_R D_I = D_I$, it indicates the actual population size in this area is consistent with the maximum population size carried by the resources and environment.

When the carrying capacity of economy exceeds actual population density, namely ${}_E D_I > D_I$, it indicates the population carried by the current economy in unit area is surplus when compared to actual population density, in other words, the population pressure does not exist; when ${}_E D_I < D_I$, it indicates the population carried by the current economy in unit area is insufficient, namely the population pressure exists; when ${}_E D_I = D_I$, it indicates the actual population size in this spatial unit is consistent with the maximum population size carried by current economy.

When the social carrying capacity exceeds actual population density, namely ${}_S D_I > D_I$, it indicates the population carried by social resources in unit area is surplus when compared to actual population density, in other words, the population pressure does not exist; when ${}_S D_I < D_I$, it indicates the population carried by social resources in unit area is insufficient, namely the population pressure exists; when ${}_S D_I = D_I$, it indicates the actual population size in this area is consistent with the maximum population size carried by social resources.

When the comprehensive carrying capacity of three factors exceeds actual population density, namely ${}_{ERS} D_I > D_I$, it indicates the population carried by comprehensive factors in unit area is surplus when compared to actual population density, in other words, the population pressure does not exist; when ${}_{ERS} D_I < D_I$, it indicates the population carried by comprehensive factors in unit area is insufficient, namely the population pressure exists; when ${}_{ERS} D_I = D_I$, it indicates the actual population size in this area is consistent with the maximum population size carried by resources and environment, economy and social resources.

The above results analyze three possible results of population distribution rationality evaluation from four aspects.

${}_R Q_I = {}_R D_I / D_I$, ${}_E Q_I = {}_E D_I / D_I$, ${}_S Q_I = {}_S D_I / D_I$

${}_{RES} Q_I = {}_{RES} D_I / D_I$

The expressions above indicate the deviation degree of carrying capacity. Criteria of evaluation is divided according to comparison of results above and 1. In addition, according to the results of model and optimization scheme of future population distribution, it may divide the whole research area into population encouraging increase area, moderate increase area, stable area, controlling increase area and population decrease area.

The population encouraging increase area will become the main area of population agglomeration and growth in the future; the moderate increase area may moderately concentrate people while paying attention to the control of aggregate population growth; the stable area should remain stable with little changes; the controlling increase area may control population agglomeration; the population decrease area has to try to reduce population.

When $Q \geq 1.1$, compared to actual population, the carrying capacity determined by the natural environment and resource conditions, economic development level, social resource foundation and comprehensive factors is sufficient obviously. The area belongs to population encouraging increase area.

When $1.0 \leq Q \leq 1.1$, compared to actual population, the carrying capacity determined by the natural environment and resource conditions, economic development level, social resource foundation and comprehensive factors is sufficient, while the degree is lighter than case 1. The area belongs to moderate increase area.

When $0.9 \leq Q \leq 1.0$, compared to actual population, the carrying capacity determined by the natural environment and resource conditions, economic development level, social resource foundation and comprehensive factors is critical, namely hold the line with actual population and there is no population pressure. The area belongs to stable area.

When $0.8 \leq Q \leq 0.9$, compared to actual population, the carrying capacity determined by the natural environment and resource conditions, economic development level, social resource foundation and comprehensive factors is insufficient, while the degree is light, indicating the population pressure exists in the area. The area belongs to controlling increase area.

When $Q \leq 0.8$, compared to actual populations, the carrying capacity determined by the natural environment and resource conditions, economic development level, social resource foundation and comprehensive factors is insufficient obviously, indicating the population pressure is serious. The area belongs to population decrease area.

6.4.4 Contribution Degree Analysis

Contribution degree is an index to analyze economic benefits initially, which is widely applied to the analysis on other social benefits. Generally, it refers to the effect of certain factor in economic and social activities. The purpose of solving contribution degree of influence factors is to acquire the contribution degree of economic development level, social resource foundation and environment and resources condition to regional population distribution.

According to the regression model of actual population density and carrying capacity of environment and resources, economy and society, coefficient R_a、E_a and S_a can be derived, and the expression of comprehensive carrying capacity is like,

$$_{ERS}D_I = _{Ra} \times _R D_I + _{Ea} \times _E D_I + _{Sa} \times _S D_I .$$

The contribution degree of each factor is indicated with $_R G_I$, $_E G_I$ and $_S G_I$ respectively, namely:

$$ {}_{R}G_{I} = \frac{R_{aR}D_{I}}{R_{aR}D_{I} + E_{aE}D_{I} + S_{aS}D_{I}} \times 100\% \qquad (6\text{-}9) $$

$$ {}_{E}G_{I} = \frac{E_{aE}D_{I}}{R_{aR}D_{I} + E_{aE}D_{I} + S_{aS}D_{I}} \times 100\% \qquad (6\text{-}10) $$

$$ {}_{S}G_{I} = \frac{S_{aE}D_{I}}{R_{aR}D_{I} + E_{aE}D_{I} + S_{aS}D_{I}} \times 100\% \qquad (6\text{-}11) $$

The contribution degree above may reflect the influence degree of economic development level, social resource foundation and resource and environment conditions on the structural change of regional population distribution. The value changes of contribution degree reflect the strengthening or weakening of influence degree. The contribution degree could identify the main factors of different population size. Therefore, different optimization strategy will be adopted for different cities.

6.4.5 Key Points

After specific analysis of the model above, in case study we focus on investigation of deviation degree and contribution degree when fitting the regression model.

The analysis of deviation degree helps reveal the residual space according to the value of deviation degree, namely the proper population size under the circumstance of current economy, society, resources and environment. The value is not constant, which will be adjusted along with the development of regional economy. Therefore, deviation degree is the guidance for macro-control.

The analysis of contribution degree reveals the factors of population movement through value comparison of the contribution degree (%). The irrationality of population size and discordance with economy, environment and society will be discovered through analysis of deviation degree.

With the multi-objective programming model introduced in next section, the deviation degree is an effective method to calculate actual residual space for optimization and to drive the evolution of regional population distribution. Deviation degree provides technical support for the optimization decision making in micro-level.

6.5 Optimization and Government Regulation

The optimization of population distribution generally is accompanied by the economic regulation, the adjustment of industrial distribution and the optimization of economic spatial structure. Regulation and control of population distribution just aims at promoting economic development before, the methods applied, however, didn't consider the tense situation of resources and environment nowadays. This research comprehensively takes the influence of resources and environment carrying capacity, economic carrying capacity and social resources carrying capacity into account, with the aim of developing an optimization model to adjust regional population distribution and achieve rational redistribution. The government formulates optimization scheme to drive the sustainable development of regional population distribution.

The regulation and control of regional population distribution will not only guarantee the sustainable development of economy, but also make contributions to the sustainable development of the society and ecological environment. Therefore, it is inevitable to optimize the structure of population distribution which is good for social and economic sustainable development. The optimization of population distribution on one hand tries to improve the serious situation of resources and environmental damages caused by mankind's producing activities and living behaviors, and on the other hand drives the updating of economic spatial structure and population spatial structure. Therefore, optimization and regulation with certain objective shall be continuous and carrying on logic acceptance, belonging to long-term strategic plan.

6.5.1 Model Development of Multi-objective Programming

As shown in the view of sustainable development, the economic growth is not all the content of sustainable development, while the most important thing has ever be neglected, namely whilst economic growth, the human activities damage and threaten the basic elements of ecological system which influence the sustainable development of human society. Therefore, compared with the adjustment of economic growth, research about optimization can be extended to sustainable development of social economy.

The optimization of regional population distribution from sustainable development perspective involves multiple industries, taking the maximum benefits in society, economy and environment as the optimal objective. It is a nonlinear risk decision problem. Urban multi-objective population optimization will maximize social, economic and environmental benefits through a series of constraint conditions.

This research develops multi-objective programming model to study the optimization function with more than one objective in given area. Multi-objective programming model is shown as follows:

$$\mathrm{opt}F(x)=\left[f_1(x),f_2(x),\cdots,f_P(x)\right]^T \quad (6\text{-}12)$$

$$g_i(x)\le b_i\,,\quad i=1,2,\cdots,m$$

The above expression indicates the feature of multi-objective in optimization function. The economy, society and environment influence the employment in each industry, therefore, it should considerate economic benefits, resources and environment benefits and social development benefits while optimizing regional population distribution. Based on the sustainable development thinking, this chapter builds the optimization model with an aim of maximizing economic benefits, social benefits and environmental benefits. For convenience, the model established below only considers the optimization in employed population distribution, without considering the non-employed population.

The model expression is as follows:

Economic benefits objective is $f_1(x)$, and here we maximize it:

$$\max f_1(x) = \sum a_i x_i \qquad (6\text{-}13)$$

Environment benefits objective is $f_2(x)$, and the maximization is:

$$\max f_2(x) = \sum b_i x_i \qquad (6\text{-}14)$$

Social benefits objective is $f_3(x)$, and the maximization is:

$$\max f_3(x) = \sum c_i x_i \qquad (6\text{-}15)$$

Constraint conditions are as follows:

Constraint of comprehensive carrying capacity of economy, society, resources and environment:

$$\sum x_i \leq_{ERT} D_I \cdot S_I \qquad (6\text{-}16)$$

Constraint of population size under the condition of urban growth:

$$\sum x_i > \sum P_i^{'} \qquad (6\text{-}17)$$

Constraint of change in population size of industry i:

$$P_i(1-\gamma_i) \le x_i \le P_i(1+\gamma_i) \qquad (6\text{-}18)$$

Where, a_i is the economic benefit coefficient of industry i; b_i is the environmental pollution coefficient of industry i; c_i is the social benefit coefficient of industry i; $_{ERT}D_I$ is the comprehensive carrying capacity of economy, society, resources and environment in city I; P is the actual population size of industry i; P_i is the actual population size of industry i last year; γ_i is the growth rate of employed population in industry i.

$f_1(x)$, $f_2(x)$ and $f_3(x)$ reflect economic benefits, environmental benefits and social benefits respectively, others are constraint conditions. x_i is decision variable, indicating the employed population in industry i.

In order to accelerate urbanization process, the constraint condition is that the employed population after optimization exceeds or equals to the population size before optimization.

We utilize genetic algorithm toolbox in MATLAB software to do algebraic cycle computation and get the optimal solution for multi-objective programming problem. The practical optimization scheme will be formulated based on the optimization results.

6.5.2 Government Regulation

Chapter 5 identifies the factors of capacity for population agglomeration and diffusion which include economic scale, traffic accessibility and comprehensive environmental level. The regional economic development directly influences population distribution, which could be reflected in the division of industrial structure. Such factors as resources, environment, population size, transportation and national policy indirectly affects the spatial structure of population distribution through restricting economic scale and development speed. Policy making should be dominant in economic structure optimization, matched with the development of transportation system and resource and environmental protection, which is a sustainable development pattern for regional population distribution.

1) Regulation at administrative level

Administrative means is the method to adjust and manage national economy adopting mandatory administrative orders, instructions and regulations through administration, and it generally plays a role together with market regulation. Administrative regulation is the rule and measure in organizations, conditions and controlling macroeconomic activities formulated and implemented by the government for economic purposes. Administrative power is exerted in the process. As for the excessive development and environmental damage during urbanization process, the government could take administrative measures like administrative orders, project approval, investment license and quota to control urban land sprawl and excessive exploitation of natural resources and grave pollution of environment, and stop such improper behaviors in terms of unfair transaction, monopoly and seeking for excessive profits at the cost of the benefits of offspring. The government may lead to participate in the resource and environmental protection and projects of infrastructures construction (road, railway, etc.), and pay attention to the sustainable region development while emphasizing economic growth and perfecting social resources. The government may also attract highly educated talents through setting talent introduction plan.

In addition, it is important to use administrative means from economic perspective. Government could plan economic distribution with graded industrial pattern. Modern service industry concentrates in urban center, therefore the new industrial park should be arranged in suburb, the assembly locates in surrounding satellite cities and the parts production area is built in the medium and small towns at lower level. This configuration mode from the top down is conductive to form areas with graded industrial pattern and extend industrial chain. It is sound industrial distribution pattern in metropolitan area. The government should attract investments through reducing entry conditions. The graded industry may provide different kinds of employment opportunities. People could choose jobs according to their preferences. The population flow will follow with employment, thus the graded population distribution pattern will be formed gradually. The industrial arrangement may not only improve the capacity of population agglomeration in medium and small cities but reduce the pressure of center cities.

2) Regulation at legal level

Both developed countries and developing countries will experience rapid urbanization process at the beginning of their development stage. Rural to urban migration will exert huge pressure on urban resources, environment and economy. This kind of urban population growth brings about urban land sprawl, because along with the economic expansion, industrial land gradually occupies the agricultural land and even wetland. It is a kind of economic growth development pattern at the cost of natural resources, which overlooks the long-term benefits of regional development.

After World War II, the economy of London developed rapidly and the urbanization process drove the urban expansion that brought huge pressure on the agrarian protection. In order to contain the loss of farmland, London's government encouraged 'development of greenbelt land' and bought land to develop Green Barriers, in order to correctly guide sustainable development, relieve environmental disruption and plunder of future benefits. In the early stage of German urbanization, the problems of residence shortage and bad living conditions appeared. In order to take social and public interest into account, the government issued a series of decree to standardize construction of municipal infrastructures and public utilities. It not only paid attention to the harmony and unity of spatial planning and municipal infrastructures, but also protected historical and cultural buildings and natural ecological environment in the inner city and periphery. Japan combined villages and towns to achieve intensive land use. As a country with special system, China may regulate population distribution through household registration system like tightly control of the household registration in metropolis and large cities, easy admission of household registration in medium and small cities. Household registration system can not only relieve such problems of high population density, resource shortage and traffic jam in center cities, but also avoid population shortage in small towns. In addition, the government may restrain land overdevelopment through tax system. In short, the government may build specialized regional planning department and incorporate regional planning into the legal obligations of local government.

6.6 Summary of the Chapter

From the perspective of sustainable development, this chapter studies the rationality evaluation and optimization model for regional population distribution. Significance, characteristics and objectives of optimization are discussed respectively. After this, rationality evaluation model and multi-objective model are developed to optimize regional population distribution. According to the optimization results, government can make effective strategies from administrative level and legal level.

Chapter 7 Framework Validation - A Case Study

7.1 Introduction

In this chapter, a practical case study which can serve as the framework validation, in essence, an integrated and systematic approach to analyzing evolution mechanism and optimizing distribution structure is conducted and the process is illustrated using a case study of Guangdong Province in China. An overview of the case study area is introduced first. Then, evolution mechanism of population distribution is analyzed using mathematical model established in Chapter 4 then. After this, the improved population density function is used in the PRD region to reveal factors of population agglomeration capacity. Finally, rationality evaluation and optimization are put into practice. Based on the case study results, strategies for sustainable evolution of regional population distribution are proposed.

7.2 Overview of Case Study Area

Guangdong is a province located in south China including 21 prefecture-level cities. According to the sixth census in 2010, with the permanent population of 104 million, Guangdong Province made up around 15 percent of the national economic aggregate which had already exceeded Singapore, Taiwan and Hong Kong. Guangdong has become the province to improve the national economy. Therefore, as a representative to show the regional population distribution under the background of rapid economic development and urbanization, China’s Guangdong Province is selected to conduct case study in this project. Results could be a reference of policy making.

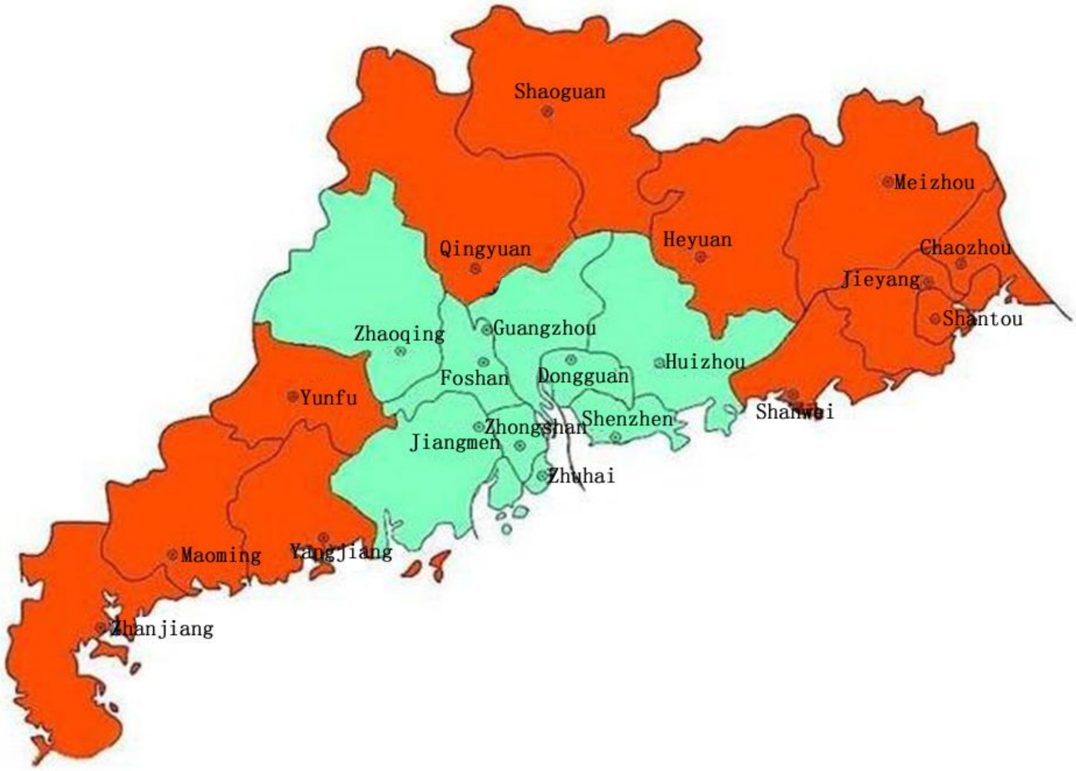

Figure 7.1 Location of cities in the PRD region

In order to describe the reality of regional population distribution exactly, when we valid the density function and factors of center cities' agglomeration and diffusion capacity, research area will narrow to the PRD in Guangdong Province and research unit is precise to county. Location of cities in the PRD region is shown in figure 7.1. The PRD region is one of the three biggest agglomerations in China, the others being Yangtze River Delta and Beijing-Tianjin-Hebei region. Since the reform and opening-up policy in 1979, the PRD has taken the lead in economic reform, development and urbanization of Guangdong province and even the whole country (Shen, 2002a; Wong et al., 2002; Yeung et al., 2005). The PRD has different definitions in different development stages. In this paper the PRD refers to the PRD Economic Region formally designated by the Guangdong government in 1994 (Shen, 2002a). It consists of nine Cities including 24 area units which are treated as independent units in this study. Being one of the three big economic circles in China, PRD has become the development engine of national economy. Meanwhile, the urbanization rate of PRD holds the first place of China. This region has a total area of 5.47 thousand square kilometers and a population of 47.86 million (the PRD yearbook, 2010). It creates about 70% GDP of Guangdong province with only 30% population. Therefore, it is a good representative to show evolution pattern of regional population distribution in this rapid urbanization world.

According to the Reform and Development Plan of the PRD region (2008-2020), the PRD region is divided into three economic circles. They are Guang-Fo-Zhao economic circle, Shen-Guan-Hui economic circle and Zhu-Zhong-Jiang economic circle (Figure 7.2). Guangzhou, Shenzhen and Zhuhai are three centers of these economic circles (NDRC, 2008).

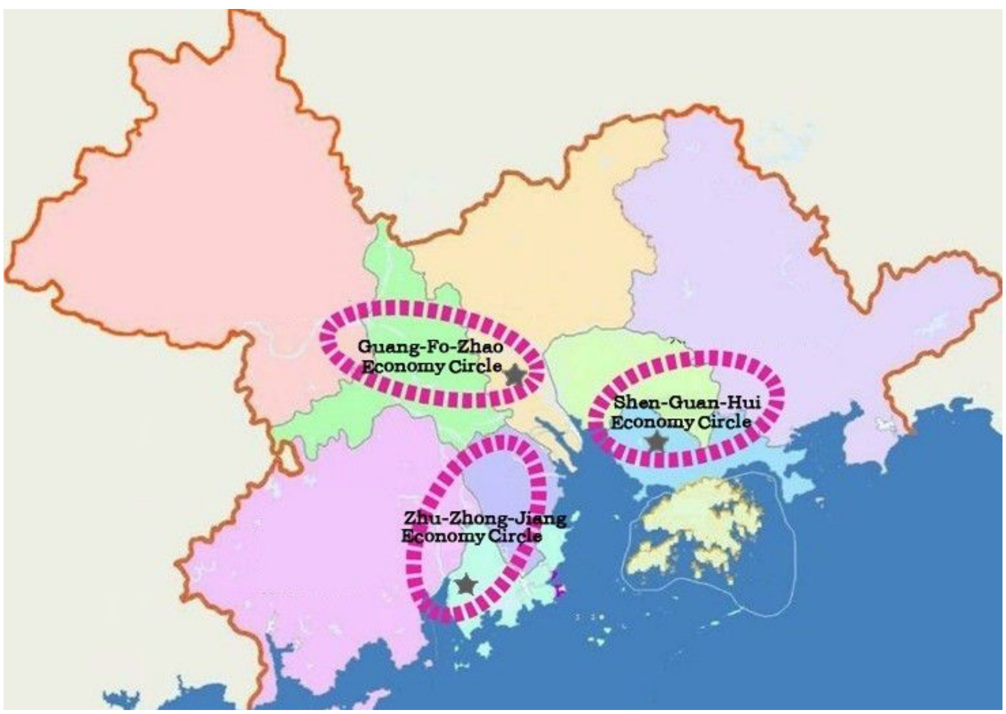

Figure 7.2 Diagram of three Economy Circles in the PRD Region [source: NDPC]

7.3 Evolution Mechanism Analysis

7.3.1 Driving Force of Sustainable Population Growth

A conceptual model of sustainable population growth has been established in Chapter 4. Regression analysis is employed to explore the relationship between theoretical factors and urban population growth in case study. As independent variables, original urban population is used to reflect urban size while residential land share of constructive land represents living environmental factor in natural increase part. Alternatively, in the mechanical increase part, as adopted in the study of Hanson (1998; 2005), transportation distance instead of transport cost is used to estimate the spatial relationship between sample city and center city (Partridge et al., 2009), while population number of the dominant industry is selected to show industrial agglomeration effect.

7.3.1.1 Indicator Selection

In Chapter 4, hypothesis is conducted according to the multi-disciplinary theoretical foundation including classical economics, spatial economics and the view of sustainable development. A set of indicators are selected to explain the growth mechanism of urban population (see Table 7.1). Selection of independent variables should follow the three principles: (1) data is available; (2) variables are measurable; and (3) serious multicollinearity problem among independent variables should be avoided. Classical shift-share tool is adopted to analyze the regional employment increase and screen out the dominant industry. Basically, shift-share analysis is decomposed into three effects: national growth effect also called share effect, industry mix effect and competitive effect (Barff & Knight, 1988). The model is expressed in mathematic terms as:

$$
\begin{aligned}
\Delta e_i &= e_i^t - e_i^{t-1} = e_i^{t-1}\left(\frac{e_i^t}{e_i^{t-1}} - 1\right) \\
&= e_i^{t-1}\left(\frac{E^i}{E^{i-1}} - 1\right) + e_i^{t-1}\left(\frac{E_i^t}{E_i^{t-1}} - \frac{E^t}{E^{t-1}}\right) + e_i^{t-1}\left(\frac{e_i^t}{e_i^{t-1}} - \frac{E_i^t}{E_i^{t-1}}\right)
\end{aligned}
\tag{7-1}
$$

Where $e_i^{t-1}\left(\frac{e_i^t}{e_i^{t-1}} - \frac{E_i^t}{E_i^{t-1}}\right)$ represents industrial competitiveness of city *i*.

Table 7.1 The independent variables and their meanings

Determinants	Detail Explanation	Variable	Code of Variable	Unit
Original urban size	Original urban population	City size of city i in terms of city population	Sizei	1000 persons
Living environment	Urban land-use structure	Residential land share of constructive land of city i	Landi	Percent (%)
Industrial agglomeration	Dominant industry competitiveness	Employed population of the competitive industry of city i	Industryi	1000 persons
Location	Transport cost	Distance from city i to the regional center cities	Distancei	Kilometers

Stepwise regression method is employed to solve multi-collinearity problems. It is an automatic procedure for statistical model selection with many potential explanatory variables.

In the case study, 21 prefecture-level cities from Guangdong province of China, with year span from 2000 to 2010, have been selected to conduct case study. Raw data were obtained from the Guangdong statistical yearbook, Guangdong Statistical Yearbook of Industry and Guangdong City Survey Statistical Yearbook. The sample data is showed in Table 7.2.

A multiple linear regression model is built up to analyze the urban growth from the perspective of population growth. Growth amount of urban population is set as dependent variable in this model, while the independent variables are original population, residential land share of constructive land, distance to Guangzhou and Shenzhen, population growth amount of dominant industry. This paper tries to find out the relationship between urban population growth and these variables.

Table 7.2 Data illustration for case study

	Population growth from 2000 to 2010 (1000 persons)	City population in 2010 (1000 persons)	City population in 2000 (1000 persons)	Residential land share of constructive land (%)	Employed population of dominant industry (1000 persons)	Distance to the regional center cities (kilometers)
Guangzhou	2761.60	12709.60	9948.00	0.32	652.80	136.00
Shenzhen	3359.60	10372.00	7012.40	0.26	2270.60	136.00
…	…	…	…	…	…	…
…	…	…	…	…	…	…
Yunfu	636.90	5883.00	5246.10	0.36	35.10	752.00

After stepwise regression, residential land share of constructive land is released in case model, since multi-collinearity exists between variables of original urban size and living environment which pose effects on the results of t-test. Original population is similar to the residential environment to a certain extent, as the residents shall prefer to live inside the city on the condition of sound living environment.

7.3.1.2 Regression Results

The best regression model with three independent variables, i.e., original urban population, employed population of competitive industry and distance between sample city and center cities, is finalized by comparing the results of regression analysis. These three variables are entered as a block in a single step in the linear regression model under the use of SPSS software package. Table 7.3 lists the results.

Table 7.3 Results of model with Size*i*, Industry*i* and Distance*i*

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
	79.3538	35.6800		2.2240	0.0399*
Size*i*	0.2411	0.0789	0.4052	3.0533	0.0071**
Industry*i*	2.7733	0.9257	0.4240	2.9956	0.0081**
Distance*i*	-0.1615	0.0717	-0.2596	-2.2517	0.0378*

Note: Dependent variable is urban population growth from 2000 to 2010. And the adjust R^2 is 0.80.

*Estimate is statistically significant at the 0.05 level.

**Estimate is statistically significant at the 0.01 level.

The regression equation is $\Delta P = 79.35 + 0.24P + 2.77E - 0.16L$ (7-2)

Overall, the results are consistent with the theoretical analysis. All the independent variables show close relationship with the urban population growth at the 5% statistically significant level. Among the three independent variables, the original urban population and competitiveness of dominant industry have positive relationships with urban population growth, whereas distance to the two center cities (Guangzhou and Shenzhen) exhibits negative relationship with dependent variable. The regression results pass F-test, with the goodness of fit of 0.8. In the natural increase part, it is the original urban population size that contributes to urban growth, while in the mechanical increase part the contributive effect arises from both industrial competitiveness and location. Owing to the fact that China's development is still at the beginning stage and its growing economy doesn't reach scale agglomeration, industry and transport factors are both the centripetal forces to urban growth. This kind of agglomeration resulting in urban population increase derives from the combined effects of industry and location.

Specifically, in order to explore the relationship between urban population and residential land, residential land share of constructive land as the independent variable is applied to run the regression model where urban population was used as the dependent variable. Regression results are presented in Table 7.4.

Table 7.4 Results of model with Land*i*, Industry*i* and Distance*i*

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
	219.6024	93.0136		2.3609	0.0304*
Land*i*	2.5973	0.7751	0.5050	3.3510	0.0037**
Industry*i*	0.0007	0.0002	0.3943	2.4993	0.0229*
Distance*i*	-0.3449	0.4369	-0.1128	-0.7892	0.4408

Note: Dependent variable is urban population in 2010. And the adjust R^2 is 0.73.
*Estimate is statistically significant at the 0.05 level.
**Estimate is statistically significant at the 0.01 level.

The variables of Land*i* and Industry*i* pass t-test, showing great significance between residential land share of constructive land and urban population with a p-level of 0.0037. However, when the dependent variable is changed to urban population growth for model regression, the residential land share of constructive land becomes not significant with population growth but the location variable gets a better result on population growth and passes t-test. It can explain 68 % of variance information. Results of residential land and location factors in Table 7.4 are not consistent with that of Table 7.5. This contradiction of Land*i* illustrates that urban growth has little significance on the residential land share of constructive land but has great significance on industry and location factors since 2000. The results imply that Guangdong Province paid more attention to the industrial development but less attention to the civilian's living conditions after entry into the new millennium. Regarding the location contradiction on urban growth, location factor has little influence on urban growth around 2000, but it becomes increasingly important in the following 10 years. The results finally show that location factor is inevitably the centripetal force of regional growth in this theoretical model. Industrial competitiveness all gets significant results on urban growth in the two models, which implies that not only in the early stage of the 20th century but also in the most recent decade, industrial agglomeration consistently influences the urban population growth.

Table 7.5 Results of model with Land*i*, Industry*i* and Distance*i*

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
	80.4217	19.8063		4.0604	0.0008**
Land*i*	0.0389	0.3267	0.0192	0.1190	0.9066
Industry*i*	4.8919	0.9654	1.1989	5.0672	0.0000**
Distance*i*	-0.1527	0.0312	-1.1406	-4.8873	0.0001**

Note: Dependent variable is urban population growth from 2000 to 2010. And the adjust R^2 is 0.68

**Estimate is statistically significant at the 0.01 level.

Urban growth derives from natural increase and mechanical increase which actually are three aspects of living, economy and location. The regression results are consistent with the theoretical analysis in that urban growth depends on the basic condition of urban size, living environment, economic promotion and location superiority. Firstly, the original urban size is always the essential part for examining urban population growth because it can reflect the basic condition of a city. There is no doubt the fact that a city with a big urban size would attract more migration and less emigration. Just like the metropolis of Guangzhou and Shenzhen, people prefer to move in while not move out, resulting in the consistent growth of total population. Population concentration is pervasive for China's cities as the economy is still at the growing stage. Secondly, in view of comfort and amenity, good living condition would attract more residents. This paper uses residential land share of constructive land to reflect the current situation of living environment. The contradiction of residential land between Table 7-4 and Table 7-5 shows that in the past decade, government paid more attention to industrial development than people's living, and concurrently recorded the symptom of unreasonable land-use structure. Thirdly, most urban growth is promoted by economy in market environment, especially in developing countries.

Economic level influences employment, and even the migration direction and population distribution (Mueser & Graves, 1995). In this paper, results of the three models imply that economic factor which also means the competitiveness of dominant industry always has principal and effective effects to promote urban growth irrespective of the dependent variables selected. Finally, the contradiction of location between Table 7.4 and Table 7.5 reveals the fact that, to some extent, the effect of location has been composited on the living condition in the early stage of this decade, so it has no significance with urban population. However, such effect appears gradually apparent in recent years. In summary, it can be generally concluded that urban size, living environment, dominant industry agglomeration and location are the influential factors for the urban and regional growth. Further issue arising from this conclusion is the question of finding an effective method to promote urban growth in cities of China, which will be discussed in depth in the following section.

7.3.2 Strategies

Regional planning deals with the efficient placement of land use activities, infrastructure, and settlement growth across a larger area of land than an individual city or town. In view of the similarity of land use, infrastructure and population growth to the determinants or driving force of urban population growth, this study could be expanded from the regional planning perspective.

The previous analysis unveils the important factors to urban growth as comprising living, economy and location among which, industrial competitiveness has consistent significance to urban growth, implying that, to a large extent, the economic factor plays an important role in promoting urban growth. Scale effect of industrial agglomeration promotes regional growth.

Government should encourage industrial agglomeration considering its function to save resources. Based on the extant dominant industry of certain city, industrial planning direction could be confirmed and some supportive policies could be developed by the government to magnify the existing dominant industry. This dominant industrial agglomeration attracts employment and brings about settlement growth. It is an effective method to promote urban and regional growth. In the past decade, location effect on urban population growth is obvious. This phenomenon proves the theory in spatial economy that manufacturer place and industrial location are the main influential factors in regional trade. The influence of center cities should be maximized through building highway and railway, which concurrently magnifies the location advantage of peripheral cities. Along with the rapid economic development, resource waste and environment pollution have become increasingly serious (Liu & Diamond, 2005). The research results show the decrease of the significance of the residential land in the past decade implies that government paid more attention to the economic development rather than the civilians' living. The unreasonable land-use structure not only resides in Guangdong Province, but also in other parts of China. (Feng & Chen, 2010; Dai, Wang & Gao, 2010). Movement of regional industrial structure leads to the transformation of land-use pattern and structure. Industries break up the constraint of land resource, and occupy residential land, arable land, even open space and green area in the city. This land-use pattern goes against to the requirements of sustainable development.

Regional development engine is the policy issue for China's government. Developed region will promote national economy through conduction effect of market mechanism. This is particular suitable to China as a developing country at the growing stage, where policy plays an important part in promoting regional development. In retrospect of the policy proposed by Dengxiaoping who is the great leader in China, faster development of coastal region could spur better development in the interior regions (Yeung & Li, 2004). Policies are urgently needed by the regional and center government to guarantee fast regional growth. Under the explanatory framework of urban growth, this study proposes detailed policies applicable for the local government to promote urban growth.

1) Policy for the economic factor

Among the four indicators, industrial factor gets the best results on urban growth no matter which model is selected. At all times, dominant industry keeps promoting the employed population and regional growth. Based on industry classification, shift-share analysis is used to find out the dominant industry in a certain city. It is important for the government to recognize the dominant industry and provide policy support to accelerate the development of those competitive industries. Thus economic factor could promote the regional growth to the maximum extent. Hence, initially, government may increase investment of technical innovation and upgrade for the dominant industry. Furthermore, investment promotion both from home and abroad is an effective method to activate the dominant industry. Finally, local government should ease the entrance requirement for the high-tech human resources and give relevant policy support such as housing and children’s education. Above all, cities should maximize the competitiveness of dominant industry in order to promote the entire regional growth.

2) Policy for the location factor

Location factor always focuses on the transport cost in New Economic Geography. In the early stage of regional development, little transport cost will promote the population and economic agglomeration. Improvement of traffic condition and transportation infrastructure will surely decrease the transport cost. So there is a necessity for the government to invest on the regional transport network. In order to maximize the location effect of the center cities, it is better for the region to build up transportation corridor system based on railways between two areas. Not only the center cities, but also cities as hubs and stops of the regional transportation corridor shall manifest its location superiority gradually with the operation of the proposed transportation corridor system. To a certain extent, such strategic behavior will increase urban service function, optimize transport system and promote the combination of regional spaces. With a net and multi-centers transportation system, it is possible for manufacturers to reduce the transport cost from one city to another. Transportation improvement is necessary to promote the regional economic integration and agglomeration development.

3) Policy for the living environment factor

Living conditions consist of many aspects, of which urban land-use structure was taken into account in this study. Government's initiative to improve the land-use structure is imperative for providing enough living space to for residents. The research results reveal that recently government has paid less attention to residents' livelihood. In developed countries, the percentage of residential land is more than 40% while the industrial land rate is relatively low. Government can properly increase the rate of transport land, green area, public and open spaces as the measures to improve the living conditions of residents. Alternatively, the government could resort to conserving prime agricultural land resources and reducing the occupation of industrial land (Zhang et al., 2011; Tan et al., 2008). Industrial land use should be changed from dispersive pattern to concentrate pattern. Transformation of industrial land-use pattern will promote spatial agglomeration. Effective coordination of urban construction, land use and living environment is a sustainable development pattern that will ensure reasonable utilities and maximize the effects of urban land. Various sectors such as land-use research area have drawn great attention to sustainable urban development (WCED, 1987). If the current and future urban areas continue to be with high rate of industrial land and low rate of residential land while the future needs are not taken into consideration, then the environmental, social and economic problems are inevitable (Daily, 1997; Millennium Ecosystem Assessment, 2003).

Reasonable regional planning is effective in promoting both urban and regional growth. Hence, government should plan for a sustainable regional development pattern while taking account of solving the problem of resource waste and optimizing population distribution and industrial structure. Effective coordination of urban construction, economic development, land use and living environment is essential to the sustainable regional development.

7.4 Regional Population Density Model

7.4.1 Regional Center Cities Identification

Population and economic centers can be calculated according to the spatial autocorrelation analysis method mentioned in Chapter 4. We use Google Earth to get the shortest travelling distance and Euclidean distance between two area units. Improved spatial weight matrix was put into software model of ArcGIS Toolbox. After calculating local Moran's I index and testing the standardized statistics Z, we got results that were shown in Table 7.6.

Table 7.6 Cities with high concentration and their agglomeration patterns

Indicator	Cities of significance distribution	Agglomeration pattern
Per Capita GDP	Guangzhou, Foshan, Shenzhen, Zhongshan, Zhuhai	High-high
Population density	Guangzhou, Dongguan, Shenzhen, Zhongshan	High-high

Most Local Moran's *I* high agglomeration areas are the coastal cities of PRD including Foshan, Zhongshan, Zhuhai, Shenzhen and Dongguan which are also the first-tier cities in Guangdong Province. Guangzhou, Shenzhen and Zhongshan which could influence peripheral cities comprehensively are all high-high agglomeration centers about the per capita GDP and population density. The factor agglomeration effect of Foshan and Zhuhai about per capita GDP is significant, however it is behind Dongguan about population agglomeration. This is because since the reform and open up policy in China in 1979, Dongguan has become the factory of the world and attracted massive labor, and this kind of agglomeration effect promoted the population growth of peripheral cities. Therefore, with the combined effect of economic and population factor, we can conclude in the PRD region, Guangzhou, Shenzhen and Zhongshan could be realized as three population and economic centers. According to the Reform and Development Plan of the PRD region (2008-2020), however, the PRD region is divided into three economic circles. They are Guang-Fo-Zhao economic circle, Shen-Guan-Hui economic circle and Zhu-Zhong-Jiang economic circle (Figure 7.2). Guangzhou, Shenzhen and Zhuhai are three centers of these economic circles (NDRC, 2008). Planning scheme is different from what we get from the spatial autocorrelation analysis method. Therefore this research will conduct the comparative study of Zhongshan and Zhuhai.

7.4.2 Comparison and Improvement of Traditional Density Functions

We use Google Earth to get the shortest travelling distance and Euclidean distance between two area units, and use the statistical software SPSS to realize data fit. The aim is to compare the regression results with these two different variables. At the first time, Guangzhou, Shenzhen and

Zhuhai are taken as three centers of the PRD region and at the second time, we take Zhongshan instead of Zhuhai. Regression results are shown in table 7.7 and table 7.8.

Table 7.7 Regression results for the three center cities of Guangzhou, Shenzhen and Zhuhai, 2010

Model	Straight-line Distance	The Shortest Road Travelling Distance
	R^2	R^2
Model (5-3)	0.846	0.861
Model (5-4)	0.891	0.921
Model (5-5)	0.827	0.836

Table 7.8 Regression results for the three center cities of Guangzhou, Shenzhen and Zhongshan, 2010

Model	Straight-line Distance	The Shortest Road Travelling Distance
	R^2	R^2
Model (5-3)	0.859	0.872
Model (5-4)	0.896	0.923
Model (5-5)	0.843	0.850

Overall the three models all fit the regional density patterns well with a $R^2 > 0.8$ in all cases. That means all the three functions can describe regional population density distribution well.

Firstly, the normal negative exponential function has the best fitting power for the regional density patterns in the PRD study area compared with the square-root negative exponential function and the reverse-exponential function. Among the three density functions, the negative exponential function yields the best R^2 . Function fit is very high. Model (5-4) is a polycentric extension of the traditional urban population density function. It came from a basic description of the American cities from 1960s to 1970s. The situation nowadays in the PRD region is similar to the one in America in 1960s and 1970s. This result is the same as the cities of Beijing and Shenyang in China (Feng, et al 2009; Qin, et al 2011). We suppose that the negative exponential function can explain the population density distribution in the PRD region more exactly.

Secondly, regression results with the shortest travelling distance are better than the results with the Euclidean distance between area units. So it corresponds to the actual situation to use the shortest travelling distance instead of the Euclidean distance when we use the negative exponential function to describe the population density distribution. One reason is that in the PRD region, cities are not spread out with the ring form. It likes a triangle. Another is the PRD region has several kinds of topography but not the homogeneous topography. This is the effective validation of hypothesis in Chapter 5. So we redefine x_{mn} in the negative exponential function as follows,

$$D_m(x) = \sum_{n=1}^{N} D_{0n} \exp(b_n x_{mn}) \tag{7-1}$$

Where, x_{mn} is the shortest road travelling distance between spatial unit m and center n. Others do not change. Here we get model (7-1) which is an improved polycentric regional density function.

Compared with Guangzhou and Shenzhen, the population density of Zhuhai is relatively low, only 902 persons/km^2, as the urban population size is relatively small. Zhongshan is another city in the Zhu-Zhong-Jiang economic circle with a population density of 1398 persons/km^2. It has more land area and higher population density than Zhuhai. According to the regression results in table 7-7 and table 7-8, we find Zhongshan is more suitable to be the development center than Zhuhai in the Zhu-Zhong-Jiang economic circle. Regression result R^2 value of 0.923 in case 3 is the one which is highest among all the twelve results, indicating a strong correlation. This result is different from the Reform and Development Plan of the PRD region (2008-2020). Government, however, plans Zhuhai as development center because of it borders on Macao. If Macao can show its economic radiation effect as Hong Kong, Zhuhai will have more location advantage.

Therefore nowadays the main task for government which could promote Zhuhai to be the third development center of the PRD is to find an effective way to stimulate population and economic growth and enhance its agglomeration capacity. Next part, we will find out factors of population density gradient in PRD region through case study. Population agglomeration capacity of Zhuhai could be enhanced by adjusting these factors.

7.4.3 Factors of Population Density Gradient in PRD Region

Following the 'Reform and Development Plan of the PRD region (2008-2020)', the three development centers of the PRD chosen for this study were Guangzhou, Shenzhen, and Zhuhai (NDRC, 2008). Data on population in the PRD region are from Guangdong's 2000 to 2010 Yearbooks. According to China's National Bureau of Statistics, there are two criteria of population density based on the administrative division. One is calculated by household population and the other by residential population. Floating people who live at an abode for more than 6 months are calculated in the residential population. Residential population density is used to study the PRD region because it closely shows the real size of the urban population. Urban land data is from the administrative area of each city. The spatial scope of the land area is consistent with that of urban residential population. Google Earth is used to measure the Euclidean distance between any two area units. Other social and economic data are from China City Statistical Yearbook. Some of the data are obtained from manual calculation based on the original data sources.

Statistical software SPSS is used to realize data fit based on regional density function. The aim is to reveal the value of population density gradient for the center cities of the PRD. Function (5-2) is used to characterize the regional population distribution and assess the changes over time. The polycentric density model is a nonlinear function. Nonlinear least square method is used to estimate the population density gradient of the three development centers of the PRD region from 2001 to 2010. R^2 is the goodness of fit of this density function. Regression results are presented in Table 7.9 below.

Table 7.9 Regression results of the polycentric density function of the PRD region

	Guangzhou		**Shenzhen**		**Zhuhai**		R^2
	D_{01}	b_1	D_{02}	b_2	D_{03}	b_3	
2001	2096.76	-0.248	3404.96	-0.264	196.94	-0.118	0.856
2002	2076.43	-0.248	3493.56	-0.265	200.14	-0.115	0.859
2003	2069.48	-0.244	3588.55	-0.266	189.29	-0.114	0.864
2004	2065.13	-0.242	3744.08	-0.270	193.07	-0.113	0.872
2005	2056.95	-0.240	3861.20	-0.272	207.26	-0.114	0.879
2006	2074.09	-0.239	4017.62	-0.274	204.43	-0.113	0.886
2007	2082.03	-0.239	4070.78	-0.280	226.50	-0.111	0.894
2008	2104.25	-0.240	4138.21	-0.283	247.61	-0.113	0.899
2009	2115.97	-0.242	4184.74	-0.287	279.25	-0.112	0.904
2010	2128.40	-0.241	4289.93	-0.290	289.42	-0.113	0.906

The results show that the polycentric density function can describe the population distribution pattern ideally from 2001 to 2010 with an average R^2=0.88. Declining density with distance from a center city indicates the diminishing influence of the center city on the population agglomeration capacity. The change of D_{0i} reflects the variation trend of population density of the center city*i*. b*i* is the population gradient, the change of which denotes the trend of regional population density distribution. The higher the absolute value of b_i is, the faster the population density decrease when the distance between the center city and the area unit increases. The increase of gradient b_i reflects the trend that the regional people from different direction converge to the center city*i*, while the density gradient decrease reflects the trend that regional population disperse from the center city*i*.

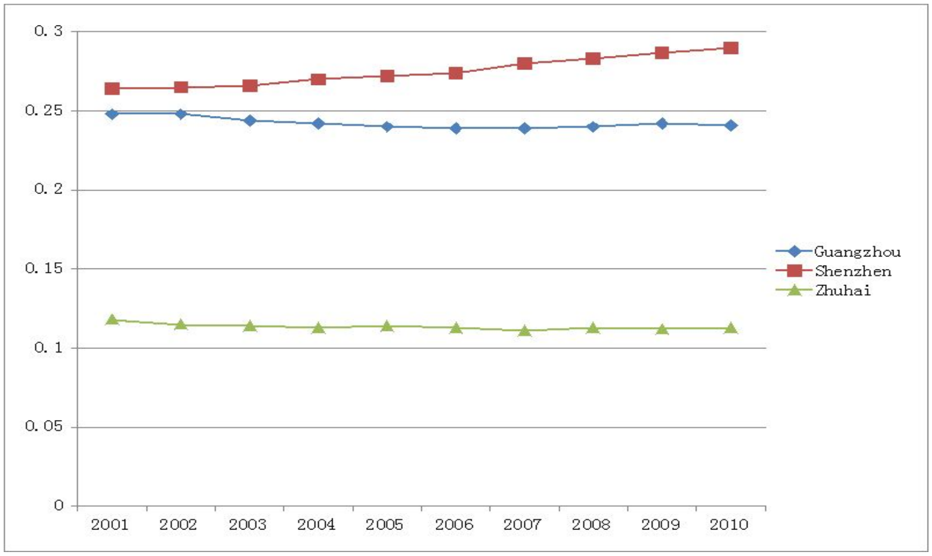

Figure 7.3 Variation of population density gradient for Guangzhou, Shenzhen and Zhuhai

As depicted in Figure 7.3 above, the change of population density gradient shows the different trends of population agglomeration and diffusion of Guangzhou, Shenzhen, and Zhuhai. The blue line for Guangzhou is relatively stable but has a trend of decrease from 0.248 to 0.241. Being the provincial capital of the whole province, Guangzhou has experienced a decrease in its capacity of population concentration in the decade. For the Special Economic Zone of Shenzhen, however, the capacity of population concentration increased to a large extent from 0.264 to 0.290. Shenzhen has the ability to absorb more and more migrants. Distinct from Guangzhou and Shenzhen, the capacity of the Special Economic Zone of Zhuhai on population concentration is very stable with minor decrease from 0.118 to 0.113. The total capacity level of Guangzhou and Shenzhen is around 0.25, which is much higher than that of Zhuhai at the level of 0.1. These results are, to a certain extent, consistent with the fact that the development of Guangzhou and Shenzhen has been better than that of Zhuhai and therefore more attractive to migrants. The low capacity of Zhuhai implies that it still has a long way towards population concentration if it wants to be at the same development level with Guangzhou and Shenzhen. Shenzhen as a center city of the PRD displays an obvious trend of regional population concentration. Guangzhou and Zhuhai are expanding towards cities with higher dispersion, although the trend is unstable. The following discusses the reasons for this from the perspective of gradient determinants.

Figure 7.4 below shows the variations of intercept for Guangzhou, Shenzhen, and Zhuhai. The intercept D0 of Shenzhen has increased substantially from 2001 to 2010, which indicates that Shenzhen has undergone fast population growth in the past decade. For Guangzhou and Zhuhai, the stable intercept reveals that there is not so much increase in population density in these two areas. This theoretical trend is consistent with data from the census.

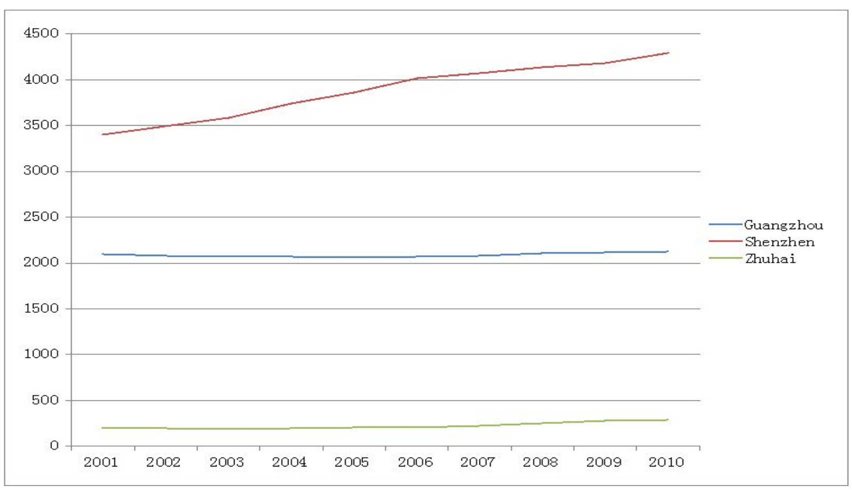

Figure 7.4 Variation of intercept for Guangzhou, Shenzhen, and Zhuhai

The decrease of population density gradient reflects that the concentration ability for the center city fell down and population distribution became dispersive. In Guangzhou and Zhuhai, however, the theoretical value and real value of urban population density kept increasing at a low growth rate. The main reason is that a huge amount of migrant workers were attracted by the economic advantages of the PRD region, resulting in the slow increase of local residents. The regression results show that the population of Guangzhou starts to disperse at the initial stage, while the features of diffusion are not obvious. Both the intercept and gradient (absolute values) of Shenzhen kept growing in the last decade. A higher intercept and a steeper gradient over time imply that the concentration ability of Shenzhen is increasing. Zhuhai, which is less concentrated than the other two center cities, presents smallest density gradient and intercept. Although Zhuhai is one of the center cities in the PRD region, its population concentration capability is not as high as that of Guangzhou and Shenzhen because of its low economic level and original urban size.

A multiple linear regression model is developed to analyze the relationship between population density gradient *b* and the four determinants. Population density gradient *b* for the center city is set as the dependent variable in this model, while the four independent variables are (1) share of employment population for the secondary and tertiary industry, (2) total fixed asset investment, (3) the amount of passenger transport that reflects the degree of accessibility outward, and (4) the integrated ecological environment value of center cities that could be calculated based on the eight indicators of the PRS framework. The first two independent variables represent the economic development level and economic structure of the center cities. This research examines the relationship between density gradient and the four independent variables in order to determine the type and closeness of the relationships.

These four variables are input as a block in a single step in the linear regression model of the SPSS software package. Table 7.10 below shows the results.

Table 7.10 Variables coefficients in the linear regression model

Model	Unstandardized coefficients		Standardized coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	Beta			Tolerance	VIF
	-1.904	0.490		-3.886	0.001		
Share23*ij*	1.467	0.512	0.098	2.864	0.008	0.125	8.025
Pas*ij*	-0.038	0.002	-0.444	-21.389	0.000	0.337	2.964
Fix*ij*	0.019	0.003	0.184	7.132	0.000	0.219	4.558
En*ij*	0.136	0.005	1.021	29.401	0.000	0.121	8.285

Note: Dependent variable is population density gradients for Guangzhou, Shenzhen and Zhuhai from 2001 to 2010. The adjust R^2 is 0.93.

The regression equation is $PDG = 0.14S - 0.04P + 0.02F + 0.14E - 1.90$ (7-4)

Overall, the results are consistent with the theoretical analysis. All the independent variables show a close relationship with population density gradient at the 1% statistically significant level. The regression results pass the F-test, with a goodness of fit of 0.93. The estimation values of variation coefficients can reveal the differences of relationship. Among the four independent variables, share of employment population for the secondary and tertiary industry, total fixed asset investment and integrated environmental value have positive relationships with density gradient, whereas the amount of passengers transport exhibits a negative relationship with the dependent variable. The result with a negative relationship could be described as the centrifugal force to density gradient, while the positive relationship is the centripetal force to density gradient.

Population concentration and dispersion derive from society, economy, and environment. Concentration capacity increase in China depends on the center city's industrial structure upgrade, effective fixed asset investment, good environment and living standard, and public transportation cost decrease. Firstly, the economic level influences employment, and even the migration direction and population distribution (Mueser & Graves, 1995). Economic structure has always been an essential and important aspect for examining density gradient because the second and tertiary industry can provide abundant employment opportunities for residents.

Affirmatively, a city with a high proportion of second and tertiary industry has a high capability to attract more migration and less emigration. For instance, people converge to the Special Economic Zone of Shenzhen because of its telecommunications industry, resulting in the consistent growth of total population and population density. Population concentration is pervasive for cities in developing countries, as the economy is still at the growing stage and the economic structure upgrade emerges from primary industries to second and tertiary industries. Secondly, the level of comfort and amenities attract more residents, resulting in an increase of density gradient. More and more people choose to move out from metropolitan cities' pervasive air pollution and traffic jams to more suitable places for accommodation. Thirdly, to a certain extent, population density gradient is promoted by investment, especially for developing countries. Proper investment promotes economic development and structural upgrades. Finally, transportation cost decreases make it easy for populations to disperse. As the centrifugal force, accessibility among cities is observable at the late development stage. In summary, it can be concluded that industrial structure, fixed asset investment, living environment, and public transportation cost are the influential factors for the population density gradient. Arising from this conclusion is the question of whether an effective method to balance concentration and dispersion in China's cities can be found, which is discussed in the following section.

7.4.4 Strategies

The formation of cities derives from population concentration. Although the urban population density rate is relatively high compared with Western countries (Demograhia, 2005; Kasanko et al., 2005), most of the cities in China are still at the beginning stage of urban development. Therefore, in the future, in the future, China's government could improve national development through urbanization, as migration from rural to urban areas provides enough labor not only for economic development but also for urban construction. In this evolution process of regional population distribution, human settlements could be optimized for sustainable development.

Distinct from prior studies conducted in Western countries where income and inner city tax were treated as economic factors, and some ethic, racial and religious problems as social factors, this study paid more attention to the economic structure and infrastructure because of the special situation of China as representative of developing countries. The regression results above show that some social and economic variables, such as employment population for the secondary and tertiary industry and total fixed asset investment, have significant positive influences on population agglomeration, while some other factors, such as transportation, are negatively correlated with population agglomeration. The research findings echo previous research results about population density gradient from social and economic perspectives, most of which only focused on the establishment of a theoretical system with a qualitative analysis approach; this research enriches the current literature by doing so with a quantitative analysis. Although some studies in the US and European countries have contended that residents move to a more comfortable living environment in order to get away from a bad downtown environment, most of them lacked data support (Clark, Lloyd, Wong, & Jain, 2002). Therefore, the research is also a quantitative investigation of sustainable human settlements. This study purposively incorporated environmental factors into the theoretical model and conducted quantitative validation.

Urban development is a process of seeking a dynamic balance between centripetal force and centrifugal force. However, one of the forces must be dominant at a certain period. China is experiencing rapid urbanization and its urban population is still in its infancy. Recently, population agglomeration has been encouraged in order to protect arable land. For most developing countries, it is better to go the way of smart growth (Yong, Yu, & Hans, 2012). Human settlements with high density including housing and employment activities benefit developing countries a lot. From a long-term oriented strategic perspective, population will surely disperse after concentration. At the same time, human settlements changes from agglomeration to diffusion. Different development stages have different dynamic characteristics. It is essential for the government of developing countries to develop policies for population agglomeration and diffusion and sustainable human settlements, according to distinct developmental situations in order to facilitate enduring economic and social development.

1) To promote industrialization

To a certain extent, the share of population employed by secondary and tertiary industries reflects urban economic development. This indicator can be used to explore the relationship between economic structure and population agglomeration and diffusion of the center cities in a certain area. The above results show that economic factors have great influence on urban population concentration and that a higher industrialization level encourages people to concentrate and settle. Therefore, at the beginning stage of a socialist market economy, population agglomeration is dominant for urban development. Accelerating industrialization and promoting economic structure upgrade can provide more employment opportunities, which could attract people to concentrate and settle. As the economy is always the biggest driving force of population agglomeration, it is recommended to make economic strategy the main policy for improving population agglomeration.

2) To increase the efficiency of the fixed asset investment

Fixed asset investment can reflect the input from government to urban construction. In China, fixed asset investment varies in different regions. The regional distribution of investment in China is fairly unbalanced, as in the last decade most of the investment has been in the eastern and central region but relatively little to the northeast and western areas. For cities that have no location superiority and are experiencing resource exhaustion, it is essential to increase fixed asset investment to facilitate regional development and attract people. However, excessive investments in some developed areas not only waste financial resources but also bring about environmental pressure. Unreasonable investment strategies cause unbalanced urban development in China. High efficiency fixed asset investment can structurally upgrade the economy, improve the urban environment, and provide abundant employment opportunities, all of which could improve population agglomeration and sustainable human settlement.

3) To improve and protect inner-city environment

A positive relationship between population density gradient and integrated environment value indicates that the better the inner-city environment is, the more people the city can attract; conversely, residents move out of cities because of environmental pollution. Take the metropolitan city of Beijing as an example, along with the aggravation of traffic congestion and serious air pollution, more and more people choose to not settle in the city but move out of the city or to the hinter land to live. Therefore, retaining a sound inner city environment is an important strategy for China's government to pursue in order to concentrate population and make human settlement sustainable. Along with the promotion of economic and population agglomeration, ecological and environmental protection should also be given more attention. Only by taking account of all these aspects can development be sustainable.

4) To decrease public transportation cost

With respect to the social factor, settlement or locality location always focuses on transport cost. In view of the difficulty of data collection, this study used the amount of passengers transport instead of transport cost. At the early stage of regional development, low transport cost promotes the population and economic agglomeration. Improvement of traffic condition and transportation infrastructure will surely decrease the transport cost. So there is a necessity for the government to invest in the regional transport network. If the transport cost decreases, more people will use public transportation to commute and choose to settle in the suburban or hub cities. In order to maximize the location effect of the center cities, it is better for the region to build up a transportation corridor system based on railways between two areas. Not only the center cities, but also hub cities as stops along the regional transportation corridor will benefit from operation of the proposed transportation corridor system. Such strategic behavior will increase urban service functions, optimize transport systems and promote the combination of regional spaces.

7.5 Optimization

7.5.1 Rationality Evaluation

According to the method for rationality evaluation of regional population distribution presented in Chapter 6, this section is to assess the rationality of population distribution in 21 prefecture-level cities in Guangdong Province. Focused on the population dwelling in urban areas, area of residential land is selected as the environmental factor, total output values of secondary and tertiary industries as the economic factor, highway and railway passenger throughputs as the social resource factor. When the economic, environmental and social resource carrying capacities are investigated, their averages of Beijing are considered as reference. To simplify the analysis and calculation, only one representative indicator for each carrying capacity factor is selected to explore. Thus, ${}_{R}D_{I}$, ${}_{E}D_{I}$, ${}_{T}D_{I}$, ${}_{RET}D_{I}$ can be written as the following forms:

${}_{R}D_{I} = R / S$, ${}_{E}D_{I} = E / S$, ${}_{T}D_{I} = T / S$, ${}_{RET}D_{I} = R_{a} \times {}_{R}D_{I} + E_{a} \times {}_{E}D_{I} + T_{a} \times {}_{T}D_{I}$

Where R is the area of residential land; E is the total output value of secondary and tertiary industries; T is the overall passenger throughput; *Ra, Ea* and *Ta* are model parameters.

Carrying capacities of land resources, economic development and traffic conditions of all prefecture-level cities of Guangdong Province are obtained according to above formulas, respectively. Taking the actual population density D_I of each prefecture-level city as dependent variable, ${}_{R}D_{I}$ 、 ${}_{E}D_{I}$ 、 ${}_{T}D_{I}$ as independent variables, and according to the method presented in Chapter 6, when Ra = 0.1, Ea = 0.6, Ta = 0.3, the goodness of fit of the regression model maximizes, $R^2 = 0.873$. The model can be written as follows:

$$D^{'} = 457.2 + 0.8(0.1{}_{R}D_{I} + 0.6{}_{E}D_{I} + 0.3{}_{T}D_{I}) \times D_{I}^{'} \quad （7\text{-}5）$$

$D_{I}^{'}$ represents the predictive value of regression of actual population density D_{I} of the city *I*. The comprehensive carrying capacity of land resources, economic development and traffic condition of all prefecture-level cities of Guangdong Province (${}_{RET}D_{I}$) are obtained by mergence. Data are shown in Table 7.11.

Table 7.11 Carrying capacity of land, economy and transportation in 2010

City	${}_{R}D_{I}$	${}_{E}D_{I}$	${}_{T}D_{I}$	${}_{RET}D_{I}$	City	${}_{R}D_{I}$	${}_{E}D_{I}$	${}_{T}D_{I}$	${}_{RET}D_{I}$
Guangzhou	1699.16	2059.53	1174.35	1757.94	Zhongshan	409.36	1464.07	1102.43	1250.11
Shenzhen	5767.11	6988.30	5169.53	6320.39	Jiangmen	242.72	234.41	264.53	244.27
Zhuhai	1554.50	1019.43	1584.08	1442.33	Yangjiang	107.78	116.51	73.33	102.68
Shantou	1141.98	833.72	194.41	772.75	Zhanjiang	130.83	160.49	145.06	152.89
Foshan	738.59	2814.20	918.95	2038.07	Maoming	105.65	185.49	84.74	147.28
Shaoguan	74.43	52.92	81.79	63.73	Zhaoqing	77.94	104.04	59.97	88.21
Heyuan	29.93	42.75	29.03	37.35	Qingyuan	72.05	80.92	72.68	97.56
Meizhou	39.70	54.80	39.76	48.78	Chaozhou	118.85	256.87	95.65	194.70
Huizhou	297.17	220.74	166.41	212.08	Jieyang	100.44	274.30	128.05	213.04
Shanwei	199.70	125.67	191.83	152.92	Yunfu	33.83	73.25	87.98	73.73
Dongguan	683.25	2453.73	4381.90	2855.13					

Data in table 7.11 divides the real population density of each prefecture-level city in Guangdong Province, and the results are shown in table 7.12.

Table 7.12 Rate of the land, economy and transportation carrying capacity to population density

City	$_{R}D_I/D_I$	$_{E}D_I/D_I$	$_{T}D_I/D_I$	$_{RET}D_I/D_I$	City	$_{R}D_I/D_I$	$_{E}D_I/D_I$	$_{T}D_I/D_I$	$_{RET}D_I/D_I$
Guangzhou	0.99	1.20	0.69	1.03	Zhongshan	0.24	0.84	0.64	0.72
Shenzhen	1.09	1.32	0.97	1.19	Jiangmen	0.52	0.50	0.57	0.52
Zhuhai	1.67	1.10	1.71	1.56	Yangjiang	0.35	0.38	0.24	0.33
Shaotou	0.82	0.32	0.07	0.30	Zhanjiang	0.23	0.29	0.26	0.27
Foshan	0.29	1.12	0.37	0.81	Maoming	0.21	0.36	0.17	0.29
Shaoguan	0.48	0.34	0.53	0.41	Zhaoqing	0.30	0.39	0.23	0.33
Heyuan	0.16	0.23	0.16	0.20	Qingyuan	1.41	0.42	0.38	0.50
Meizhou	0.15	0.21	0.15	0.18	Chaozhou	0.14	0.30	0.11	0.23
Huizhou	0.72	0.54	0.40	0.51	Jieyang	0.09	0.24	0.11	0.19
Shantou	0.36	0.23	0.34	0.27	Yunfu	0.11	0.24	0.29	0.24
Dongguan	0.20	0.74	1.31	0.86					

The results show that cities with the value greater than 1.1 include Shenzhen and Zhuhai which have significantly sufficient comprehensive carrying capacity and fall into the encouraging increase area; cities with the results ranging from 1 to 1.1 include Guangzhou, suggesting that its carrying capacity is in a relatively sufficient state but inferior to Shenzhen and Zhuhai, which falls into the moderate increase area; there is no city with the result ranging from 0.9 to 1; cities with the results ranging from 0.8 to 0.9 include Foshan and Dongguan, where there have been certain deficiencies in comprehensive carrying capacity and certain population pressure, but not so severe, falling into the controlling increase area; value of comprehensive carrying capacity in other areas are less than 0.8 on average, suggestive of gravely insufficient comprehensive carrying capacity in these cities and relatively severe population pressure, falling into the population decrease area. These results suggest that, in Guangdong Province, except for the three center cities, population distribution of other prefecture-level cities are facing gravely insufficient comprehensive carrying capacities of resources, economy and society, with varying degrees of population pressure.

Firstly, the reason for excessive comprehensive carrying capacities in Guangzhou, Shenzhen and Zhuhai is that they are the center cities of Guangdong Province. They have obvious location advantages and abundant resources compared with the other cities. Secondly, policy support leads to rapid economic development, superior traffic and other infrastructure conditions; and due to the demands for expansion of urban construction, a certain amount of residential land areas guarantee people's basic living needs. Population growth rates in Shenzhen and Guangzhou always kept a high level for long time, but good urban construction and high economic development level can still satisfy such dense population. For example, Tokyo and Hong Kong with high population density have no big problem in their urban development and operation in spite of a large population. Therefore, the sound development of a high-density city relies on high economic development level, perfection of urban infrastructure and improvement of overall living environment quality.

In Guangdong Province, except for three center cities, Guangzhou, Shenzhen and Zhuhai, other prefecture-level cities show an insufficient state of comprehensive carrying capacity. Among them, it is less insufficient in Foshan and Dongguan, but in the rest, resource, economic, social and comprehensive carrying capacities have been in a significantly insufficient state. Some important cities, such as Zhongshan, Jiangmen, Zhaoqing and Huizhou in the PRD region, show insufficiencies in carrying capacities in all aspects, suggesting that there are still gaps in economic development, urban transportation infrastructure construction and improvement of people's living and environmental levels compared with standard cities. And there are greater gaps in these aspects in other cities scored 0.2 to 0.3 or so.

From regression models of actual population density and environmental, economic and social carrying capacities, an equation, ${}_{RET}D_I = 0.1{}_R D_I + 0.6{}_E D_I + 0.3{}_T D_I$, can be obtained. According to this, we can get the contribution degree value of effects of environmental conditions, economic development level and social transportation on population spatial structure respectively. ${}_R G_I$, ${}_E G_I$ and ${}_T G_I$ are presented as follows:

$$ {}_R G_I = 0.1{}_R D_I / (0.1{}_R D_I + 0.6{}_E D_I + 0.3{}_T D_I) \times 100\% \quad (7\text{-}6) $$

$$ {}_E G_I = 0.6{}_E D_I / (0.1{}_R D_I + 0.6{}_E D_I + 0.3{}_T D_I) \times 100\% \quad (7\text{-}7) $$

$$ {}_T G_I = 0.3{}_T D_I / (0.1{}_R D_I + 0.6{}_E D_I + 0.3{}_T D_I) \times 100\% \quad (7\text{-}8) $$

Values of contribution degree are obtained according to above definitions, as shown in Table 7.13.

Table 7.13 Contribution degree of land, economy and transportation in Guangdong's prefecture-level cities (%)

City	${}_R G_I$	${}_E G_I$	${}_T G_I$	City	${}_R G_I$	${}_E G_I$	${}_T G_I$
Guangzhou	9.67	70.29	20.04	Zhongshan	3.27	70.27	26.46
Shenzhen	9.12	66.34	24.53	Jiangmen	9.94	57.58	32.49
Zhuhai	24.64	42.41	32.95	Yangjiang	10.50	68.08	21.43
Shantou	27.72	64.73	7.55	Zhanjiang	8.56	62.98	28.46
Foshan	3.62	82.85	13.53	Maoming	7.17	75.57	17.26
Shaoguan	11.68	49.82	38.50	Zhaoqing	8.84	70.77	20.40
Heyuan	8.01	68.67	23.31	Qingyuan	27.88	49.77	22.35
Meizhou	8.14	67.41	24.45	Chaozhou	6.10	79.16	14.74
Huizhou	14.01	62.45	23.54	Jieyang	4.71	77.25	18.03

Shanwei	13.06	49.31	37.63	Yunfu	4.59	59.61	35.80
Dongguan	2.39	51.56	46.04				

Data in Table 7.13 show economic development contributes the most to population distribution of 21 prefecture-level cities in Guangdong Province. Among them, the most prominent is Foshan (up to over 80%), followed by Guangzhou, Zhongshan, Maoming, Zhaoqing, Chaozhou and Jieyang (up to over 70%); and economic contribution in other cities is also largely higher than 50%, but slightly inferior in Shaoguan and Qingyuan. Again, this also shows that urban economic development level has significant effect on regional population distribution.

The transportation gap of Guangzhou reflects that, it is insufficient for current passenger carrying capacity compared with the actual population. This is mainly because Guangzhou is located inland where the carrying capacity of large port is inferior to Shenzhen and Zhuhai. Due to the location disadvantage, Guangzhou should strengthen the efforts on construction of airport, railway and highway in order to meet the living and business demand.

In Shenzhen, there are big surpluses of the carrying capacity of economy, but resource and social capacities are roughly balance with the actual population density, suggesting that in the context of existing economic conditions and population size, the government should make effective strategies to improve living environment for citizens and increase the traffic carrying capacity to keep abreast of the population and economic development. In the long run, only this can ensure sustainable development in Shenzhen in the long term.

For such city as Zhuhai, there are big surpluses of resource and social carrying capacity, but the economic carrying capacity roughly balances with the actual population density. It is necessary to use economic means to stimulate Zhuhai's population growth like industrial upgrade and adjustment. Competitive industries can drive the economic growth of the entire city. Meanwhile, it is significant to develop such tertiary industry as service industry and information industry which could ensure an enormous momentum of the economic development in the long term.

For most other cities in Guangdong Province, the economic development lags behind. Facilities shortage makes resource, economic, social and comprehensive carrying capacities not satisfy the existing demand of population. Thus, for these areas, attention should be paid to improve people's living standard and living environment, and increase the urban infrastructure construction in order to meet the demand of existing urban population size while promoting economic growth.

It should be noted that, in terms of such city as Shenzhen, in spite of excess environmental, economic, social and comprehensive carrying capacities, additional large-scale population agglomeration is not encouraged because of the existing relatively high population density; rather, measures should be taken to disperse the population to surrounding cities and promote the development of peripheral cities. Such dispersion effect drives the surrounding cities to develop rapidly.

7.5.2 Multi-objective Programming

The multi-objective programming of center cities' population in Guangdong Province pursues the maximization of comprehensive benefits of society, economy, resources and environment. Hence, according to Chapter 6, economic, social and environmental benefits maximization are defined as an objective function when modeling. There are many aspects covered by economic benefits. To facilitate the calculation and improve the model operation, maximization of GDP is defined as the goal of the maximization of economic benefit. Environmental benefit usually investigates the indicators of emissions of waste water, solid waste and waste gas, but nowadays, water scarcity has been one of the bottleneck problems that widely restrict the sustainable development of cities in China. Therefore, the model is to minimize the discharge of urban sewage and waste water and ensure the sustainable urban development from the perspective of population. Comprehensive social benefits involve in many aspects, such as people's living and welfare standards. For a developing country, urban development is still at the early stage, and the public transportation and infrastructure investment may reflect high comprehensive social benefits. Therefore, the maximization of investment volume of transportation, warehousing and postal industries is used as the optimization objective for social benefits. Due to the difficulty of data acquisition, the employed population of target cities is only divided according to three industries.

Economic benefit objective which aims to maximize the urban GDP is as follows.

$$\max f_1(x) = a_1x_1 + a_2x_2 + a_3x_3 \tag{7-9}$$

where, x_1, x_2, x_3 are numbers of employed population of the primary, secondary and tertiary industry respectively; a_1, a_2, a_3 are economic benefit coefficients which are the per capita GDP of each industry.

Environmental benefit objective aims to minimize the discharge of urban sewage and waste water. The total discharge of urban domestic sewage and waste water includes two parts that are urban sewage and industrial waste water.

In order to facilitate model solution, the objective function $\min f(x) = \sum b_i x_i$ is converted into $\max f_2(x) = -\sum b_i x_i$

$$\max f_2(x) = -b_1(x_1 + x_2 + x_3) - b_2 x_2 \qquad (7\text{-}10)$$

Where, b_1 , b_2 are environmental benefit coefficients. b_1 is per capita domestic sewage discharge; b_2 is per capita industrial waste water discharge (the waste water discharge of the secondary industry is replaced by the industrial waste water discharge due to the difficulty of data acquisition of waste water discharge of the construction industry).

Social benefit objective aims to maximize the investment of urban transportation, warehousing and postal service.

$$\max f_3(x) = c_1(x_1 + x_2 + x_3) \qquad (7\text{-}11)$$

Where c_1 is social benefit coefficient, and per capita investment of urban transportation, warehousing and postal service is taken here.

Each industry is not considered separately because this investment focuses on the city regardless of industries.

Constraints are:

$$(1)\ \sum x_i \leq {}_{ERT} D_I \cdot S_I \qquad (7\text{-}12)$$

where, ${}_{ERT}D_I$ is comprehensive carrying capacities of resources environment, society and economy.

$$(2)\ x_2 + x_3 \geq P_2' + P_3' \qquad (7\text{-}13)$$

Suppose that promotion of the urbanization remains the short-term objective to be achieved. Thus, the constraint is the total employment of the secondary and tertiary industries in planning year is higher than that in current year.

（3） $0.95P_1 \le x_1 \le 1.05P_1$ （7-14）

$0.95P_2 \le x_2 \le 1.05P_2$ （7-15）

$0.95P_3 \le x_3 \le 1.05P_3$ （7-16）

According to the growth rate of the employed population of each industry previously, we select the average maximum increase/decrease in employed population of each industry by less than 5% as another constraint.

It can be seen from results of the rationality evaluation of the population size of each city in Guangdong Province that, except for Guangzhou, Shenzhen and Zhuhai, comprehensive carrying capacities of economy, society, resources and environment in other cities are lower than the actual population density, suggestive of excessive pressure on the current population. Thus, positive measures should be taken to improve infrastructure conditions (dwelling, economy and transportation) in order to meet the current demand for the urban population. Theoretically speaking, these cities should make an appropriate reduction in population because encouragement of more immigrants only can exert pressure on the economy, society, resources and environment. In addition, most of the employed population is rural population who are in the primary industry. Such rural surplus labor would provide safeguard to the employment market of the regional center cities; prefecture-level cities, as the hinterland, provide labor for center cities in order to play a role in population agglomeration. On this basis, satellite cities should increase urbanization rates to comply with national macroscopic development policies while promoting their own economic and social development. The sum of employed population in the secondary and tertiary industries must be above the baseline. Comprehensive carrying capacities in Guangzhou, Shenzhen and Zhuhai remain surplus to some extent, therefore theoretically speaking, they should continue to exert agglomeration effect and encourage immigration. In the following part, optimization of regional population distribution using multi-objective programming model established in Chapter 6 and validation of the above theoretical assumption will be conducted.

The year 2010 is selected as the current year, while the year 2011 as the planning year. Model data are processed using the genetic algorithm in the Matlab software. The results obtained are illustrated in Table 7.14.

Table 7.14 Comparison before optimization and after optimization in 2011

	Before Optimization (2011)				After Optimization (2011)			
	Primary Industry	Secondary Industry	Tertiary industry	Total	Primary Industry	Secondary Industry	Tertiary Industry	Total
Guangzhou	62.90	282.93	397.34	743.18	59.80	286.16	396.29	742.25
Shenzhen	0.32	382.91	381.31	764.54	0.36	378.78	385.22	764.36
Zhuhai	6.36	46.34	51.39	104.09	6.51	48.11	53.39	108.01
Shantou	70.28	104.77	63.50	238.55	69.93	106.87	61.4	238.2
Foshan	26.40	265.22	153.50	445.13	26.40	255.98	161.02	443.4
Shaoguan	60.29	31.08	51.28	142.65	58.14	31.90	50.46	140.5
Heyuan	72.26	29.39	33.82	135.47	68.65	30.86	34.51	134.02
Meizhou	95.89	46.81	66.78	209.48	91.09	49.15	70.12	210.36
Huizhou	52.56	133.12	82.27	267.94	51.36	135.66	86.38	273.4
Shanwei	53.60	31.70	33.93	119.23	50.92	33.29	34.61	118.82
Dongguan	5.88	478.87	143.79	628.54	5.92	454.93	150.98	611.83
Zhongshan	10.03	141.49	57.11	208.64	10.01	146.58	59.61	216.19

Jiangmen	76.53	110.37	66.12	253.03	73.65	107.99	69.44	251.08
Yangjiang	51.28	46.73	39.87	137.87	50.42	43.84	37.25	131.51
Zhanjiang	203.97	46.69	78.47	329.13	191.46	44.38	79.77	315.61
Maoming	148.57	56.08	70.94	275.58	141.22	60.63	68.32	270.17
Zhaoqing	116.77	51.91	46.44	215.13	113.31	51.68	45.46	210.45
Qingyuan	105.85	45.32	46.32	197.49	102.11	46.31	45.38	193.8
Chaozhou	37.88	68.14	32.78	138.80	37.5	70.27	32.85	180.1
Jieyang	93.10	96.31	84.14	273.55	89.69	96.12	85.69	271.5
Yunfu	76.62	30.29	25.82	132.73	73.58	27.80	25.87	127.25

It can be seen that the result of the total employed population of three industries in Guangzhou after optimization is largely consistent with the actual situation. Decrease in employed population of the primary industry indicates the continuous advancement of the urbanization process; the employed population of the secondary industry increases and that of the tertiary industry changes not too much compared with that in the base period. This is mainly because the population of Guangzhou is basically consistent with the actual population size in economic, social, resources and environmental and comprehensive carrying capacities, without too large gap or surplus. Therefore, there is no significant difference between optimization results and the actual situation. Moreover, recent economic development of Guangzhou is mainly driven by the secondary industry. The total employed population of Shenzhou after optimization also remains unchanged, but the employment structure changes. The employed population of the secondary industry shifts to the tertiary industry, being equivalent to reallocation of the originally employed population of the secondary and tertiary industries of Shenzhen.

On one hand, compared to the secondary industry, the tertiary industry contributes a lot to environmental protection. On the other hand, investigation on pollution control of secondary industry could be partly shifted to other investigation in the tertiary industry. This is undoubtedly an effective measure for densely populated Shenzhen, while changes in employment structure will reduce the pressure on economy, society, resources and environment. In addition, optimization results also show that the population growth slows down and the urban population in Shenzhen tends to diffuse. Zhuhai shows a sharp increase in either the employed population size of each industry or the sum of employed population size of three industries after optimization, reflecting the features of urbanization. In Zhuhai, as the third center city in the PRD region, its resident population has been ranked at the bottom of Guangdong Province. Too small population size is difficult to support the economic growth. Meanwhile, due to excess carrying capacity of economy, society, resources and environment, only devoting greater efforts to encourage immigration and play an agglomeration role as a center city can further boost the development of the surrounding hinterland and satellite cities.

This research realizes the optimization and adjustment of the employed population of three industries in different cities by developing a multi-objective programming model of population distribution under the constraints of economy, society, resources and environment. These empirical analysis results are significant to guide population planning of Guangdong Province. The adjustment direction of the employment structure and the general direction of the whole urban population planning of each city can be made based on the employment changes in each city before and after optimization.

7.5.3 Strategies

Optimization of population distribution, also interpreted as spatial structure evolution of regional population from a sustainable perspective, needs to find the balance of changes between population distribution and the economic, social, resource and environmental system. However, sustainability cannot be realized if it only depends on the market. Therefore, it is essential for the government to regulate and support the evolution process.

7.5.3.1 Strategies of Economic Structure Optimization

Economic development is a major impetus for the evolution of regional population distribution. No damage to market regulation is the precondition of government intervention when optimizing the economic structure. The intervention is to remedy market failure and guarantee orderly competition. In developing countries with imperfect market mechanism, it is quite necessary to promote the formation of large enterprises which have advantaged industry competition by means of government intervention. Abundant jobs opportunity could promote population agglomeration in order to to achieve the objective of optimizing the regional population distribution. Specific measures are to replace non-governmental capital to perform part of functions of the market subject by participating in some dominant competitive industries; encourage investment and control tax deduction and exemption; conduct technical reform, innovation and business reform for sunset industries; provide social insurance for unemployed population triggered by industrial restructuring; attach importance to technical research and development, and boost investment, etc.

1) To enhance the competitiveness of advantaged industries

Again, for example, Zhuhai's good location advantage and natural environment lay a favorable foundation for its development. However, nowadays, population size and economic scale of Zhuhai are far from the level an international metropolis should have. What should to be done now is to find effective methods to attract population and other economic factors to Zhuhai. Thus, regulation by virtue of economic leverage should start with the industrial structure adjustment, while the government is also required to participate in boosting the economic structural transition. Firstly, government should expand the original advantages to the utmost, strive to develop dominant competitive industries and boost urban growth through employment. Secondly, the government can upgrade leading industries by increasing technology investment and relaxing admission conditions to stimulate growth of competitive industries by encouraging domestic and foreign investment. Local government may lower requirements for human resources with high technology, and provide them with supports such as housing and children's education. The government can promote regional growth by maximizing the competition of leading industries.

2) To promote updating of the industry structure

Besides, adjustment of industrial structure, development of modern service industry and advanced manufacturing industry, enhancement of innovation capacity may all accelerate the development of regional center cities and help promote the economic structure to shift from the traditional industry to the service and advanced manufacturing industries. Irrational economic structure will directly impact on population agglomeration capacity of a center city. After 30-year accumulation of reform and opening up, Zhuhai now has a group of pillar industries with certain development power, but they are uneven in development. 'GREE Electric Appliance' along with 'Flextronics' accounts for 40 percent of total industrial output in Zhuhai, which is a pretty amazing number and will result in a weak anti-risk ability of Zhuhai's economy and vulnerability. Once international economy fluctuates and the order quantity decreases, the entire enterprise and even the industry will collapse. In addition, the proportion of the service industry in the economic structure of Zhuhai gets close to fifty percent. However, its modern service industry still lags behind, which also influences its momentum of development. Therefore, through promoting development of advanced manufacturing industry and modern service, industrial upgrading will help enhance agglomeration capacity of center city efficiently.

7.5.3.2 Strategies of Infrastructure Construction

Being an important part of regional spatial structure, infrastructure is an important factor to drive evolution of the regional population distribution. Functions of external economy, such as infrastructure development of transportation and communication, offer facilities for geographic mobilization of the population and economic factors, which directly promote the agglomeration of labor force and economic activities to the downtown. Scale economy reduces the average production cost and transaction cost. From another perspective, agglomeration of economic activities in a certain area can reduce unit service cost of infrastructure and improve utilization efficiency, which will be benefit to the development and improvement of the infrastructure itself and make it work smoothly. Urban and intraregional infrastructure plays a vital role in the formation and development of population spatial structure. In order to accelerate regional development, the government should increase support to the infrastructure construction at appropriate time.

1) To cultivate a network and poly-centric regional transportation system

Materials, energy and information flow among regions brought large-scale agglomeration economy, and continuously spread outward through road, railway and other transportation networks. Finally, it forms a poly-centric, networked and high grade development region. Cultivation of a networked and poly-centric regional transportation system should begin with the improvement of existing traffic arteries from center cities to surrounding ones, which leads to an efficient urban road network connection between center cities and other secondary node cities, as well as an efficient connection among secondary node cities. Only when all the cities within the region realize optimal resource allocation through the transportation network, labor force will move effectively and efficiently in the region. Meanwhile, such flow also promotes the optimization of regional population spatial structure and achieves transformation from a closed mono-centric structure to an open poly-centric network structure, so as to promote overall harmonious development of the region. In the PRD region, Zhuhai enjoys exceptional regional advantages, and could receive the economic radiation from Hong Kong and Macau. However, lack of railway connection outward prevents free flowing of production factors including labor force. It is also difficult for Gaolan Harbor District to realize integrated development for the same reason. Besides, due to inconvenience of external contacts, passenger throughput of the Zhuhai Airport only gets a fraction of its annual design capacity. Deficiency in the transportation system is one of the big issues that restrict the population agglomeration and the economic development of Zhuhai. Therefore, in order to narrow the gap between Zhuhai, and Shenzheng and Guangzhou as soon as possible, infrastructure investment should increase and construction for the intercity transportation network system should be improved, which could lay a solid foundation for attracting more human resources and economic resources.

2) To improve comprehensive development of housing, education, health care and cultural facilities

In order to promote a leap of regional population spatial structure to a higher level, it is noted that overall regional service function should be improved as well. For example, construction of housing, education, health care and social humanity on a regional scale should be strengthened and public service system, such as housing guarantee system, high-quality education system, health care system that covers both urban and rural areas should also be developed. Together with the humanistic facilities system of Lingnan style, these effective strategies could narrow the regional development gap, improve people's livelihood, realize equalization of the basic public service and help build human settlement with cultural prosperity, social harmony and beautiful environment. In general, the stronger social service function is, the stronger agglomeration capacity it will bring. However, when construction of regional basic service facilities is integrated, it means the urban social service function is strengthened, and the city will have stronger external radiation and diffusion abilities. Moreover, in the process of implementation, attention should be paid to strengthen the connection and coordination among departments, so as to avoid repeated construction and achieve seamless connection of transportation, medical treatment and education between cities in the region.

7.5.3.3 Strategies of Environmental Resource Protection

Environmental resource protection has always been the most important content of sustainable development. As the foundation of people's producing and living relied on, resources and environment have suffered from a severe crisis with urban population growth and massive industrial development. When people try to promote urban population agglomeration and economic development, attention should be paid to resources protection and reduction in emissions of harmful materials in order to provide livable producting and living environment for citizens. In the long term, this will be the urban population agglomeration in a sustainable way. However, improvement of environmental problems cannot be simply solved by the market. Therefore, scholars in developed countries put forward the viewpoint of 'economy relies on market and environmental protection relies on government'.

In the past 20 years, promotion of economic development most relied on the market. However, government intervention is indispensable because the market economy cannot protect the environment spontaneous. For example, specific measures include formulation of the standard for factory emissions through compulsory means of economy, law and administration; restriction to the excessive land use and development; solution of external environmental issues through taxation, etc.

1) To create the ecological environment with urban-rural integration and mutual development of nature and humanity

The existing ecological resources in Guandong Province include rivers, lakes, sea, mountains and forests. It is abundant in natural resources. In order to protect these existing rich resources and make them match sustainable region development, cities should rely on these resources to build regional greenbelt and connect various natural and ecological resources, so as to form into a multi-level, multi-functional, three dimensional, and networked regional ecological environment support system. Based on the principle of ecological priority, mechanism for ecological compensation should be built up, as well as the legislation for ecological protection. Strict control to ecological footprint could ensure balanced and stable development of regional ecological system. For inner city environment protection and rebuilding, the city should limit industrial pollutant emission, and provide adequate and high-class living space for citizens. It is imperative for the government to actively improve land utilization structure. In the developed countries, proportion of residential land in urban development land is more than 40%, while the proportion of industrial land is relatively lower. Improvement of transportation and greenbelt, increase of public and open spaces using rate will improve resident's living conditions. In addition, living conditions could be improved through protecting the existing agriculture land resources and reducing overdevelopment of industrial land. Moreover, the better the inner city environment is, the more population will be attracted to the city. On the contrary, the residents will move out from one city due to environment pollution. Therefore, sound dwelling conditions of inner city is good for the government to promote the population agglomeration. More attentions would be paid on ecological and environmental protection along with the economy and population agglomeration.

2) To strengthen resources and environmental protection and restrain excessive economic development

At the beginning of economic development of many cities in the PRD region, most factories depended on processing of supplied materials, processing with given samples, assembling with provided parts and compensation trade. Such rapid development pattern damaged the ecological environment. However, in the process of economic growth, municipal governments in Zhuhai always stuck to the principle of 'green mountains and clear water, blue sky and white clouds', and that is the reason why many processing enterprises with low economic benefit and heavy pollution are kept out of Zhuhai. This principle brings part of economic loss, but the ecological environment is protected in Zhuhai. For example, the investigation results of the municipal atmospheric environment and water quality in 2009 showed that number of days with excellent air quality accounted for more than two-third of the whole year, and the water qualification rate of portable water was one hundred percent. Compared to the occurrence of sustained hazy weather and drinking water pollution problems in many cities recently, actual living conditions in Zhuhai are indeed satisfactory. This is a positive example that the government provides support to the environmental protection in the economic development. In the short term, at the early stage of economic development, environmental level cannot have too large effect on population agglomeration and diffusion; however, in the long term, environmental protection is absolutely a good development mode that will benefit future generations.

7.6 Summary of the Chapter

Empirical study in this chapter is quantitative validation of the framework modules presented in Chapters 4, 5 and 6. Three experimental studies are involved in the framework validation. Firstly, it identifies the driving force of urban population growth through testing the hypothesis. Secondly, an improved regional population density model is proposed and the factors of agglomeration and diffusion capacities of center cities in the PRD are defined. Thirdly, Based on the analysis results of rational evaluation and multi-objective programming from the perspective of carrying capacity, this chapter finds out the problems of current population distribution in Guangdong Province. For the three modules, it proposes effective strategies of regional population distribution for sustainable development respectively.

Chapter 8 Conclusions

8.1 Introduction

This chapter addresses the research conclusions by summarizing corresponding research findings. Firstly, the research aim and objectives are reviewed to present how they are achieved followed by a summary of research findings and conclusion of evolution and optimization of regional population distribution from the perspective of sustainable development. Then, a summary of the contributions is given. Last but not least, limitations of the research and recommendations for further research are discussed.

8.2 Review of the Research Aim and Objectives

Population problem has become a primary problem affecting sustainable development. With the rapid development of China's urbanization and regional economy, population distribution changes gradually and evolves from junior to senior level. At the same time, however, problems like resource waste and environmental destroy emerge. Proper population size and rational population distribution will improve coordinated development of population, resource, environment and economy. It is significant to investigate population distribution from the perspective of sustainable development especially in the modern society. However, it is determined by a comprehensive literature review that there are few research work about evolution mechanism analysis from the perspective of sustainable development and quantitative optimization model for regional population distribution. The research gaps are identified in Chapter 2. 1) Population density model innovation taking environmental factors into account needs to be conducted. 2) Research about evolution and optimization of population distribution at regional level is urged to be developed. 3) A practical and sustainable evaluation and optimization model to formulate policy control for regional planning has yet to be developed. This research was designed aiming at filling these gaps, and the overall aim of this research was:

To develop an integrated framework for qualitatively and quantitatively exploring the spatial evolution mechanism and optimization model of regional population distribution and assisting regional development planning with a special focus on sustainability of regional development in China.

In order to achieve the above overall research aim, five detail research objectives needed to be completed, which were:

1) To investigate the evolution mechanism of regional population distribution through qualitative and quantitative method from the perspective of sustainable development;

2) To identify the factors of population growth for sustainable development;

3) To set up an evolution model at regional level by identifying the determinants of density gradient;

4) To develop an optimization model for sustainable regional population redistribution;

5) To validate the integrated framework of evolution and optimization for sustainable development.

Qualitative research of evolution mechanism analysis both from macro and micro perspective and the quantitative research of corresponding models of urban population growth and regional population density from the perspective of sustainable development are investigated in Chapter 4 and Chapter 5. To achieve objective 2, a conceptual model of urban population growth which consisted of natural increase and mechanical increase is built up in Chapter 4 and conducted to valid this hypothesis in Chapter 7. Chapter 5 identified the determinants of population density gradient from the perspective of sustainable development, and set up evolution models of population density at regional level. Compared with the previous research about density functions, this research makes extension taking environmental factor and travelling distance into account. In order to provide an effective method for optimizing population distribution, chapter 6 builds up rationality evaluation model and multi-objectives programming model which are the quantitative support of the framework to achieve objective 4. Finally for objective 5, Chapter 7 uses a case study of Guangdong Province and the PRD Region in China to validate the integrated framework of evolution mechanism and optimization model for sustainable development.

8.3 Findings and Conclusions

The following research findings and conclusions can be drawn based on the developed mathematical models:

1) Driving force of urban population growth

Urban growth derives from natural increase and mechanical increase which actually are three aspects of living, economy and location. The model regression results are consistent with the theoretical analysis in that urban growth depends on the basic condition of urban size, living environment, economic promotion and location superiority. Firstly, the original urban size is always the essential part for examining urban population growth because it can reflect the basic condition of a city. There is no doubt the fact that a city with a big urban size would attract more migration and less emigration. Just like the metropolis of Guangzhou and Shenzhen in China, people prefer to move in while not move out, resulting in the consistent growth of total population. Population concentration is pervasive for China's cities as the economy is still at the growing stage. Secondly, in view of comfort and amenity, good living condition would attract more residents. This paper uses residential land share of constructive land to reflect the current situation of living environment. The contradiction of residential land shows that in the past decade, government paid more attention to industrial development than people's living, and concurrently recorded the symptom of unreasonable land-use structure. Thirdly, most urban growth is promoted by economy in market environment, especially in developing countries. Economic level influences employment, and even the migration direction and population distribution (Mueser & Graves, 1995). In this thesis, regression results imply that economic factor which also means the competitiveness of dominant industry always has principal and effective effects to promote urban growth irrespective of the dependent variables selected. Finally, the contradiction of location reveals the fact that, to some extent, the effect of location has been composited on the living condition in the early stage of this decade, so it has no significance with urban population. However, such effect appears gradually apparent in recent years. In summary, it can be generally concluded that urban size, living environment, dominant industry agglomeration and location are the influential factors for the urban and regional growth.

2) Determinants of population density gradient and the improved regional population density model

Population concentration and dispersion derives from society, economy, and environment. Enhancement of concentration capacity in China depends on the center city's industrial structure upgrade, effective fixed asset investment, good environment and living standard, and public transportation cost decrease. Firstly, the economic level influences employment, and even the migration direction and population distribution (Mueser & Graves, 1995). Economic structure has always been an essential and important aspect for examining density gradient because the second and tertiary industry can provide abundant employment opportunities for residents. Affirmatively, a city with a high proportion of second and tertiary industry has a high capability to attract more migration and less emigration. For instance, people converge to the Special Economic Zone of Shenzhen because of its telecommunications industry, resulting in the consistent growth of total population and population density. Population concentration is pervasive for cities in developing countries, as the economy is still at the growing stage and the economic structure upgrade emerges from primary industries to second and tertiary industries. Secondly, the level of comfort and amenities attract more residents, resulting in an increase of density gradient. More and more people choose to move out from metropolitan cities with pervasive air pollution and traffic jams to more suitable places with sound environment for accommodation. Thirdly, to a certain extent, population density gradient is promoted by investment, especially for developing countries. Proper investment promotes economic development and structural upgrades, and surely the population concentration. Finally, the decrease of transportation cost makes it easy for population to disperse. As the centrifugal force, accessibility among cities is observable at the late development stage. In summary, it can be concluded that industrial structure, fixed asset investment, living environment, and public transportation cost are the influencing factors for the population density gradient. Arising from this conclusion is the question of whether an effective method to balance concentration and dispersion in China's cities can be found, which is discussed in the following section.

3) Effective model of optimization for regional population distribution

As a useful and effective tool for better assessing the current situation, rationality evaluation is to reveal whether regional population distribution is good enough for sustainable development.

Multi-objectives programming model is an effective and applicable approach for population distribution optimization, by which the economic factor, environmental factor and social factor can be collectively investigated. Compared to the previous qualitative study of optimization, the quantitative method could provide technical support. In the case study, rationality evaluation results shows that except for Guangzhou, Shenzhen and Zhuhai, other cities in Guangdong Province go through excessive pressure on population. In order to meet current demand for urban population, positive measures like infrastructure improvement and transportation system construction should be put into practice because too many immigrants would only exert great pressure on the economy, society, resources and environment. On the contrary, integrated population carrying capacities in Guangzhou, Shenzhen and Zhuhai remain surplus to some extent, theoretically they should continue to encourage immigration and play a role in population agglomeration. The same as Shenzhen, total employment population in different industries of Guangzhou only changed a little after optimization because there is no large gap between real situation and optimization results. Decrease in employed population of the primary industry indicates the continuous urbanization of Guangzhou, and the dominant industry is the secondary industry because of the increased employed population. Urbanization should be encouraged and most people are in the secondary industry which can drive economic development. The population growth in Shenzhen slows down and the urban population tends to be decentralized. Its employment structure changes from secondary industry to the tertiary industry. It is good for Shenzhen's development because on one hand, compared to the secondary industry, the tertiary industry contributes a lot to environmental protection and on the other hand, investigation on pollution control of secondary industry could be partly shifted to other investigation in the tertiary industry. This is undoubtedly an effective measure for densely populated Shenzhen, while changes in employment structure will reduce the pressure on economy, society, resources and environment. Zhuhai as the third center city in the PRD region shows rapid urbanization. Due to excess economic, social, resources and environmental carrying capacities, Zhuahai should devote greater efforts to encourage immigration in every industry and play a role of agglomeration in order to boost the development of surrounding hinterland and satellite cities. In all, multi-objectives programming model under co-constraints of economy, society, resources and environment helps to optimize and adjust the employed population of three industries in different cities of Guangdong Province. Effective strategies could be made according to the optimization results.

8.4 Contributions

1) Contribution to the research of regional population distribution from the perspective of sustainable development

This study has constructed a framework which integrates evolution mechanism and optimization model of regional population distribution together. This framework can be used as a guideline for government policy making for sustainable regional population and economic development. It is an attempt to investigate the evolution and optimization together from the perspective of sustainable development, which fills the gaps identified in the literature. All these contribute to the research of regional population distribution.

2) Development of conceptual model for investigating the driving force of urban population growth

Taking the worldwide metropolitan area for reference, this research divides the evolution process into five phases from the time dimension. Driving force of regional population distribution evolution derives from economic expansion demand, social development demand and resource and environmental protection demand, and this research provides qualitative analysis both from macro and micro perspective. As the technical support, a conceptual model that quantifies the driving force is developed in order to reveal the interactions between factors and urban population growth.

3) Improvement of traditional population density model

Compared with Alperovich's VPM about the factors of population density gradient, this research expands to the resource and environmental aspect. According to the sustainable thinking, this research integrates economic, social and environmental factors and builds up the regression model to identify the factors and reveal the interactions between factors and population density gradient. Spatial autocorrelation is an objective method to reveal center cities and with the factors get above, regional population density model is improved. This is also a contribution to the research scale of urban agglomeration capacity for sustainable development.

4) Provision of a new model of optimizing regional population distribution for sustainable development

This research offers a quantitative method that helpes government optimize the current population distribution. It proposes the definition of comprehensive carrying capacity which integrates resource and environment, economic development and social resources together. Based on the results of rationality evaluation, contribution degree could be computed. Multi-objective programming model for sustainable development provides a quantitative method to optimize regional population distribution. Through rationality evaluation and multi-objective optimization, government could make effective policies to promote sustainable evolution.

8.5 Limitations of the Research

Four points of limitations in this research are acknowledged.

Firstly, due to limited time, the research area is confined to China and research findings are developed based on case study in China. Thus, the understanding of these findings only refers to Chinese regional population distribution. In addition, only one case study is conducted to validate the feasibility of research framework. The main reason of this limitation is due to time limits and data shortage. More case studies could be conducted to better demonstrate the feasibility of the framework and effectiveness of the mathematical models.

Secondly, about model validation, only ten years population growth data is tested. This limitation is because it is really hard to get enough data especially in developing countries. If the sample size is enlarged and the time span is longer, urban population growth model could be investigated more significantly. Factors would be identified more comprehensively and accurately. In the big city, taking Guangzhou for example, around 30% of residents are floating population. Of course, there is no doubt the fact that results of framework validation will be more accurate if the floating population is taken into account. However in the developing countries like China, it is really hard for the scholars to collect enough data like floating population. Data shortage is the biggest problem and challenge the government and scholar confront.

Thirdly, in the multi-objective programming model, only GDP, discharge of urban sewage and waste water and investment volumes of transportation, warehousing and postal industries about economic, ecological and social benefits are involved as the optimization objective. If time and data is enough, more influencing factors about economic, ecological and social benefits should be taken into account, thus optimization model would be more convincing. It will broaden the scope of research and is better to perfect theoretical system.

8.6 Directions for Future Research

This thesis dose relatively comprehensive research about evolution mechanism and optimization model of regional population distribution for sustainable development in China, however, regional population planning is a huge project, future investigation needs to be developed as follows.

More case studies could be used to do validation in order to verify the generality of the framework.

This research can be expanded to other countries both developing and developed countries that would help make comprehensive investigation about regional population distribution and optimization for sustainable development.

Appendix 1: The Original Data for Case Study of Urban Population Growth

The Original Data for Case Study of Urban Population Growth

	Population growth from 2000 to 2010 (1000 persons)	City population in 2010 (1000 persons)	City population in 2000 (1000 persons)	Residential land share of constructive land (%)	Employed population of dominant industry (1000 persons)	Distance to the regional center cities (kilometers)
Guangzhou	2761.60	12709.60	9948.00	0.32	652.80	136.00
Shenzhen	3359.60	10372.00	7012.40	0.26	2270.60	136.00
Zhuhai	325.10	1561.60	1236.50	0.37	282.90	284.00
Shantou	718.40	5396.20	4677.80	0.35	132.20	782.00
Foshan	2627.50	9662.20	7034.70	0.55	714.80	177.30
Shaoguan	93.70	2830.20	2736.50	0.18	37.10	581.00
Heyuan	690.40	2958.20	2267.80	0.25	43.20	405.00
Meizhou	439.40	4244.60	3805.20	0.26	45.30	782.00
Shanwei	1383.10	4601.10	3218.00	0.36	361.30	260.00
Dongguan	481.90	2939.00	2457.10	0.26	20.90	452.00
Zhongshan	1776.40	8224.80	6448.40	0.29	551.10	147.00
Jiangmen	758.00	3122.70	2364.70	0.31	450.30	215.90
Yangjiang	498.40	4450.80	3952.40	0.31	146.00	250.90
Zhanjiang	253.30	2425.30	2172.00	0.33	19.30	543.00
Maoming	969.50	7003.80	6034.30	0.34	35.20	985.00
Zhaoqing	578.20	5826.40	5248.20	0.31	16.20	777.00
Qingyuan	545.30	3922.20	3376.90	0.29	49.30	326.40
Chaozhou	554.00	3703.80	3149.80	0.35	60.80	278.80
Jieyang	267.70	2672.10	2404.40	0.61	23.70	824.00
Yunfu	636.90	5883.00	5246.10	0.36	35.10	752.00

Appendix 2 Composition of the PRD Region and Population and Land Area in 2011

Composition of the PRD region and population and land area in 2011

Administrative division	Research unit	Land area (km^2)	Population (million)	Population density (persons/km^2)
Provincial capital	Guangzhou	3,843	8.99	2340
Special economic zone	Shenzhen	1,992	9.09	4564
	Zhuhai	1,701	1.53	902
Prefecture-level city	Foshan	3,848	6.00	1558
	Dongguan	2,465	6.33	2569
	Zhongshan	1,800	2.52	1398
	Jiangmen	1,822	1.62	890
	Huizhou	2,687	1.81	672
	Zhaoqing	748	0.62	830
County-level city	Conghua	1,975	0.53	266
	Zengchegn	1,616	0.81	504
	Taishan	3,286	1.00	303
	Kaiping	1,659	0.68	409
	Heshan	1,108	0.49	438
	Enping	1,698	0.47	274
	Sihui	1,163	0.49	423
	Gaoyao	2,196	0.77	350
Counties	Huidong	3,535	0.88	250
	Bohuo	2,858	0.97	341
	Longmen	2,298	0.33	144
	Guangning	2,459	0.49	198
	Deqing	2,257	0.35	153
	Fengkai	2,723	0.42	155
	Huaiji	3,573	0.81	227

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