MODELING THE DYNAMICS OF DESAKOTA REGIONS: GLOBAL – LOCAL NEXUS IN THE TAIPEI METROPOLITAN AREA

A Dissertation

by

BING-SHENG WU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2009

Major Subject: Geography

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Approved by:

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ABSTRACT

Modeling the Dynamics of Desakota Regions: Global – Local Nexus in the Taipei Metropolitan Area. (August 2009)

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Since the 1970s, Asia has experienced rapid urbanization processes, which are distinct from U.S. society, and the direction of Asian urbanization is more strongly affected by economic globalization. The desakota model, proposed by McGee and Ginsburg in 1991, focuses on how internal domestic and local forces drive the specific rural-urban transformation in Asia. However, the McGee-Ginsburg model does not emphasize the importance of globalization on Asian urbanization. To fill the gap, this study develops a GIS-based CA framework based on the desakota model to not only simulate the unique urbanization processes in Asia but also integrate the influence of globalization into Asian urban dynamics. Three approaches are developed in the CA simulation: 1) physical constraints and land-use classification from remotely sensed images in 1993, 2000, and 2008, are incorporated into micro-scale transformation; 2) population dynamics, shifts of economic activities, and foreign direct investment (FDIs), a representative of the impact of globalization, are applied for multi-scale interconnection; 3) the Monte Carlo mechanism is finally introduced to combine the above two approaches and implement the simulation process. The Taipei metropolitan area, a rapid urbanizing region that highly interacts with the global economy in Asia, is chosen to examine this model. The CA simulation model establishes a strong interaction between FDIs, an indicator representing impacts of globalization, and the dazzling Asian urban model. The combination of multi-scale economic factors and micro-scale land-use transformation also reveals how urban growth of the Taipei metropolis in recent years fits the characterization of the desakota model, and how desakota regions, the growth generators, interact with city cores. As a result, the research not only successfully links the influence of globalization with the desakota model and simulates urban dynamics of Asian cities but also provides scenarios of different FDI inputs for governments to better handle urban growth with global impacts under the deep economic recession since 2007.

DEDICATION

To

My father, Rong-Chang Wu

My mother, Hsiu-Min Lin

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Smith, a renowned geographer in the United States. He always encouraged me to be enthusiastic about doing research. In addition to research, he also reminds me to have an optimistic attitude towards life. I believe these are the key reasons why he is productive and successful in the academia.

I would also like to thank my committee members, Dr. Bednarz, Dr. Liu, and Dr. Brody, for their guidance and support throughout the course of this research. Dr. Bednarz's expertise in urban/ economic geography gives me a solid understanding while studying urbanization processes with economic activities. Dr. Liu's knowledge in GIS and remote sensing technologies helps me solve many critical issues regarding spatial analyses. Dr. Brody leads me into the real world of conflicts between environmental protection and urban development, and stimulates me to think about the importance of environmental impacts on future urban growth.

Thanks also go to my friends and the department faculty and staff for making my time at Texas A&M University a great experience. Finally, thanks to my mother and father for their love and encouragement. Their endless support is the strongest motivation for achieving the milestones in my life.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

1. INTRODUCTION

1.1. Background

Urbanization is a universal phenomenon taking place across the globe (Sudhira et al. 2004). By the end of 2005, world urban population increased from 1.52 billion in 1975 to 3.17 billion, while urban population in Asia increased from 0.57 billion to 1.55 billion during the same time period (UNPD 2005). Population growth during the last three decades in Asia results in rapid urban expansion and urbanization. However, compared with the significant urban transition taking place in the West during the late 19th century that was primarily driven from the industrial revolution and rural-to-urban migration in terms of labor-intensive economic activities, rapid urbanization in Asia during the late 20th century has exhibited a process distinctively different from that of the West (Sui and Zeng 2001).

The desakota model, developed to describe the unique urban pattern and process in Asia, is proposed by McGee and his colleagues (Ginsburg 1991; McGee 1991). Though the desakota model captures key features of Asian urbanization, for instance, urbanization in densely populated rural regions and the mixture of agricultural and non-agricultural activities between rural / urban areas, the descriptive model focuses more on

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This dissertation follows the style of *Annals of the Association of American Geographers.*

interpretations of static spatial patterns and structure rather than discussing spatial-temporal dynamics of urban patterns in terms of various driving forces. In addition, the model concentrates on internal domestic and local forces contributing to urban transition, and emphasizes the effects of population dynamics and sectoral shift during rural-urban interaction (Rimmer 2002). However, globalization also has had a dramatic and positive effect on cities in Asia (Lo and Marcotullio 2000), and studies have shown the influence of globalization on the distinct urbanization processes in Asia (Sit and Yang 1997; Qadeer 2000; Ng and Hills 2003; Smith 2004; Lin and Ho 2005). Thereafter, study of global impacts on urban form and urbanization processes can better draw urban dynamics as well as changes of urban landscape in Asia, and also reveal the significant rural-urban transformation in contemporary Asian cities. Cellular automata (CA), serving as a powerful metaphor for the complex interaction of urban dynamics (Couclelis 1997), is viewed as useful as a tool for modeling urban spatial dynamics (Li and Yeh 2000). Through the integration of socio-economic data, remotely sensed images and GIS technologies into cellular automaton modeling, this research incorporates global/ regional/ local scale of factors into the desakota model and develops a dynamic model for simulating Asian urban growth.

1.2. Research objectives

Unlike conventional Western city-based urban theories and patterns, the time-space compression of Asian urbanization challenges classical theories of urban transition and exhibits different processes. The desakota model reveals a new type of urban spatial structures and shapes a unique urban landscape in terms of globalization and local socio-economic factors. Yet no study has been done to draw a thorough picture showing the dynamics between global /local drivers and the urban pattern in Asia. Hence this research bridges the global influence and local development into the desakota urban model and synthesizes multi-scale socio-economic driving factors to simulate Asian urban dynamics.

Specifically, I want to address the following questions through the CA-based simulation of the desakota model under global and local contexts:

- How does economic globalization interact with local socio-economic activities and contribute to the distinctive desakota urban region in Asia?
- Under the spatial-temporal compression of Asian urbanization, what could be the possible trajectory of current desakota regions under the wave of globalization?
- How does economic globalization offer promise in addressing the unique issues, challenges, and opportunities that desakota characteristically face?

1.3. Significance

1.3.1. Theoretical perspective

The major contribution of this dissertation is to conduct a systematic study of Asian urban dynamics by linking influences of globalization with the domestic-oriented desakota urban model. Contemporary urban studies in Asia emphasize either specific urban patterns/ spatial phenomena (Qadeer 2000; Whitehand and Gu 2006), or global impacts on Asian urbanization (Lo and Marcotullio 2000; Marton 2002; Seto and Kaufman 2003). However, a linkage of the unique urban form and urban processes, especially globalization, is rare. Xie and others (Xie et al. 2007), for instance, apply a CA model and try to combine the static desakota model with external driving factors. In their model, governments are viewed as external factors for the top-down process without thinking about the influence of globalization. Hence the major contribution of this research is to directly apply foreign direct investments (FDIs) data to represent globalization and link the global driver with domestic economic data as external factors which reflect multi-scale impacts on urban expansion. The conjunction of urbanization processes and urban patterns will help urban geographers refine the descriptive desakota model with fruitful urban processes and better understand how the dazzling Asian urban form is driven.

1.3.2. Methodological perspective

Asian urbanization processes involve various scales of driving factors, including FDIs (global level), national economies (national/ regional level), and local economic developments (local level). However, one of the defining characteristics of CA modeling is the simulation for every single cell. This dissertation develops a new CA-based modeling approach to simulate the evolution of the desakota urban pattern through multi-scale urbanization processes. This research applies statistical methods and integrates GIS, remotely sensed images and economic data to implement the connection between micro-level transformation and mesa-/macro-level processes in CA urban simulation.

1.3.3. Policy perspective

Urbanization and industrialization are stimulated by economic factors in the West and East. In western cities, urbanization and industrialization are driven by economies of scale and agglomeration in cities and towns, while economic globalization spurs rapid rural urbanization in Asia. Economic developments in Asian countries rely much on foreign investments. If the amount of foreign capital flows from transnational corporations (TNCs) in developed countries is decreasing, will the growth rate of urbanization in Asia cities still remain fast? How should governments consider future urban planning under the impacts of globalization? The CA-based simulation urban model in this dissertation examines several scenarios to mimic different levels of capital inputs and evaluate possible urban growth with various impacts of globalization, so the governments can understand how foreign investments change urbanization processes and develop proper urban policies, if a deep economic recession hits Asian countries.

In addition, rapid urban expansion in Asia has concomitantly caused severe environmental problems. Accelerated urbanization in Asia has not only further worsened problems of air, water, and soil pollutions surround the cities, it has also disturbed the ecological cycle at a broader scale. However, to pursue higher economic growth and more profit, neither governments nor businesses have given environmental problems the attention they deserve. The spatial-temporal urban simulation model developed in this dissertation can help stakeholders examine scenarios for future urban growth based on different policies so they can examine environmental impacts under various developments. Consequently, governments, urban planners and policy makers can design feasible plans and reach the goals of sustainable urban development.

2. LITERATURE REVIEW

2.1. Globalization and Asian urbanization processes

2.1.1. The desakota model: an overview

For years, theoretical explanations for the process of urbanization have been guided primarily by a city-based paradigm that values the advantages of agglomeration in cities and the economies of scale as fundamental to urbanization (Xie et al. 2006), and the rural-urban dichotomy has been widely accepted as the core of classic urban theories. However, since the 1970s, scholars of urban studies in Asia have reported a new type of urban form as well as urbanization process that challenge conventional western urban theories (McGee 1991; Johnson and Woon 1997; Wang 1997; Douglass 2000; Lin 2001b; Qadeer 2004). McGee (1991, pp. 4-5) argues that the conventional view of Western urban transition is inadequate in Asia from three respects:

1. It is too narrow in its view that the widely accepted spatial separation of rural and urban activities will persist as urbanization continues,

2. It is inadequate in its assumption that the urbanization transition will be inevitable because of the operation of "agglomeration economies" and

comparative advantage, which are said to facilitate the concentration of the population in linked urban places,

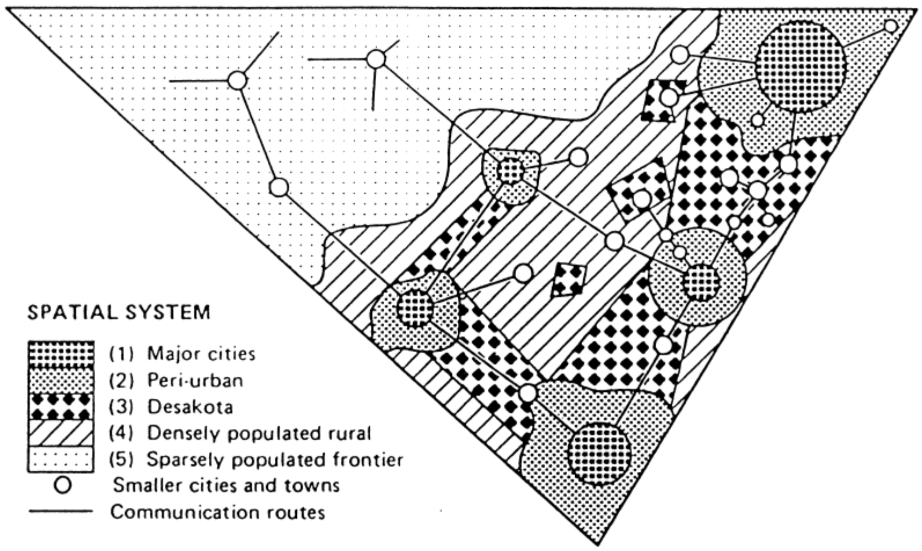
3. The Western paradigm of the urban transition, which draws its rationale from the historical experience of urbanization as it has occurred in Western Europe and North America in the 19th and 20th century, is clearly not neatly transferable to the developing countries' urbanization process.

The significant difference between Western and Asian urbanization is the rural-urban interaction. Classic urban theories emphasize the importance of the rural-to-urban migration. The progress stimulates urban expansion and rapid population growth in urban regions while population in rural regions decline. The rural-to-urban migration in the West results in clear distinction between urban and rural areas. Yet in contemporary Asian urbanization, the rural-to-urban interaction is a two-way, rural/ urban "transformation" – the linkages between rural and urban sectors and achieves the goals of successful development (McGee 2008), and the unique progress blurs the division between rural and urban. In terms of the dissimilarity of urbanization processes and patterns between the West and Asia, new urban patterns and models are developed for contemporary Asian urbanization. Among the growing urban studies in Asia, the desakota model is the well-known, and widely discussed model showing the uniqueness of Asian urbanization processes.

McGee and Ginsburg (1991) propose a hypothetical model to describe the rural-urban transformation, new urban landscape, and urbanization processes in Asia. McGee coins the term “desakota”, which is combined from two Indonesian words: *desa* (village) and *kota* (town), to capture the unique spatial phenomenon that is emerging from villages/ towns in Asia. The McGee-Ginsburg model elaborates a distinctive urban form in Asia, and further discusses socio-economic factors driving the spatial structure. In the model, space-economy changes affect the emergence of particular regions of economic activities and represent the uniqueness of Asian urbanization.

In the desakota model, McGee (1991, pp 6-7) identifies five major landscape characteristics to represent an ideal Asian urban structure, where he labels “Asiatica Euphoria (Figure 2-1)”. The five main regions in the urban pattern include:

1. <u>Major cities</u>: extremely large cities
2. <u>Peri-urban</u>: areas surrounding the cities within a daily commuting reach of the city core
3. <u>Desakota</u>: regions of an intense mixture of agricultural and nonagricultural activities that often stretch along corridors between large city cores
4. <u>Densely populated rural</u>: regions that occur in many Asian countries, particularly those practicing wet-rice agriculture
5. <u>Sparsely populated frontier</u>: regions that offer opportunities for land colonization schemes and various forms of agricultural development



(Source: McGee 1991)

Figure 2-1 The ideal desakota spatial system

Classical urban models developed for western, especially American cities, such as Burgess's concentric-zone model of urban land-use (Burgess 1925), Hoyt's sector model (Hoyt 1939), and multiple-nuclei model addressed by Harris and Ullman(1945), define distinct boundaries for various land use types, for instance, commercial centers, industrial regions, and residential areas. However, there is no land use type showing a mixture of agricultural and non-agricultural activities which is a dazzling characteristic in Asian urban structures. Thereafter, McGee (1991, pp. 16-17) identifies six features to defines desakota regions of the landscape morphological pattern to illustrate the specific structure stretching along corridors between major city cores:

1. a large population on smallholder cultivation of rice
2. an increase in non-agricultural activities

3. extreme fluidity and mobility of population
4. a mixture of land uses, agriculture, cottage industries, suburban development
5. increased participation of the female labor force
6. ‘grey-zones’, where informal and illegal activities group

In the ideal desakota urban pattern, several urban features are quite similar to classical urban theories – city cores, peri-urban, and sparsely populated frontiers, while desakota and densely populated rural regions are rarely seen in western urban regions. There are certain conditions and processes underlying the emergence of these two unique characteristics (McGee 1991, pp. 14-16):

1. The labor force of these rice-bowl areas was “culturally” prepared to commit its labor to various forms of “new” nonagricultural activity.
2. There were large cities or clusters of cities that provided both opportunities for seasonal labor and important markets for rural rice and other products. The linkages with these cities were important for the surrounding rural areas for cultural and economic reasons.
3. These regions were frequently characterized by a well-developed infrastructure of roads and canals that allowed an intense movement of commodities and people.
4. By the early 1950s all these regions were large, cheap labor reservoirs waiting to be tapped by state, international, and private capital investment.

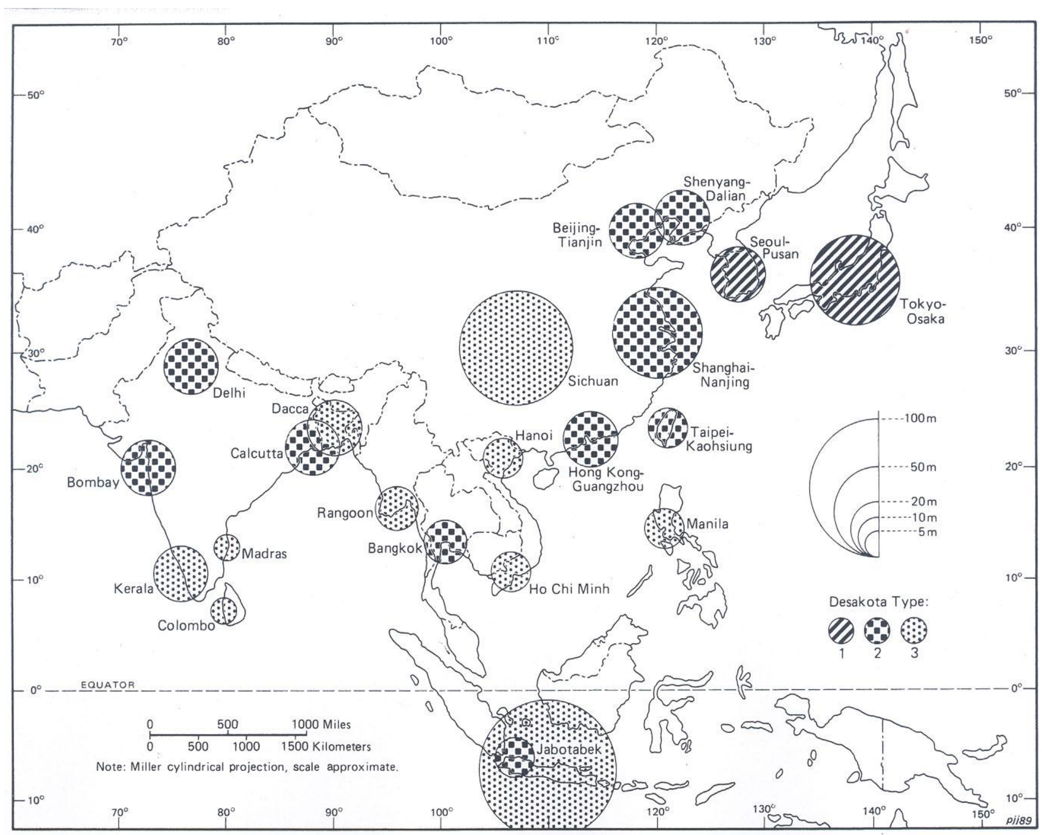
5. All the desakota regions were characterized by highly integrated “transactive” environments in terms of movement of people and commodities, for example.
6. It is important to acknowledge the role of the expansion of the global economy and the international division of labor, which create a situation where national governments responsible for gigantic, cheap labor pools have adopted different policies with respect to permitting or encouraging their countries’ labor to be tapped for national and international industrial growth.

The above processes help spatial-economic changes in different degrees. McGee (1991, pp. 12-14) defines three main desakota types in terms of the various processes of Asian urbanization, and groups those core regions in Asia into three types (Figure 2-2):

Type I: The countries that have experienced a rapid transformation of the spatial economy in terms of rural-to-urban shift in population, although agricultural land use may remain quite persistent. Ex: Japan and South Korea.

Type II: The regions that have experienced a rapid change in their economic features in the past thirty years (a decline portion of people in agriculture and a concurrent growth of small to medium-sized industries in rural). Ex: Taipei-Kaohsiung corridor in Taiwan and Bangkok-Central Plains region in Thailand.

Type III: Those regions of countries that bears some spatial and economic resemblance to Type II but is characterized by changes that occur because of high population growth and slower economic growth. Ex: Kerala and Tamil Nadu in India and Sichuan Basin in China.



(Source: McGee 1991)

Figure 2-2 Growth of core areas in Asia

An important factor resulting in the features of desakota regions is the well-developed infrastructure, such as transportation network in these regions. The infrastructure are established during late 19th century, because most cities in Asian countries, especially south-east Asia, are growing rapidly because they were colonized since late 19 century (Dick and Rimmer 1998) by western countries. To acquire raw materials and produce commodities for exporting from their colonies, Western governments established infrastructure such as roads, railways, and ports. Machinery and other new technologies were also adopted while they build up manufacturing factories. After independence of these Asian countries, the well-developed infrastructure, especially transportation, plays a fundamental role in rapid Asian urban transition. Considering cheaper land prices and convenient transportation, corporations built up factories in towns around major cities to lower down the cost of investment. In addition, the establishment steered the economic activities of these towns, allowed an intense movement of commodities and people, and also enhanced to preconditions for growing populations (McGee 1991).

Another essential driving factor encouraging the emergence of deskaota regions is sectoral shift from agricultural activities to non-agricultural activities, especially manufacturing industries, in towns and villages close to major cities in terms of effective transportation routes and cheap motor vehicles such as two-stroke motorbikes. For manufacturers, domestically or internationally, they build up factories near city cores to reduce land cost. Moreover, manufacturing industries require considerable size of labors, and the regions close to city cores have high density of population whose major work is seasonal agricultural activities. Compared to the hard working but limited gains from agricultural activities, many rural laborers change their occupation to work in factories. Those who still work in their farms sometimes go to factories to get more income during off-seasons. Wives often go to firms and bring some components to assemble them into a part of certain products, such as umbrellas, and chairs. The transformation of economic activities changes the major direction of movement from rural to urban. Rural residents can still live in rural regions and commute from their hometowns to manufacturing factories which are most located in the desakota regions. With less population migration from rural to urban, rural population is growing. With population growth, rural regions are getting urbanized. The mobility of rural residents blurs the distinction of rural and urban.

2.1.2. Impacts of globalization on Asian cities

Globalization is essentially a process driven by economic forces. Its immediate causes are: the spatial reorganization of production, international trade and the integration of financial markets (Sideri 1997, p. 38). Since the 1960s, due to innovation of information technology, advanced telecommunication systems, blooming internet, high-capacity cargo freighters, and rapid air transport, world economy has experienced fundamental adjustments in production, resource utilization, and wealth accumulation so that global interdependence and regional economic blocs have emerged as notable consequences (Lo and Yeung 1995; Lo and Marcotullio 2000). In addition, industrial capitalism, aided by the transaction revolution and transnational financial institutions, also has accelerated the growth of a global economy (Ng and Hills 2003). For the capital costs down to a minimum and the profits up to a maximum, precise use of location and ownership strategies by transnational corporations (TNCs) or multinational enterprises (MNEs) is the very essence of increasing globalization (Buckley and Ghauri 2004).

The major strategies of MNEs are subcontracting and licensing. MNEs are looking for mid-income, less developed countries with cheap labor cost and/or rich raw materials. Private capital from MNEs flowing to less-developed countries is applied to invest local firms in these countries for producing authorized products, and sell them back to the markets. The outsourcing processes stimulate economic development and create more job opportunities in less-developed countries in terms of the influx of foreign direct investments (FDIs). Asian countries are considered as new industrial sites in terms of the following factors:

First of all, many cities in Asian countries, especially south-east Asia, were colonized by western countries since late 19th century (Dick and Rimmer 1998). To acquire raw materials and produce commodities for exporting from their colonies, Western colonials established infrastructure such as roads, railways, and ports. Machinery and other new technologies were also adopted while they build up manufacturing factories. Moreover, western colonies bring political systems and develop something in these countries. After independence of these Asian countries, the well-developed infrastructure, especially transportation, plays a fundamental role in rapid Asian urban transition.

Second, the major economic activities of most Asian countries were cultivation agriculture, commonly wet-rice. The economic activities can only substitute family life because they are not able to get more income (money) to support daily life. In addition, only men work in farms, and women often stay at home for some basic activities such as raise poultry, and peasants will have no money during off-season, so there are lots of potential laborers in Asia, especially during off-seasons. Traditional MNEs are manufacturing industries, and they are labor-intensive industries. Asian countries have many cheap labors, so MNEs are willing to either set up factories in these areas or subcontract local factories.

Third, government policies also play an important role attracting MNEs. FDIs can help national economy, so Asian governments create many policies to attract MNEs. Some countries define economic policies for national economy and develop lots of infrastructure. Some countries build up industrial parks with tax incentives and loose economic restrictions. Some countries develop economic zones with good infrastructure and cheap land cost. For instance, the export-oriented economic policies by Japan, Korea, and Taiwan affect urban development (Kuznets 1988). The development of export-processing zones (EPZs) and industrial parks at the outskirts of cities by governments is an example to stimulate exports and foreign investments (Lo and Marcotullio 2000). China's household registration system, is another example to restrict migration of rural people from seeking employment and living opportunities in cities (Zhu 2002). After the 1978 economic reforms, one of the major policies of Chinese government is rural urbanization (Marton 2002). Along with the household registration system, township and village enterprises (TVEs), or small and medium enterprises (SMEs) emerge and play an important role in rural urbanization(Zhu 2002). Therefore, government policies also drive the share of economic activities and change intra-urban structure in Asia (Smith 2004).

2.2. Current issues of Asian urban dynamics

2.2.1. Criticism of the desakota model

The desakota model reveals a different perspective from conventional western urban models. Recent urban studies in Asia, also following, explicitly or implicitly, the framework of this distinctive Asian urban model, and further discuss more unique urban features/ patterns/ transitions in Asia (e.g. Johnson and Woon 1997; Lo and Marcotullio 2000; Lin 2001b). However, the model concentrated on local/regional forces contributing to urbanization, and emphasized the effects of population dynamics and sectoral shifts during rural-urban interaction, (Rimmer 2002), but the direct effects of globalization was not considered. Lo and Marcotullio (2000) reviewed globalization and urban transformations in the Asia-Pacific region and argued how globalization and global activities, and especially FDIs from TNCs, have been shaping regional functional city systems, and stimulating changes of urban structures in East Asia. Sit and Yang (1997) studied the impacts of FDIs in the Pearl River Delta of South China, one of the desakota regions addressed by McGee, and argued that the urbanization process in that area have been significantly influenced by FDIs.

How and to what extent have the sectoral and spatial restructuring of the regional economy reshaped the geographical distribution of population? Qadeer (2000) argued that the desakota processes are essentially the result of the infiltration of urban activities into a rural area, and an extension of the metropolitan economy through the countryside. He views desakota processes as comparable to the urban sprawl of western cities. Qadeer coined the term "ruralopolis" to better express the rural-urban dynamics, and more accurately describe the economic growth of rural regions linked hierarchically to towns and cities for higher-order services. Heikkila and his colleagues (2003) also took McGee's desakota descriptive model as documenting and describing a geographic phenomenon rather than an alternative to measure peri-urbanization. Last but not least, the desakota model has yet to provide a satisfactory explanation for the processes of settlement transition (Lin 2001a).

In summary, criticisms on the desakota model can be grouped into two major categories: 1) the desakota model does not consider global influences; 2) the definition of desakota processes remains unclear. McGee applies endogenous/local factors to describe the Asian urban pattern without incorporating external factors, explaining Asian regional variation, or discussing causes and transitional phases. Since desakotas are an emerging urban form that interlocks bottom-up rural urbanization with top-down urban expansion (Lin 1997; Wang 1997, 1998; Lin 2001a; Xie et al. 2007; McGee 2008), it is essential to consider bottom-up factors based on local economic development and top-down forces under global contexts for driving the desakota pattern.

2.2.2. Urban policies and urban sustainable development

Urban systems consume more natural resources and energy, and generate more impacts to natural environment than other ecological systems. Rapid urban expansion requires more vacant land for human settlements and diminishes the amounts of original species and their habitats. In addition, coming with urbanization, industrialization results in serious air, water, and soil pollution threaten human being's health and quality of life. Recently environmental sustainability has become an important issue in the world. Various studies have discussed human impacts on natural environments and how to propose policies to take a balance between developments and environmental protections (e.g. Styperek 2000; Kline et al. 2001; Pickett et al. 2001; Brody et al. 2003; Randolph 2003). Nonetheless, even though environmental sustainability has become the mainstream in urban planning worldwide, the consciousness of environmental protection has yet been widely recognized in Asian societies. Governments and businesses focus more on developments of transportation networks, manufacturing factories, residential buildings, skyscrapers, other infrastructure and so forth, for more profits and pursuing higher economic growth, without paying enough attention to environmental impacts of human-made constructions. As a result, rapid environmental deterioration, large-scale, often haphazard, land conversion, and infrastructure backlogs are major policy challenges in Asia (Webster 2002).

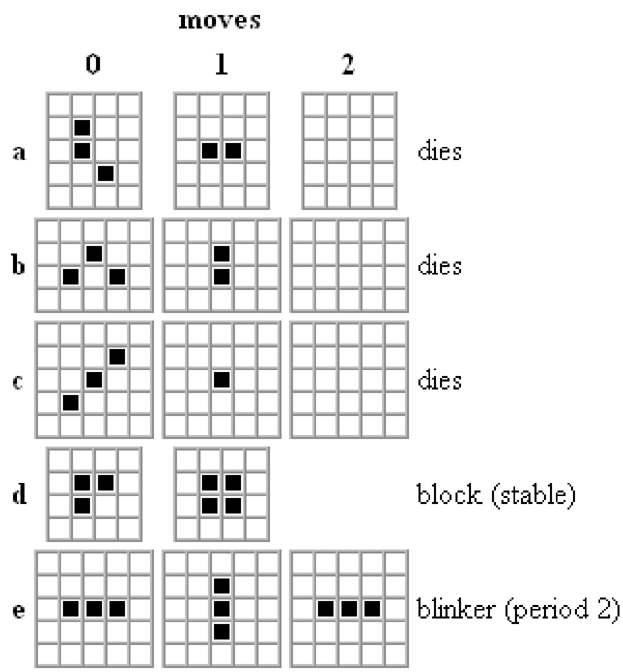
Moreover, in terms of the specific feature in Asian urbanization—rapid urbanization taking place not only in (peri-) urban regions, but also densely populated rural areas, the extent of constructed land is larger than extension of metropolitan areas. It is crucial to monitor and model the growth of these regions and analyze their ecological impacts in devising effective policies to guide further development. The integration of GIS with urban modeling techniques, such as cellular automata, fractals, fuzzy theory, and neural networks (Batty and Xie 1994; Yeh and Li 2001; Heikkila et al. 2003; Liu and Seto 2008), has helped users conduct urban simulation and modeling. Furthermore, the concept of loose developments on open land in rural areas is similar to the phenomenon of urban sprawl in West, which is defined as "a spreading, low-density, automobile-dependent development pattern of housing, shopping centers and business parks that wastes land needlessly (Johnson 2001)." Indeed the formation of urban sprawl in West and Asia may vary and it is far beyond this study, but the consequences of urban development both highly influence natural environment. Coupling these cutting-edge GIS technologies and urban modeling with western experiences of urban policies for sustainable development into real decision making, meticulous empirical analysis and simulation can help governments and urban planners formulate realistic policies to achieve better urban growth, effective environment management, and ultimately, the goal of urban sustainable development.

2.3. CA-based modeling of urban dynamics

2.3.1. The basis of cellular automata

Cellular automata (CA) are simple models for the simulation of complex systems (Wolfram 1984; Waldrop 1992). A cellular model defines a finite action space which is divided into equal units. Each regular unit is called a cell, and there is a set of initial conditions on every cell. Several behavior (or transition) rules are defined to control the status of every cell. Transition rules allow the identification of thresholds for each cell to response to the change of its status (parameter). For example, if a cell is determined to be "lived" according to certain transition rules, its status will be changed. Yet if it is decided to be "dead", the cell will not change its status. When iterations start, every cell will change or keep its statuses based on the transition rules and/or its adjacent neighborhood. With the progresses of iterations, the space will keep evolving beyond the initial conditions until the processes stop or cells are all "dead".

One of the classical CA examples is "Game of life", which is developed by John H. Conway (Gardner 1970). It is an easy-to-understand CA simulation process. In this application, a finite space is divided into equal cells. A random initial condition is set up: cells are drawn either black for "lived" or white for "dead". Three transition rules are defined as following:



(Source: Gardner 1970)

Figure 2-3 Transition processes of "Game of Life"

1. *Survivals (Lived)*:

   A *lived* cell with two or three *lived* neighboring cells will survive for the next generation. (Figure 2-3, a0→a1)

2. *Deaths (Dead)*:

   Each cell with four or more *dead* neighbors cells will die (be removed) for the next generation. (Figure 2-3, c1→c2)

3. *Births*:

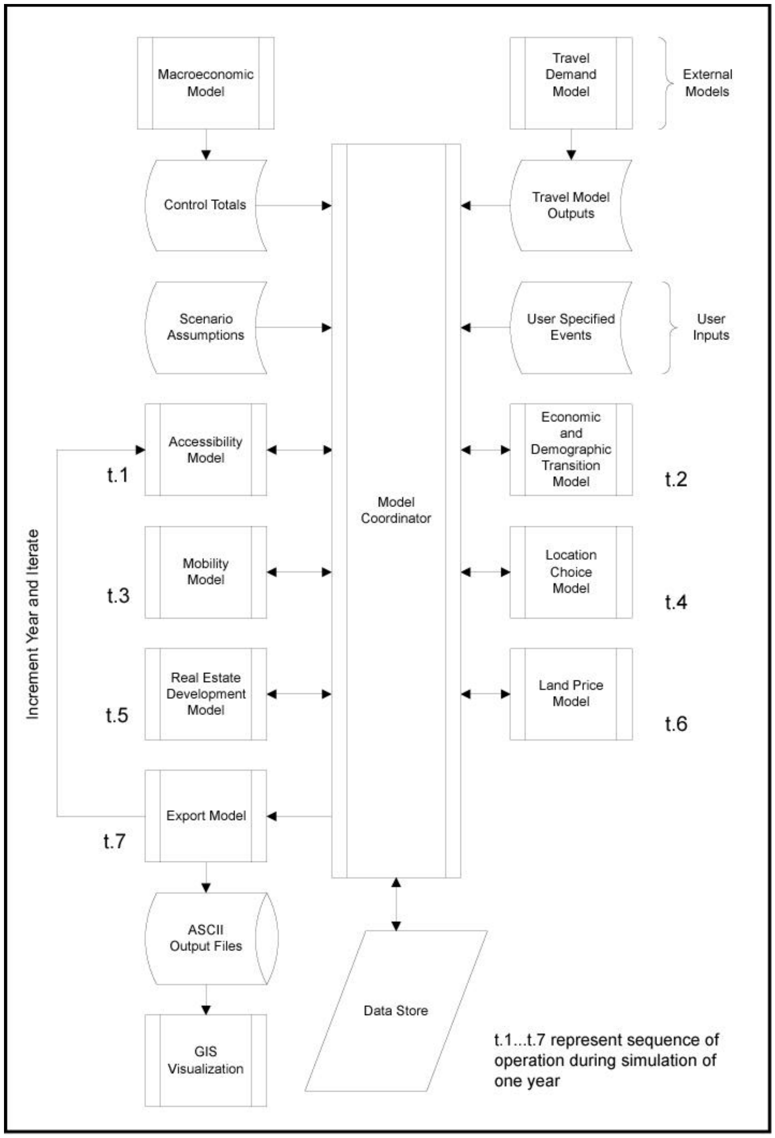
   Each empty (*dead*) cell adjacent to exactly three neighbors—no more, no fewer—is a *birth* cell, and it will turn to a *lived* cell in the next generation. (Figure 2-3, b0→b1)

When the iteration starts, the transition rules are first applied to "lived" cells to identify whether they will be survivals or not for the next iteration. Then all cells will be checked if they meet the "death" transition rule and need to change their statuses for the next move. Finally all dead cells are investigated to determine where births will occur. After all the above patterns have been checked, change or keep the status of all cells, and then move to next iteration. The same procedure is repeated to produce subsequent generations until all cells are in a stable situation (Figure 2-3, d0→d1), or a "blinker" situation. (Figure 2-3, e0→e1→e2).

2.3.2. Current CA-based urban models

Urban regions are considered as non-linear, complex, self-organizing, and dynamic systems, and CA, the non-linear process serving as a powerful metaphor for the complex interaction of urban dynamics (Couclelis 1997). CA provides effective ways of simulating the process of landscape transformation as well as offering a means of evaluating alternative planning scenarios (Ward et al. 2000). Today CA is broadly introduced to GIS-based urban simulation and has become especially, useful as a tool for modeling urban spatial dynamics (Li and Yeh 2000). Following the bottom-up CA concept stressing how local rules and variations change urban land-use types and form spatial patterns, current CA-based urban models are developed based on endogenous factors that affect local urban growth. Alberti and Waddell (2000) develop the UrbanSim model for metropolitan planning of land-use, transportation, and the environmental planning. The UrbanSim model is driven by user-specific events because Alberti and Waddell (2000) believe “urban development evolves over time and space as the outcome of the microscopic interactions of individual choices and actions taken by multiple agents – households, businesses, developers, and governments.” A number of choices by households, businesses, and developers are simulated on an annual basis, and their outcomes are implemented as scheduled events (Waddell 2002). In the UrbanSim model, five core models are incorporated (Waddell 2002): demographic and economic transition model, household and employment mobility model, household and employment location model, real estate development model, and land price model (Figure 2-4).

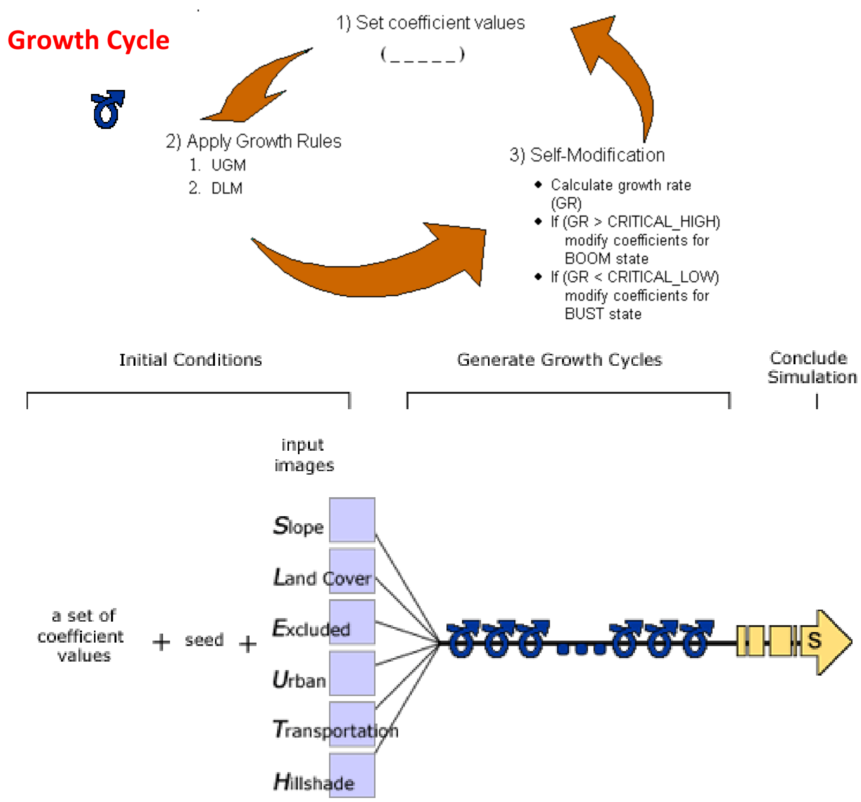
Through the model coordinator module, the UrbanSim model reveals how local scales of factors, for instance, socio-economic activities and behaviors of various agents, change land use in urban regions.



(Source: Waddell 2002)

Figure 2-4 UrbanSim model structure and processing

Unlike the UrbanSim model, which focuses on socio-economic drivers, Clarke and his colleagues (1997) develop another CA model considering how physical constraints affect urban growth. The SLEUTH model, formally named “the Clarke Cellular Automaton Urban Growth Model”, is applied to landscape matrix of urban structures by integrating remote sensing images and indices of landscape (Herold et al. 2002). The term SLEUTH is the abbreviation of six essential constraints of urban developments: *Slope, Landuse, Exclusion, Urban extent, Transportation, and Hillshade*. The model develops four types of urban growth (spontaneous growth, diffusive growth, organic growth, and road influenced growth.) based on five coefficients (diffusion factor, breed coefficient, spread coefficient, slope resistance factor, road-gravity factor) through self-modification processes (Figure 2-5). This model is broadly applied to various cities in North America, including Washington, DC, and San Francisco (Clarke and Gaydos 1998; Silva and Clarke 2002).



(Source: Clarke 1998)

Figure 2-5 Growth cycle and simulation processes in SLEUTH model

Although these two famous urban growth models concentrate on different aspects of parameters to stimulate urban growth, they both follow the same fundamental CA concept: altering the characteristics of each regular cell relies on its neighbor cells. In basic CA models, a cell with regular size represents an automaton. A set of rules are defined to distinguish the change of each cell according to the status of its neighborhood, and influences outside the neighborhood hardly affect the situation of cells. Locations of cells are fixed in the simulated space and unable to move. In real world, however, not every spatial object is static and fixed in the same location. Life organisms or lifeless elements may be influenced by not only their environments but also by their own decision, and their activities may change status of land. Torrens and Benenson (2005) argue the restriction of static transition rules in CA models is insufficient in dealing with mobile objects, such as residents or households. To improve the simulation in terms of real situation, agent-based modeling (ABM), the new framework of dynamic spatial systems, is developed.

Agent-based modeling was initially derived from distributed artificial intelligence in the 1980s (Boman and Holm 2004). It has been successfully applied in various disciplines such as ecology and biology, humans and artificial societies, economics, traffic and vehicle simulations, and animation and interactive multimedia (Benenson and Torrens 2004; Torrens and Benenson 2005). Agent-based model can be viewed as an improved CA model. Like CA models, status of every automaton in agent-based model is changed in terms of certain transition rules. However, the most significant difference between agent-based model and conventional CA model is the mobility and flexibility of automata. Derived from CA models, agent-based models define the behaviors of each agent, which represents the human and social units which plays a role in causing urban growth. Transition rules for each agent can correspond to human-like behaviors, and socio-economic characteristics can be represented as the states that are attributed to social science agents (Benenson and Torrens 2004).

Torrens and Benenson (2005) develop a geographic automata system (GAS) based on agent-based modeling, and apply the model to simulate urban sprawl in the Midwestern megalopolis region around Lake Michigan in the United States (Torrens 2006). They defines geographic automata as spatial objects characterized by states and transition rules, and three sets of transition rules are introduced to enable the explicit consideration of space and spatial behavior for geographic automata (Torrens and Benenson 2005):

1. *Geo-referencing rules*:

   Situating geographic automata in space

2. *Neighborhood rules*:

   Replacing conventional neighborhood rules that rely on fixed neighborhood patterns and are incapable of being varied in space or time once delineated

3. *Movement rules*:

   Considering the mobility introduced by the agent-based paradigm and developing the navigation of geographic automata

Through the three sets of transition rules, the GAS model successfully represents spatial influences on geographic automata and the interactive behaviors of the elementary spatial objects. The system also "reinforces the strengths of the simulation environment and the basis on geographic relationships makes possible some simple, but important, steps toward including the ideas of self-organization and time-management in complex systems (Torrens and Benenson 2005)."

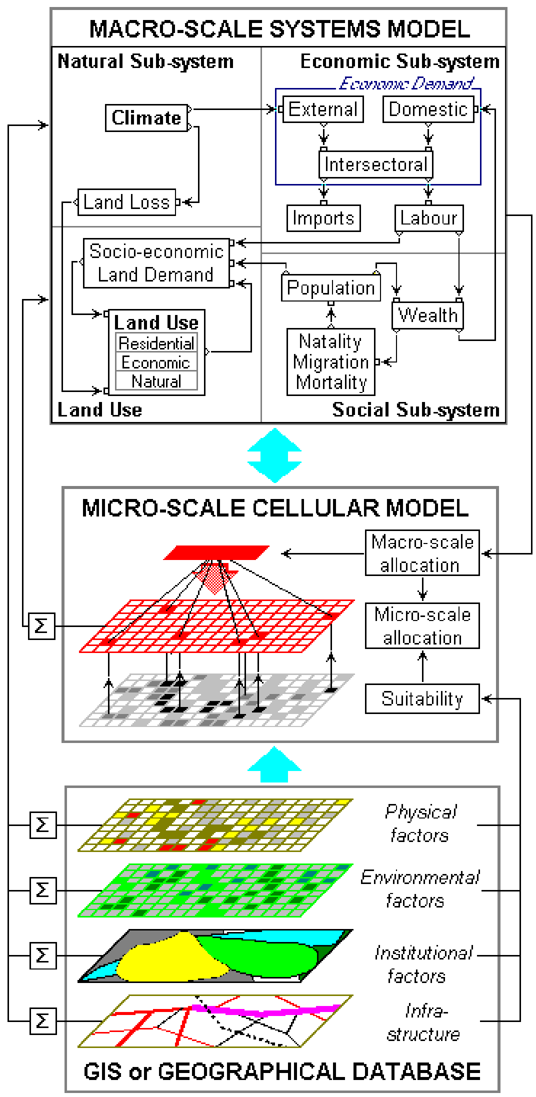
2.3.3. Selection of CA approaches

Traditional CA framework has been criticized for its inability to allow for automata movement (Brown et al. 2004; Torrens and Benenson 2005), and the shortcoming catalyzes researchers' interest in agent-based simulation. However, it doesn't mean CA modeling cannot provide better urbanization simulation results than agent-based models. Actually the usage of CA/ agent-based modeling, to some extent, relies on the scale of factors for urbanization (Benenson 2007). If land-use change or urban growth is seen as a natural evolution, some fundamental but significant features are selected as driving factors resulting in urban growth. Even though some micro-scale features, like local economic development, may be considered as important forces driving urban growth, most of features are broad-scale factors/ constraints, for instance, distances to the road network, rivers and lakes. An example is the CA model developed by White and his colleagues (White et al. 2000). The framework of their SimLusia model explains the essential parameters influencing urban growth, and how these broad-scale factors/ constraints interact with micro-scale land units/ cells (Figure 2-6).

On the other hand, if human-induced obstacles are considered into the land-pattern generator, behaviors of various “agents”, e.g. decisions made by planners and developers, and impacts on spatial units are emphasized. It implies the simulation is highly influenced, directly or indirectly, by human activities which are mostly considered as local-scale drivers, and the scope of simulation often locks on local areas. As a consequence, based on the complex of human behaviors, sets of best-fitting parameters obtained from micro-scale socio-economic driving factors are introduced to agent-based models.

It seems that agent-based models deal more with micro-level urban development, and handle agent’s behavior and endogenous factors, while transition rules in CA models mostly consider how large scale features and/or exogenous factors influence land-use types. Since economic globalization influences Asian urbanization process, CA modeling stands a better chance to interpret the evolution of Asian urban dynamic.

Another issue regarding CA modeling is the theoretical framework of urban models. Although current GIS-based CA models are widely adopted in Western urbanization, and gradually applied in Asian urban growth (Li and Yeh 2001; Sui and Zeng 2001; Yeh and Li 2003; Liu and Zhou 2005), these models are developed based upon conventional western city-based urbanization processes: transportation, restriction of physical features, accessibility to central business districts (CBDs), and so forth. Influences of globalization (e.g. foreign direct investments), shifts of economic activities, and population dynamics between rural-urban regions, which are significant factors resulting in Asian urbanization, are rarely emphasized.



(Source: White et al. 2000)

Figure 2-6 The framework of the SimLusia model

Xie and others (2007) develop an agent-based model based on the framework of the desakota model, and incorporate various economic factors into their model (Table 2-1). However, there are two problems in the model. First, although the authors claim their model as an agent-based model, they only use the term “agent” to define those who affect land-use changes, but they don’t clearly define behaviors of these agents. What they’ve done still follow conventional CA processes: define parameters that influence land units and develop some transition rules, and then apply every cell into these rules and see if the status of each cell changes or not. Second, they collect several socio-economic parameters into their model; nonetheless, these indicators can be only represented as influences of national/local economic activities on Asian urbanization processes, but are not able to link with economic globalization.

The contribution of Xie’s simulation is still significant because they propose a framework on how a CA-based urban model for Asia should be developed based on Asian urban theories, and how a CA-based urban model integrates local and global factors for simulating Asian urban dynamics. Hence, as long as the gaps (scales and frameworks) are better filled, CA-based urban modeling for Asia can better interpret Asian urban dynamics.

Table 2-1 Parameters considered in Xie's stepwise regression model

Description
Agricultural population
Nonagricultural population
Total population
Land area in cultivation
Total output value of agriculture, forestry, animal husbandry, and fishery
Gross domestic product value
Gross product value of primary and secondary industries
Gross product value of tertiary industries
Total value of fixed assets investment
Total income of rural economy
Income in agriculture, forestry, animal husbandry, and fishery
Income in non-agriculture, non-forestry, non–animal husbandry, and non-fishery
Total expense in rural economy
Total income of the farmers
Total value of industrial assets
Net value of the fixed assets
Number of factories
Number of employed people at the year’s end
Total tax value
Sold ratio of the product value

(Source: Xie et al. 2007)

3. STUDY AREA AND DATA ACQUISITION

3.1. Study area

Taipei metropolis serves as the political, economic, and cultural center of Taiwan. The spatial extent of this area covers four counties/cities: City of Taipei, City of Keelung, Taipei County, and Taoyuan County. As the largest metropolitan area in Taiwan, the area is 3678 km^2, approximately 10% of the total area of Taiwan. At the end of 2005, around 8.6 million people, 38 percentage of total population, live in this area. In addition, restricted by the rugged terrain, the population distribution is uneven. Most residents aggregate in the northwest side of this region. In the southeast side of Taipei metro area is mountainous landform, which belongs to part of Central Mountain Ridge, the back-born ridge of Taiwan (Figure 3-1).

Like most of Asian countries, the majority of economic activities in Taiwan were agriculture sector until the end of World War II. After World War II, the government engaged in industrial recovery from the war. The first phase is called “primary import-substituting industrialization”(Dicken 2003, pp. 183-186). The government targeted the growth of light industries to shift from imports to local manufacture of basic consumer goods, such as textiles, footwear, plastics, leather, fur and allied product manufacturing. The national policy stimulated economic restructuring from agricultural to manufacturing industries from the 1950s and caused the emergence of Small and medium enterprises (SMEs).

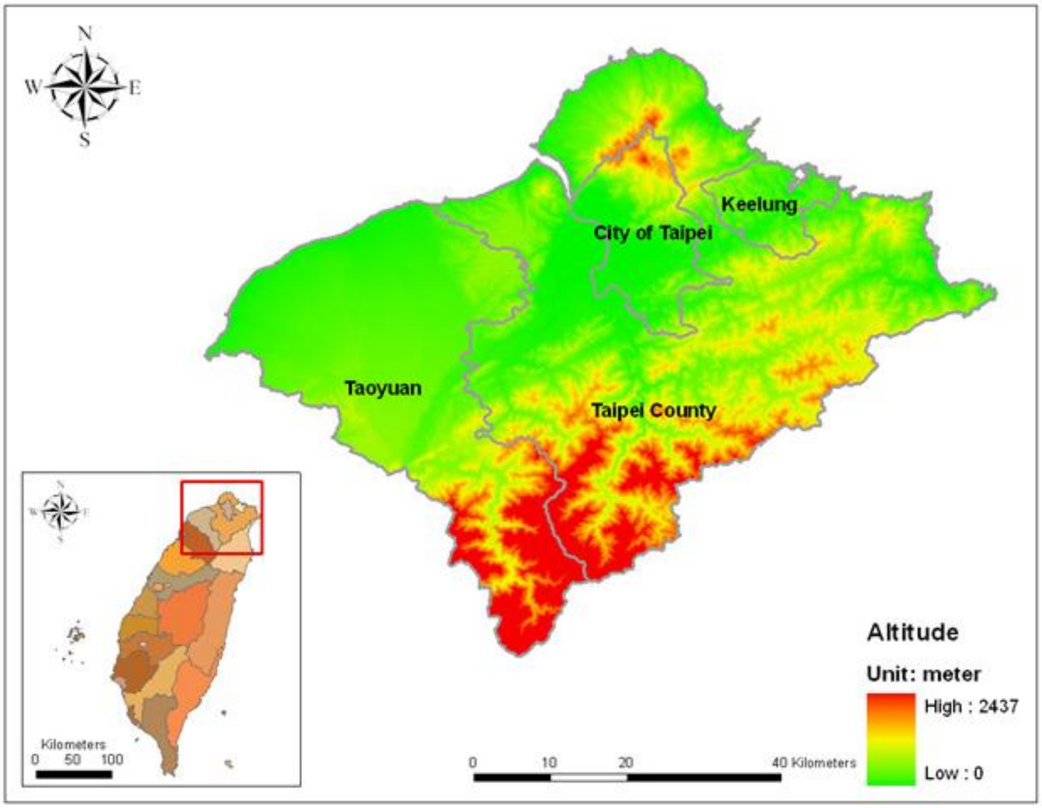


Figure 3-1 Geographic location of Taipei metropolitan area

SMEs are labor-intensive industries and appear in the countryside close to towns and villages. SMEs create more job opportunities for surplus labor in rural and attract surplus laborers from the agricultural sector gradually reallocating to manufacturing and industrial sectors (Huang 1998). In Table 3-1, SMEs occupy the major proportion of all manufacturing firms since 1961, and produce over one-third production values of all manufacturing output. These labor intensive firms provide various kinds of commodity and industrial components for further assembling and outsourcing.

Table 3-1 Small and medium enterprises (SMEs) in Taiwan (1960-1990)

Year	*SMEs as a proportion of all manufacturing firms (%)*	*SME product value as a proportion of all manufacturing output (%)*	*Average employee number*
1961	***99.57***	***–***	***5.98***
1966	***99.28***	***–***	***7.04***
1971	***98.96***	***37.09***	***8.72***
1976	***98.90***	***32.27***	***8.79***
1986	***99.00***	***34.46***	***8.49***
1991	***91.24***	***41.23***	***7.94***

(Source: Hsu 2005)

The success of economic shift and blooming of SMEs encouraged the government to further focus on export trade policies. The second phases, “Primary export-oriented industrialization”, emphasizes on exports of manufactures, especially labor-intensive products (Dicken 2003, pp. 183-186). Hence, manufacturing industries became key agents for the expansion of foreign trade (Liu and Tsai 1991) and helped Taiwan emerge as a newly industrializing country to occupy a role of export processing in the new international division of labor in the early 1960s (Frobel et al. 1980; Wade 1990; Hsu 2005). Foreign retailers such as Wal-Mart, JC Penny, Nike and others started to place orders to these SMEs (Hsu 2005). Since capital flows from foreigner investments played a critical role to in stimulating rapid industrialization and economic growth in Taiwan, it was no exaggeration to assert that SMEs constituted the pillars of Taiwan’s postwar economic miracle (Orru 1991; Zhou 1999; Hsu 2005).

After two more adjustments of exporting policies (Second import-substituting industrialization and Secondary export-oriented industrialization), Taiwan's economic development is tightly interacting with global economy. According to World Investment Report published by United Nations Conference on Trade and Development (UNCTAD 2001, 2008), inward foreign direct investment as a share of Gross Domestic Product (GDP) in Taiwan are 6.1 (1990), 8.0 (1999), and 12.7(2007). Since the attraction of FDIs has been an integral part of export trade policies in Taiwan, in the 1970s, the government carried out "the Ten Infrastructures Project" to construct a solid foundation of transportation and electricity infrastructure for future industrialization and establish better investment environment for foreign businesses. The Ten Infrastructures Project aimed on fundamental utilities such as railway, roads, airports, cargo ports, and electronic utilities (nuclear power plants). Good quality infrastructure is not only conducive to economic production, but also important in attracting investment (Peck 1996). Due to the well-developed utilities and transport linkages, international trades and the growth of manufacturing FDI are more related to changes of economic structure within developing economies in the region (Lo and Marcotullio 2000).

3.2. Data acquisition

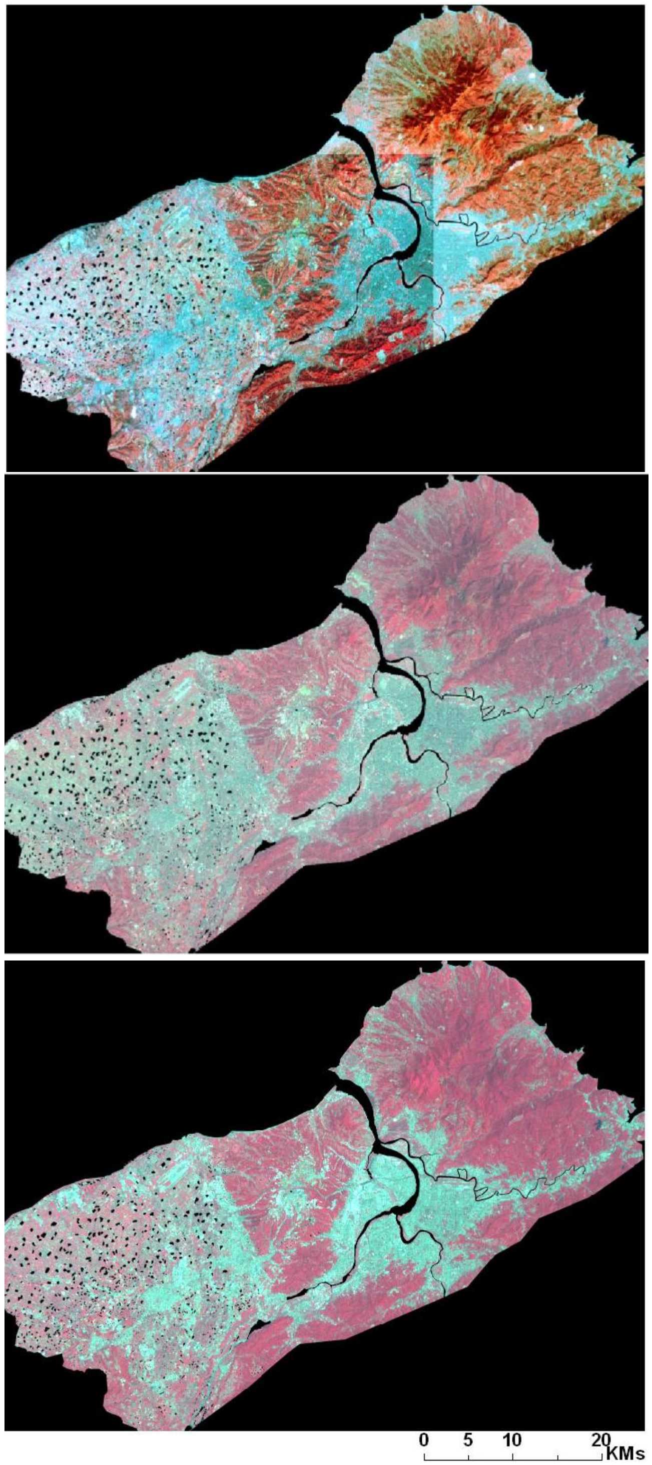
3.2.1. Remote sensing images

Remote sensing technologies are often applied to classify land cover types and detect land use changes. To draw urban patterns of Taipei metropolitan area, various remotely sensed images are acquired. Two types of satellite images are used in order to have better classification results (Table 3-2). Landsat satellite imagery, which is broadly applied for studies of land cover/use changes and urban landscape, is majorly applied to represent the spatial patterns and modeling in the study area. Two Landsat images are taken in 2001 and 2008. Nonetheless, due to the weather condition in Taiwan, Landsat images have more cloud covering the study area in the 1990s. Therefore, Spot images become an alternative to fill in the gap (Figure 3-2). DEM raster data is acquired to evaluate impacts of terrain to urban growth. For various types of images originally have different pixel resolution and projected coordinate system, these images will be first re-sampled to the same pixel resolution (12.5m) and re-projected to TM 2 degree projection. The projected coordinate system is based on Transverse Mercator coordinate system and the datum is named Hu-Tsu-Shan (Spheriod: International 1909). The central Meridian is 121^{o} E. False of Easting is -250000 meters, and False of North is 0 meter. After the data pre-processing, all raster images have the same pixel resolution and can be overlaid properly in terms of the same projection.

In addition to raster images, vector GIS data are used in this study as well, including the administrative jurisdictions of each district within Taipei metropolitan area, and road network. The coordinate system of all these GIS data will be also projected to the same coordinate system of remotely sensed images for further data analysis and CA modeling.

Table 3-2 Acquired remote sensing images

Type	**Date**	**Coordinate System**	**Band**	**Original Resolution**
SPOT	1994	TM2	3 Bands	12.5 m
Landsat ETM+	2001	TM2	6 Bands	30 m
Landsat ETM+	2008	TM2	7 Bands	25 m
DEM	1994	TM2	1 Band	40 m



Spot 1994
(mosaiked from two images)

Landsat 2001

Landsat 2008

Figure 3-2 Remote sensing images for different years

3.2.2. Socioeconomic data

Multi-scaled socioeconomic data are applied for modeling and estimating influences of globalization on local developments. Data acquired for this study are shown below:

1. *Foreign investment data*: National-level Foreign Direct Investment (FDI) with three categories (primary, manufacturing and service sector) is applied as an indicator to reveal how global economy affects Asian urbanization and economic activities (Figure 3-3). The FDI data is from The Investment Commission, Ministry of Economic Affairs (The Investment Commission 1978-2007). The temporal frame of FDI in Taiwan is from 1978 to 2007. From the chart below, the majority of FDIs in Taiwan were manufacturing industries. However, capital flows of service industries grew up rapidly since the late 1980s.

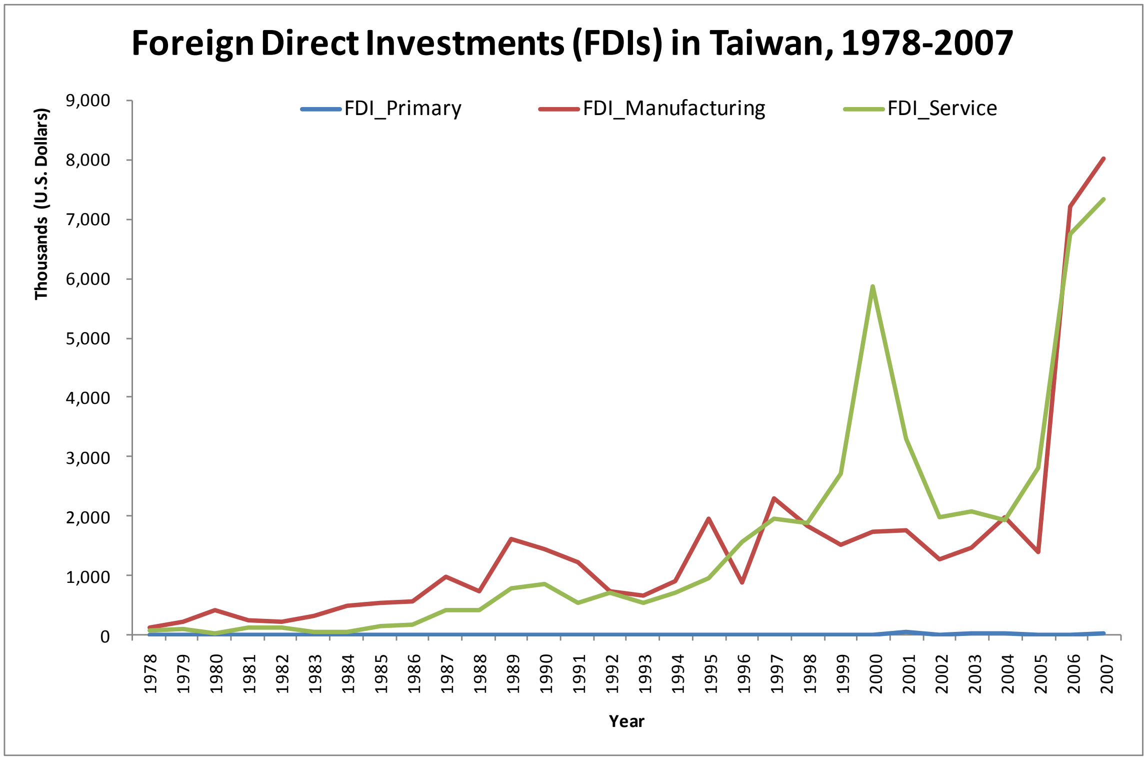


Figure 3-3 Foreign direct investments (FDIs) in Taiwan

2. *Population data*: Population data including county-level (Figure 3-4) and district-level population are collected from yearly statistic books of four counties (City of Taipei, Taipei County, Taoyuan County, and City of Keelung). The definition of population for counties and districts is the amounts to the number of residents whose households are registered in a county/ district at the end of every year. Within the four counties, there are total 60 districts (12 in City of Taipei, 29 in Taipei County, 13 in Taoyuan County, and 7 in City of Keelung). The temporal extent of population covers from 1991 to 2007.

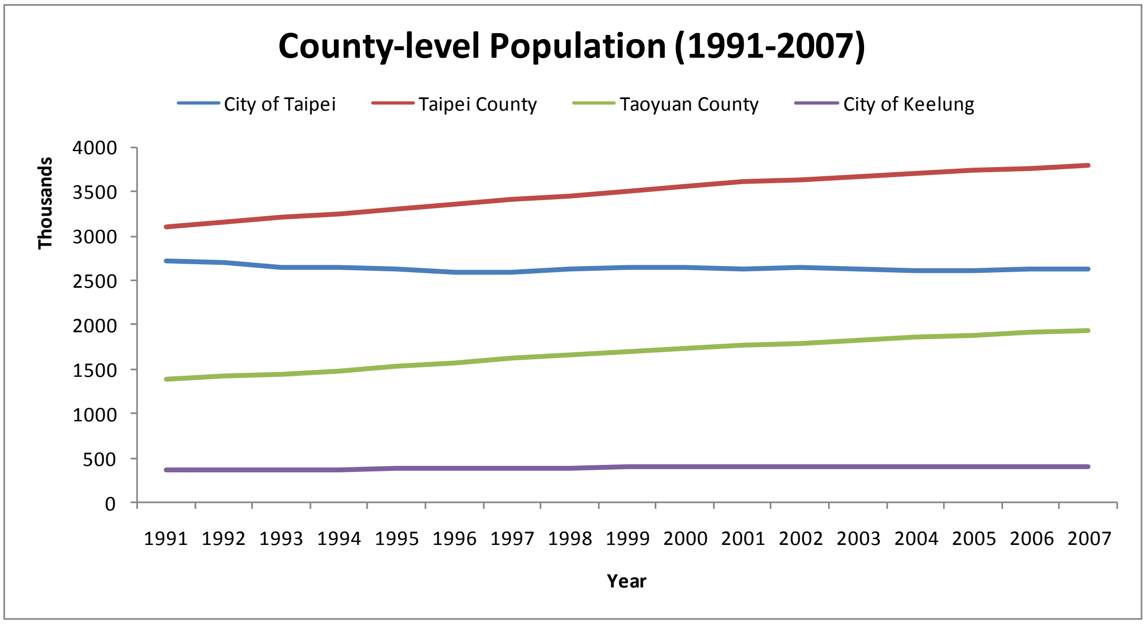
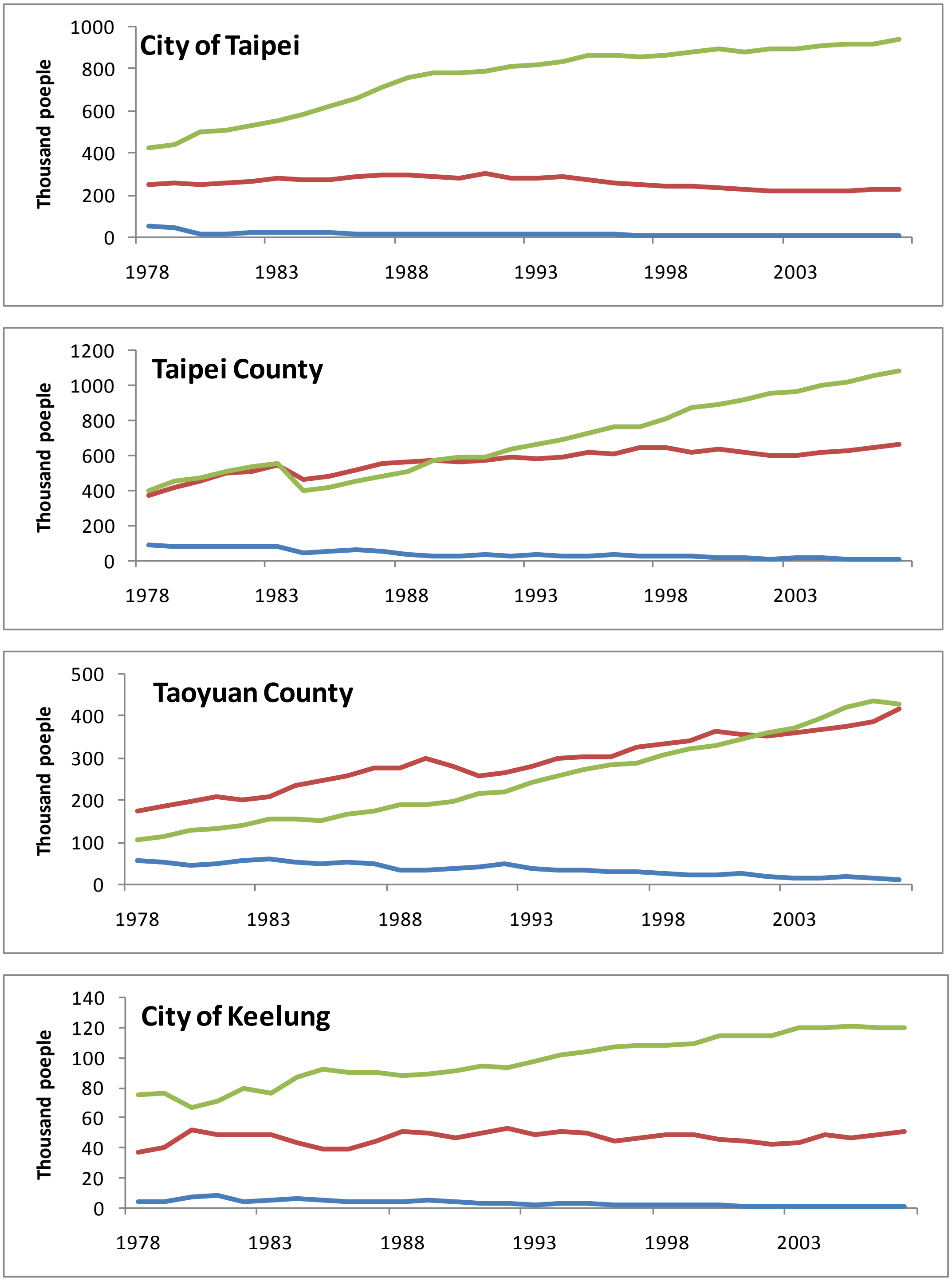


Figure 3-4 County-level population in Taipei metropolitan area

3. *Employment data*: Employment data surveys the working population for primary, secondary, and tertiary sectors to reflect economic shift of each sector. The county-level sectoral shift data are collected from yearly statistic books of four counties as well, and the time frame is from 1978 to 2007 (Figure 3-5).



Blue: Primary, Red: Secondary, Green: Tertiary

Figure 3-5 Employment data (1978-2007) in Taipei metropolitan area

4. METHODOLOGY

4.1. Multi-scale analysis

In Asia, the desakota process reveals that shift of economic activities has led to population migration and result in urban change, and the direction of urban change is more strongly affected by the global economy (McGee 1991; Seto and Kaufman 2003; Cohen 2004; Xie et al. 2007). Thus, the first step is to establish the linkage of national/local economic activities and the influence of economic globalization, and then discover how population changes with the fluctuation of economic shift under the wave of globalization. Various sources from multiple scales are applied to the process. First of all, FDI data, a representative of the influence of globalization on Asian economies, is a national-level parameter. There are two major categories of FDI data: FDI for manufacturing, and FDI for service. Second, employment data of the three major economic sectors—primary, secondary, and tertiary industries shows the sectoral shift in county level. Annual population data for county and district level is also collected into the multi-scale analysis.

To integrate multiple scales of economic and population data, Xie and his colleagues (2007) develop a top-down approach based on a linear stepwise regression model to reflect township-level socioeconomic conditions in two time periods (1990-1995 and

1995-2000). In the statistical model, they define the relationship between population change rates and socioeconomic variables in the following form:

$$\mathrm{R_k}(\Delta \mathrm{T}) = \alpha(\mathrm{T}) + \sum_{\ell} \beta_k^{\ell} \chi_k^{\ell}(\mathrm{T}) + \varepsilon_k(\mathrm{T}) \tag{4-1}$$

In the above equation, β_k^{ℓ} are weights on $\chi_k^{\ell}(\mathrm{T}), \ell = 1, 2, \ldots, \mathrm{L}$, the $\mathrm{L_{th}}$ independent socioeconomic variables defined at the township level k. $\alpha(\mathrm{T})$ is a constant, and $\varepsilon_k(\mathrm{T})$ is the randomly system error.

Although variety of socioeconomic parameters (Table 2-1) are considered in the linear model above, only parameters with significant meanings (i.e. P value < 0.05 for each parameter, according to t-statistics) are best fit into the equation. Therefore, equations for two time periods are different. In the first time period (1990-1995), rural (non-urban) population, urban population, and the total employment (labor force) are three major factors in population change rate. Nonetheless, in the second time period (1995-2000), total tax levied, income in the nonagricultural sectors, gross domestic product, the net value of fixed total assets, and the expenditure in rural economy, have more influences on population rate changes. Yet there are two major issues in Xie's (2007) linear regression model. First, parameters in two equations are rarely the same and hardly describe a general pattern how and what economic activities consistently play an important role in population dynamics from 1990 to 2000. Second, various economic parameters are adopted to represent economic conditions and policy imperatives, but these parameters are township-level and no global parameters are included.

This study incorporates multi-level socioeconomic sources, including FDI as a global parameter to the linear regression model. Since population dynamics is affected by shift of diverse economic activities that are also influenced by global factors, the interaction of various economic activities on population changes can be defined as follow:

$$\mathrm{Pop_{county}} = f\left(\mathrm{E_{primary}}, \mathrm{E_{secondary}}, \mathrm{E_{tertiary}}, \mathrm{FDI_{manufacturing}}, \mathrm{FDI_{service}}\right) \quad (4\text{-}2)$$

In the stepwise linear regression model, every independent variable is evaluated if it has significant impact on population change through a statistical P value. Thus not all economic variables have the same impacts on population for every county. The above relationship can be expressed as a linear regression equation for estimating population in county level:

$$\mathrm{Pop_c} = \alpha_c + \sum_i \beta_{ic} X_{ic} + \varepsilon_c \quad (4\text{-}3)$$

County population ($\mathrm{Pop_c}$) is linearly estimated by i_{th} economic factors (X_{ic}). The intercepts (α_c) and the coefficients (β_{ic}) vary among counties (c), and ε_c is the system error. Through the above equation, county-level population can be estimated through actual socio-economic data.

When population dynamics with external economic factors is successfully connected, county-level population is still too coarse for analysis and conjunction with pixel-level land-use developments. The next step is to break down the estimated county-level population result into smaller spatial units—district level. Because annual demographic data contain county and district level of population, percentage ($\omega_{r_{dc}}$) of d_{th} district-level population ($Pop_{r_{dc}}$) in every county (Pop_{r_c}) can be calculated and estimated by real statistical data:

$$\omega_{r_{dc}} = \frac{Pop_{r_{dc}}}{Pop_{r_c}} * 100\% \tag{4-4}$$

In order to re-distribute county-level population into district level, the relationship of population in district and county level should be defined. Through observation of annual demographic data (1991-2008), values of the parameter ω_{dc} of every district have a linear pattern. Thus a linear regression model is developed to examine the value of ω_{dc} in Year *T*, where ΔT means the time period between1991 and Year T:

$$\omega_{dc\,T} = \alpha_{jc} + \beta_{jc} * \Delta T \tag{4-5}$$

Now population of each district in Year T can be computed through estimated county-level population (Pop_c) and the evaluated percentage (ω_{dc}):

$$\mathrm{Pop}_{\mathrm{dc}_T} = \mathrm{Pop}_{\mathrm{c}_T} \times \omega_{\mathrm{dc}_T} \tag{4-6}$$

The multi-scale interaction processes successfully combine population dynamics and various scales of economic activities, including global parameters. Annually district-level population can therefore be calculated based upon national-level FDI data and county-level economic activities. After the estimation of yearly district-scale population, population change from year T to year T+1 can be counted as well. The growing population will later be used to create a linear relationship with converting pixels from satellite images in the Monte Carlo mechanism.

4.2. Micro-scale transformation

In CA-based simulation, two approaches for developing transition rules are widely adopted: deterministic and stochastic approaches. Deterministic methods develop heuristic rules in determining if the status of each cell will be changed. Game of life is a typical example using deterministic approach for CA simulation. However, in reality, changes of each land unit cannot be easily judged by the zero-one method because various parameters have dissimilar weights on the processes of land conversion, and sometimes even land cells match all the required criteria, land-use changes may not happen. Instead, it is more reasonable to evaluate the probability of land-use changes. Stochastic approaches are developed to evaluate the transition probability of every land unit, and widely accepted in current CA-based urban simulation models. Thus, the micro-scale transformation process adopts stochastic modeling to estimate changes of land-use types.

The major purpose of the micro-scale transformation process is to observe how vacant land cells convert to urban units under some physical constraints. In this study, two land-use types are required in the process: non-urban and urban classes. The definitions of these two classes in this research are as below:

- *Non-urban*:

  Pixels contain no artificial construction such as road, building, bridges, or concrete on the pixel surface. In general, non-urban class refers to rural regions. The terms “non-urban” and “rural” will be used interchangeably in this study to represent the same land-use type. Examples of non-urban pixels include farm, vacant land, mountain, or grassland.

- *Urban:*

  Pixels reveal artificial construction or impervious areas like factories, buildings, or roads. In addition, trees along road or parks within city cores are included into this class.

To acquire land-use types for Taipei metropolitan area, two Landsat satellite images (Year 2001 and 2008) and one Spot satellite image (Year 1994) are applied. These images are first classified through ISO-DATA unsupervised classification in ENVI 4.3. The unsupervised classes are grouped into two classes: non-urban and urban, and labeled as 0(non-urban) and 1(urban).

After creating the above two dummy classes, the next step is to evaluate the transition probability of conversion from non-urban to urban pixels in terms of physical constraints. In this study, three physical constraints, 1) Accessibility to city centers, 2) slope, and 3) Accessibility to transportation network, are incorporated into the multinomial logistical regression model:

- *Accessibility to city centers (D_c)*

The relationship between development factors and urban spatial structure is conceptualized by the bid-rent theory in urban economics (Wu 2002). The main determinant of urban land use change, according to the mono-centric bid-rent theory, is the distance to the city center (Alonso 1964). City centers provide convenient utility functions and attract various land users. Those who are willing to pay higher prices (land bid rent) will obtain the land. However, to satisfy their needs, land uses have to consider the balance between transportation cost and land rent and maximize their profitability. In this study, how rural land units are influenced by their neighbor clustered urban regions is one of the major issue, so I simplify and deduct some theoretical concepts, and only focus on the influence of accessibility to city cores on land use change without considering the impact of land rent and transport cost.

Since urban growth comes with population aggregation, the amount of population can be used as an indicator showing the attractiveness of certain urban areas. In this study, a polygon layer with district population in 1993 is used for developing the accessibility of city centers. Centroid points of each district are extracted and joined with population data in 1993. Next, to calculate a magnitude per unit area from point features, a kernel density function (Silverman 1986) is applied. The concept of the kernel density function is to create a smoothly curved surface that is fitted over each point. The highest value of a surface is at the location of the point and diminishes with increasing distance from the point, reaching 0 at the Search radius distance from the point. After the kernel density analysis in ArcGIS, the raster grid of accessibility to city centers is shown in Figure 4-1. In the six groups, 1 means the highest accessibility to city cores and 6 means the lowest accessibility.

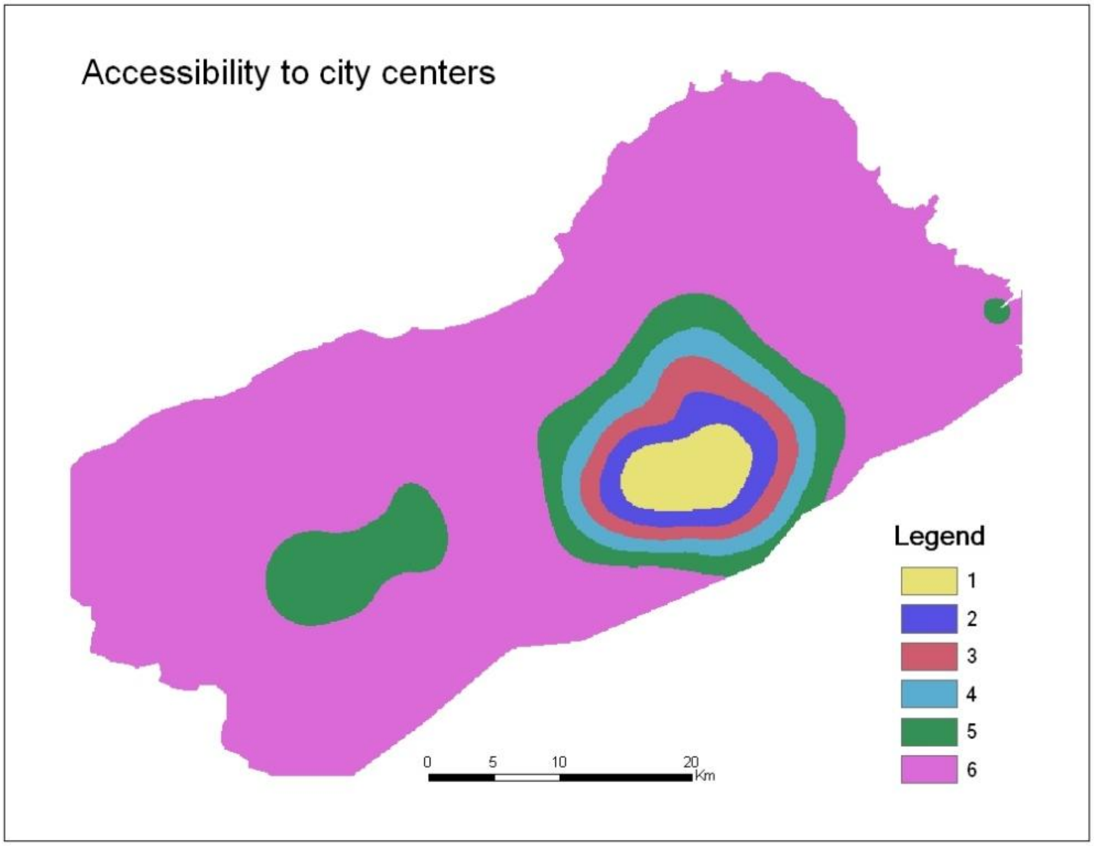


Figure 4-1 Accessibility to city centers

- *Accessibility to transportation network (D_r)*

The emergence of urban regions can often be found near transportation facilities such as railroads, rivers or intersections of road systems. Urbanized cells are encouraged to develop along the transportation network. Thus the accessibility increases if land units are close to transportation systems, and land conversion is more likely to take place.

The vector-based road data in Taipei metropolitan area contain various types of roads. Some types of roads such as avenues in cities and lanes in countryside have less influence to urbanization processes, so only three types of roads are extracted and applied to evaluate accessibility to transportation network. The three types are: Highway, expressway, and county-level major roads (Figure 4-2).

After the extraction of road network data, a raster buffer is created (Figure 4-3). In the road buffer, 6 classes are defined as below:

Class 1: the distance to major roads is within 500 meters

Class 2: the distance to major roads is within 100 meters

Class 3: the distance to major roads is within 1500 meters

Class 4: the distance to major roads is within 2000 meters

Class 5: the distance to major roads is within 3000 meters

Class 6: the distance to major roads is larger than 3000 meters

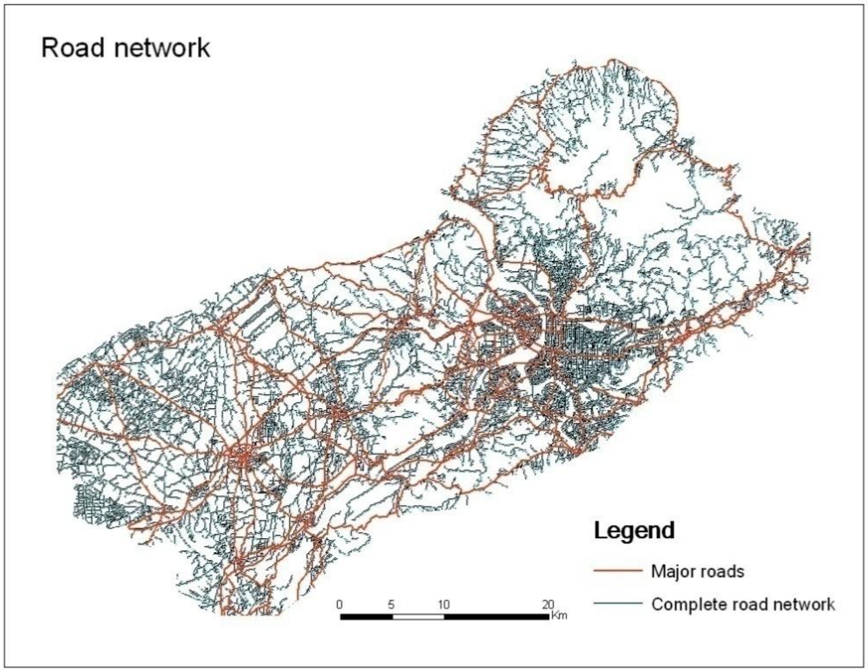


Figure 4-2 Road networks in Taipei metropolitan area

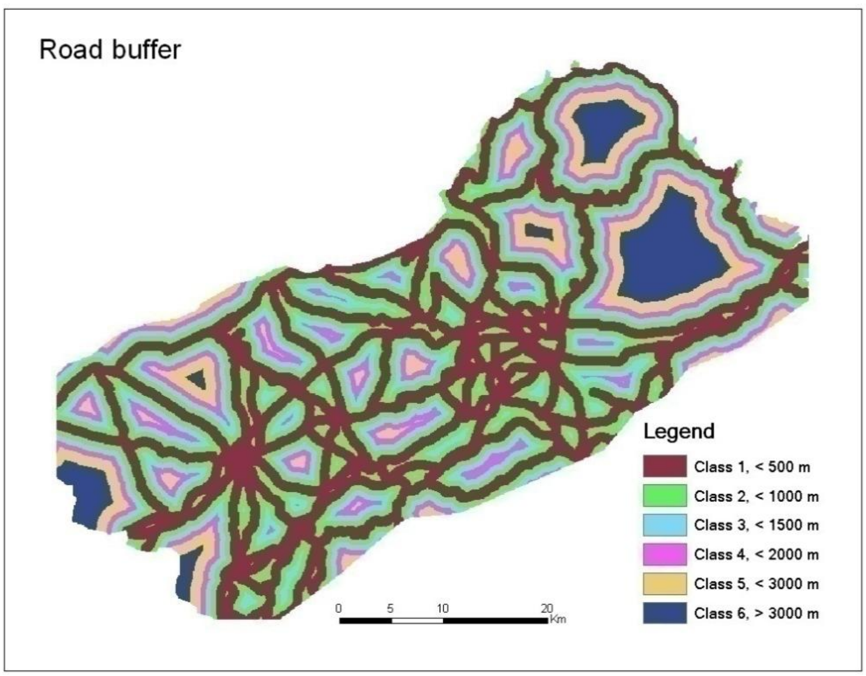


Figure 4-3 Accessibility to transportation network

- *Slope (S)*

Terrain is an important physical factor influencing urban development because flat plains are easier for urban expansion than rugged, mountainous regions. If slope is steeper, establishing buildings would be more difficult. Many urban models consider elevation/slope as an important factor affecting urban growth (e.g. Li and Yeh 2000; Sui and Zeng 2001; Silva and Clarke 2005). The study area, Taipei metropolitan area, is a relatively rugged region comparing to other rapid growing Asian metropolises, such as Tokyo, Shanghai, or Bangkok. As a consequence, terrain is a critical element in urban growth of Taipei metropolitan area, and in this study, slope will be adopted as an indicator to represent the influence of terrain on urban growth.

The slope raster layer (Figure 4-4) is extracted from Taiwan DEM through spatial analyst extension in ArcGIS 9.1. According to the urban planning law of Taiwan government, vacant land with slope larger than 30 degrees is prohibited to establish buildings. In the reclassifying process from slope data, 5 classes are defined and the last class represents regions that are not allowed to develop:

Class 1: slope is smaller than 5 degrees

Class 2: slope is smaller than 10 degrees

Class 3: slope is smaller than 20 degrees

Class 4: slope is smaller than 30 degrees

Class 5: slope is larger than 30 degrees

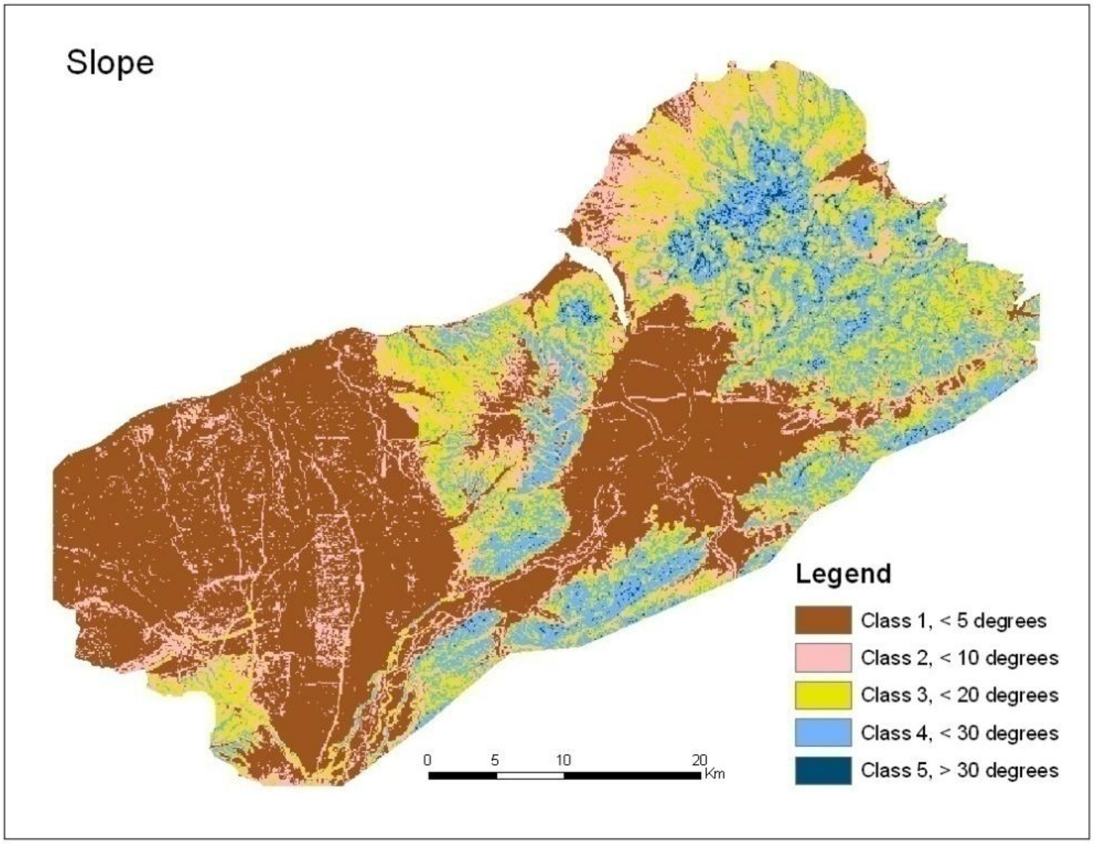


Figure 4-4 Slope of Taipei metropolitan area

After GIS spatial analyses, raster-based data layers of the above three physical constraints are generated, and the ordinal grid layers all influence land-use changes. Logistic regression or the multinomial logistic model, can be used to examine the relationship between land use changes and their locational characteristics (McMillen 1989; Wu 2002). Consequently, in order to figure out the probability of transformation from non-urban to urban pixels under these physical constraints, multinomial logistic regression model is incorporated into the micro-scale transformation process.

- *Multinomial logistic regression model*

Multinomial logistic model (or multinomial logit model) is a type of nontraditional regression analysis addressing the binomial distribution through the logit transformation, which is the natural log of an odds ratio of the probability that an event will occur (Berry et al. 1996). It is useful for land-use change modeling to quantify the relationships between driving factors and land-use/change patterns because relationships between land-use categories and physical constraints/ socio-economic factors can be structured as a matrix, and probabilities of transition from one land-cover category to any possible category for a given landscape condition based on the matrix can be estimated through the model (Dendoncker et al. 2007).

The fundamental function calculating transition probability in multinomial logistic regression model lists as follow:

$$\mathrm{Prob}_{i\to j} = \frac{e^{y}}{1+e^{y}} \tag{4-7}$$

In the above function, e is the mathematical constant, and y is the linear regression function composed of various parameters (i.e. different constraints/ socio-economic factors) and reflects land-use changes from category i to category j. The linear regression is shown in (4-8, where α is the constant intercept and β_{kz} is the coefficient of k_{th} condition of variable X_z; ε is the statistical system errors.

$$y = \alpha + \sum_{k=1}^{n} \beta_{kz} X_z + \varepsilon \tag{4-8}$$

Through multinomial logit regression model, the ideal results of transition probabilities (from 0 to 1) under different landscape conditions should be an S-shape (Figure 4-5). In Figure 4-5, X axis means the influences of landscape parameters. If more landscape parameters contribute land-use changes (right side of the X axis), the probability of transition from category *i* to category *j* is higher. On the other hand, if landscape parameters have no or negative influences on land-use changes (left side of the X axis), the probability of transition will be lower.

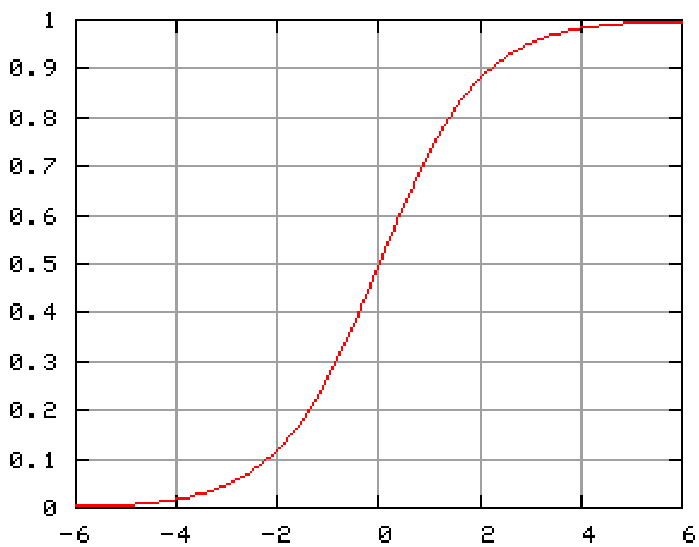


Figure 4-5 The ideal results of multinomial logistic regression model

Probabilities of transition from non-urban to urban pixels under the three major physical constraints (accessibility to city centers, accessibility to transportation network, and slope) are the major concern in this study. Therefore, to estimate the probability of conversion for each cell ($\mathrm{Prob}_{\mathrm{non-urban} \rightarrow \mathrm{urban}}$) in multinomial logistic regression model, the transition rule is defined in (4-9) and (4-10):

$$\mathrm{Prob}_{non-urban \rightarrow urban} = \frac{e^{y}}{1+e^{y}} \qquad (4\text{-}9)$$

$$\text{where } \mathrm{y} = \alpha + \beta_1 \mathrm{X}_{D_r} + \beta_2 \mathrm{X}_{D_c} + \beta_3 \mathrm{X}_{S} + \varepsilon \qquad (4\text{-}10)$$

After the transition equation is developed, the constants ($\alpha, \beta_1, \beta_2, \text{and } \beta_3$) can be computed by the classification results from remotely sensed images and three raster grids of physical constraints. First of all, land-use changes from rural to urban during 1993 and 2000 is created as a dummy raster grid (0 means no change and 1 means changes from rural to urban) and overlaid with the three constraint grids. Then 20,000 points are randomly selected within Taipei metropolitan area by the Hawth's Analysis Tools (http://www.spatialecology.com/htools/) in ArcGIS. Hawth's Tools is a very powerful extension in GIS spatial analysis between raster and vector data. In "Sampling Tools" submenu, the "Generating Random Points" function can randomly generate 20,000 points as a shapefile. Through the "Intersect Point Tool" function in "Analysis Tools" submenu, the point vector data can be linked with the three raster-based constraint layers, and values of each raster layer on every point can be extracted and stored in an attribute table of the point shapefile layer. All the attributes are stored in a 2-dimentional matrix and saved as a database file (.dbf). The database file is loaded in

SPSS 15 for further analysis. In SPSS 15, the "multinomial logistic regression" function is applied to calculate constant values in (4-10). The transition probability of land transformation (no-urban to urban) is created in terms of various land-use conditions/ restrictions from the three physical factors. After the development of micro-scale transformation process, the next step is to combine the micro-scale process with multi-scale interaction process via Monte Carlo mechanism.

4.3. Monte Carlo simulation

Through multi-scale processes, we can estimate population at district level from multi-scale economic activities. From micro-scale transformation, we get a transition rule derived from multinomial logistic regression to distinguish if a spatial unit will change it status from non-urban to urbanized condition. Since population growth stimulates urban growth, to some extent, population growth also result in the increase of urbanized areas. From the classified satellite images, we've had the total amount of urban pixels for different year. With the district-level administration boundary, (non-) urban pixels can be counted for each district by zonal statistical analysis. Compared with the change from non-urban to urban pixels and population growth for each district from time t to t+1 in two years, a linear equation can be conducted:

$$\mathrm{Area}_{rural \rightarrow urban} = \alpha + \beta \times \Delta\mathrm{Pop}_{\mathrm{district}\ (\mathrm{t} \rightarrow \mathrm{t+1})} + \varepsilon \tag{4-11}$$

Based upon this equation, we employ standard random Monte Carlo simulation to determine if an increased urban pixel should be assigned in space. First, the estimated population for a district in different years can be estimated from (4-6). Then the increase of population (Δ Pop) can be direct calculated. Applying the increase of population into (4-7), the amount of converting pixels (non-urban to urban) can be estimated. The last step is to assign the changed pixels in the metropolitan area. Since the probability of the conversion from a non-urban to an urban pixel (P_c) is computed from (4-6), we can randomly assign a value (P_{random}) between 0 and 1 for each non-urban cell in the space. If $P_{random} < P_c$, it implies the non-urban cell has higher opportunity to change its status, so the cell will change it status to urbanized. The comparison/ conversion process will repeat until all converting pixels are assigned to the space. Through the Monte Carlo simulation, we can successfully connect two different methods and link multi-scale processes to implement a CA-based urban model and illustrate the interaction of urban processes, especially globalization, on the desakota urban pattern.

5. RESULTS AND DISCUSSIONS

5.1. Globalization and local development on population growth

Interaction between local economic development and globalization impacts on population growth varies in the four counties of Taipei metropolitan area. Based on the multi-scale interaction process (4-2), FDI data (national level), employment data (county level) and population data (county level) are incorporated into SPSS 15 for stepwise linear regression analysis. The multivariate stepwise linear regression model is developed to connect the relation between population dynamics and economic features, and the analytical results of linear regression models for City of Taipei (CTP), Taipei County (TPC), Taoyuan County (TAO) and City of Keelung (KEE) are:

Population growth in City of Taipei:

$$\mathrm{Pop}_{\mathrm{CTP}} = 2597147 + 97891.558 * \mathrm{Primary}_{\mathrm{CTP}} \tag{5-1}$$

Population growth in Taipei County:

$$\mathrm{Pop}_{\mathrm{TPC}} = 920846.4 + 44571.657 * \mathrm{Tertiary}_{\mathrm{TPC}} + 0.016 * \mathrm{FDI\_Service} \tag{5-2}$$

Population growth in Taoyuan County:

$$\mathrm{Pop}_{\mathrm{TAO}} = 459960.5 - 29500.2 * \mathrm{Secondary}_{\mathrm{TAO}} + 27722.871 * \mathrm{Tertiary}_{\mathrm{TAO}} + 0.015 * \mathrm{FDI\_Service} \tag{5-3}$$

Population growth in Keelung:

$$Pop_{KEE} = 143937.9 + 3381.274 * Tertiary_{KEE} + 0.001 * FDI\_Service \quad (5\text{-}4)$$

As an urban core of Taipei metropolitan area, it is surprising that globalization and economic activities have little influence on population growth in City of Taipei. The main reasons why globalization impacts do not reflect population growth lie in physical constraints and increasing land prices for residential. First of all, the city core is located in Taipei Basin surrounded by mountains with steep slopes. The lack of plains restricts urban development. On the other hand, fewer constructions imply relative fewer residential buildings and capacity of living population. However, since City of Taipei is the political and economic center in Taiwan, it inevitably attracts investments from foreign companies and creates more job opportunities to attract people from other cities/counties. The aggregation of working population demands more living space, but the supplies are limited. The imbalance of demand and supply causes the raising land price for residential. In Figure 5-1, the average land price in City of Taipei is much higher than its neighbor counties (Taipei County, Taoyuan County, and City of Keelung) and is still rising. People working in City of Taipei may not able to afford high living expenses, so they either rent a house or move out to suburbs of the city core in terms of cheaper land prices. This is why total population in City of Taipei is decreasing, and sectoral shifts of secondary/ tertiary sectors (Figure 5-2) and foreign investments (Figure 3-3) do not influence population changes statistically.

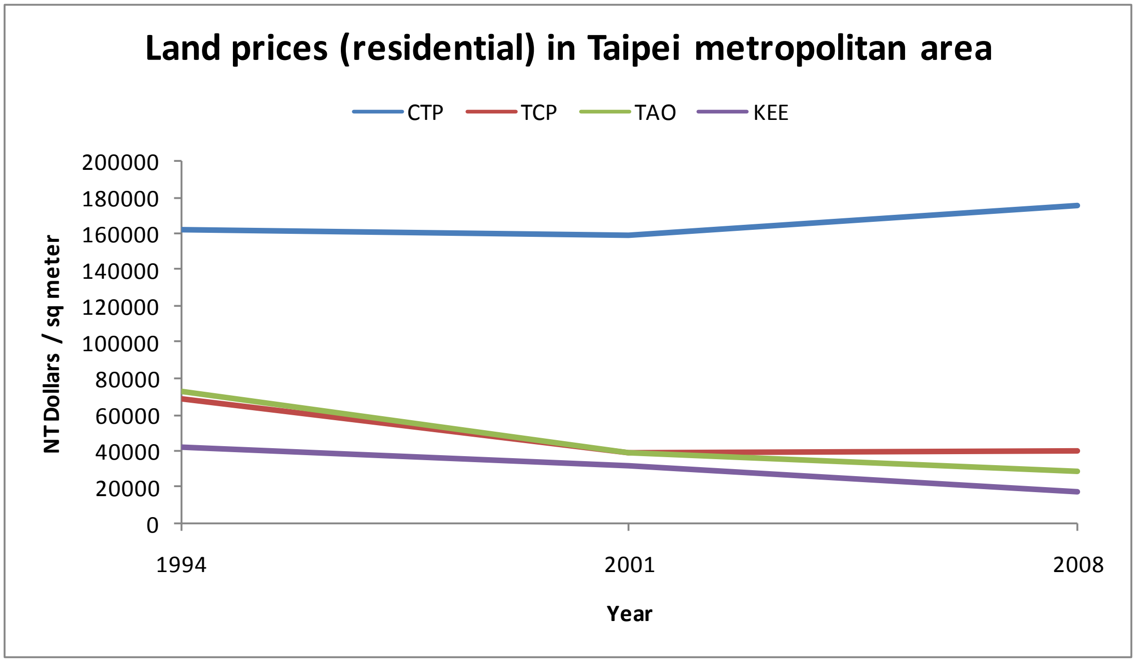


Figure 5-1 Land prices for residential regions

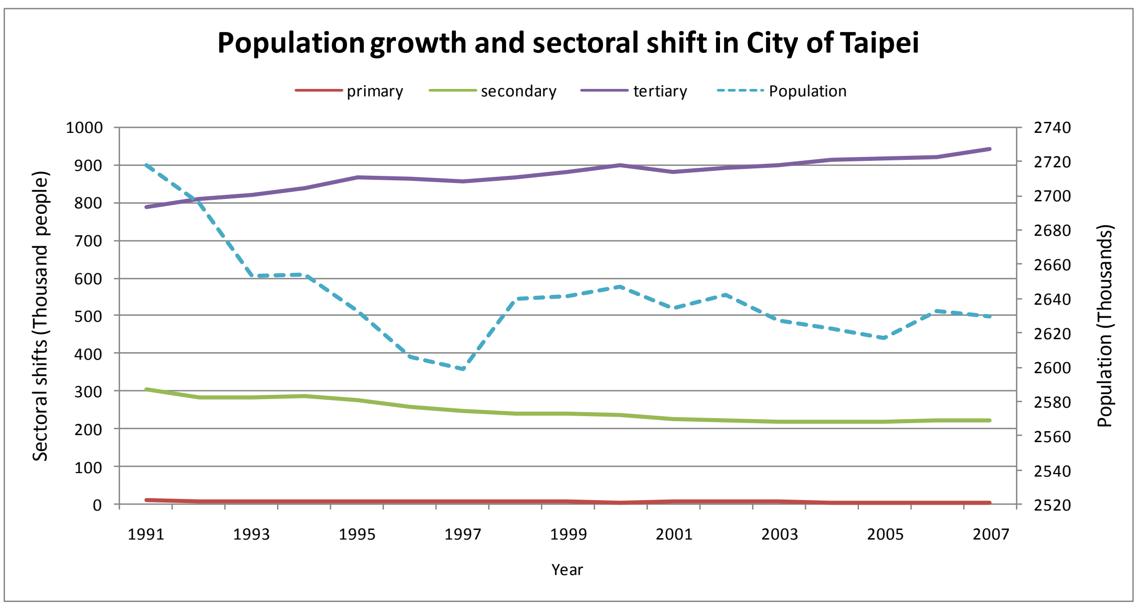


Figure 5-2 Population growth and sectoral shifts in City of Taipei

The peri-urban regions are mostly located in Taipei and part of Taoyuan County. In these two counties, population growth is linearly related to foreign investments and different economic sectors. Close to the city core, Taipei County, where the majority of manufacturing industries are located, shares rapid urban development with City of Taipei since the 1960s. Low-tech job opportunities provided by those labor-intensive industries recruit more people migrating in Taipei County and stimulate population increases. In the late 1980s, lower land prices and convenient transportation network to the city core attract service-based firms originally located in City of Taipei and some foreign investments. Tertiary sector gradually becomes the major economic activities in Taipei County and the proportion of tertiary sector is steadily growing during the past two decades when employees from secondary sector still occupy a considerable proportion of all economic activities (Figure 5-3). Growing economic activities from domestic and foreign investors imply more people are aggregated in Taipei County, and affordable land prices for residential encourage employees dwell in the peri-urban region. This is the reason why population growth in Taipei County is positively influenced by foreign investments and tertiary sector.

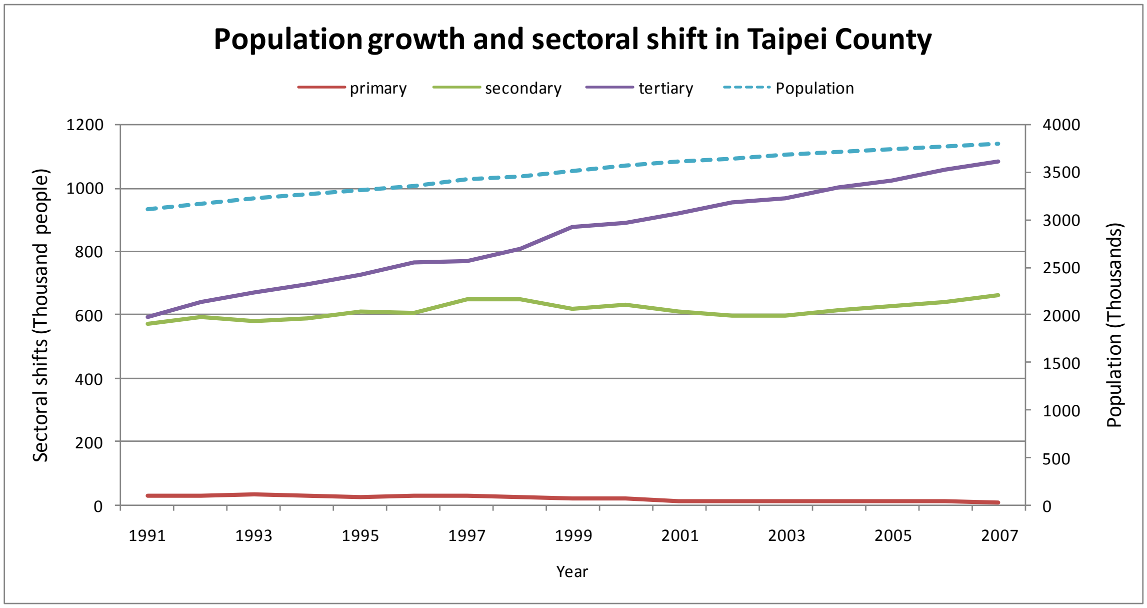


Figure 5-3 Population growth and sectoral shifts in Taipei County

In Taoyuan County, the major sector was secondary sector since there are 11 industrial parks producing various labor-intensive manufactures also technological-intensive computer components. These economic activities attract different levels of employees and implicitly change economic structures. Manufacturing industries recruit lower-educated employees with fewer wages, but high-tech companies require higher-educated employees for complicated operations or research and development (R&D). Therefore, high-tech companies are more willing to pay higher wages to employees to acquire the skills of the workers. When the number of higher-educated employees is growing, needs of service activities also increase. Then service industries are emerged and fast growing. The trend can be found in Figure 5-4. The proportion of tertiary sector passes secondary sector and becomes the dominant economic activities since 2001 while population is rising with a stead step from 1991.

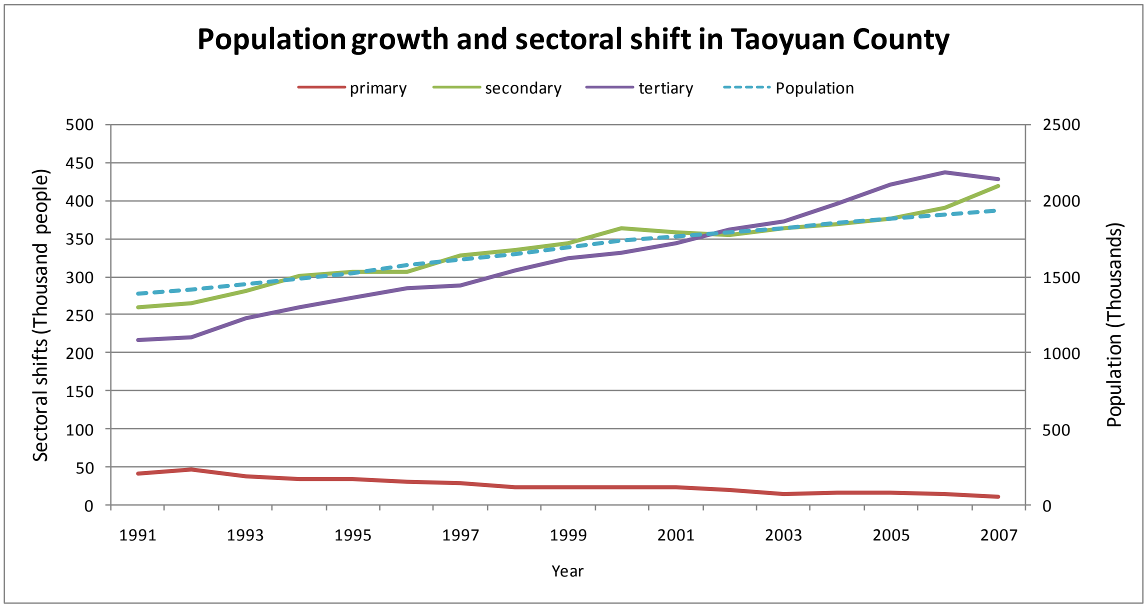


Figure 5-4 Population growth and sectoral shifts in Taoyuan County

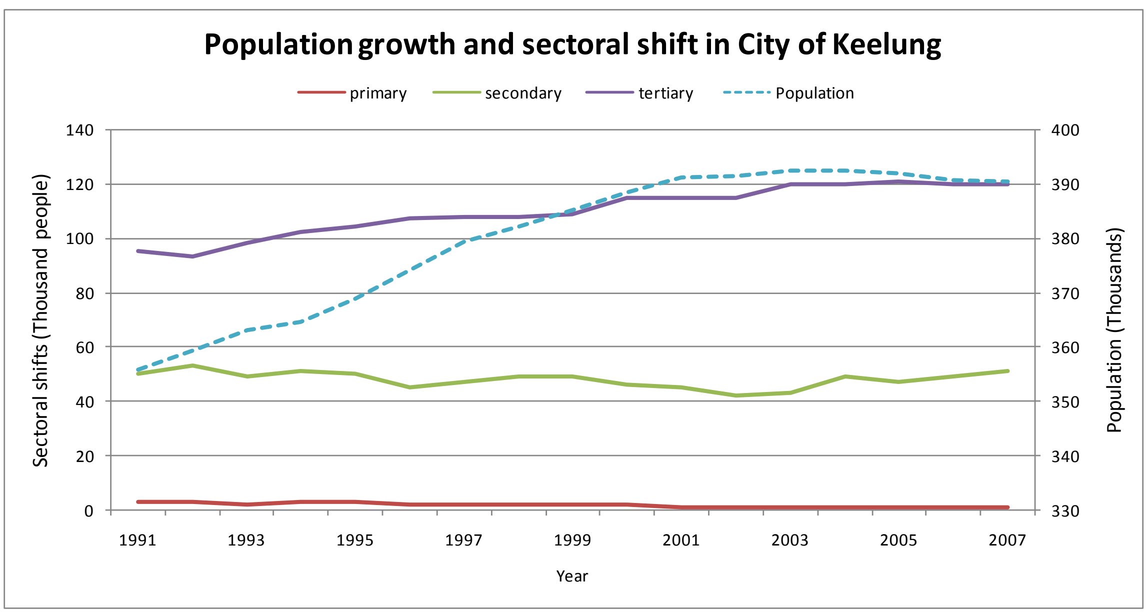


Figure 5-5 Population growth and sectoral shifts in City of Keelung

City of Keelung is a seaport city with a cargo port that transfers goods and products domestically and internationally. Therefore, the tertiary sector is the major economic activity. However, the hinterland of City of Keelung is very small because this city is limited by the physical constraint – mountainous terrain. There are few plain areas and most of buildings are established along the side of a mountain. As a fact, economic activities are also restricted, and the three major sectors do not change and remain relatively stable since 1991 (Figure 5-5). Although population is growing in City of Keelung, most of dwellers are migrating from City of Taipei in terms of congested living space and higher housing expense.

5.2. Modeling urban growth and spatial pattern

To developing a CA-based model to simulate urban growth in Taipei metropolitan area, classification results of non-urban/urban land-use types are required. By ISO-Data unsupervised classification in ENVI 4.3, these two classes are labeled as 0(non-urban) and 1(urban) for three satellite images (Figure 5-6). After raster calculation, the layer of land-use changes from non-urban to urban between 1994 and 2001 is created. This land-use change layer is overlain with three physical constraint layers (slope, distance to economic center, and distance to road), and 20,000 random points are selected to record land-use changes and physical constraints. Through Multinomial Logistic Regression model in SPSS, the estimated parameters for probability of land-use changes from non-urban to urban pixels are listed in Table 5-1.

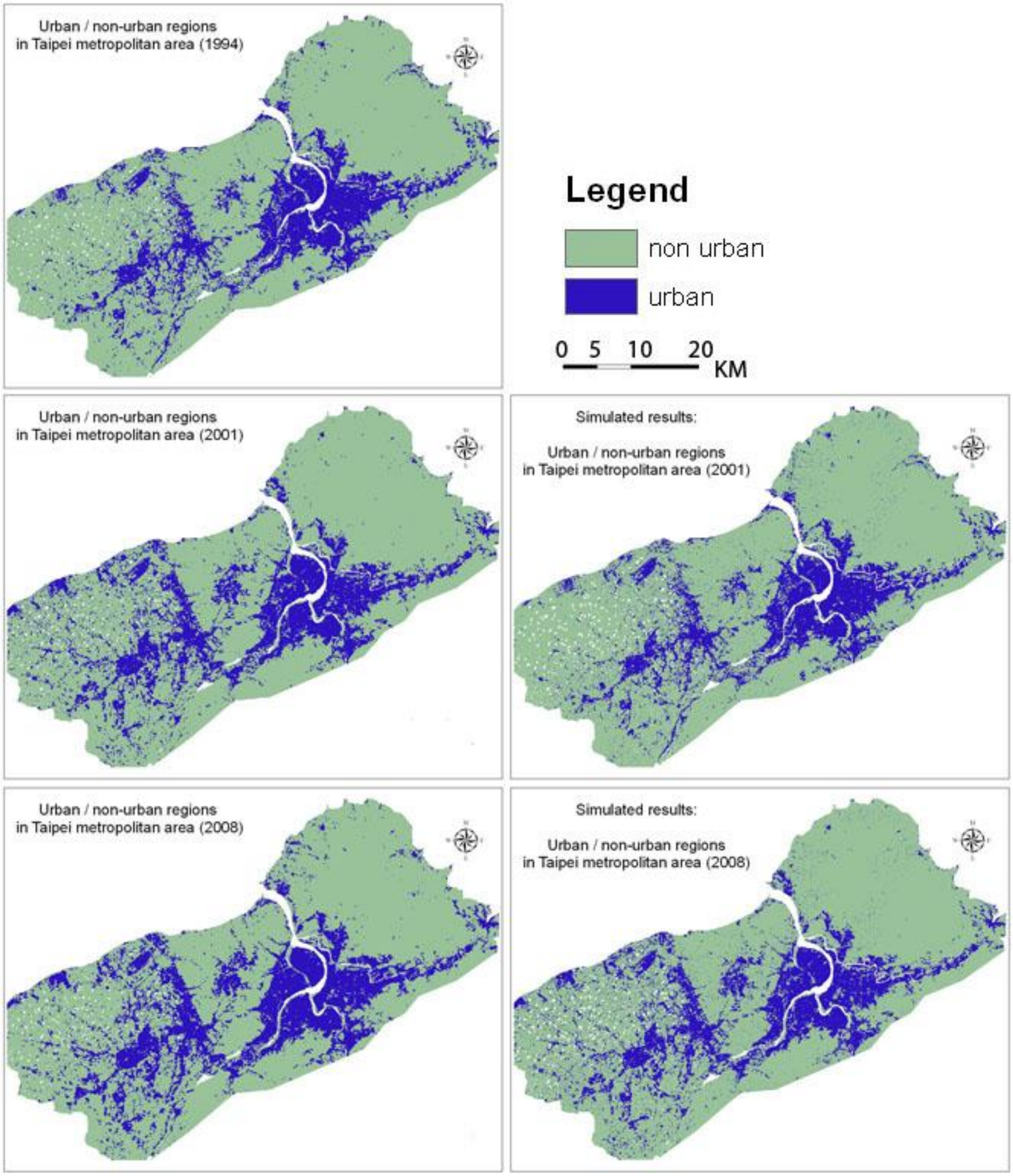


Figure 5-6 Classification and simulation results in various years

Table 5-1 Parameters for multinomial logistic regression model

Parameter	B value	Sig.	Parameter	B value	Sig.	Parameter	B value	Sig.
[cbd=1]	1.287	.000	**[slope=1]**	1.651	.000	**[road=1]**	2.241	.000
[cbd=2]	1.147	.000	**[slope=2]**	0.884	.000	**[road=2]**	1.777	.000
[cbd=3]	1.166	.000				**[road=3]**	1.709	.000
[cbd=4]	0.810	.000				**[road=4]**	1.768	.000
[cbd=5]	0.652	.000				**[road=5]**	0.855	.005
Intercept	-5.775	.000						

**Land-use change from non-urban (0) to urban (1)*

The integration of multi-scale interaction processes and micro-scale transformation is implemented by Arc-Object macro language in ArcGIS. Based on the classification layers of SPOT image (1994) and Landsat image (2001), two simulated land-use change layers are generated (Figure 5-6). To validate if simulated transformation results are close to original classification results, a convolution matrix is adopted to examine if all pixels of two layers are the same. In 2001, 10,348,281 pixels keep their own status (the same land-use type) in original and simulation layer while 1,526,231 pixels have wrong transformation results. The accuracy is 87.15%. In 2008, 10,464,088 pixels are the same and 1,414,548 pixels have wrong land-use type after transformation. The accuracy is 88.09%. In addition to the comparison of whole layers, the accuracy of randomly selected pixels is also computed. In the validation approach, 10,000 points are chosen randomly to examine if simulation results in two years are similar to originally classified layers. In 2001, 8717 points show their status remains the same and 1283 points do not match their status after comparing two layers. The accuracy is 87.17%. In 2008, 8830 points keep the same status and only 1170 points do not match. The accuracy is 88.30%.

Hence the transformation rules of the multinomial logistic model represent reliable simulation results for Asian urbanization.

In Figure 5-6, even though simulated images represent similar spatial distribution with classified images in 2001 and 2008, it is not intuitive to recognize if the spatial structure is close to the ideal desakota pattern. In addition, urbanized pixels in simulated images are not as aggregated as in original layers, and some urban pixels occur in the regions that should not be urbanized. This is why the accuracy of simulation is high, but differences between simulated and original images can be visually pointed out. As a result, the measurement of urban density is applied to help explain the spatial pattern and reduce the influence of noise pixels.

According to McGee's definition of five main regions in the desakota pattern (McGee 1991, p. 6): major cities, peri-urban, desakota, densely populated rural and sparsely populated frontier, first two regions are in general highly urbanized areas, so urban density should be also high. Since spatial economy in the desakota region is the mixture of agricultural and manufacturing activities, large areas of non-urban land-use types such as paddy farms, vacant lands, and other agricultural land can be found in this region. At the same time, urban land-use types such as factories, buildings, and residential houses also appear. Consequently, density of urban pixels in the desakota region will not be as high as peri-urban and city cores in terms of large non-urban pixels, but still keep a certain proportion of whole land-use types. The definition of densely populated rural can be interpreted as some urbanized/impervious areas located in rural regions. Therefore, the density of urbanized areas is relatively lower than the first three categories of the desakota pattern. The last category, sparsely populated frontier, can be viewed as the region that urbanized areas are rarely found. The urban density in this region should be the lowest, even zero.

Followed by the above definitions, the classified raster layers in three years are converted to represent urban density in Taipei metropolitan area and draw the spatial patterns. The ideal desakota pattern is compared with the urban density image derived from classified image in 1994 (Figure 5-7). The pixel resolution of the newly created image is 500m by 500m. The value of each spatial unit is the count of total urbanized pixels within the 500*500m square and then converted to percentage of urban pixels. Groups of various urban density types are created by the natural break method in ArcGIS because this approach can maximize variation between groups and minimize differences within each group (Price 2008). After the grouping process, spatial patterns can be visually better distinguished. Urban density ranging between 80 to 100% are major city cores, and peri-urban regions can be found in the category in which urban density has more than 50% and less than 80%. The third category can used to explain the spatial feature of desakota regions in terms the urban density distributed from 30 to 50%. However, it is vague to define the fourth category as densely populated rural areas. Thereafter, if pixels within the fourth category are aggregated, the areas can be defined as the desakota region; otherwise, pixels in this category are defined as densely populated rural. And the last group that has less than 10% urban density can be defined as the sparely populated frontier.

The results of computing urban density in different years reflect several spatial characteristics:

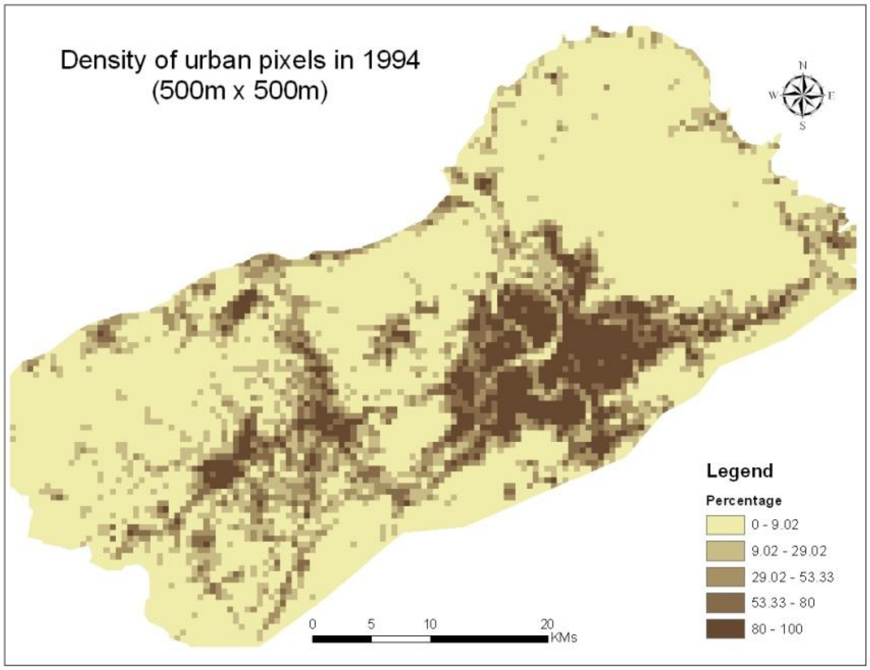


Figure 5-7 Urban density in Taipei metropolitan area (1994)

1. In Figure 5-6, urbanized regions in the stimulated image are visually not as large as those in the classified image because simulated urban pixels are not aggregated together even though accuracy for validation is good for simulation results. Yet after computation of urban density and grouping into several categories, spatial structures of two images in 2001 and 2008 look alike in Figure 5-8 and Figure 5-9, especially

rapid growing regions on the left side of each image. Moreover, in Figure 5-6, many urban pixels appear either in the regions that should not be urbanized, for instance, mountainous areas with steep slope, or by random transformation probability controlled by Monte Carlo simulation. After the process of calculating urban density, these new images help improve accuracy of visual interpretation and avoid system errors caused by modeling, and spatial classes can be easier drawn.

2. Highly urbanized regions on the right side of images (City of Taipei and Taipei County) are hardly to find areas that have lower urban density because the constraint of terrain limits urban expansion of these two regions. This is why desakota regions only emerge in Taoyuan County, left side of Taipei metropolitan area, and surround major city cores.

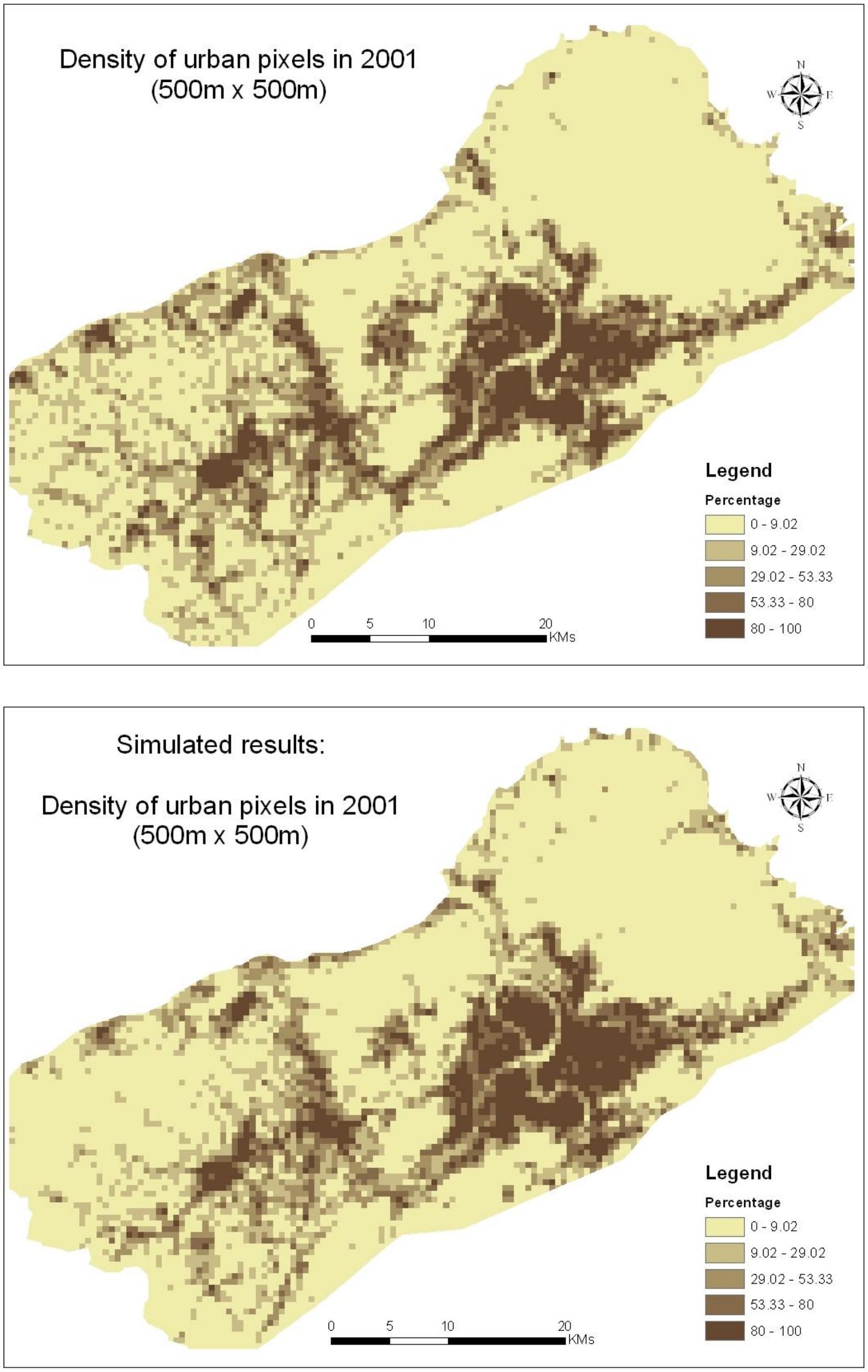
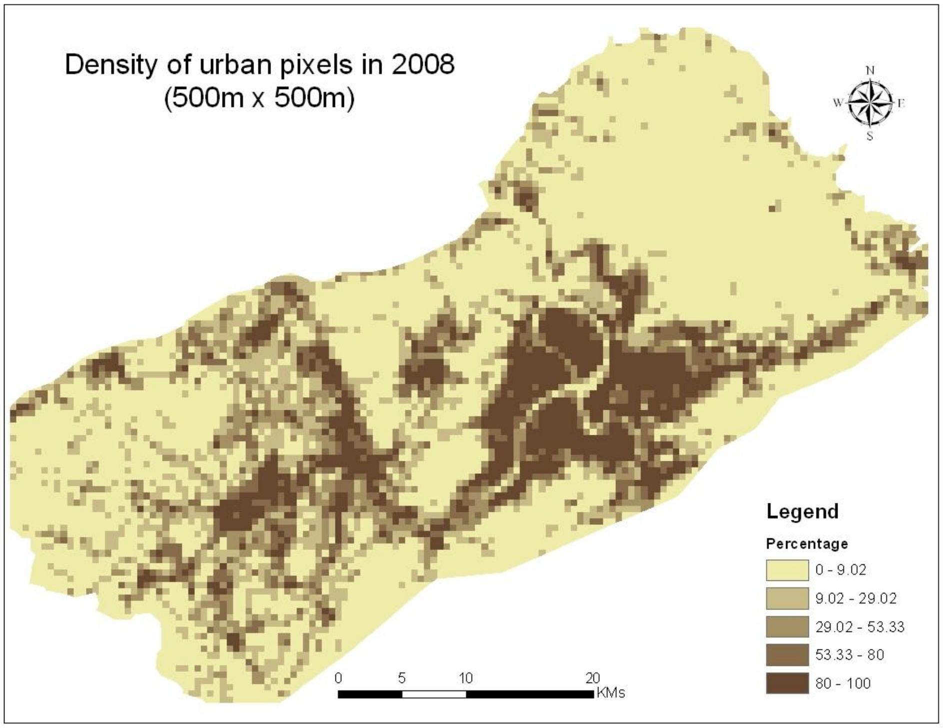


Figure 5-8 Classified and simulated spatial pattern in 2001



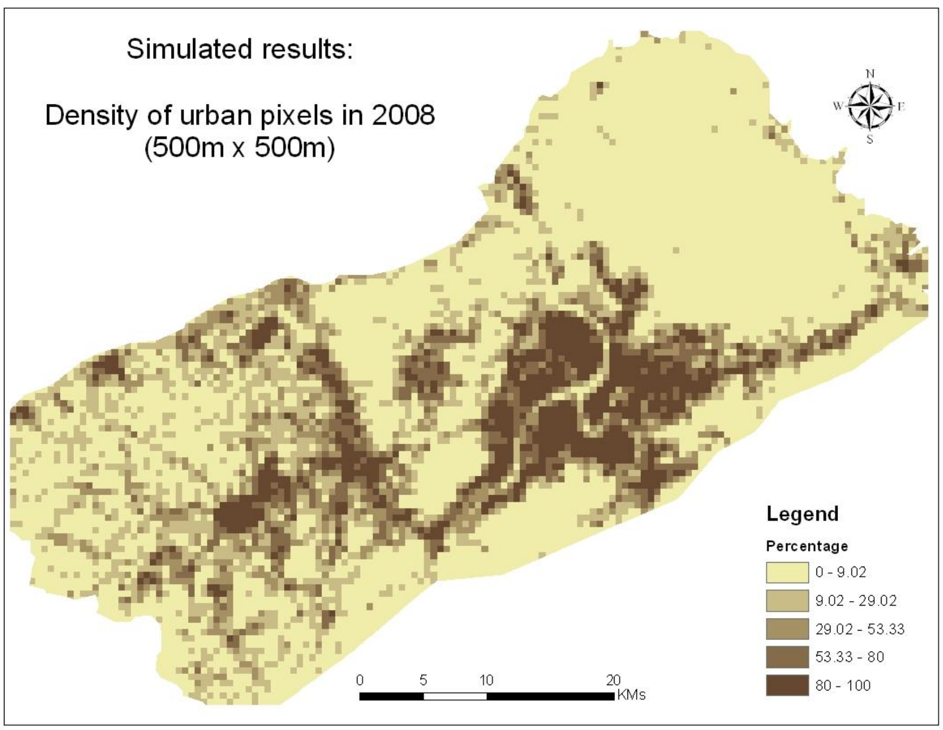


Figure 5-9 Classified and simulated spatial pattern in 2008

3. Rapid urban expansion taking place in desakota regions from 1994 is influenced by global/local factors. For example, Taoyuan County experiences high percentage of secondary industries and dramatically increasing service activities. The interaction of globalization and local economic development results in the expansion of desakota regions and link city cores and peri-urban areas.

5.3. Scenario simulation

The evolution of spatial characteristics represents how desakota zones grow in Taipei metropolitan area with changes of FDIs. Since economic development in Taiwan has tight interaction with global economy, and relies on foreigner investments after World War II, how would the desakota spatial pattern expand under different levels of FDI inflows in the near future? Followed by the regular growth of FDI input (see Figure 3-3), the simulation of urban growth from 2015 to 2050 is shown in Figure 5-10. The desakota regions (circled zones) are located outside major cities/towns and urban density in the desakota regions is getting higher. In addition, expansion of desakota regions also link with city cores/ peri-urban (high density of urban pixels) and form an extended urban region.

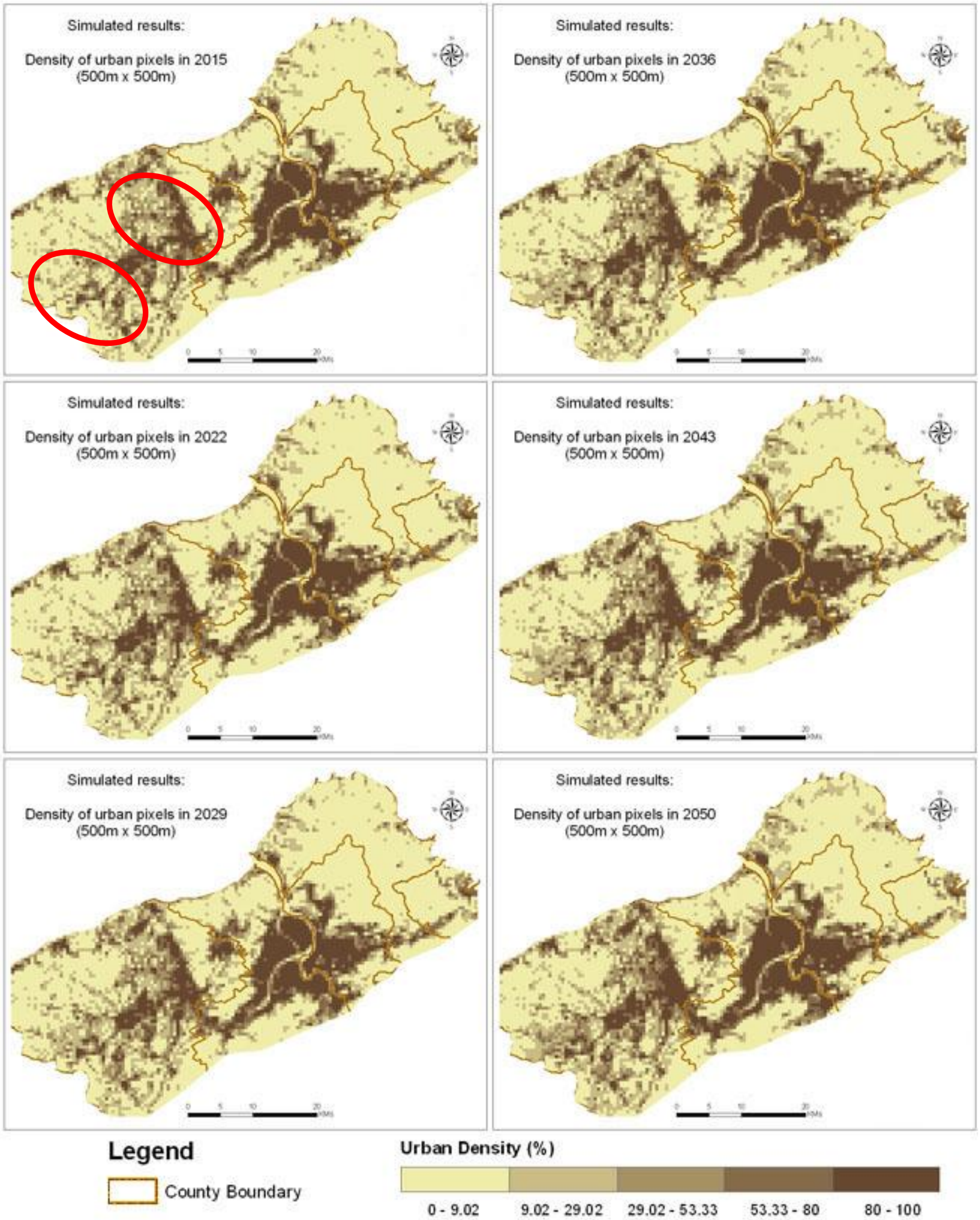


Figure 5-10 Simulated results from 2015 to 2050

The trajectory of simulation results reveals the difference of urban expansion from West. Traditional western urban growth takes place from highly urbanized city cores to peri-urban areas or suburbs that contain low density of urbanized, residential areas. The suburbanization process drives urban sprawl in Western cities and creates huge residential areas with low urban density. However, compared with simulation result in Taipei metropolitan area from 2001 to 2050, urbanizing areas are expanding not only from urban centers, but also from rural areas that have a certain proportion of impervious areas, with a mixed land-use type of industrial and residential functions, under the growth of foreign investments.

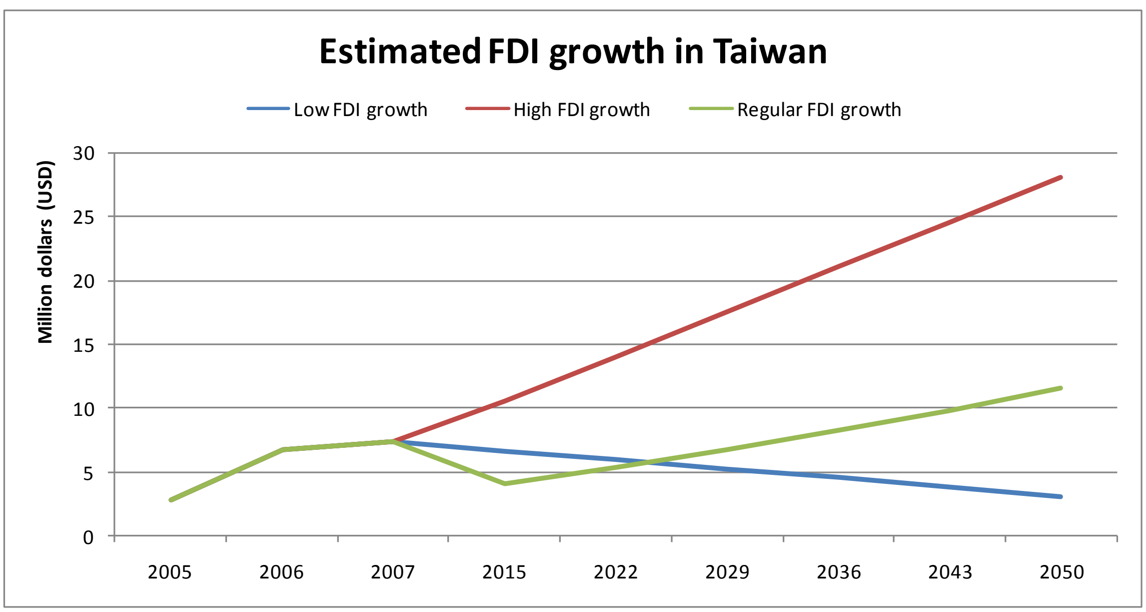


Figure 5-11 Estimated FDI growth in Taiwan

In late 2008, financial crisis originated from the United States causes a deep economic regression and shocks enterprises, especially TNCs, around the world. To survive under the rigid economic environment, TNCs are forced to adopt various approaches to cut down unnecessary expenses and/or reduce the amount of foreign investments. With the decreasing FDI inputs to Asian counties, what kind of impacts may induce to urban growth in Asian cities? Does the trend of urbanization and industrialization will also slow down? Two scenarios are developed to simulate urbanization process of Taipei metropolis under low FDI growth and extremely high FDI inputs. Figure 5-11 shows different situations of estimated FDI growth from 2015 to 2050, and the urban model adopts FDI values to simulate urban changes in the future. The outcomes of various FDI inputs are shown in Figure 5-12.

Since the trend of FDI growth in Taiwan has been exponential increasing, the scenario of high FDI growth is similar to the simulated result under regular growing FDI. However, low FDI growth induces different spatial structure in the circled zones. In Figure 5-12, although the desakota regions are slightly expanding and urban density is getting higher under low FDI growth in 2029 and 2050, the expansion of urbanized areas is not as significant as other scenarios. In other words, if the amount of foreign investments is decreasing, urbanization process taking place in desakota regions will slow down; on the other hand, increasing foreign investments will accelerate urbanization process in desakota regions. However, urbanization process will not be accelerated dramatically even though FDI inputs grow rapidly. As a result, FDI inputs play a critic role in spurring urbanization process in desakota regions at certain level, but when FDI inputs rise up, the influences are less significant.

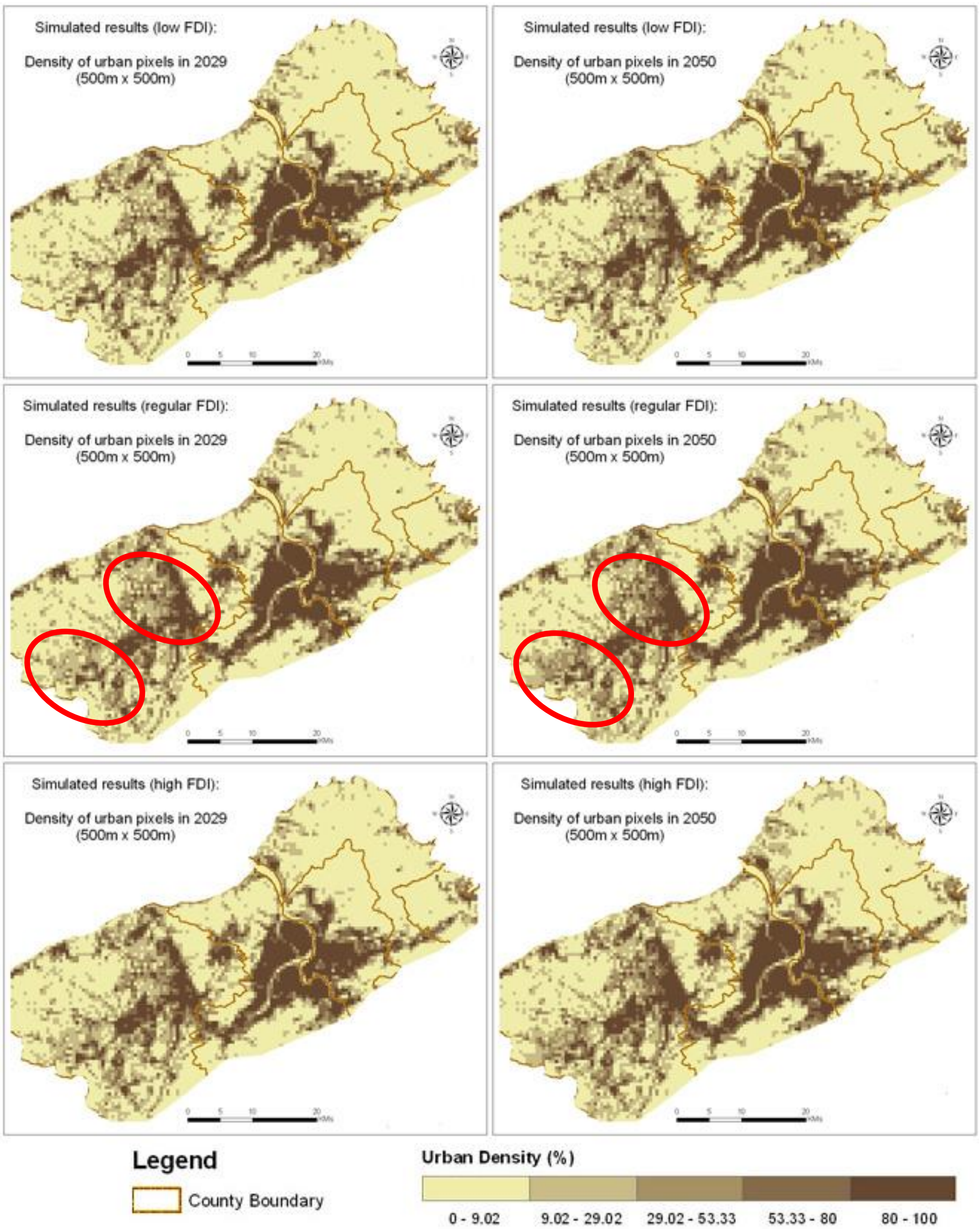


Figure 5-12 Scenarios under different levels of FDI growth (2029 and 2050)

6. CONCLUSIONS

6.1. Conclusions

Since desakota is an emerging urban form that interlocks bottom-up rural urbanization and top-down urban expansion driven by economic impetus, this study adopts CA-based simulation model to draw spatial restructuring and urban expansion of Taipei metropolitan area under impacts of economic globalization and local population growth. First, FDI is used to measure the impact of globalization on local economic shifts (primary, secondary, and tertiary sectors) and population changes in this study. Results reveal that FDI and various economic activities have different degree of influences on population growth within Taipei metropolitan area: 1.) Population in City of Taipei, the core of Taipei metropolis, has almost no influence with FDI and major economic activities because City of Taipei is a highly urbanized region, and the phenomenon of suburbanization causes population decreasing and affects the interaction with local economy. 2.) Population in Taipei County, the peri-urban region of the city core, is affected by FDI and tertiary sector in terms of the urban expansion from City of Taipei. 3.) Population in Taoyuan County is related to FDI and secondary/ tertiary sector due to the larger plain areas and industrial parks. 4.) Increasing population in City of Keelung is majorly interacted with tertiary sector and FDI because the cargo port in Keelung City transports goods and products internationally. The above analytical outcomes reflect the importance of economic globalization and interrelationship between global and local economic factors on the desakota regions.

Second, the global/local driving factors are incorporated into the CA-based urban model to examine how transformation of settlement patterns reflects the rapid and substantial social, economic, demographic and structural changes (Jones 2004). After the combination of multi-scale analysis and micro-scale transformation, simulation results illuminate the unique urbanization process driven by the growth of nonagricultural activity in the countryside and by industrial dispersion from cities and towns (Lin 2001b). The desakota regions with densely urban pixels are growing significantly under growing manufacturing/ service sectors and foreign direct investments, and gradually link urban centers/ peri-urban areas. The desakota zones play the critical role as ‘growth generators’ in Asian urbanization processes where foreign and domestic capitals are concentrated (Lin 2001b) and merge city cores and generate a mega-urban region (Douglass 2000) in the future.

Finally, unlike the long-term, mature urbanization process in West, the spatial-temporal compression of Asian urbanization is still evolving. In this study, it seems the agglomerative tendencies will take over when desakota regions are gradually transferred to highly urbanized areas. When economic globalization influences Asian countries after World War II, rapid FDI growth interacts with national-level secondary/tertiary sectors and involve in rural-urban transformation. Increasing FDI inputs stimulate local economic growth and attract more people moving into desakota regions. Mixture of various land-use types (residential, manufacturing, service) can be found simultaneously in the growing generators of rural urbanization and eventually create an extended metropolitan area. While Asian countries rely more on global economy, governments should consider the influence of globalization and understand how urban growth will be changed with different levels of foreign investments so governments can develop proper urban policies to keep capital flows for foreign investors and control rapid growing urban areas for urban sustainable development.

6.2. Limitations

Although this study examines how spatial patterns evolve through interaction of globalization and local socio-economic activities, and generates a CA simulation model to interpret urbanization processes in one of the rapid growing Asian city – Taipei metropolitan area, in terms of time limit, several issues exist in the study and are required for further improvements:

1. *Scale of socio-economic data*: Although this study successfully integrates various scales of data sources to urban simulation, the national-level FDI data is not able to precisely reflect its influence on county-level economy and population changes because it is not intuitive to observe direct relationship between population growth and international /domestic economy at the same level.

2. *Selection of variables:* In this study, selections of parameters for multi-scale analysis and micro-scale transformation are limited to economic factors. Urbanization processes are influenced by not only domestic/global economy but also other perspectives such as cultural influences, historical reasons, and governmental policies. Various factors will have different degree of impacts on urban dynamics and change urban patterns. As a result, selection of diverse variables can improve the accuracy of urban simulation and generate better scenarios for future urban growth.

3. *Measurement of desakota regions*: The desakota model has been criticized for the definition of the concepts or "parameters" in the hypothetical spatial system (Lin 2001b). This study adopts the concept of urban density to help distinguish spatial structures of Taipei metropolitan area and visually compare the spatial pattern with the original desakota model. Although this approach helps better visual interpretation of spatial changes in desakota regions, it is still too vague to define unique spatial attributes of five categories in the desakota model and parameterize characteristics of the desakota regions.

6.3. Future works

Based upon the current study, there are three major topics I will continue in the future. From theoretical perspective, this study has shown that urban dynamics in Asia is driven by factors that are different from western cities. Hence it is worth to further discuss Asian urban dynamics and compare the variation of urbanization processes between western and Asian.

From policy perspective, economic and urban growth requires considerable natural resources, but the natural ecosystems of the Earth cannot sustain current levels of economic activity and material consumptions. Nonetheless, in most Asian developing countries, rapid economic/urban growth is always prior to environmental protection. The economy-oriented policies in most of Asian countries cause serious environmental problems. These severe environmental impacts not only degrade natural resources of the Earth but also threaten public health. Urban economic and ecological systems are physically connected by the throughput of energy and matter from natural ecosystems, and by other environmental goods and services which sustain economic activity (Huang 1998). For the sake of protecting natural resources and environments, a comprehensive evaluating system of energy transformation shall be developed to access environmental impacts on urban systems.

In order to examine how globalization and socio-economic factors influence Asian urban dynamics and estimate how energy transformation occurs between urban and natural environments with high economic and urban growth, this study will develop a CA-based model of urban sustainable development in Asia. Through the integration from these three major components: theories of Asian urban transition, evaluation of urban environmental impacts, and CA-based urban simulation, this study will extend current urban growth models from merely simulating urbanization processes to tightly coupling evaluation of sustainability into urban dynamics.

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