AN ABSTRACT OF THE DISSERTATION OF

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Environmental quality and the spatial distribution of economic activities affect each other in many ways. The primary purpose of this dissertation is to contribute to understanding the complex interrelationship and its policy implications. This dissertation consists of three essays.

The first essay examines the roles that locational amenities and increasing returns to scale play in the formation of urban development patterns and regional economic growth. The spatial distribution of amenities is shown to be a major determinant; and the effects of amenities are reinforced by external scale economies and localized information spillovers, both of which promote agglomeration and human capital accumulation. Workers in amenity locations are more productive because of increasing returns, which encourage investment on human capital development. The decentralized equilibrium is not optimal because of the externalities associated with human capital investments. The efficiency can be improved by public policies encouraging human capital investments. Such policies also increase the number and size of cities and the pace of urbanization and economic growth.

The second essay examines the effects of natural disasters on population growth across U.S. counties during the period of 1960-2000. Results suggest that except earthquakes and most serious hurricanes, the risks of natural disasters have no statistically significant effects on population growth. We also estimate the effects of natural disasters on county socioeconomic and demographic characteristics, including human capital, age and ethnic composition of population, industrial composition, and income inequality, which correlate with county population growth. The insignificance of those effects indicates that natural disasters have no indirect effects on population growth, either.

The third essay considers the roles of mandatory building codes for regulating land development in a natural disaster-prone area as self-insurance and self-protection. To find the optimal building codes, a simple urban economics model is constructed for the analysis. A number of comparative statics results are presented to describe how optimal building codes are affected by the endowed probability of the disaster, the expected loss, productivity levels of self-insurance and self-protection, and socioeconomic characteristics of the area such as wage, population, and the share of land area in the risky region.

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Essays on Environment and the Spatial Distribution of Economic Activities

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my theses to any reader upon request.

Chunhua Wang, Author

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CONTRIBUTION OF AUTHORS

Dr. JunJie Wu was involved in the analysis and writing of Chapter 2. Dr. Wu also assisted in interpreting the results of Chapter 3 and Chapter 4.

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CHAPTER 1

1 GENERAL INTRODUCTION

Environmental quality and the spatial distribution of economic activities affect each other in many ways. A general observation is that places with higher environmental quality are more attractive to people by providing higher level of amenities, consumption or production. On the other hand, concentration of economic activities in those places brings pressures on environmental quality and stability. For example, recent trends have increased the vulnerability of the human beings to several major types of natural disasters. The combination of growing population, development in coastal zones, the draining of wetlands, and changing climatic trends, such as global warming are increasing the potential for loss of life and property in coastal and many other natural disasters-prone regions.

Investigating the interrelationship between environment and the spatial distribution of economic activities is an important issue in natural resource and environmental economics and policy. It also helps explain the spatial inequality in the concentration of economic activities, which is one of the central questions in regional science and urban economics. Numerous recent studies find that local amenities have strong effects on migration patterns, employment growth, and regional inequalities in wages, housing prices and human capital accumulation (Deller *et al*., 2001; Glaeser *et al*., 2001; Khan, 2000; Rappaport and Sachs, 2003). However, the relationship among amenities, agglomerations of economic activities, and regional economic growth and development are not well understood (Deller *et al.*, 2001). The primary purpose of this dissertation research is to contribute to understanding the relationship.

The first manuscript (Chapter 2), entitled *Locational Amenities, Increasing Returns, and Urban Development*, examines the roles of locational amenities and increasing returns to scale in the formation of urban development patterns, with a focus on how they interact with each other. The model developed in this paper highlights the importance of environmental amenities as a determinant of urban development patterns, and shows how that role is reinforced by scale economies and localized information spillovers, both of which promote agglomeration and human capital accumulation. Empirical evidence is also reported to support major theoretical findings.

This analysis is related to several bodies of literature. Many studies in the compensating differential literature conclude that locational amenities and nominal wages are negatively correlated (e.g., Roback, 1982). The present paper argues that workers in a city with more amenities may receive higher wages if more workers choose to work and live in the city and there are agglomeration effects associated with scale economies and local knowledge spillovers.

This paper also draws from the urban economics literature, in particular Black and Henderson's (1999) model of urban growth and Eaton and Eckstein's model (1997) of the parallel growth of cities. However, most studies in this line of literature only examine urban growth within a system of cities. The present paper distinguishes between partial urbanization and full urbanization of the population and finds that the mechanisms of city formation are quite different in the two cases and increasing returns play opposite roles. In a dynamic context, this paper also studies the effects of spatial distribution of locational amenities and increasing returns on the transformation of an economy from partial urbanization to full urbanization.

The third related literature is on endogenous growth (e.g. Lucas, 1988; Romer, 1986). As in many studies in this body of literature, scale economies and knowledge spillovers drive economic growth in our model of the present paper. In addition, we investigate how locational amenities affect economic growth and how they interact with increasing returns, which, to our knowledge, has received little attention in the literature.

The second manuscript (Chapter 3), entitled *Did Natural Disasters Affect U.S. County Growth*, aims to contribute to the literature on the effects of natural disasters on economic growth by estimating the effects of natural disasters on population growth across U.S. counties during 1960-2000. More specifically, we intend to answer the following questions in this paper: Did the risk of natural disasters in a county affect its population growth? Did different types of disaster events have the same impacts?

This paper has four major innovations. First, we assemble and analyze a detailed county-level dataset including data on disasters in the United States, complementing the literature in which most of the studies use country-level data. Second, this paper employs a newly developed estimation method in spatial econometrics by Kelejian and Prucha (2007) to account for spatial dependencies in the endogenous variable and the error term with heteroskedastic disturbances. Third, considering that states may vary in responsiveness to natural disasters, this paper also calculates the effects of natural disasters for each individual state. Fourth, this paper distinguishes between direct and indirect effects of natural disasters. By indirect effects, we estimate the impacts of disasters on human capital accumulation, age and ethnic composition of the population, industrial composition, and income inequality which are found to be correlated with regional population growth and income growth by many previous studies in the regional literature (see, for example, Beeson *et al*.[2001], Higgins, *et al*.[2006], Glaeser *et al*.[1995], Rappaport and Sachs [2003]). It is hoped that the results obtained in this paper are helpful for measuring the long-run economic and social consequences of natural disasters, especially for those low-probability high-consequence events which are not well studied in the literature. The findings of the present paper may also provide a basis for assessing the outcomes of disaster relief policies and understanding issues in natural resource management such as land use.

This paper continues a limited number of empirical studies in the literature of natural disasters which empirically estimate the effects on economic growth. The findings by the previous studies are far from conclusive, and even the signs of the net effects of natural disasters are not consistent. In this study, we not only control for correlated natural attributes, socioeconomic characteristics, and initial conditions which are found by the literature of regional and urban economics to be important for growth, but also take into account two types of spatial interdependencies in the econometric model. This paper also uses detailed data for measuring the number and intensity of four types of major natural disasters which allows us to explore more on the effects of natural disasters.

The third manuscript (Chapter 4), entitled *Land Development Regulation in a Natural Disaster-Prone Area: the Roles of Building Codes*, constructs a simple urban economics model to derive the optimal level of expenditure on self-insurance and self-protection set by government when implementing mandatory building codes for land development in a disaster-prone region.

One lesson learnt from recent natural disasters such as Hurricane Katrina in 2005 is that implementing mandatory building codes in disaster-prone areas is one of the important approaches to preparation. Through establishing structural standards of properties built in the disaster-prone area, building codes reduce the size of the loss from a disaster and/or reduces the probability of occurrences of the disaster. These two effects can be termed as self-protection and self-insurance, respectively. For example, earthquake codes in the seismic zone require builders to use techniques that allow structures to flex without breaking when the ground shakes, thus reduce the loss from earthquake. Some flood codes reduce the building's probability of being flooded in a given year by prohibiting development in areas below a certain elevation; some other flood codes can reduce the loss from flooding by requiring builders to use waterproof building materials.

Though the potential benefits of building codes are evident by looking at and comparing some raw facts, the protection level and stringency of building codes are criticized by many authors who argue that they are arbitrary, not justified, and too costly.

We derive a number of comparative statics to describe the impacts of variables such as endowed probability and loss from disaster, wage, population, commuting cost, the share of land area of the risky region, and technological improvements in self-protection and self-insurance on designing optimal codes.

CHAPTER 2

2 LOCATIONAL AMENITIES, INCREASING RETURNS, AND URBAN DEVELOPMENT

2.1 Introduction

The spatial distribution of economic activities is highly uneven in many countries, including both developed and developing economies. Both increasing returns and locational fundamentals have been empirically demonstrated as the primary causes of spatial disparities in economic development (Davis and Weinstein, 2002; Henderson *et al*., 2001). The purpose of this paper is to examine the roles of these two determinants in the formation of urban development patterns, with a focus on how they interact with each other. Specifically, this paper develops a theoretical model of urban development in which both increasing returns and natural endowments play fundamental roles. The model highlights the importance of environmental amenities as a determinant of urban development patterns, and shows how that role is reinforced by scale economies and localized information spillovers, both of which promote agglomeration and human capital accumulation. Empirical evidence is also reported to support major theoretical findings.

This analysis is related to several bodies of literature. Many studies in the compensating differential literature conclude that locational amenities and nominal wages are negatively correlated (e.g., Roback, 1982). The present paper argues that workers in a city with more amenities may receive higher wages if more workers choose to work and live in the city and there are agglomeration effects associated with scale economies and local knowledge spillovers. Numerous empirical studies find that local amenities have a strong effect on migration patterns, employment growth, and regional inequalities in wages, housing prices and human capital accumulation (Deller *et al*., 2001; Glaeser *et al*., 2001; Khan, 2000; Rappaport and Sachs, 2003). However, the linkages among amenities, agglomerations of economic activities, and regional economic development are not well understood (Deller *et al.*, 2001). In this paper, we focus on these linkages.

This paper also draws from the urban economics literature, in particular Black and Henderson's (1999) model of urban growth and Eaton and Eckstein's model (1997) of the parallel growth of cities. However, most studies in this line of literature only examine urban growth within a system of cities.[1] The present paper distinguishes between partial urbanization and full urbanization of the population[2] and finds that the mechanisms of city formation are quite different in the two cases and increasing returns play opposite roles. In a dynamic context, this paper also studies the effects of spatial distribution of locational amenities and increasing returns on the transformation of an economy from partial urbanization to full urbanization.

The third related literature is on endogenous growth (e.g. Lucas, 1988; Romer, 1986). As in many studies in this body of literature, scale economies and knowledge spillovers drive economic growth in our model of the present paper. In addition, we investigate how locational amenities affect economic growth and how they interact with increasing returns, which, to our knowledge, has received little attention in the literature.

The remainder of this chapter will proceed as follows. The next section describes and solves the basic model. Section 2.3 uses the basic model to analyze the cases of partial urbanization and full urbanization with a focus on the effects of locational amenities and increasing returns on city formation and the economy's transformation from partial to full urbanization. A simple welfare analysis is conducted in Section 2.4. Section 2.5 discusses three extensions of the basic model and their implications. Section 2.6 presents empirical evidence. Section 2.7 offers a concluding summary.

2.2 The basic model

Consider the spatial distribution of economic activities within an economy with K different regions. A region could be a local jurisdiction such as a county, or a statistical district like a Metropolitan Statistical Area as defined by the U.S. Census Bureau. The regions differ by their environmental amenities, and are indexed such that $a_1 > a_2 > ... > a_K$. If a region includes any urban area, it will be referred to as an urbanized region; otherwise, it will be referred to as a rural region.

There are two types of individuals (farmers and factory workers) and two types of firms (farms and non-agricultural firms) in the economy: factory workers produce non-agricultural goods in firms; farmers live in rural areas and produce agricultural goods on farms.[3] Urban populations are endogenously determined in our model in the case of partial urbanization. Decision problems for individuals are analyzed below.

2.2.1 Non-agricultural firms

Consider first the production decisions of a non-agricultural firm. Following Black and Henderson (1999), we assume that each firm is composed of one worker and identical workers use their private human capital to produce a homogeneous good and the production technology for each firm is

$$y_{it} = Dn_{it}^{\delta}\overline{h}_{it}^{\theta}h_{it}^{\psi}, \qquad (1)$$

where i is an index of region; t is an index of time period; y_{it} is the output per worker; D is a positive constant; n_{it} is the total number of workers in the region; $\overline{h}_{it}$ is the average level of human capital in the region; and h_{it} is the amount of human capital each worker has. In this formulation, δ measures the elasticity of the firm's output with respect to the total number of firms in the region, representing the scale economies arising from the total volume of local communications or information exchanges. Parameter θ is the elasticity of the output with respect to the average level of human capital in the region, representing the spillover benefits of local levels of human capital. $\theta + \delta < 1$ is assumed to ensure well-behaved solutions.

A worker's gross income is assumed to be his output, y_{it}. However, he has to spend a portion of his gross income to produce his human capital,[4] and the production function is

$$h_{it} = BH_{t-1}^{\beta}(y_{it} - w_{it}), \qquad (2)$$

where w_{it} is the worker's disposable income. Thus $(y_{it} - w_{it})$ is the amount of income the worker spends on building his human capital, H_{t-1} is the available knowledge base in the economy at time t upon which all workers draw when they study,[5] and B and β are positive constants. As the knowledge base accumulates, it requires less investment to build a specific amount of human capital.

Each worker lives for only one period, and he is free to choose a place to work and live. At each location, a worker chooses the level of human capital investment to maximize utility:

$$\max_{h_{it}} u_{it} = \frac{a_i}{n_{it}^{\chi}} w_{it} \tag{3}$$

with $\chi > 0$, where a_i is the overall level of environmental amenities in region i which is constant over time; $\frac{1}{n_{it}^{\chi}}$ is a term measuring congestion effects in this city. Environmental amenities are assumed to be public good in this city.[6] From the production functions of the final good and human capital in (1) and (2), the relationship between the worker's disposable income and the level of his human capital can be written as

$$w_{it} = D n_{it}^{\delta} \bar{h}_{it}^{\theta} h_{it}^{\psi} - \frac{h_{it}}{B H_{t-1}^{\beta}}. \tag{4}$$

Given that all workers are identical, in a given region, they must have the same level of human capital (i.e., $h_{it} = \bar{h}_{it}$) in symmetric equilibrium. Solving the first order conditions of the maximization problem (3) gives the worker's choice of human capital:

$$h_{it} = \left(\psi B D n_{it}^{\delta} H_{t-1}^{\beta}\right)^{\frac{1}{1-(\theta+\psi)}}. \tag{5}$$

Substituting (5) into (4) gives the disposable net income for a representative worker in region i at time t:

$$w_{it} = (1-\psi)(\psi B)^{\frac{\theta+\psi}{1-(\theta+\psi)}} D^{\frac{1}{1-(\theta+\psi)}} H_{t-1}^{\frac{\beta(\theta+\psi)}{1-(\theta+\psi)}} n_{it}^{\frac{\delta}{1-(\theta+\psi)}}. \tag{6}$$

Denote that $M \equiv (1-\psi)(\psi B)^{\frac{\theta+\psi}{1-(\theta+\psi)}} D^{\frac{1}{1-(\theta+\psi)}}$. It is also helpful to define that $\kappa \equiv \frac{\beta(\theta+\psi)}{1-(\theta+\psi)}$ and $\eta \equiv \frac{1-(\theta+\psi)}{\chi[1-(\theta+\psi)]-\delta}$ for later use.[7] Combining equations (3) and (6) can represent utility level for a representative worker in region *i* at time *t* as a function of population in this region

$$u_{it} = MH_{t-1}^{\kappa} a_i n_{it}^{-\frac{1}{\eta}} . \qquad (7)$$

We assume that workers are free to move and that migration is costless. Under these assumptions, all workers in all regions of the economy must receive the same level of utility in equilibrium. The equilibrium level of utility at time *t* is denoted by u_t .

2.2.2 Farms

We assume that the utility level for farmers is γ , and it is constant over time. This is a result of the assumptions that farmers engage in a traditional method of production in the rural areas and that they have no incentives to invest on human capital (Bertinelli and Black, 2004).[8] If $u_t > \gamma$, some farmers will go to cities to work; conversely, if $u_t < \gamma$, some workers would go to rural areas to farm. In equilibrium, $u_t \geq \gamma$, and the inequality can hold only if the whole economy is fully urbanized (i.e., no farmers in the economy).

2.2.3 Static equilibrium

A stable equilibrium where there are multiple urbanized regions in the economy can exist only when $(1/\eta) > 0$ holds in equation (7). Otherwise, a representative worker's utility is increasing in the number of workers in a region, which leads to a single urbanized region in the economy. That is equivalent to the condition $\chi\left[1-(\theta+\psi)\right] > \delta$, which is more likely to hold if the parameters measuring increasing returns, δ and θ , are small and the parameter measuring congestion effects, χ, is large. From (7), the equilibrium urban population in region i at time t equals

$$n_{it} = \left(Mu_t^{-1}H_{t-1}^{\kappa}a_i\right)^{\eta}, \tag{8}$$

where u_t is the equilibrium level of utility at time t.

To see the effects of environmental amenities on urban population, human capital accumulation, and wages, we calculate the ratios of these variables between region i and region j using equations (8), (5), and (6):

$$\frac{n_{it}}{n_{jt}} = \left(\frac{a_i}{a_j}\right)^{\eta}, \tag{9}$$

$$\frac{w_{it}}{w_{jt}} = \frac{h_{it}}{h_{jt}} = \left(\frac{a_i}{a_j}\right)^{\frac{\delta\eta}{1-(\theta+\psi)}}. \tag{10}$$

Equation (9) states that urbanized regions with higher amenity advantages have greater urban populations. Increasing returns affect the ratio through parameter η. Because $\frac{\partial\eta}{\partial\delta} > 0$ and $\frac{\partial\eta}{\partial\theta} > 0$, external scale economies and localized information spillovers reinforce the effects of environmental amenities on the distribution of populaiton. Equation (9) also suggests that the ratio of urban populations between any two regions will stay constant over time. Much empirical research documents this type of parallel growth, especially for the largest cities (Eaton and Eckstein, 1997, among many others). For example, over the past hundred years, while the share of the U.S. population that are farmers has fallen from 70% to 2%, and the share that is rural has fallen from 90% to 24%, the share of the population that is rural, but not farmers, has stayed remarkably stable at about 22% (Mills, 1995). This pattern is also observed in OECD countries. Kilkenny (2005) asks how could the non-farm rural share of the U.S. population has stayed constant over such a long period of time. Our results provide one possible explanation. Because the rural definition in the U.S. has not changed since 1880 (Barkley, 2005),[9] and very few rural places have been gaining populations, most of the areas designated as rural over a hundred years ago are still rural today. As a result, the share of the population that is rural, but not farmers, is determined by the relative levels of amenities between rural and urban areas, which do not change over time.

Equation (10) indicates that regions with higher amenities have higher wages, which is the opposite of the prevailing wisdom from the compensating differential literature. Glaser and Saiz (2003), Roback (1982), and several other studies find that amenities have a negative effect on wage rates. The basic argument offered by their studies is that households are willing to accept lower wages for better amenities. The reason for the different results is that we adopt a production function of increasing returns to scale. Because amenities attract workers, locations with better amenities have more workers and thus enjoy a larger economy of scale directly and increasing returns to human capital investment indirectly. Therefore, those regions have higher income.

Regions with higher amenities also have higher levels of human capital. Because of the economies of scale, the marginal products of human capital are higher in regions with higher amenities. This leads to more investment in human capital by individual workers. Shapiro (2006) argues that regions with higher concentrations of human capital experience faster growth in consumer amenities, and thus human capital and employment co-vary positively. The mechanism for the positive correlation between human capital and employment is different in the model of the present paper; the positive correlation is driven by the fact that both are positively affected by amenities.

As indicated by the positive effect of the parameters δ and θ on the exponential powers in equation (10), the positive effects of environmental amenities on wages and human capital are reinforced by external scale economies and localized information spillovers.

In sum, the regions with higher locational environmental amenities have larger urban populations, higher wages, and higher levels of average human capital. The effects of environmental amenities are reinforced by increasing returns. In the next section, we apply the basic model to analyze the effects of amenities and increasing returns on the process of urbanization in the economy.

2.3 City formation

We distinguish between partial urbanization and full urbanization. In the case of partial urbanization in which there are still farmers living in rural areas of the economy, the total urban population is endogenous, while the level of utility for workers equals farmers' utility. If workers' utility is higher, more farmers will go to the cities to work and live, bring more congestion and lowering workers' utility. In this case, $u_t = u_{rt} = \gamma$ in equilibrium. In contrast, in the case of full urbanization, all people in the economy are workers, so total urban population is exogenous, while a worker's utility is endogenous.

2.3.1 Partial urbanization

From equation (8) and the equilibrium condition $u_t = \gamma$, urban population in region i at time t, n_{it}, can be derived as

$$n_{it} = \left(M\gamma^{-1}H_{t-1}^{\kappa}a_i\right)^{\eta}. \tag{11}$$

Because $\frac{\partial\eta}{\partial\delta} > 0$, $\frac{\partial\eta}{\partial\theta} > 0$, $\frac{\partial\kappa}{\partial\theta} > 0$, and $\frac{\partial M}{\partial\theta} > 0$, equation (11) indicates that the stronger the effects from external scale economies and information spillovers, the larger the urban population. The growth rate of the population is determined by the growth rate of the economy's knowledge base and increasing returns. As the knowledge base increases, populations in all urbanized regions increase because it costs less to obtain human capital and people working in urban areas are more productive.

Suppose a city emerges in a region when the total number of workers in the region exceeds a certain threshold n_0. From equation (11), a city exists in region i at time t if and only if

$$a_i \geq n_0^{\frac{1}{\eta}}M^{-1}H_{t-1}^{-\kappa}\gamma. \tag{12}$$

Condition (12) indicates that regions with higher amenities are urbanized earlier because it requires a smaller knowledge base for a city to form in these regions. The model might be used to explain a feature of urban growth in the Unites States.[10] At the early stage of development, the U.S. economy had a relatively small knowledge base; cities could exist only in places with higher levels of amenities such as Northeast seaports. As knowledge accumulated, more sites were developed. Kim

(1999) documented that there were few cities before the 18th century, and the number and size of cities significantly increased in the early 19th and early 20th centuries.

Any model parameter affecting η, M and κ also affects the formation of new cities. These include the production technology parameters δ and θ. Because $\frac{\partial \eta}{\partial \delta} > 0$, $\frac{\partial \eta}{\partial \theta} > 0$, $\frac{\partial \kappa}{\partial \theta} > 0$, and $\frac{\partial M}{\partial \theta} > 0$, a city could emerge even in a region with a relatively low level of amenities if there are large scale economies and large knowledge spillovers across firms. More discussion on the relative strength of the locational amenity and increasing returns on the process of urbanization in a dynamic setting is provided later in this section.

2.3.2 Full urbanization

If the knowledge base in the economy reaches a sufficiently high level, the economy may become fully urbanized. In the case of full urbanization, the total number of workers in the economy in each time period, n_t, is given. From equation (8), the distribution of the workers over the regions can be derived as:

$$n_{it} = \frac{a_i^{\eta}}{\sum_{j=1}^{K_0} a_j^{\eta}} n_t, \qquad i = 1, 2, ..., K_0, \tag{13}$$

where K_0 is the number of urbanized regions in the fully urbanized economy and $K_0 = max\left\{ J : n_t\, a_J^{\eta} \Big/ \sum_{j=1}^{J} a_j^{\eta} \geq n_0 \right\}$. This suggests that the population distribution in an urbanized economy is determined by the distribution of amenities across the system of urbanized regions. As total population increases, more cities will emerge in the economy.

By assumption, a city emerges in a region when the total number of workers in the region exceeds n_0. Thus, region i includes a city at time t if and only if $n_{it} \geq n_0$ and $i \leq K_0$, which, together with (13), implies that in a fully urbanized economy, region i with locational environmental amenities a_i includes a city at time t if and only if

$$\frac{a_i^\eta}{\sum_{j=1}^{i} a_j^\eta} n_t \geq n_0 . \tag{14}$$

Condition (14) indicates that population growth is the sole force driving the formation of new cities in this fully urbanized economy. In contrast, in the case of partial urbanization, as shown by equation (11), the driving force is the accumulation of human capital, i.e., increasing knowledge base. Condition (14) also implies that cities form earlier in regions with higher amenities, which is consistent with the case of partial urbanization. However, the effects of increasing returns on the formation of new cities in the case of full urbanization are opposite to those in the case of partial urbanization. Given that $\frac{\partial \eta}{\partial \delta} > 0$, $\frac{\partial \eta}{\partial \theta} > 0$, and $\frac{\partial \left[a_i^\eta \Big/ \sum_{j=1}^{N} a_j^\eta \right]}{\partial \eta} < 0$, condition (14) is less likely to hold with larger values of δ and θ. In contrast, increasing returns have positive effects on the formation of new cities in the case of partial urbanization.

2.3.3 Growth dynamics

In this section, we study the dynamics of economic growth and the economy's possible transformation from partial to full urbanization as driven by human capital accumulation. We assume that the knowledge base is determined by the average level of human capital in the prime city, that is, $H_{t-1} = \max_i \{h_{i,t-1}\}$. Because the largest city in the economy is the one with the highest level of environmental amenities (indexed 1), $H_{t-1} = h_{1,t-1}$. Our focus here is on the role of amenities and increasing returns in the process of human capital accumulation. For simplicity, we assume that total population in the economy stays constant over time.

In the case of full urbanization, the number of cities and populations in the cities are fixed over time. Denote population in city 1 as n_1, which depends on the distribution of amenities across regions in the economy.[11] Using equation (5), the dynamics of average level of human capital in this city can be derived as

$$h_{1t} = \left(\psi BDn_1^{\delta}\right)^{\frac{1}{1-(\theta+\psi)}} h_{1,t-1}^{\frac{\beta}{1-(\theta+\psi)}}. \tag{15}$$

Using equation (7), utility level of individuals at time period t can then be written as

$$u_{1t} = Mh_{1,t-1}^{\kappa} a_1 n_1^{-\frac{1}{\eta}}. \tag{16}$$

It should be equal to or greater than the utility level obtained by individuals in the case of partial urbanization, γ. If the economy becomes fully urbanized in some time period T, then average level of human capital in city 1 at time period $T-1$ which serves as knowledge base for workers at time T must be equal to or greater than

$$\tilde{h}_{1,T-1} = \left(\gamma M^{-1} a_1^{-1} n_1^{\frac{1}{\eta}}\right)^{\frac{1}{\kappa}}, \tag{17}$$

which is obtained by solving (16) for $h_{1,t-1}$ and using the condition that $u_{1t} = \gamma$.

Now consider the process of human capital accumulation in a partially urbanized economy. Substituting (11) into (15) yields

$$h_{1t} = \left[\psi BD\left(M\gamma^{-1}a_1 \right)^{\delta\eta} \right]^{\frac{1}{1-(\theta+\psi)}} h_{1,t-1}^{\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}}. \tag{18}$$

Setting $h_{1t} = h_{1,t-1}$ in equation (18) and solving for h_{1t}, we obtain the steady-state level of knowledge base: $H^* \equiv h_{1t}^* = \left[\psi BD\left(M\gamma^{-1}a_1 \right)^{\delta\eta} \right]^{\frac{1}{1-(\theta+\psi)-\kappa\delta\eta-\beta}}$. Figure 2.1 illustrates the paths of knowledge accumulation in a partially urbanized economy, where the solid curve represents the case when $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}<1$ and the dashed curve for $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}>1$.

[Figure 2.1 about here]

If $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}<1$, the steady state of knowledge base is stable. Then a partially urbanized economy will never be developed into the fully urbanized state if the steady-state level of knowledge base $H^* < \tilde{h}_{1,T-1}$. By using H^* and the results in the previous sections, we can solve for the steady-state level of disposal income and human capital for an individual in each city and the number and size of cities in the partially urbanized economy. For example, the steady-state level of disposal net income for an individual in city i can be derived as $w_i^* = M\left(M\gamma^{-1}a_i \right)^{\frac{\delta\eta}{1-(\theta+\psi)}} \left(H^* \right)^{\frac{\beta(\theta+\psi)+\delta\kappa\eta}{1-(\theta+\psi)}}$ by using equations (6), (11), and (18). If $H^* \geq \tilde{h}_{1,T-1}$, a fully urbanized economy will emerge before the knowledge base reaches H^*.

If $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}>1$, H^* is not a stable steady state. The knowledge base and the economy will shrink over time if its initial level, H_0, is below H^*, and the number and size of cities in the economy will decrease over time as a result.

If $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}=1$, a partially urbanized economy will become fully urbanized only if $\psi BD\left(M\gamma^{-1}a_1\right)^{\delta\eta}>1$. If $\psi BD\left(M\gamma^{-1}a_1\right)^{\delta\eta}<1$, the knowledge base will shrink over time, and the economy will degrade into an agrarian state.

Note that the steady-state level of knowledge base H^* is an increasing function of a_1, δ, and θ and $\tilde{h}_{1,T-1}$ in (17) is an decreasing function of them. These imply that the economy is more likely to grow and become full urbanized if the level of amenities in the prime city is higher and the scale economies and knowledge spillovers are larger because the sufficient condition for it, $H^*\geq\tilde{h}_{1,T-1}$, is more likely to be satisfied with stronger effects from increasing returns.

After the economy achieves full urbanization, the growth path of the knowledge base is governed by equation (15). If $\frac{\beta}{1-(\theta+\psi)}<1$, there is a stable steady-state equilibrium in the fully urbanized economy and the steady-state level of knowledge base is $H^{**}=h_1^{**}=\left(\psi BDn_1^{\delta}\right)^{\frac{1}{1-(\theta+\psi)-\beta}}$, which is obtained by setting $h_{1t}=h_{1,t-1}$ and then solving (15) for h_{1t}. Steady-state levels of income, human capital, consumption, and other endogenous variables in the model could then be easily derived. If $\frac{\beta}{1-(\theta+\psi)}=1$, by equation (15), the fully urbanized economy achieves steady-state growth and the knowledge base grows at the rate of $\left(\psi BDn_1^{\delta}\right)^{\frac{1}{1-(\theta+\psi)}}-1$. Positive steady-state growth requires that $\psi BDn_1^{\delta}>1$, and the steady-state growth rates of income and consumption can be derived. Equation (6) then implies that disposable net income per capita in any city grows at the rate of $\left(\psi BDn_1^{\delta}\right)^{\frac{\beta(\theta+\psi)}{[1-(\theta+\psi)]^2}}-1$. Thus, the distribution of amenities across regions has an evident effect on the growth rates because it determines population in the prime city. If $\frac{\beta}{1-(\theta+\psi)}>1$ and $\psi BDn_1^{\delta}>1$, the economy experiences explosive growth with an ever increasing growth rates of knowledge base. Figure 2.2 illustrates the development process of an economy from partial urbanization to full urbanization with the assumptions that $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}>1$ and $\frac{\beta}{1-(\theta+\psi)}<1$. It indicates that the economy achieves full urbanization after $\tilde{h}_{1,T-1}$ is reached, that is, at time period T. After that time, the economy continues to grow and achieves the steady-state level of human capital H^{**} in a fully urbanized state. Table 2.1 summarizes different scenarios of long-run growth of the economy.

[Insert Figure 2.2 here]

[Insert Table 2.1 here]

2.4 Welfare

So far, we have examined the equilibrium distribution of population across regions in an economy. A natural question is whether the equilibrium distribution is socially optimal. In this section we explore this important question.

Clearly, the equilibrium is not optimal. The source of inefficiency is the externalities involved in human capital investment decisions made by individual workers. As demonstrated by utility function in (3) and income function (4), if there is a social planner who could specify the levels of human capital of workers to maximize workers' utility in each city, he would choose human capital in city *i* at time *t* at the level that $h_{it} = \left[(\theta + \psi) BDn_{it}^{\delta} H_{t-1} \right]^{\frac{\beta}{1-(\theta+\psi)}}$. Comparing this result with equation (5) indicates that individual workers underinvest in human capital development. In addition, solving the social planner's problem in a manner similar to that used in section 2.3, we can derive the number of cities, population distribution, and welfare change in the optimal equilibrium.

If the economy is fully urbanized, the optimal number of cities and population distribution across cities are the same as those in the decentralized equilibrium. However, both accumulated human capital and wages in the decentralized equilibrium are below the socially optimal levels at a given time, although the ratios of these variables between any two cities are the same in the two equilibria. If the knowledge bases (in the decentralized equilibrium and optimal equilibrium) were the same, workers would be better off in the optimal equilibrium as shown by the ratio of utility levels in the two equilibria, $\frac{\left[1-(\theta+\psi)\right](\theta+\psi)^{\frac{\theta+\psi}{1-(\theta+\psi)}}}{(1-\psi)(\psi)^{\frac{\theta+\psi}{1-(\theta+\psi)}}} > 1$ because the planer chooses a higher level of human capital. In fact, the knowledge base is larger in each period under optimal equilibrium because the planner chose a higher level of human capital in all previous periods. Thus, workers in later time periods are also better off because of a larger knowledge base.

In the case of partial urbanization, a social planner's choice has no effects on workers' welfare because the workers' utility is determined by the exogenous utility level for farmers. But the planner would make more investment in human capital, and the economy's knowledge base would then accumulate faster. Thus, urbanization would proceed faster under the social planner. That is, at a given time period, the number of cities in the optimal equilibrium is greater than that in the decentralized equilibrium given that the planner chooses a higher level of human capital and then the threshold of locational amenity for a region to be urbanized is lower than that in the decentralized equilibrium. Also, each urbanized region would have a larger population in the optimal equilibrium. As a result, the equilibrium levels of human capital and wages in cities are higher. If farmers' utility levels also increase with the growth of the knowledge base, then everyone in the economy would be better off. Results (9) and (10) about ratios of populations, wages, and human capital between any two cities still hold in this case of partial urbanization in optimal equilibrium.

2.5 Model extensions

In this section we consider three extensions of the model. The first is to include productive amenities in the analysis. This can be done by specifying the production technology as $y_{it} = D g_i n_{it}^{\delta} \overline{h}_{it}^{\theta} h_{it}^{\psi}$, where g_i is an index of productive amenities in region i. Under this setup, we solve the extended model for population in region i at time t,

$$n_{it} = \left[M u_t^{-1} H_{t-1}^{\kappa} g_i^{\frac{1}{1-(\theta+\psi)}} a_i \right]^{\eta}. \tag{19}$$

Compared with equation (8), a new term, $g_i^{\frac{1}{1-(\theta+\psi)}}$, is introduced into equation (19). Analogs to expressions (9)–(18) could also be obtained by replacing a_i with $g_i^{\frac{1}{1-(\theta+\psi)}}a_i$ which captures the effects of both consumption amenities and productive amenities. Thus, consideration of productive amenities does not change the basic results of this paper.

The second possible extension is to consider different types of non-agricultural industries in the economy that differ in scale economies and knowledge spillovers. A relevant question is: Does industrial location across regions matter? For the ease of exposition, we assume that there are only two regions with amenities $a_1 > a_2$. Each region specializes in one of the two industries. Firms in region i produce good s with the production technology $y_{si} = Dn_{si}^{\delta_s}\overline{h}_{si}^{\theta_s}h_{si}^{\psi_s}$, where $s = 1, 2$ is an index of industry. Good z_1 and good z_2 enter a representative individual's utility function as $u_i = \frac{a_i}{n_i^{\chi}} z_{1i}^{\varepsilon} z_{2i}^{1-\varepsilon}$ and his budget constraint is $w_i = z_{1i} + p_2 z_{2i}$, where good z_1 is the numeraire, and the equilibrium price for good z_2 is p_2. Other variables are defined as in Sections 2.2 and 2.3. We then solve the model with multiple industries and find that industry location does matter for workers' welfare.

Consider first the case of full urbanization where the population is distributed between these two urbanized regions. As a special case of the production technologies, we assume that $\delta_1 > \delta_2$ and $\theta_1 + \psi_1 = \theta_2 + \psi_2$, which mean that industry 1 has a larger economy of scale generated by local employment in its own industry. Solving this model, we find that the equilibrium utility level is higher when region 1 produces good 1 (and region 2 produces good 2) than when region 1 produces good 2 (and region 1 produces good 1). This result implies that workers' utility is higher when the industry with a larger economy of scale is located in the region with higher amenities. The intuition is straightforward: the region with a higher level of amenities will attract a larger population. Those workers will contribute more to productivity if employed by the industry with a larger economy of scale.

In the case of partial urbanization, there will be more urban workers in the economy if the industry with a larger economy of scale is located in the region with a higher level of amenities. These location patterns of industries also result in a larger knowledge base and more urban development. Thus, when industries differ in scale economies and regions have different levels of amenities, regional planning of industry locations as well as public policies for human capital development could potentially improve the social welfare.

Thirdly, we might also want to consider an extension where there is a housing development sector and a commercial sector in cities. Assuming an appropriate production technology for each sector, employment in each sector is a fixed share of total population labor in the city (see production function in the development sector specified by Haurin (1980) for an example). It is easy to show that our results in the previous sectors are not fundamentally changed in this extension.

2.6 Empirical evidence

A major finding of the theoretical analysis is that urban development patterns are heavily influenced by the spatial distribution of amenities. In this section, we test this result empirically using a constructed dataset for metro areas in the continental

U.S. Specifically, we test two hypotheses. First, population in a city is positively correlated to its amenities. Second, cities with higher level of amenity hit a population mark earlier. This second is a direct test of the model's overall implication. To the best of our knowledge, the second hypothesis has not been tested in the literature, although empirical evidence supporting the first hypothesis has been well documented.

The unit of observation in our data sample is the consistently defined metropolitan area. The dataset consists of urban population, climate data, and geographic locations of U.S. metro areas. Population data covers 10 census years from 1900 through 1990, while climate conditions were measured using means of historical records over the 1961–90 period. We also construct a dummy variable that takes value one if the associated metro area contains one or more coastal counties, as designated by the National Oceanic and Atmospheric Administration (NOAA, 2006).

Urban population data for consistently defined metro areas are almost the same as those constructed and used by Black and Henderson (2003).[12] Several minor corrections and adjustments to their raw dataset are made in this paper. First, while we use the same criteria of selecting counties for constructing the dataset for population,[13] we correct their data by matching the counties in their sample according to 1993 FIPS (Federal Information Processing Standards) codes.[14] Second, we drop all metro areas in Florida because "reconsolidation [of counties] leaves us unable to distinguish modern Metro Statistical Areas."[15] Doing these modifications reduces their sample of 282 metro areas covering 695 counties to 280 metro areas covering 676 counties. For each metro area, we use its principal city's climate to represent its amenity. Climatic data are obtained from the *County and City Data Book 1994*. We also drop those areas whose principal city's climate data cannot be found in the *Data Book*. Doing this further reduces the sample to 268 observations (metro areas). From 1950, all metro areas in our sample have urban population. Summary statistics of the variables in the data sample is presented in Table 2.2.

[Insert Table 2.2 here]

We first examine to what extent variations in urban population across metro areas in the United States can be attributed to variations in amenities. From equation (11),

$$\log n_{it} = \beta_0 + \beta_1 \log H_{t-1} + \beta_2 \log a_i, \qquad (20)$$

where $\beta_0 = \eta \log(M / \gamma)$, $\beta_1 = \kappa\eta$, and $\beta_2 = \eta$. This suggests that the population of a metro area in a specific year is related to its amenities and some other common variable for all regions. An augment of this equation allows for different knowledge bases across the metro areas.

Table 2.3 reports OLS estimates of equation (20) for two specific years (1970 and 1990) after controlling for historic population and Census regional dummies. For each designated year, two specifications are estimated corresponding to different assumptions about the knowledge base. In the first specification, the knowledge base H_{t-1} is assumed to be the same across the metro areas, and in the second specification, the knowledge base is assumed to be different across the metro areas and is measured using the percent of college-educated adults (25 year or older) in 1960.[16] Results for the years of 1970 and 1990 in this table show that metro areas with temperate and drier weather (fewer heating degree days, less precipitation) have larger populations, which is suggested by the negative coefficients on the weather variables. The signs and statistical significance of the coefficients on the coastal dummy in the regressions imply that coastal metro areas have larger populations, which might be a result of coastal proximity to productivity and natural amenities (Rappaport and Sachs, 2003). Estimation results[17] for other years also indicate a negative correlation between regional population and the weather variables and a positive correlation between population and the coastal dummy. The correlations and significance of estimated coefficients are robust when controlling for initial conditions of historical population and human capital stock.

[Insert Table 2.3 here]

Second, we test the hypothesis that regions with higher amenities hit a given population mark earlier. To do the test, we order the metro areas by the first census year they hit a population mark. In the first test, we use 200,000 as the population mark. The metro areas with a population greater than this population mark in 1900 are ordered first, those that hit this mark in 1910 are ordered second, those that hit in 1920 are ordered third, and so on. A multinomial ordered logit regression model is estimated, and the estimation results are reported in Table 2.4. To test the robustness of the regression results, we use different population marks in the estimation. Table 2.4 also reports the estimation results when 100,000 and 500,000 are used as the population mark. All three sets of results are consistent with the theoretical finding that regions with higher amenities hit a given population mark earlier. Specifically, estimated coefficients on the coastal dummy are positive and significant. The coefficients on "average annual heating degree days" are negative and significant.

Although the coefficients on "average annual precipitation" are not statistically significant, they take negative signs. Given the signs of the estimated coefficients reported in Table 2.4, it is found that regions with higher amenities have higher probabilities of hitting a population mark in year 1900 and/or some time before 1990. Because of the nature of the multinomial ordered logit model, the effects of amenities on the probabilities of a region hitting a mark in a specific year between 1900 and 1990 are ambiguous. By using a different rule for ordering the regions in our sample, Table 2.5 reports results from another set regressions, in which regions are ordered first if they hit a population mark before 1950;[18] otherwise they are ordered second. The signs of the estimated coefficients roughly suggest that regions with higher amenities hit a population mark earlier.

[Insert Tables 2.4 and 2.5 here]

2.7 Concluding remarks

In this paper we develop a theoretical model to better understand the major determinants of urban development patterns and the process in which an economy evolves from partial to full urbanization. The model considers both locational amenities and increasing returns associated with external scale economies and knowledge spillovers. Results show that urban development patterns are strongly influenced by the spatial distribution of amenities. Regions with relatively high amenities tend to be developed earlier and have larger populations. The effects of amenities on urbanization are reinforced by the increasing returns derived from scale economies and knowledge spillovers. Increasing returns play quite different roles in the formation of new cities in partial and full urbanized economies. Empirical evidence is presented to support the argument that the spatial distribution of amenities and the level of accumulated human capital are major determinants of urban development patterns.

This paper also analyzes how the spatial distribution of amenities and increasing returns affect the trajectories of human capital accumulation and economic growth. Locations with higher environmental amenities attract workers and thus tend to have a higher level of human capital. Workers in those amenity locations are more productive because of scale economies and knowledge spillovers. Higher productivity encourages workers to invest more on human capital, which drives economic growth. In particular, our result suggests that an economy with few environmental amenities will have a very low growth rate or even shrink if the effect of increasing returns is not large enough. The decentralized equilibrium is not optimal because of the externalities associated with human capital investments made by individual workers. The efficiency can be improved by public policies encouraging human capital investments. Such policies also increase the pace of urbanization and economic growth.

2.8 Endnotes

[1] An exception is the paper by Bertinelli and Black (2004) on urbanization and growth. But the number of cities is not a focus in their paper.

[2] Partial urbanization is defined as the situation where there are still some farmers living in rural areas who are potential labor forces for firms in urban areas. Full urbanization is defined as the situation where all people of the economy live and work in cities.

[3] We assume that agricultural goods are perfect substitutes for non-agricultural goods for consumers. So there is no trade between workers and farmers. By assumption, there are no farmers in the case of full urbanization.

[4] Alternatively, the spending can be interpreted as the payment for the worker's educational loans.

[5] In this model, we assume that the knowledge bases for workers in all urbanized regions at a specific time are the same. For example, there is a prime city in the economy that serves as the sole source of knowledge.

[6] We do not consider the effects of location of amenities within the region on urban spatial structure; see Wu and Plantinga (2003) for a treatment on this subject.

[7] It is important to note that $\frac{\partial \eta}{\partial \delta} > 0$, $\frac{\partial \eta}{\partial \theta} > 0$, and $\frac{\partial \kappa}{\partial \theta} > 0$, which means that these parameters are increasing in the scale economies parameter δ and the knowledge spillover parameter θ. Scaling H_{t-1} and h_{it} in (2) appropriately such that B and D large enough to ensure that $\frac{\partial M}{\partial \theta} > 0$.

[8] As an alternative, one may assume that output per rural worker is an increasing function of knowledge base; but there are no knowledge spillovers or externalities. This alternative assumption would not provide much additional insight, so it is not adopted here.

[9] In 1880, the Bureau of the Census defined a rural place as any place with a population of fewer than 2500. Even now, 125 years later, an area with 2500 or fewer people is "rural" in the United States.

[10] So far, we only consider consumption amenities. As illustrated in Section IV, the model can be extended without much difficulty to a case that also includes productive amenities.

[11] From (13), we know that $n_1 = n a_1^{\eta} \Big/ \sum_{j=1}^{K_0} a_j^{\eta}$, where $K_0 = max\left\{ J : n a_J^{\eta} \Big/ \sum_{j=1}^{J} a_j^{\eta} \geq n_0 \right\}$ and n is total population in the fully urbanized economy.

[12] For a detailed description of the construction of consistently defined metro areas and related statistical issues, see section 2.1 of their paper.

[13] Hereafter, "population" in this section refers to urban population in the associated metro area.

[14] Related information is available online at:
http://www.census.gov/population/estimates/metro-city/93mfips.txt

[15] This drop is mentioned in their text, but observations of Florida are still in the dataset that we obtained from J. V. Henderson and Jim Davis.

[16] We choose 1960 as the initial year here because it is the first year detailed data on "the percent of college-educated adults (25 year or older)" are available from our data source.

[17] Available from the authors upon request.

[18] The year "1950" is arbitrarily chosen here. In fact, regression results do not change qualitatively if other alternative years are used.

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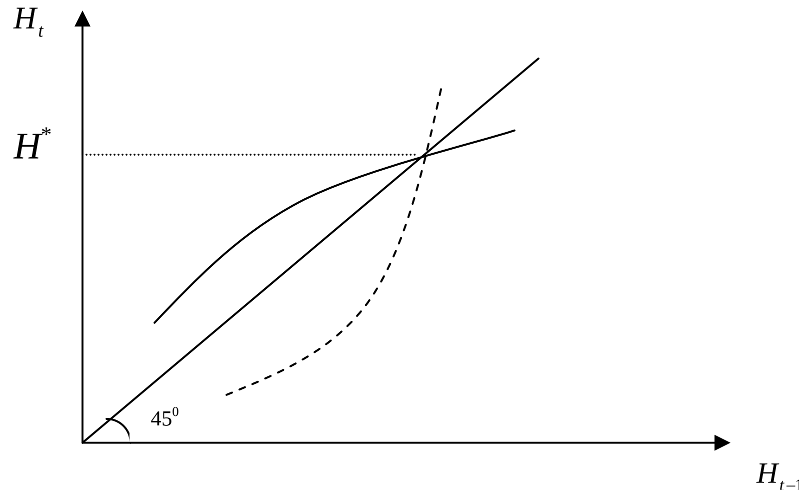
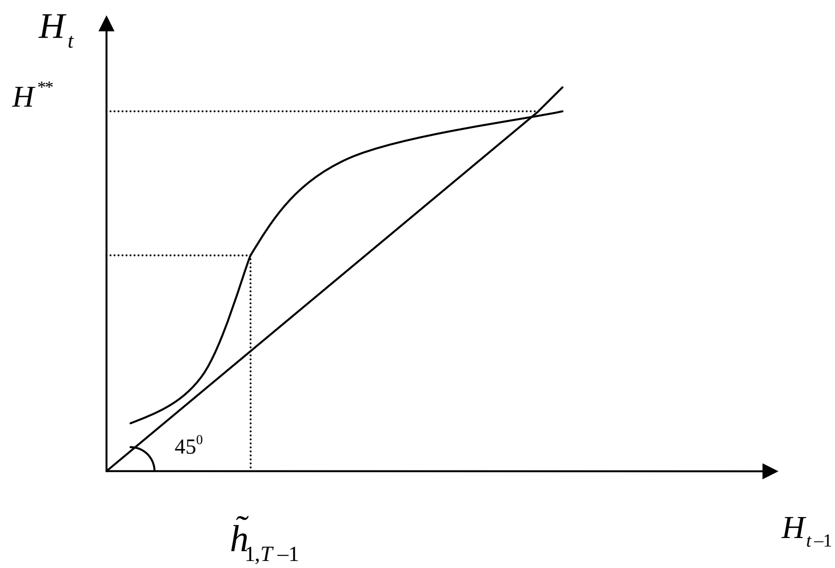


Notes: The solid and dashed curves in the figure represent $h_{1t}=\left[\psi BD\left(M\gamma^{-1}a_1\right)^{\delta\eta}\right]^{\frac{1}{1-(\theta+\psi)}} h_{1,t-1}^{\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}}$ for $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}<1$ and $\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}>1$, respectively.

Figure 2.1: Knowledge accumulation in a partially urbanized economy



Notes: The economy becomes fully urbanized at the point right after $\tilde{h}_{1,T-1}$, and achieves steady state at H^{**} with full urbanization.

Figure 2.2: Evolution from partial urbanization to full urbanization: An example

Table 2.1: Long-run growth of the economy

<table>
<tr><th colspan="3">Parameters and Conditions</th><th>Long-run growth</th></tr>
<tr><td rowspan="2">$\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}<1$</td><td colspan="2">$H^{*}>\tilde{h}_{1,T-1}$</td><td>Full urbanization with a steady-state level of human capital H^{**}</td></tr>
<tr><td colspan="2">$H^{*}<\tilde{h}_{1,T-1}$</td><td>Partial urbanization with a steady-state level of human capital H^{*}</td></tr>
<tr><td rowspan="2">$\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}=1$</td><td colspan="2">$\psi BD\left(M\gamma^{-1}a_1\right)^{\delta\eta}>1$</td><td>Full urbanization with a steady-state level of human capital H^{**}</td></tr>
<tr><td colspan="2">$\psi BD\left(M\gamma^{-1}a_1\right)^{\delta\eta}<1$</td><td>No cities in the economy</td></tr>
<tr><td rowspan="4">$\frac{\kappa\delta\eta+\beta}{1-(\theta+\psi)}>1$</td><td colspan="2">$H_0<H^{*}$</td><td>No cities in the economy</td></tr>
<tr><td rowspan="3">$H_0\geq H^{*}$</td><td>$\frac{\beta}{1-(\theta+\psi)}>1$</td><td>Explosive growth</td></tr>
<tr><td>$\frac{\beta}{1-(\theta+\psi)}=1$</td><td>Full urbanization with the knowledge base growing at the steady-state rate $\left(\psi BDn_1^{\delta}\right)^{\frac{1}{1-(\theta+\psi)}}-1$</td></tr>
<tr><td>$\frac{\beta}{1-(\theta+\psi)}<1$</td><td>Full urbanization with a steady-state level of human capital H^{**}</td></tr>
</table>

Table 2.2: Summary Statistics

Variable		Mean	Std. Dev	Min	Max
urban population,	1900	94,997	295,596	0	3,576,826
	1910	131,534	397,380	0	5,011,670
	1920	168,163	481,510	0	5,933,861
	1930	214,498	608,694	0	7,393,539
	1940	227,279	643,906	0	7,956,640
	1950	293,729	737,929	7,663	8,513,109
	1960	377,465	853,955	17,413	8,638,873
	1970	448,473	950,288	17,684	8,947,067
	1980	493,499	955,549	25,540	8,182,206
	1990	549,724	1,041,515	27,247	8,786,200
average annual precipitation		36.1377	13.0882	3.17	63.96
average annual heating degree days		157.2295	67.8861	23.1	327.2667
coastal dummy		0.3993	0.4907	0	1
Census region dummies					
Northeast		0.1679	0.3745	0	1
Midwest		0.2985	0.4585	0	1
South		0.3396	0.4744	0	1
% 25 yrs and older college educated, 1960		9.0867	4.5156	2.8	38.7
Number of observations	268				

Notes: 1. “Average annual precipitation” measured in inches.

2. For “% 25 yrs and older college educated, 1960”, there are 248 observations.

Table 2.3: Estimates of the urban population regression model

Indep. variables \ Dep. variables	log (1970 population)		log (1990 population)	
Intercept	12.8803***	1.2539***	13.5658***	2.4633***
	(0.3125)	(0.2259)	(0.2991)	(0.2842)
Log(1950 population)		0.9732***		0.9203***
		(0.0162)		(0.0203)
% 25 yrs and over college educated, 1960		0.0196***		0.0285***
		(0.0040)		(0.0051)
Average annual precipitation	-0.0133*	-0.0072***	-0.0147**	-0.0099***
	(0.0074)	(0.0019)	(0.0071)	(0.0024)
Average annual heating degree days	-0.0059***	-0.0016***	-0.0064***	-0.0024***
	(0.0016)	(0.0004)	(0.0015)	(0.0005)
Coastal dummy	0.6932	0.1040**	0.6754***	0.1355***
	(0.1539)	(0.0401)	(0.1473)	(0.0505)
Census region dummies				
Northeast	0.9562***	-0.2988***	0.5074*	-0.6017***
	(0.3070)	(0.0827)	(0.2939)	(0.1040)
Midwest	0.7997***	-0.1790**	0.4009	-0.4710***
	(0.2668)	(0.0698)	(0.2554)	(0.0877)
South	0.0438	-0.1810**	-0.1934	-0.3600***
	(0.2749)	(0.0722)	(0.2632)	(0.0908)
Adj. R^2	0.1497	0.9483	0.1668	0. 9157
Number of observations	268	248	268	248

Note: Standard errors are in parentheses; ***, ** and * indicate significance at 1%, 5%, and 10% respectively.

Table 2.4: Estimates of the ordered logit regression model

	population mark		
Indep. Variable	100,000	200,000	500,000
Average annual precipitation	-0.0124	-0.0119	-0.0210
	(0.0121)	(0.0128)	(0.0159)
Average annual heating degree days	-0.0055**	-0.0063**	-0.0101***
	(0.0027)	(0.0029)	(0.0037)
Coastal dummy	0.8700***	1.0702***	0.8880***
	(0.2547)	(0.2647)	(0.3197)
Census region dummies			
Northeast	2.0958***	1.2469**	1.5523**
	(0.5185)	(0.5321)	(0.6684)
Midwest	1.0901**	0.7475	1.0446*
	(0.4440)	(0.4746)	(0.6227)
South	0.2079	-0.0018	-0.1489
	(0.4503)	(0.4752)	(0.5922)
-2logL	1084.311	928.206	572.057
Number of observations		268	

Notes: 1. Standard errors are in parentheses; ***, ** and * indicate significance at 1%, 5% and 10%, respectively.

2. The 9 intercepts are not reported in this table.

Table 2.5: Estimates of the binomial logit regression model

	population mark		
Indep. Variable	100,000	200,000	500,000
Intercept	-0.0126	-0.5441	-2.1536**
	(0.5969)	(0.6535)	(0.9251)
Average annual precipitation	-0.0084	-0.0090	0.0219
	(0.0142)	(0.0164)	(0.0236)
Average annual heating degree days	-0.0059*	-0.0076**	-0.0076
	(0.0032)	(0.0037)	(0.0053)
Coastal dummy	0.7602***	0.8013**	0.9532**
	(0.2958)	(0.3202)	(0.4518)
Census region dummies			
Northeast	2.1303***	1.6870**	0.8396
	(0.6327)	(0.6974)	(0.8796)
Midwest	1.3422**	1.3483**	0.7596
	(0.5416)	(0.6406)	(0.8439)
South	0.6193	0.0245	-1.2350
	(0.5335)	(0.6190)	(0.9034)
-2logL	342.711	294.887	181.935
Number of observations		268	

Notes: Standard errors are in parentheses; ***, ** and * indicate significance at 1%, 5% and 10%, respectively.

CHAPTER 3

3 DID NATURAL DISASTERS AFFECT U.S. COUNTY GROWTH?

3.1 Introduction

Over the past decade, many countries around the world experienced the largest natural disasters in their history. Recent trends have increased the vulnerability of the human beings to several major types of natural disasters. The combination of growing population, development in coastal zones, the draining of wetlands, and changing climatic trends, such as global warming are increasing the potential for loss of life and property in coastal and many other natural disasters-prone regions. As in many other countries, natural disasters afflict the United States every year, causing tremendous amount of economic damage and loss of life. A recent example is Hurricane Katrina which formed in late August 2005. It is the costliest hurricanes in the history of the United States and the third deadliest hurricane since 1900.

Natural disasters have gained increasing attention from economists in recent years. While many studies in the literature are focused on the short-term impacts of specific disaster events on several aspects of local economy and society, there is a growing body of literature on the effects of natural disasters on economic growth and welfare (e.g., Kahn [2005], Skidmore and Toya [2002], Tavares [2004]). In the regional context, population growth is an appropriate measure for economic growth (Glaeser *et al*., 1995). The objective of the present paper is to contribute to this line of literature by estimating the long-run effects of natural disasters on population growth across U.S. counties during the period of 1960-2000. More specifically, we intend to answer the following questions in this paper: Did the occurrence of natural disasters in a county affect its population growth? How did different types of disaster events vary in the impacts?

This chapter has four major innovations. First, we assemble and analyze a detailed county-level dataset including data on disasters in the United States, complementing the literature in which most of the studies use country-level data. Second, this paper employs a newly developed estimation method in spatial econometrics by Kelejian and Prucha (2007) to account for spatial dependencies in the endogenous variable and the error term with heteroskedastic disturbances. Third, considering that states may vary in responsiveness to natural disasters, this paper also calculates the effects of natural disasters for each individual state. Fourth, this paper distinguishes between direct and indirect effects of natural disasters. By indirect effects, we estimate the impacts of disasters on human capital accumulation, age and ethnic composition of the population, industrial composition, and income inequality which are found to be correlated with regional population growth and income growth by many previous studies in the regional literature (see, for example, Beeson *et al*.[2001], Higgins, *et al*.[2006], Glaeser *et al*.[1995], Rappaport and Sachs [2003]). It is hoped that the results obtained in this paper are helpful for measuring the long-run economic and social consequences of natural disasters, especially for those low-probability high-consequence events which are not well studied in the literature. The findings of the present paper may also provide a basis for assessing the outcomes of disaster relief policies and understanding issues in natural resource management such as land use.

This paper continues a limited number of empirical studies in the literature of natural disasters which empirically estimate the effects on growth, including the studies by Tavares (2004), Skidmore and Toya (2002), and Rossi *et al*. (1978). The findings by the previous studies are far from conclusive, and even the signs of the net effects of natural disasters are not consistent. Using a panel data at the country level, Tavares (2004) find some evidence that the occurrence of natural disasters has a negative and significant effect on per capita GDP growth rate. However, Skidmore and Toya (2002) demonstrate that higher frequencies of climate disasters are correlated with higher rates of human capital accumulation, increases in total factor productivity, and economic growth across countries. Rossi *et al*. (1978) find that there are no discernible net effects of natural disasters (floods, hurricanes, and tornadoes) on growth trends in the period 1960 to 1970 in the United States. This present paper is closely related to the study by Rossi *et al*. (1978) which also focuses on the effects on population growth across U.S. counties. But we not only control for correlated natural attributes, socioeconomic characteristics, and initial conditions which are found by the literature of regional and urban economics to be important for regional growth, but also take into account two types of spatial interdependencies in the econometric model. This paper also uses detailed data for measuring the number and intensity of four types of major natural disasters which allows us to explore more on the effects of natural disasters.

The rest of this chapter proceeds as follows. Section 3.2 presents a conceptual framework in which we discuss the possible theoretical links between natural disasters and population growth in counties. Econometric model and estimation methods are also discussed. Section 3.3 describes the data set we constructed in this paper for empirical research. Section 3.4 then presents and discusses the empirical results. Concluding remarks are offered in Section 3.5.

3.2 Model

3.2.1 Theoretical model

This section develops a simple model for estimating the effects of natural disasters on population growth in counties. It is an extension of the formulation proposed by Glaeser *et al*. (1995) and Glaeser *et al*. (2004).

Consider an economy composed of a set of counties $i \in \{1, 2, ..., I\}$. Suppose that population in county i at time t is represented by $L_{i,t}$. Following Ciccone and Hall (1996), we assume that the aggregate production function for county i is given by

$$A_{i,t} L_{i,t}^{\gamma} S^{1-\gamma}, \tag{1}$$

where $A_{i,t}$ denotes the level of productivity in county i at time t. S denotes total land area in this county, which is constant over time. Wage rate for an individual in this county, $R_{i,t}$, is the marginal product of labor, thus

$$R_{i,t} = \gamma A_{i,t} L_{i,t}^{\gamma-1} S^{1-\gamma}. \tag{2}$$

A representative individual in county i at time t derives utility from local quality of life and wage rate she received:

$$V_{i,t} = \left[Q_{i,t} L_{i,t}^{-\alpha} S^{\psi} \right] R_{i,t}, \tag{3}$$

where the product of $Q_{i,t} L_{i,t}^{-\alpha} S^{\psi}$ is an index of local quality of life in which $Q_{i,t}$ denotes exogenous environmental amenities such as climate and $L_{i,t}^{-\alpha} S^{\psi}$ represents congestion effects in this county with $\alpha > 0$ and $\psi > 0$.

Combining (2) and (3) gives that

$$V_{i,t} = \gamma Q_{i,t} A_{i,t} L_{i,t}^{\gamma-1-\alpha} S^{1-\gamma+\psi}. \tag{4}$$

Assume that migration across counties is free and costless. In equilibrium, utility levels across counties are equal. Let V_t denote equilibrium level of utility at time period t, then $V_t \equiv V_{i,t}$ for any county i in the economy. Thus, for each county i,

$$\log\left(V_t\right) = \log\gamma + \left(1-\gamma+\psi\right)\log S + \log Q_{i,t} + \log A_{i,t} + \left(\gamma-1-\alpha\right)\log\left(L_{i,t}\right). \quad (5)$$

Natural disasters may contribute to local productivity growth by encouraging the adoption of new production technologies by firms through replacing the damaged machines and equipment in the afflicted regions (Tol and Leek, 1999). Some affected locations also benefit from a massive inflow of capital for rebuilding, and from technological innovations in the construction sector (Albala-Bertrand, 1993). Disasters could also have adverse productivity effects through destroying physical capital stock, lowering marginal product of labor. Thus, the net effects of natural disasters on local productivity growth are not clear in theory.

In addition to productivity effects, the occurrences of natural disaster events also change the level of quality of life by directly destroying amenity structures and bringing inconvenience for people in the affected regions. However, some case studies find that natural disasters improve local quality of life through promoting and reinforcing a sense of regional identity amongst population in the affected region (Geipel, 1982). Thus, the net effects on quality of life are also ambiguous.

To describe the dynamics of productivity and quality of life, A_{it} and Q_{it} are assumed to change over time and are functions of natural disaster events and other characteristics of the associated county (Glaeser *et al.*, 2004). Formally,

$$\log\left(\frac{A_{i,t+1}}{A_{i,t}}\right) = D_{i,t}^{'}\delta_A + C_{i,t}^{'}\pi_A + \upsilon_{i,t+1}, \text{ and} \quad (6)$$

$$\log\left(\frac{Q_{i,t+1}}{Q_{i,t}}\right) = D_{i,t}^{'}\delta_Q + C_{i,t}^{'}\pi_Q + \mu_{i,t+1}, \tag{7}$$

where $D_{i,t}$ is the vector of measures of natural disasters and $C_{i,t}$ is the vector of some other natural and socioeconomic characteristics of the associated county. The error terms in the two processes are represented by $\upsilon_{i,t+1}$ and $\mu_{i,t+1}$, respectively. Neither of the two error terms is correlated with natural disasters or county characteristics. It is well documented in the regional literature that locational fundamentals such as weather and coastal proximity have great impacts on regional growth. The growth literature also finds substantial evidence on the importance of human capital, political and social characteristics, industrial composition, and many other factors for growth. Those related variables are grouped in $C_{i,t}$. Combining (5), (6), and (7) yields the expression for population change between two periods:

$$\log\left(\frac{L_{i,t+1}}{L_{i,t}}\right) = \frac{1}{1+\alpha-\gamma} D_{i,t}^{'}\left(\delta_A + \delta_Q\right) + \frac{1}{1+\alpha-\gamma} C_{i,t}^{'}\left(\pi_A + \pi_Q\right) + u_{i,t+1}, \tag{8}$$

where $u_{i,t+1} = \frac{1}{1+\alpha-\gamma}\left[\log\left(\frac{V_{t+1}}{V_t}\right) + v_{i,t+1} + \mu_{i,t+1}\right]$.

Equation (8) suggests that the magnitude of net effect and its sign of natural disasters on population growth in counties depend on the relative importance of their net amenity effects and net productivity effects, which are represented by the sum of $\delta_A + \delta_Q$. One of our major objectives of this paper is to estimate the sum by using U.S. county-level data. A more detailed discussion on the error term, $u_{i,t+1}$, in equation (8) will be given later in this section.

3.2.2 Econometric model

When studying the determinants of population distribution and growth across counties, agglomeration effects must be taken into account. The effects may exist not only within a county, but also across counties especially when they are within the same metropolitan area. Then it is natural to allow spatial interdependencies across counties on the endogenous variable—population growth rate. We also assume disturbances in the econometric model to be spatially correlated, which is possibly caused by measurement errors in the dependent variables and the omission of some spatially correlated independent variables. Let y denote population growth, and independent variables are collected in X which may include natural attributes, county characteristics, state and coastal dummies, and natural disasters. Based on (8), the econometric model is formally written as:

$$y = X\beta + \lambda Wy + u \,, \tag{9}$$

and

$$u = \rho Mu + \varepsilon \,. \tag{10}$$

This is referred to as a spatial autoregressive model with autoregressive disturbance of order (1,1), for short SARAR(1,1) (Anselin and Florax, 1995). In (9) and (10), β, λ and ρ are parameters to be estimated. As indicated by Table 3.2, counties differ greatly in land area and population so it is also reasonable to assume that the innovations in the disturbance process, ε, in equation (10) are heteroskedastic. Here y and X are defined as usual. W and M are spatial weight matrices which are discussed in details below.

The conventional estimators of OLS, GLS and MLE have evident drawbacks. Kelejian and Prucha (2007) develop a GMM estimation methodology for this SARAR(1,1) model. To implement it, they propose a three-step procedure. In the first step the model is estimated by 2SLS using instruments for $\left(X \;\; Wy\right)$.[1] In the second step the autoregressive parameter, ρ, is estimated by using a GMM based on the 2SLS residuals obtained from the first step. In the third step the regression model is re-estimated by 2SLS after transforming the model to account for the spatial correlation. Several nice points of this estimation method deserve mention here. First, it allows for heteroskedasticity in innovations which is a recent development in the literature of spatial econometrics. Second, it gives the joint asymptotic distribution of all model parameters, including those for spatial autocorrelation which makes it possible to test the significance of the estimates, especially for the spatial autoregressive parameter in equation (10).

It is helpful to discuss the ways to construct the spatial weights matrices employed later in the empirical section of this paper. The spatial weight matrix, W, in (9) is used for measuring spatial interdependencies in the endogenous variables among counties. Its element, w_{ij}, takes the value of one if counties i and j belongs to the same metropolitan area, otherwise $w_{ij} = 0$. In this setup, elements in W are regarded as measuring "economic distance" between counties. With equation (9), it models explicitly that population growth of a metropolitan county is correlated with that of any other counties in the same metropolitan area. This might be true because of agglomeration effects from various sources, such as increasing return to scales in production and labor market pooling. As to the spatial weight matrix for the error term, M, in equation (10), its element, m_{ij}, is set to be one if the counties i and j are geographic neighbors. Otherwise, $m_{ij} = 0$. All diagonal elements of W and M are set to be zero. The spatial weight matrices are normalized such that each row sums to unity.

3.3 Data description

The dataset constructed for this paper consists of county-level population data, socioeconomic data, data on natural attributes, and data for natural disasters. 1960 serves as the initial year for the analysis because it is the first year detailed data on natural disasters are available. One of the important reasons of using county-level data in this study is that the occurrences of disaster events are reported at county level in many data sources such as those cited below. To keep county boundaries constant over time, we do several minor adjustments[2] and obtain 3077 counties in the contiguous United States.

The dataset includes four major types of natural disasters: earthquake, volcanic eruption, tornado, and hurricane. For each type of natural disasters, this paper uses measures that are exogenous—magnitudes and number of occurrence. Our analysis only considers the events with significant magnitudes in the data sample.

Data on the number and magnitudes of earthquakes occurred during 1960-2000 are taken from Significant Earthquakes Database of National Oceanic and Atmospheric Administration (NOAA).[3] The Ritcher scale is often used to report the magnitude of an earthquake. The earthquakes at Ritcher 2.5 or below are not felt. Those between Ritcher 2.5 and 5.0 are often felt, but only cause minor damages. Our data sample includes all those earthquakes with Ritcher 5.0 or higher occurred during

1960-2000. The sample also documents data for volcanic eruptions which afflicted only four counties in the State of Washington in May 1980 when Mount St. Helens erupted.

Tornadoes are one of the most destructive winds found on the earth's surface. On average, 850 tornadoes are reported annually, of which 600 originate in the United States (Bryant, 2005). The intensity of a tornado is often measured by Fujita Scale, which is based on wind speed and has a range from 0 to 5. If the wind speed is between 254-332 km/hour, the tornado has a scale of F3, severe damages will be caused. Those F5 tornadoes generally result in incredible damages. We collect data on tornado from National Climatic Data Center's Storm Event Database.[4] For each tornado with F3, F4 or F5 scale, our dataset includes the number of occurrence and its location in each year during 1960-2000.

The force of a hurricane is measured on the Saffir/Simpson Scale, which is a 1-5 rating based on the hurricane's present intensity. A hurricane landfall causes potential property damage and flooding along the coast. The Saffir/Simpson Scale gives an estimate of the damage and flooding. Although all categories are dangerous, Categories 3, 4, and 5 are considered major hurricanes (Fitzpatrick, 1999). Data on the number and categories of hurricanes comes from NOAA Coastal Service Center. Our data sample includes all C3, C4 and C5 hurricanes landed in each year during 1960-2000. Affected inland counties are impossible to be identified from our data sources.[5]

Total number of counties afflicted by each type of natural disasters is presented in Table 3.1. It documents that 111 coastal counties were hit by hurricanes and tornadoes affect 1449 counties during 1960-2000. But geographic disasters are much less widespread. Only 31 counties experienced significant earthquakes with Ritcher 5.0 or higher during this period. Looking into the disasters data, we also observe that the juxtaposition of hazard events varies spatially in the United States. The Gulf and Atlantic coasts are much more prone to tropical storms whereas the Pacific coastal states are much more to earthquakes and other types of tectonic hazards. The central part of the U.S. is traditionally known as "Tornado Alley", which covers the states from Texas northward to the Dakotas and has the highest annual average of tornadoes (Thomas and Mitchell, 2001). The distribution of economic activities across regions in the United States is also highly uneven which is found and analyzed by many previous studies. It is overwhelmingly concentrated at ocean and Great Lakes coasts (Rappaport and Sachs, 2003). Counties with better climate have denser population (Beeson *et al*., 2001).

Population growth rate is major dependent variable in this paper. Independent variables include the following ones besides natural disasters. Two variables are taken to measure weather: mean temperature for January and that for July, which are calculated as a land weight average of the variables borrowed from McGranahan (1999). Socioeconomic variables include educational attainment, industrial composition, age and ethnic composition of the population, and income inequality, which are taken from County and City Data Book (1962, 1967, 1983, 1988, and 2000 editions). Computer files for the data books are found in Haines (2005). In addition, we construct dummies for states and another dummy variable that takes value one if the associated county is a coastal county, as designated by the Strategic

Environmental Assessments Division of the NOAA (NOAA, 2006). Initial conditions of some socioeconomic variables in years 1960 and 1980 also serve as independent variables in the regression analysis. Summary statistics of the above variables are presented in Table 3.2.

3.4 Empirical results

3.4.1 Natural disasters and population growth

This section estimates the direct effects of natural disasters on population growth. To test the robustness of the result, we use several different specifications of the econometric model in the regression exercises. We also split our data sample into two periods: 1960-1980 and 1980-2000. Table 3.3 presents the results of the regressions. Each regression has a constant term and controls for initial population in the associated time period. The number of each type of natural disasters in a county is normalized by its land area, and then the measures of natural disasters in the regressions take the form of $\log\left(1+\frac{hits}{land\ area}\right)$.

Column 1 presents a simple version of regression results on county population growth during 1960-1980 as a function of initial population, weather, coastal and state dummies and measures of natural disasters. This paper focuses on the effects of natural disasters.[6] Results indicate that there are no significant effects of most types of natural disasters on population growth rate during this period, except that the estimated coefficients for F3 tornadoes and C3 hurricanes take positive signs and are statistically significant at 10%. Column 2 estimates the effects after additional socioeconomic characteristics of counties are taken into account. The additional variables are levels of educational attainment, age composition, share of labor employment in manufacture, and non-white population share, and a measure of income inequality within counties in the initial year. These variables capture most of socioeconomic indicators shown to be associated with population growth in regional literature (Beeson *et al*., 2001; Rappaport and Sachs, 2003; Higgins *et al*., 2006). It gives a result that no measures of natural disasters has any effect on population growth during 1960-1980.

We repeat the regressions for the 1980-2000 period. As seen from Columns 3 and 4 of Table 3.3, the picture for this period is quite similar as that for 1960-1980 in that most estimates for variables on disasters are statistically insignificant. Column 3 indicates that the most intensive hurricane, C5, has a negative effect, while the C3 hurricanes are found to contribute to population growth during 1980-2000. Earthquakes are negatively and statistically significantly related to population growth, which is also the case when the social and economic characteristics are controlled in Column 4. From this column it is also seen that there are no net effects of any other measures of natural disasters. The results provide some limited evidence supporting Skidmore and Toya's (2002) hypothesis that climatic disasters promote growth and geological disasters hinder growth. But it is not valid for the most intense climatic disasters, a negative coefficient for the C5 hurricanes suggests that it cause growth rate to decline.

Consistent with previous studies in the literature, growth rates are positively related to its initial levels of educational attainment and manufacturing share of employment and it is negatively related to the share of non-white population. These linkages are statistically significant over the two periods and quite robust among our specifications of regression models in Table 3.3. Moreover, some estimated coefficients are quite stable in each time period. For example, estimated coefficient for share of non-white population is about -0.004 for the 1960-1980 period, which suggests that a 1% increase in this share predicts that population growth rate decreases by 0.004%. As to age composition, the share of the population under 5 years old has a statistically significantly positive effect during 1960-1980, but it becomes insignificant in the 1980-2000 period. The share of the population 65 years old or older hinders population growth during 1980-2000. Table 3.3 also shows that the percent of the families that are poor (has income below $3,000 in 1959) has no effect on population growth during 1960-1980, but it (the percent of the households that has income below $10,000 in 1980) hinders growth during 1980-2000.

In each column of Table 3.3, the estimated coefficient for the spatial autoregressive parameter in growth rates is statistically significant at 1% level and takes a positive value, suggesting that growth rates across counties in the same metropolitan area are positively correlated.

3.4.2 Estimated marginal effects on population growth for individual states

While the severity or intensity of disaster is an important factor for predicting the effects of natural disasters, geographical conditions, individuals' preparation for disasters, and reconstruction and mitigation activities following disaster events, such as insurance claims and government disaster relief in affected areas also play critical roles in determining the effects. Studies report that states vary remarkably in such disaster assistance activities. For instance, states politically important might receive higher Federal Emergency Management Agency (FEMA) disaster expenditures than other states (Garrett and Sobel, 2003). To account for the effects of the variations among states, this paper conducts additional regressions which include all independent variables in Columns 2 and 4 in Table 3.3 and one more series of independent variables: natural disasters interacted with the state dummies.

Based on the results from the above regressions, it is interesting to compute marginal effects of natural disasters on population growth for each individual state in the two separate time periods, which may shed new light on the effects at a more disaggregate level. For example, if some counties in the State of Oklahoma are affected by F3 tornadoes, the marginal effect is equal to the sum, $\tilde{\beta}_{F_3} + \tilde{\beta}_{F_3 * OK}$.

Tables 3.4 reports the computed results about the effects of earthquakes and volcano eruptions for each individual state in the two periods. In most of the affected states, the occurrence of earthquakes is negatively correlated with population growth, but volcano eruption has no effect on growth. The effects of tornadoes are presented in Table 3.5. The estimated coefficients are statistically insignificant in a majority of the affected states during each time period. In some states that have a large percent of counties that has been hit by tornadoes such as the State of Oklahoma, there are no long-run effects of tornadoes on population growth. For those states that have significant effects, the signs are divergent. A few States did grow faster because of the occurrences of tornadoes; several others lost population during the past decades. Similar patterns are observed for the estimated effects of hurricanes, which are summarized in Table 3.6.

3.4.3 Natural disasters and socioeconomic characteristics

The regressions above confirm the findings by many previous studies in the regional literature that that initial levels of educational attainment, age and ethnic composition of population, industrial composition, and income inequality have significant effects on population growth. A natural question is: Did natural disasters contribute to changes in these demographic characteristics? If such linkages do exist, then natural disasters may have indirect effects on population growth through affecting the associated variables for socioeconomic characteristics. Related possible linkages between natural disasters and community and regional characteristics are discussed in the literatures of sociology, demography and economics, but past studies find different effects.

As to the effects on human capital accumulation, the literature of regional and urban economics provides much evidence supporting that locations with higher level of amenities have more immigration of better educated individuals (Cullen and Levitt, 1999; Kahn, 2000). Thus, linkages between natural disasters and human capital accumulation could exist because of amenity effects of natural disasters. Studies also document that locations with higher level of amenities attract the retirees, which implies a possible link between natural disasters and age composition of population. Also, it is found by studies in the literature of demography and natural disasters that fertility rate responses to natural disasters in the affected regions (Jones, 1987; Rogers *et al*., 2005). Natural disasters do not affect all social groups equally, and the poor people bear a disproportionate share of losses and the older are over-represented among the dead and the injured (Cochrane, 1975). Thus, disasters could deepen existing income inequalities and change age composition of population.

To test the possible linkages in our data, we perform several regressions of county characteristics in 1980 on the variables for natural disasters and other controls. The level, not growth rate, of the associated characteristics is used as dependent variable. Regression 1 of Table 3.7 examines the effects of natural disasters occurred during 1960-1980 on the share of population 25 years and older with 16 or more years of schooling in 1980. Results suggest that no measures of natural disasters have any effects on this measure of human capital stock in counties. Regression 2 presents the effects on the share of non-white population and a similar insignificance of measures for natural disasters is found. The insignificance of the effects of natural disasters on manufacturing share of employment in Columns 3 is unexpected because disasters, especially the most intense ones, could reduce the value of infrastructure and equipment significantly. The effects on the share of population 65 years and older are given by Column 4, which show that F3 tornadoes and C3 and C5 hurricanes have statistically significant effects, but the effects are weak in magnitude. Column 5 reports the regression on income inequality and finds no effect of any type of natural disasters.

It is seen from Table 3.7 that there are no evident effects of natural disasters on socioeconomic characteristics of counties. This implies that disasters have no indirect effects on population growth through those correlated variables. As a very rough test of the above findings, Column 1 of Table 3.8 presents a regression of growth rates during 1980-2000 on natural disasters occurred during 1980-2000 and those during 1960-1980 separately as well along with other control variables. All estimated coefficients for natural disasters occurred during 1960-1980 are found to be statistically insignificant. Thus, it confirms that there are no significant, indirect effects of natural disasters on population growth across counties in this period.

In summary, this paper finds that earthquakes have statistically significant effects on population growth; volcano eruption has no effect; the effects of tornadoes and hurricanes are insignificant in most of the affected states. These findings are consistent whether we use the above measures for disasters or either of the following two alternatives: 1) keeping the number of disaster events un-normalized and 2) adding up all significant events for each type of disasters.[7] In stead of choosing population growth rates as dependent variables, employment growth rates are used as dependent variables in the regressions and generate similar results.

3.4.4 The effects of forecasts about future occurrences of disasters

In addition to historical and current county characteristics, public forecasts about future occurrences of disasters in counties are also considered by individuals when making their location decisions.

We try to control and estimate the effects of forecasts about future occurrences of disasters, but we should overcome the difficulties of no available data for such forecasts. Assuming that what occurred exactly in a future time period is a good approximate of the forecasts, we perform a regression exercise of population growth between 1960 and 1980 on a series of independent variables which include measures for disasters occurred during 1980-2000 as well. Results presented in Column 2 of Table 3.8 suggest that “predictions” about future disaster events almost have no effects on county growth except that earthquakes have statistically significantly negative effects and the sign for the coefficient on F5 tornado is statistically significant at 10% percent. The results in the upper division of Column 2 confirms the findings by Column 2 in Table 3.3 and suggests that disasters have no statistically significant effects when the forecasts are controlled. Individuals may not consider the future events in such a long time as 20 years. In Columns 3, we use the measures for disasters occurred during a ten year period between 1980 and 1990 as measures for the forecasts and repeat the regression. Comparing Columns 2 and 3 of Table 3.8, we find that the patterns are very similar and only earthquakes have negative effects. The significance of a negative correlation between growth rates and future earthquakes is possibly a result of individuals' perception of significant disasters as a major threat to life. The statistical significance could also be meaningless if the actual number of earthquakes is not a good measure of forecasting. There are two possible explanations for the insignificance of future occurrences of other types of natural disasters. First, prior to a disaster many individuals believe the event will not happen to them, so they behave as if the likelihood of a disaster causing damage to their property is zero. Those people at risk do not even seek out information on probabilities in making their decisions on low probability, high consequence events (Kunreuther and Pauly, 2006; Magat *et al.*, 1987; Camerer and Kunreuther, 1989). Second, individuals believe that government will respond with disaster assistance following the disasters events in the future.

3.5 Concluding remarks

The paper estimates the direct and indirect effects of natural disasters on population growth in the U.S. counties during 1960-2000. It is found that, except earthquakes and most serious hurricanes, the risks of natural disasters have no statistically significant direct effects on population growth. We also estimate the effects of natural disasters on county socioeconomic and demographic characteristics, including human capital, age and ethnic composition of population, industrial composition, and income inequality which correlate with county population growth. The insignificance of those effects indicates that natural disasters have no indirect effects on population growth, either. Estimates from the spatial econometric models employed in this paper also confirm that growth rates in counties within a metropolitan area are positively correlated. Our results differ substantially from those in some previous studies which use country-level data and find significant effects of natural disasters on economic growth.

We also computed the direct direct effects of natural disasters on population growth at the State level. Results show that the effects of tornadoes and hurricanes (except most serious hurricanes) are statistically insignificant in a majority of the affected states. In those having statistically significant impacts, disasters contribute to population growth in some states, but they hinder growth in some others. It is interesting to explain the empirical findings. However, data collected in this paper could not uncover the sources, which is left for future research.

3.6 Endnotes

[1] The instruments used in this paper are $\left(X, WX, W^2X, MX, MWX, MW^2X\right)$ as recommended by Kelejian and Prucha (2007).

[2] Changes in county boundaries are documented by Bureau of Census. For more information, see http://www.census.gov/geo/www/tiger/ctychng.html.

[3] The website is http://www.ngdc.noaa.gov/nndc/struts/form?t=101650&s=1&d=1.

[4] It is available online at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms.

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[5] NOAA Coastal Services Center identifies coastal counties which are affected by hurricanes from 1900 through 2000; details are available online at http://maps.csc.noaa.gov/hurricanes/pop.jsp. In a reply to the author's query, Edward Rappaport at NOAA noted in an email that "we're unaware of any study assessing the meteorological impact (e.g., category) for inland counties."

[6] It is noted that the regression results confirm the well-known facts that counties with nice weather and western counties attract more people in the past decades.

[7] Regression results are available upon request from the author.

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Table 3.1: Number of counties/states afflicted by natural disasters

Disaster Type	Time Period		
	1960-1980	1980-2000	1960-2000
Earthquake	8/4	25/5	31/7
Hurricane	71/11	96/12	111/12
C3	65/11	90/12	107/12
C4	15/2	4/2	18/3
C5	8/2	3/1	11/2
Tornado	1053/41	833/36	1449/43
F3	849/41	674/35	1231/43
F4	360/29	270/28	580/30
F5	57/13	20/7	74/15
Volcanic Eruption	0/0	4/1	4/1

Table 3.2: Summary statistics of the variables

	MIN	MAX	MEAN	STD
Log(population 1980)-log(population 1960)	-0.910	1.977	0.174	0.296
Log(population 2000)-log(population 1980)	-0.602	1.944	0.125	0.255
Non-white population share (%), 1960	0	84.100	10.673	16.447
Population under 5 years (%), 1960	5.600	20.400	11.131	1.760
Population 65+ years (%), 1960	1.000	24.900	10.632	3.296
% persons 25+ w 12+ yrs schooling, 1960	0	80.400	34.615	11.065
Manufacturing share of employment (%), 1960	0	60.986	18.921	12.923
1959 family income <$3000 (1960), (%)	0	80.800	35.558	16.183
Non-white population share (%), 1980	0	93.950	11.514	14.977
Population under 5 years (%), 1980	0	16.575	7.690	1.343
Population 65+ years (%), 1980	0.814	33.963	13.281	4.079
Manufacturing share of employment (%), 1980	0	61.546	20.919	12.141
% persons 25+ w 16+ yrs schooling, 1980	25.100	95.300	59.226	12.304
% households w/ income <$10,000, 1980	8.955	67.134	36.053	9.305
Volcano eruption, 1980	0(0)	1(0.953)	0.001(0.001)	0.036(0.023)
Earthquake, 1960-1980	0(0)	1(3.774)	0.003(0.005)	0.051(0.088)
1980-2000	0(0)	5(0.617)	0.013(0.001)	0.181(0.022)
F3 Tornado, 1960-1980	0(0)	14(3.034)	0.402(0.315)	0.797(0.553)
1980-2000	0(0)	6(4.615)	0.296(0.241)	0.647(0.493)
F4 Tornado, 1960-1980	0(0)	4(3.051)	0.148(0.135)	0.448(0.396)
1980-2000	0(0)	5(2.299)	0.106(0.093)	0.377(0.317)
F5 Tornado, 1960-1980	0(0)	2(2.525)	0.021(0.020)	0.158(0.154)
1980-2000	0(0)	2(1.550)	0.008(0.006)	0.102(0.076)
C3 Hurricane, 1960-1980	0(0)	3(2.097)	0.028(0.024)	0.208(0.176)
1980-2000	0(0)	2(3.104)	0.032(0.036)	0.190(0.223)
C4 Hurricane, 1960-1980	0(0)	1(1.520)	0.005(0.004)	0.070(0.059)
1980-2000	0(0)	1(0.801)	0.001(0.001)	0.036(0.024)
C5 Hurricane, 1960-1980	0(0)	1(1.796)	0.003(0.003)	0.051(0.055)
1980-2000	0(0)	1(0.659)	0.001(0.001)	0.031(0.018)
Mean Temperature for January (1941-70)	1.1	67.2	32.893	12.068
Mean Temperature for July (1941-70)	55.5	93.7	75.863	5.355
Coastal (dummy)	0	1	0.2064	0.405

Note: Summary statistics for $\log\left(1+\frac{hits}{land\ area}\right)$ are reported in parentheses for the associated disaster; land area is in 1,000 km^2.

Table 3.3: The effects of natural disasters on population growth

Independent Variables	Dependent Variable: log(Population 1980)-log(Pop 196		Dependent Variable: log(Population 2000)-log(Pop 198	
	(1)	(2)	(3)	(4)
Earthquake	0.033	0.039	-0.130***	-0.099*
	(0.266)	(0.252)	(0.035)	(0.051)
Volcano			0.163	0.112
			(0.117)	(0.131)
Tornado, F3	0.013*	0.008	-0.006	-0.001
	(0.008)	(0.007)	(0.007)	(0.006)
F4	-0.003	-0.004	-0.001	-0.007
	(0.011)	(0.010)	(0.010)	(0.008)
F5	0.016	0.013	0.039	0.010
	(0.025)	(0.020)	(0.040)	(0.029)
Hurricane, C3	0.074*	0.052	0.042*	0.024
	(0.044)	(0.038)	(0.022)	(0.020)
C4	0.076	0.041	0.226	0.198
	(0.135)	(0.137)	(0.279)	(0.253)
C5	-0.093	-0.085	-0.552***	-0.625***
	(0.206)	(0.156)	(0.174)	(0.219)
Education (%)		0.007***		0.003***
		(0.001)		(0.001)
Non-white population		-0.004***		-0.003***
(%)		(0.001)		(0.000)
Manufacturing share of		0.003***		0.001*
Employment (%)		(0.001)		(0.001)
Population under 5 years		0.017**		-0.008
(%)		(0.006)		(0.006)
Population 65+ years old		0.003		-0.012***
(%)		(0.004)		(0.002)
Income inequality		0.000		-0.002**
(%)		(0.001)		(0.001)
Spatial AR parameters:				
λ	0.449***	0.357***	0.411***	0.300***
	(0.045)	(0.043)	(0.049)	(0.043)
ρ	0.441***	0.456***	0.470***	0.483***
	(0.026)	(0.025)	(0.027)	(0.025)

Note: 1. Standard errors in parentheses. ***, **, * denote significant at 1%, 5%, and 10%, respectively.
2. All regressions control for initial population, weather, state and coastal dummies and a constant.

Table 3.4: Estimated coefficients on natural disasters in affected States: Earthquakes and volcano eruptions

STATE	1960-1980	1980-2000	
	earthquake	earthquake	volcano eruption
CA	0.039	-0.098*	
	(0.252)	(0.050)	
ID	-0.495***	-0.043	
	(0.077)	(0.415)	
OR		-0.253**	
		(0.105)	
UT	0.367***		
	(0.119)		
WA	-1.063***	-0.232**	0.114
	(0.261)	(0.110)	(0.128)
WY		-0.369	
		(0.636)	

Note: Standard errors in parentheses. ***, **,* denote significant at 1%, 5%, and 10%, respectively.

Table 3.5: Estimated coefficients on natural disasters in affected States: Tornadoes

STATE	1960-1980			1980-2000		
	F3	F4	F5	F3	F4	F5
AL	0.041	0.009	0.081**	-0.005	0.130***	-0.301
	(0.031)	(0.053)	(0.039)	(0.029)	(0.053)	(0.221)
AR	0.065	-0.094		0.024	-0.044	
	(0.041)	(0.058)		(0.028)	(0.038)	
AZ	0.009					
	(1.203)					
CA	0.641***	1.232***				
	(0.083)	(0.412)				
CO	-0.362*	-0.347		-0.316		
	(0.208)	(0.376)		(0.404)		
CT	-0.036*	-0.169***			-0.029	
	(0.018)	(0.032)			(0.018)	
DE	-0.112**					
	(0.047)					
FL	-0.106	-0.196		-0.141**		
	(0.131)	(0.138)		(0.071)		
GA	-0.050	0.032		0.026	0.088	
	(0.033)	(0.047)		(0.037)	(0.076)	
IA	0.021	-0.014	0.000	0.004	-0.019	
	(0.017)	(0.019)	(0.055)	(0.013)	(0.014)	
IL	0.028	0.086*		0.001	-0.030**	0.126*
	(0.020)	(0.044)		(0.015)	(0.014)	(0.074)
IN	0.030	-0.012	0.054**	-0.015	-0.013	
	(0.024)	(0.024)	(0.024)	(0.018)	(0.019)	
KS	0.030	-0.016	-0.060	0.022	-0.062**	0.050
	(0.031)	(0.031)	(0.096)	(0.019)	(0.030)	(0.066)
KY	0.042*	0.029	0.099	0.068**	0.037	
	(0.022)	(0.025)	(0.114)	(0.034)	(0.051)	
LA	-0.052	-0.308**	-0.065	-0.005	0.039	
	(0.036)	(0.122)	(0.069)	(0.019)	(0.024)	
MA	0.083	-0.211***		0.021	-0.271***	
	(0.095)	(0.080)		(0.134)	(0.079)	
MD	0.085			0.066	-0.167**	
	(0.094)			(0.083)	(0.078)	
MI	0.076	-0.030		-0.045		
	(0.054)	(0.040)		(0.032)		
MN	-0.058	-0.004	-0.032	-0.064***	-0.009	-0.045
	(0.047)	(0.064)	(0.156)	(0.021)	(0.026)	(0.046)
MO	0.008	-0.030		-0.004	-0.019	
	(0.033)	(0.039)		(0.030)	(0.069)	
MS	0.004	0.032	-0.064	0.003	-0.049*	
	(0.028)	(0.031)	(0.071)	(0.024)	(0.028)	
MT				0.098		
				(0.081)		
NC	0.002	-0.024		-0.025	-0.008	
	(0.029)	(0.032)		(0.019)	(0.028)	

(to be continued)

(*Table 3.5 continued*)

STATE	1960-1980			1980-2000		
	F3	F4	F5	F3	F4	F5
ND	-0.044	-0.374***		0.067	0.197**	
	(0.095)	(0.093)		(0.134)	(0.088)	
NE	-0.024	0.139	-0.002	0.025	0.030	
	(0.037)	(0.119)	(0.048)	(0.016)	(0.025)	
NH	0.227***					
	(0.076)					
NJ	0.059			0.166**		
	(0.041)			(0.070)		
NM	-1.157*					
	(0.639)					
NY	-0.022	0.074*		-0.065**	-0.011	
	(0.077)	(0.042)		(0.028)	(0.046)	
OH	-0.012	0.008	-0.029	-0.013	-0.010	-0.022
	(0.022)	(0.028)	(0.049)	(0.020)	(0.050)	(0.031)
OK	0.056	-0.070	0.022	-0.006	0.036	0.022
	(0.044)	(0.054)	(0.068)	(0.023)	(0.029)	(0.063)
OR	-0.513***					
	(0.088)					
PA	0.035			0.066	-0.056**	
	(0.056)			(0.053)	(0.023)	
SC	-0.005	0.044		-0.004	-0.047	
	(0.053)	(0.058)		(0.032)	(0.036)	
SD	-0.003	-0.034	-0.503**	0.083	-0.091**	
	(0.048)	(0.134)	(0.221)	(0.053)	(0.044)	
TN	0.002	-0.004		-0.048***	0.070*	
	(0.024)	(0.038)		(0.018)	(0.040)	
TX	0.025	-0.049	0.119	0.008	-0.101*	
	(0.035)	(0.050)	(0.095)	(0.028)	(0.059)	
UT				-0.794***		
				(0.259)		
VA	0.027			-0.001	0.216*	
	(0.042)			(0.035)	(0.117)	
WA	0.104					
	(0.244)					
WI	-0.033	0.012		-0.004	-0.040	0.025
	(0.032)	(0.056)		(0.026)	(0.033)	(0.039)
WV	0.066**			0.093***		
	(0.033)			(0.020)		
WY	-0.348			-0.222		
	(0.242)			(0.160)		

Note: Standard errors in parentheses. ***, **, * denote significant at 1%, 5%, and 10%, respectively.

Table 3.6: Estimated coefficients on natural disasters in affected States: Hurricanes

STATE	1960-1980			1980-2000		
	C3	C4	C5	C3	C4	C5
AL	-0.003			0.192		
	(0.314)			(0.468)		
DE	-0.035			-0.723***		
	(0.036)			(0.108)		
FL	0.084	0.020		-0.148*	1.135***	
	(0.176)	(0.720)		(0.079)	(0.142)	
LA	0.143**		-0.219	-0.092		-0.451**
	(0.070)		(0.175)	(0.061)		(0.184)
MD	0.155***			0.118		
	(0.051)			(0.078)		
MS	-1.052***		1.246***	-0.091		
	(0.229)		(0.362)	(0.174)		
NC	0.007			0.043		
	(0.033)			(0.057)		
NJ	0.111			0.020		
	(0.154)			(0.024)		
NY	1.011***			-0.159***		
	(0.141)			(0.026)		
SC				0.715***	-0.118	
				(0.215)	(0.226)	
TX	-0.172	0.201		-0.046		
	(0.135)	(0.157)		(0.085)		
VA	0.103			0.083***		
	(0.133)			(0.028)		

Note: Standard errors in parentheses. ***, **,* denote significant at 1%, 5%, and 10%, respectively.

Table 3.7: The effects of natural disasters on socioeconomic characteristics in 1980

Independent Variables	% persons 25+ w 16+ yrs schooling	Non-white population share	Manufacturing share of employment	% Population 65 yrs and older	% households w/ income <$10,000
	(1)	(2)	(3)	(4)	(5)
Earthquake	1.127	1.581	2.240	0.075	3.136
	(2.528)	(4.492)	(3.276)	(1.541)	(3.783)
Tornado, F3	-0.068	-0.223	0.222	0.139**	-0.260
	(0.130)	(0.138)	(0.168)	(0.067)	(0.162)
F4	-0.098	-0.030	0.301	0.037	-0.170
	(0.185)	(0.145)	(0.243)	(0.093)	(0.230)
F5	0.058	-0.053	-0.306	-0.191	0.109
	(0.331)	(0.351)	(0.572)	(0.200)	(0.440)
Hurricane, C3	0.184	-0.915	-0.812	0.589**	0.411
	(0.555)	(0.596)	(0.594)	(0.263)	(0.555)
C4	1.707	-1.316	1.283	0.130	-2.028
	(1.860)	(1.673)	(1.635)	(0.845)	(1.367)
C5	0.095	5.698	0.831	-0.814	1.464
	(1.720)	(3.984)	(1.017)	(0.706)	(3.112)
Persons 25+ w/12+ yrs	0.663***	-0.035	-0.061***	0.000	-0.077***
schooling, 1960, (%)	(0.028)	(0.027)	(0.018)	(0.011)	(0.025)
Non-White share, 1960,	-0.008	0.889***	-0.006	-0.001	0.078***
(%)	(0.012)	(0.018)	(0.013)	(0.006)	(0.011)
Manufacturing share,	-0.060***	-0.072***	0.671***	0.004	-0.044***
1960, (%)	(0.013)	(0.013)	(0.015)	(0.006)	(0.014)
Population under 5 yrs,	-0.268**	-0.061	0.338***	-0.172***	-0.644***
1960, (%)	(0.107)	(0.141)	(0.099)	(0.058)	(0.110)
Population 65+,	0.047	-0.445***	0.248***	0.833***	-0.060
1960, (%)	(0.060)	(0.075)	(0.058)	(0.039)	(0.064)
1959 family income <$3000 (1960), (%)	-0.146***	0.013	0.107***	0.006	0.326***
	(0.024)	(0.023)	(0.016)	(0.010)	(0.022)
Spatial AR parameters:					
λ	0.050***	-0.122***	-0.077***	-0.092***	-0.104***
	(0.004)	(0.028)	(0.011)	(0.013)	(0.010)
ρ	0.415***	0.484***	0.552***	0.473***	0.438***
	(0.025)	(0.035)	(0.020)	(0.024)	(0.022)

Note: 1. Standard errors in parentheses. ***, **,* denote significant at 1%, 5%, and 10%, respectively.
2. All regressions control for population, land area, weather, state and coastal dummies, and a constant.

Table 3.8: The effects of "future" natural disasters on population growth

Independent Variables	Dependent Variable log(Population 2000)-log(Pop 1980)	log(Population1980)-log(Pop 1960)	log(Population1980)-log(Pop 1960)
	(1)	(2)	(3)
Disasters in 1960-1980			
Earthquake	0.008	0.031	0.031
	(0.144)	(0.243)	(0.247)
Tornado, F3	0.003	0.009	0.010
	(0.006)	(0.007)	(0.007)
F4	0.004	-0.004	-0.005
	(0.009)	(0.010)	(0.010)
F5	-0.021	-0.002	0.000
	(0.020)	(0.020)	(0.020)
Hurricane, C3	-0.012	0.044	0.045
	(0.026)	(0.040)	(0.038)
C4	-0.007	0.069	0.006
	(0.087)	(0.119)	(0.124)
C5	-0.077	-0.107	-0.108
	(0.080)	(0.126)	(0.127)
Disasters in 1980-2000			
Earthquake	-0.130***	-0.145***	-0.123**
	(0.035)	(0.051)	(0.056)
Volcano eruption	0.161	0.205	0.203
	(0.116)	(0.129)	(0.127)
Tornado, F3	-0.006	-0.006	-0.015
	(0.007)	(0.008)	(0.012)
F4	-0.002	-0.001	0.005
	(0.010)	(0.011)	(0.016)
F5	0.040	0.107*	0.023
	(0.039)	(0.055)	(0.056)
Hurricane, C3	0.048**	0.015	0.020
	(0.022)	(0.030)	(0.031)
C4	0.225	0.059	-0.192
	(0.279)	(0.319)	(0.243)
C5	-0.539***	-0.602	
	(0.197)	(0.514)	
Spatial AR parameters:			
λ	0.415***	0.385***	0.389***
	(0.048)	(0.040)	(0.039)
ρ	0.468***	0.426***	0.429***
	(0.027)	(0.026)	(0.026)
Controlling for economics and social characteristics	No	Yes	Yes

Note: 1. Standard errors in parentheses. ***, **, * denote significant at 1%, 5%, and 10%, respectively.
2. All regressions control for initial population, weather, state and coastal dummies and a constant.
3. Column 3 uses "Disasters in 1980-1990" instead of "Disasters in 1980-2000". No C5 hurricanes in this period.

CHAPTER 4

4 LAND DEVELOPMENT REGULATION IN A NATURAL DISASTER-PRONE AREA: THE ROLES OF BUILDING CODES

4.1 Introduction

High consequences caused by recent natural disasters such as Hurricane Katrina raised again many public concerns about insufficient human preparation for disasters. One lesson learnt is that implementing mandatory building codes is one of the important approaches to preparation.[1]

The potential benefits of building codes are evident by looking at and comparing some raw facts. Earthquakes with similar strength in California killed quite fewer people than that in some developing countries because California has strict building codes in seismic zones. Florida may have experienced greater loss from hurricanes if there were no strict building codes which require structures built under it are the ones left standing after a 120 MPH wind rips through.

Through establishing structural standards of properties built in the disaster-prone area, building codes reduce the size of the loss from a disaster and/or reduces the probability of occurrences of the disaster. These two effects can be termed as self-insurance and self-protection, respectively.[2] For example, earthquake codes in the seismic zone require builders to use techniques that allow structures to flex without breaking when the ground shakes, thus reduce the loss from earthquake. Some flood codes reduce the building's probability of being flooded in a given year by prohibiting development in areas below a certain elevation;[3] some other flood codes can reduce the loss from flooding by requiring builders to use waterproof building materials.

Though the potential benefits are widely realized and observed, the protection level and stringency of building codes are criticized by many authors who argue that they are arbitrary,[4] not justified, and too costly (Green *et al*., 2000; Listokin and Hattis, 2005; Stein and Tomasello, 2004). In a general sense, the purpose of building codes is to protect the housing consumer and the society at large. There are many reasons for designing and implementing mandatory (but not voluntary) building codes, among which a major one is that the individuals may not have sufficient knowledge to check the safety and other conditions of their houses.[5] Beyond general-purpose codes, those designed for the properties in the disaster-prone regions contain special requirements about preparation for disaster. Clearly, the costs and potential benefits of building codes would affect land market (e.g. rent payment) through competition for locations within the area and thus alter the spatial pattern of land development, which in turn affects the design of optimal building codes. Then optimal building codes for those regions should account for the effects of relevant socioeconomic conditions and their own effects on land market.

In this paper, we construct a simple urban economics model to derive the optimal level of expenditure on self-insurance and self-protection set by government when implementing mandatory building codes for land development in a disaster-prone region. We derive a number of comparative statics to describe the impacts of variables such as wage, population, commuting cost, land area share of the risky region, and technological improvements in self-protection and self-insurance on designing optimal codes. We find that the properties of preferences and the production functions for self-insurance and self-protection determine the signs and significance of the effects of changes in the above and some other exogenous variables on the choices of optimal building codes.

This remainder of the paper is organized as follows. Section 4.2 describes the economy of a city that the paper focuses on. Decisions on self-insurance, self-protection, and joint determination are discussed in Section 4.3. The final section concludes.

4.2 Model

The spatial structure of a city with N individuals is described by Figure 4.1, which is quite similar to that formulated by Frame (2001). Point O is the exogenous central business district (CBD) and land development takes place around the CBD. The region that surrounded by two dashed rays starting at point O with angle θ in Figure 1 represents the risky region of the community. Then θ is a measure of the land area share of the risky region in the city.

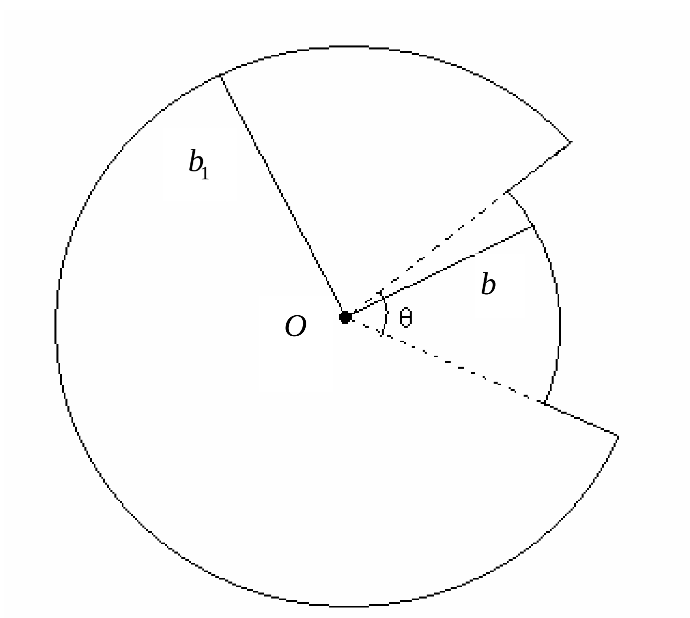

Figure 4.1: Land development in the city

To keep the analysis simple we assume only two states of nature—natural disaster or no natural disaster with endowed probabilities p_0 and $1-p_0$ respectively. The reservation price of one unit of land is r_0 and it is independent of location and the severity of natural disasters. Without loss of generality, we further assume that $r_0 = 0$.

Individuals are identical with regard to tastes. Each of them works in the CBD and receives the same level of wage, w, and inhabits only one unit of land in the community. Individuals are free to bid for residential land.[6] An individual derives utility from a composite private good, g, and her preference is represented by a monotonically increasing function $u(g)$. For people living in the risky region, the ex post consumption of the composite commodity is uncertain due to the financial costs associated with the loss and subsequent replacement of housing contents and structure, which are included as part of the composite good. For each unit of land space, the endowed loss from disaster is represented by l.

If the outer boundary of development in the risky region is b in equilibrium, then the outer boundary of the risk-free region, b_1, is equal to $\sqrt{\frac{2N-\theta b^2}{2\pi-\theta}}$ given population N and lot sizes of one. Land rent at locations on the outer boundaries in both the risk-free and the risky region are equal to the reservation price, 0. Denote k as commuting cost (per unit of distance) of a round trip. Total land rents within the city is then given by

$$k\theta\int_0^b (b-v)vdv + k(2\pi-\theta)\int_0^{b_1}(b_1-v)vdv,$$

where two parts are rents collected from the risky region and the risk-free region, respectively.[7] Assume that total land rents are collected by the local government and are distributed to residents in the city on an equal basis, then each individual receives the amount that equals to $\frac{1}{N}k(\theta\int_0^b (b-v)vdv + (2\pi-\theta)\int_0^{b_1}(b_1-v)vdv) \equiv R$.

Define that $y \equiv R - kb$ and $y_1 \equiv R - kb_1$, where kb is total expenditure on land rent and commuting cost by an individual in the risky region; and kb_1 is the amount by an individual in the risk-free region. We interpret y and y_1 as net profits received by an individual in the risky region and that in the risk-free region from the land market, respectively. Therefore, the amount of the composite private good consumed by an representative individual in the risk-free region is equal to $w + y_1$; and the amount consumed by an individual in the risky region is described later, which depends on the state of nature and the building codes that implemented. For later use, we note that $y > y_1$, $y^b \equiv \frac{\partial y}{\partial b} = k\theta b(\frac{1}{2N}(b-b_1)-1) < 0$ and $y_1^b \equiv \frac{\partial y_1}{\partial b} = k\theta b(\frac{1}{2N}(b-b_1) + \frac{1}{2\pi-\theta}\frac{1}{b_1}) > 0$, given that the outer boundary in the risky region is closer to the CBD, $b < b_1$. Note also that $y^\theta \equiv \frac{\partial y}{\partial \theta} < 0$, $y_1^\theta \equiv \frac{\partial y_1}{\partial \theta} < 0$, $y^N \equiv \frac{\partial y}{\partial N} < 0$, $y_1^N \equiv \frac{\partial y_1}{\partial N} < 0$, and $y_1^k \equiv \frac{\partial y_1}{\partial k} < 0$. But the sign of $y^k \equiv \frac{\partial y}{\partial k}$ depends on the differences between the boundaries in the two regions, b_1 and b.

The exogenous condition of the economy can be described by a set of exogenous variables $(N, w, k, \theta, l, p_0)$ and parameters measuring productivity levels of self-insurance and self-protection which are defined later. Endogenous variables are (b, b_1, y, y_1) and the respective levels of self-insurance and self-protection chosen by the city government.

4.3 Self-insurance and self-protection

For some types of natural disasters such as flood, implementing building codes can reduce both the probability and loss. However, building codes can play only one role as a means for preparing for some other types of disasters. For instance, it is not technically easy to reduce the probability of earthquake. A major goal of earthquake codes is to reduce the loss. This section distinguishes the role of building codes as self-insurance and that as self-insurance and solves the model for the respective optimal level of expenditure on each of them. It also considers the impact that those exogenous socioeconomic characteristics of the city have on the optimum and equilibrium. Joint determination on self-insurance and self-protection is also analyzed.

4.3.1 Self-insurance

We start the analysis with determining optimal expenditure on self-insurance required by the mandatory building codes, which reduces the loss from disaster. Within the city, land rents adjust so that individuals cannot increase welfare by moving in the community, which means that the expected utility level for a representative individual who lives in the risky region is equal to the utility level achieved by one in the risk-free region of the city. That is to say, given any expenditure on self-insurance required by building codes, s, individuals within the city will be distributed across the locations so that

$$p_0 u(w + y - s - f(s,l,\alpha)) + (1 - p_0)u(w + y - s) = u(w + y_1), \qquad (1)$$

where $f(s,l,\alpha)$ is the amount of loss from disaster given the severity, l; the expenditure on self-insurance, s; and the productivity level of self-insurance, α. The productivity level may be affected by engineering technology, innovations in building materials industry, and other relevant factors. Assume that $f(s,l,\alpha)$ has the properties that $f^s \equiv \frac{\partial f(s,l,\alpha)}{\partial s} < 0$, $f^{ss} \equiv \frac{\partial^2 f(s,l,\alpha)}{\partial s^2} > 0$, $f^l \equiv \frac{\partial f(s,l,\alpha)}{\partial l} > 0$, and $0 \le f(s,l,\alpha) \le l$ for any $s \ge 0$. The effects of productivity level of self-insurance are described by the assumptions that $f^\alpha \equiv \frac{\partial f(s,l,\alpha)}{\partial \alpha} < 0$ and $f^{s\alpha} \equiv \frac{\partial f^s}{\partial \alpha} < 0$. The partial derivative $f^{s\alpha} < 0$ states that an increase in productivity level increases the absolute value of f^s for a given s .

The government chooses the level of s to maximize the expected utility or utility for an individual in the city, which are represented by two sides in equation (1). Clearly, the optimal level of s is one at which makes b , the outer boundary of development in the risky region, achieve the highest possible level because $\frac{\partial u(w+y_1)}{\partial b} = u'(w+y_1)\frac{\partial y_1}{\partial b} > 0$. Formally, the maximization problem can be written as

$$\text{(MP1)} \quad \max_s b \quad \textit{subject to } (1) .$$

We differentiate both sides of equation (1) with respect to s and then solve it for $\frac{\partial b}{\partial s}$. The value of s that maximizes equation (1), s^*, satisfies the first-order condition,

$$-\frac{p_0(f^s+1)u_d' + (1-p_0)u_e'}{u_1' y_1^b - p_0 u_d' y^b - (1-p_0)u_e' y^b} = 0 , \tag{2}$$

where subscript d denotes the state with disaster; and e denotes the state without disaster. Superscripts denote derivatives or partial derivatives. In (2) and thereafter, u_d and u_e are the utility levels achieved by an individual in the risky region in states d and e , respectively; u_1 denotes the utility level for an individual in the risk-free region. Obviously, $u_d < u_1 < u_e$ and $u_d^{'} > u_1^{'} > u_e^{'}$ in equilibrium if the utility function is strictly concave. Condition (2) implies that a necessary condition for a positive amount of self-insurance is $f^s + 1 < 0$. We also note that the denominator in condition (2) is positive, i.e., $u_1^{'} y_1^b - p_0 u_d^{'} y^b - (1 - p_0) u_e^{'} y^b > 0$.

The second-order condition requires that

$$\frac{p_0 (f^s + 1)^2 u_d^{''} - p_0 f^{ss} u_d^{'} + (1 - p_0) u_e^{''}}{u_1^{'} y_1^b - p_0 u_d^{'} y^b - (1 - p_0) u_e^{'} y^b} < 0, \tag{3}$$

which would be satisfied if $u^{''} \le 0$.

The solution to the maximization problem (MP1) represents a mapping from $(N, w, k, \theta, l, p_0, \alpha)$ to s which can be written as

$$s^* = s(N, w, k, \theta, l, p_0, \alpha).$$

Given this level of self-insurance chosen by the local government in the building codes, the equilibrium outer boundary in the risky region can be written as

$$b^* = b(N, w, k, \theta, l, p_0, \alpha),$$

which is achieved through competition for locations in land market.

The effect of a change in the productivity level of self-insurance

As the productivity level of self-insurance increases, optimal building codes should response with a change in the requirement for self-protection. Equilibrium outer boundary in the risky region will also change as a result. Totally differentiating equation (1) with respect to α and combining with condition (2) yields

$$\frac{\partial b^*}{\partial \alpha} = \frac{p_0 f^{\alpha} u_d^{'}}{p_0 u_d^{'} y^b + (1 - p_0) u_e^{'} y^b - u_1^{'} y_1^b}. \tag{4}$$

Since $y^b < 0$, $y_1^b > 0$ and $f^\alpha < 0$, equation (4) implies that $\frac{\partial b^*}{\partial \alpha} > 0$. It indicates that more land in the risky region would be developed and the outer boundary in this region expands if the productivity level of self-insurance increases.

To find the effects of technological improvement in self-insurance on the optimal expenditure on self-insurance required, we totally differentiate the first-order condition (2) with respect to α and obtain

$$\frac{\partial s^*}{\partial \alpha} = \frac{[p_0(f^s+1)u_d'' + (1-p_0)u_e'']y^b \frac{\partial b^*}{\partial \alpha} + p_0 f^{s\alpha} u_d' - p_0(f^s+1) f^\alpha u_d''}{p_0(f^s+1)^2 u_d'' - p_0 f^{ss} u_d' + (1-p_0)u_e''}. \quad (5)$$

The sign of $\frac{\partial s^*}{\partial \alpha}$ is ambiguous, and it depends on preferences and the production function for self-insurance.[8] If the absolute value of $f^{s\alpha}$ is large enough, then $\frac{\partial s^*}{\partial \alpha} > 0$, which suggests that technological improvement would increases optimal self-insurance and then decrease the equilibrium loss from disaster if other conditions were the same.

Equation (5) also indicates how decision within this framework of urban economics where individuals compete for locations differ from the decision made by individuals without considering the effects of land market in the model.[9] The difference is mainly shown by the term $[p_0(f^s+1)u_d'' + (1-p_0)u_e'']y^b \frac{\partial b^*}{\partial \alpha}$ in equation (5). The source is that a change in productivity level of self-insurance influences net profit received by all individuals from land market and then impacts consumption which further requires responses in the design of optimal expenditure on self-insurance.

The effect of the productivity growth on equilibrium level of welfare in the city is given by $\frac{\partial u^*}{\partial \alpha} = u_1^{'} y_1^{b} \frac{\partial b^*}{\partial \alpha} > 0$ for people living in the risk-free region. The source is that an individual receives more net profit from the land market as more land in the risky region are developed. For those living in the risky region, the expected level of utility also increases. The amount of the composite private good consumed by an individual in the risky in each of the two states—disaster and without disaster—may increase or decrease. The net changes depend on the preference and production function for the self-insurance.

These positive effects of productivity change on land development in the risky region and community welfare are independent of its net impacts on optimal building codes. Whether it requires a higher or lower expenditure on self-protection in new equilibrium, the increase in productivity would reduces the loss from disaster for each household if it occurs. It is seen that the benefit brought by technological improvement is eventually shared by all residents in both the risky and the risk-free regions of the city through changing land rent payments and the pattern of land use.

The effect of changes in endowed probability of and loss from natural disaster

An increase in probability reduces land development in the risky region in equilibrium, $\frac{\partial b^*}{\partial p_0} < 0$, which is implied by totally differentiating equation (1) with respect to p_0 and then combining the result with (2):

$$\frac{\partial b^*}{\partial p_0} = \frac{u_e - u_d}{p_0 u_d^{'} y^b + (1 - p_0) u_e^{'} y^b - u_1^{'} y_1^b} . \qquad (6)$$

The effects of endowed probabilities of natural disaster on optimal expenditure on self-insurance can be found by totally differentiating (2) with respect to p_0 and solving it for

$$\frac{\partial s^*}{\partial p_0} = \frac{[p_0(f^s+1)u_d''+(1-p_0)u_e'']y^b\frac{\partial b^*}{\partial p_0}+(f^s+1)u_d'-u_e'}{p_0(f^s+1)^2u_d''-p_0f^{ss}u_d'+(1-p_0)u_e''}. \quad (7)$$

Equation (7) indicates that the sign of $\frac{\partial s^*}{\partial p_0}$ depends on preferences and the production function for self-insurance. An interesting implication is that the city with lower endowed probability of disaster may choose more expenditure on self-insurance in optimality if $p_0(f^s+1)u_d''+(1-p_0)u_e''$ is negative and it is large enough in absolute value. Equation (7) in an urban economics context also differs from that of individual choice without land market in that the benefits of self-protection are shared by all residents, including those in the safe region, through adjustment in land rents. Without the effects from the land market, lower endowed probability of disaster requires less expenditure on self-insurance.

By similar reasoning and one more assumption that $\frac{\partial f^\alpha}{\partial l}=0$, we know that the effects of a change in endowed loss

$$\frac{\partial s^*}{\partial l} = \frac{[p_0(f^s+1)u_d''+(1-p_0)u_e'']y^b\frac{\partial b^*}{\partial l}-p_0(f^s+1)u_d''f^l}{p_0(f^s+1)^2u_d''-p_0f^{ss}u_d'+(1-p_0)u_e''}, \quad (8)$$

with $\frac{\partial b^*}{\partial l}<0$, which is suggested by

$$\frac{\partial b^*}{\partial l} = \frac{p_0f^lu_d'}{p_0u_d'y^b+(1-p_0)u_e'y^b-u_1'y_1^b}. \quad (9)$$

Substituting (9) into (8) gives that

$\frac{\partial s^*}{\partial l} = \frac{p_0 f^l [(f^s+1)u_d'' u_1' y_1^b + (1-p_0)(u_e'' u_d' - (f^s+1) u_e' u_d'') y^b] / p_0 u_d' y^b + (1-p_0) u_e' y^b - u_1' y_1^b + p_0 f^{sl} u_d'}{p_0 (f^s+1)^2 u_d'' - p_0 f^{ss} u_d' + (1-p_0) u_e''}$, which has a positive sign given one more assumption that $f^{sl} \leq 0$. It indicates that larger endowed loss from disaster would require more expenditure on self-insurance. The reason is that, an increase in loss from disaster, i.e., a decline in consumption in the state of disaster, would increase marginal utility of consumption in that state. The above analysis also suggests that both an increase in endowed probability of and in loss from natural disaster would reduce land development in the risky region and community welfare.

The effect of changes in exogenous socioeconomic variables of the city

Within a city, the requirement of building codes presents potential benefits for individuals in the risky region and then alters the spatial distribution of households, which, along with other variables such as wage, population, land area share of the risky region, and unit commuting cost, finally affects total net profits from the land market. These effects should be taken into account when designing the optimal building codes in a general equilibrium model.

Totally differentiating equation (1) with respect to w and combining with (2) yields

$(1 + y^b \frac{\partial b^*}{\partial w})(p_0 u_d' + (1-p_0) u_e') = (1 + y_1^b \frac{\partial b^*}{\partial w}) u_1'$ which implies that $1 + y^b \frac{\partial b^*}{\partial w} > 0$ [10] and

$$\frac{\partial b^*}{\partial w} = \frac{p_0 u_d' + (1-p_0) u_e' - u_1'}{u_1' y_1^b - p_0 u_d' y^b - (1-p_0) u_e' y^b}. \quad (10)$$

Equation (10) suggests that an increase in wage would increase or decrease land development in the risky region, and the net effect depends on preferences and production function for self-insurance.[11]

To find the effect of a change in exogenous income on the optimal expenditure on self-insurance, we differentiate the first-order condition (2) with respect to w and solve it for $\frac{\partial s^*}{\partial w}$:

$$\frac{\partial s^*}{\partial w} = \frac{[p_0 u_d''(f^s+1)+(1-p_0)u_e''](1+y^b \frac{\partial b^*}{\partial w})}{p_0 u_d''(f^s+1)^2 - p_0 u_d' f^{ss} + (1-p_0)u_e''} . \tag{11}$$

Thus, the sign of $\frac{\partial s^*}{\partial w}$ is the same as that of $-[p_0(f^s+1)u_d'' + (1-p_0)u_e'']$, which depends on preferences. Equation (11) also shows the effects of the competition for land on the optimal building codes. The total effect of an increase in wage would be amplified or reduced by changes in net profit received by individuals from the land market. If preferences and the production for self-insurance are such that $\frac{\partial b^*}{\partial w} < 0$ then the competition amplify the effect of wage increase. Otherwise, the effect is reduced.

By similar reasoning, the effects on optimal quantity of self-insurance of the changes in other key variables in the model such as population, land area share of the risky region, and unit commuting cost are found to depend on the sign of $p_0(f^s+1)u_d'' + (1-p_0)u_e''$, too. It is positive if the coefficient of absolute risk aversion, $ARA(g) \equiv -\frac{u''(g)}{u'(g)}$, is decreasing with respect to consumption g, because that $p_0(f^s+1)u_d' + (1-p_0)u_e' = 0$ from condition (2) and $g_d < g_e$.[12] The following lemma 1 summarizes the comparative-statics results about the effects of changes in exogenous socioeconomic variables of the city.

Lemma 1. If $\frac{\partial[ARA(g)]}{\partial g} < (=,>)0$, then $\frac{\partial s^*}{\partial w} > (=,<)0$, $\frac{\partial s^*}{\partial N} < (=,>)0$, and $\frac{\partial s^*}{\partial \theta} < (=,>)0$.

Proof: See Appendix A.

Lemma 1 implies that an increase in exogenous wage leads to a higher level of optimal expenditure on self-insurance if the coefficient of absolute risk aversion is decreasing in consumption. Both population and land area share of the risky region have opposite effects.

4.3.2 Self-protection

Self-protection reduces the probability of the state with disaster. Given the expenditure on self-protection, r, the probability is assumed to be $p = p(p_0, r, \beta)$, where the parameter β denotes the productivity level of self-protection. Assume further that $p^r \equiv \frac{\partial p}{\partial r} < 0$, $p^{rr} \equiv \frac{\partial p^r}{\partial r} > 0$, $p^\beta \equiv \frac{\partial p}{\partial \beta} < 0$, and $p^{r\beta} \equiv \frac{\partial p^r}{\partial \beta} < 0$.

Given r, the spatial distribution of individuals in the two regions of the city will be adjusted so that it always holds that the expected utility for an individual in the risky region is equal to the level of utility for one in the safe region:

$$p(p_0, r, \beta)u(w + y - r - l) + (1 - p(p_0, r, \beta))u(w + y - r) = u(w + y_1)\,. \tag{12}$$

The maximization problem for the local government becomes

$$\text{(MP2)} \quad \max_r b \quad \textit{subject to } (12)\,.$$

The optimal expenditure on self-protection, r^*, satisfies the first-order condition,

$$\frac{p^r(u_d - u_e) - pu_d^{'} - (1-p)u_e^{'}}{u_1^{'}y_1^b - pu_d^{'}y^b - (1-p)u_e^{'}y^b} = 0\,. \tag{13}$$

The second-order condition requires that

$$\frac{p^{rr}(u_d - u_e) - 2p^r(u_d^{'} - u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}{u_1^{'}y_1^b - pu_d^{'}y^b - (1-p)u_e^{'}y^b} < 0\,, \tag{14}$$

which would be satisfied if $p^{rr}(u_d - u_e) - 2p^r(u_d^{'} - u_e^{'}) + pu_d^{''} + (1-p)u_e^{''} < 0$. Different from the second-order condition (3) in analyzing self-insurance, condition (14) indicates that decreasing marginal utility of the composite good is neither a necessary nor a sufficient condition.

The solution to problem (MP2) represents a mapping from $(N, w, k, \theta, l, p_0, \beta)$ to r which may be written by

$$r^* = r(N, w, k, \theta, l, p_0, \beta) .$$

The outer boundary in the risky region is given by

$$b^* = b(N, w, k, \theta, l, p_0, \beta) .$$

As shown in Appendix B, advances in technology of self-protection would lead to more land development in the risky region of the city. But the effect on the optimal expenditure on self-protection is ambiguous:

$$\frac{\partial r^*}{\partial \beta} = -\frac{[p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}]y^b \frac{\partial b^*}{\partial \beta} - p^\beta(u_d^{'} - u_e^{'}) + p^{r\beta}(u_d - u_e)}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'} - u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}} . \tag{15}$$

The above comparative-statics result describes the effects of technological improvements in self-protection. The term $[p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}]y^b \frac{\partial b^*}{\partial \beta}$ shows why competition for location on the land market affects the optimal self-protection. Ignoring the indirect impacts from the land market, it always gives a positive sign for $\frac{\partial r^*}{\partial \beta}$. But it is not necessarily positive with the presence of the competition for location on the land market. Equation (15) suggests that the net effect of a change in the productivity level of self-protection depends on preferences and the production function for self-protection. Note that it is shown in Appendix B that $\frac{\partial b^*}{\partial \beta} > 0$. If $p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''} \le 0$, then $\frac{\partial r^*}{\partial \beta} > 0$ which implies that an increase in productivity level of self-protection requires more expenditure on self-protection required by optimal building codes under such circumstances. However, if $p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''} > 0$ and the value is large enough, then $\frac{\partial r^*}{\partial \beta} < 0$.

The effects of changes in endowed probability of and loss from natural disaster, wage, population, land area share of the risky region, and unit commuting cost are described by the associated derivatives in Appendix B, all of which are obtained by differentiating (12) and (13) with respect to respective variables. The effects on optimal demand for self-protection depend on preferences and the production function for self-protection. Specifically, the sign of $p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}$ determines the signs of the derivatives.

LEMMA 2. If $p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''} < (=,>) 0$,[13] then $\frac{\partial r^*}{\partial w} < (=,>) 0$, $\frac{\partial r^*}{\partial N} > (=,<) 0$, and $\frac{\partial r^*}{\partial \theta} > (=,<) 0$.

Proof: See Appendix B.

As in the analysis on self-insurance, the effect of a change in unit commuting cost also depends on the relative magnitude of the boundaries in the risky and the risk-free regions as well as preferences. As in the previous analysis on self-insurance, the total effects on changes in each variable of w, N, θ, and k are amplified or reduced by competition in the land market. Table 4.1 summarizes comparative-statics results that obtained from analyses in this and the previous section.

4.3.3 Self-insurance and self-protection: joint determination

Assume that building codes simultaneously control expenditures on both self-protection and self-insurance. Expected utility level and utility level of an individual in two regions of the city are given by two sides of the following (16), respectively,

$$p(p_0, r, \beta)u(w + y - r - s - f(s, l, \alpha)) + (1 - p(p_0, r, \beta))u(w + y - r - s) = u(w + y_1) \text{ .(16)}$$

The optimal self-insurance, s^*, and self-protection, r^*, solves the following maximization problem:

$$\text{(MP3)} \quad \max_{s,\, r} b \quad \textit{subject to } (16) .$$

The first-order conditions require that

$$-\frac{p(f^s + 1)u_d' + (1-p)u_e'}{u_1' y_1^b - p u_d' y^b - (1-p)u_e' y^b} = 0 , \tag{17}$$

$$\frac{p^r (u_d - u_e) - p u_d' - (1-p)u_e'}{u_1' y_1^b - p u_d' y^b - (1-p)u_e' y^b} = 0 . \tag{18}$$

The second-order conditions require that

$$\frac{p(f^s + 1)^2 u_d'' - p f^{ss} u_d' + (1-p)u_e''}{u_1' y_1^b - p u_d' y^b - (1-p)u_e' y^b} < 0 , \tag{19}$$

$$\frac{p^{rr} (u_d - u_e) - 2 p^r (u_d' - u_e') + p u_d'' + (1-p)u_e''}{u_1' y_1^b - p u_d' y^b - (1-p)u_e' y^b} < 0 , \tag{20}$$

and

$$\Delta = \frac{\partial^2 b}{\partial s^2}\frac{\partial^2 b}{\partial r^2} - \left(\frac{\partial^2 b}{\partial s \partial r}\right)^2 > 0 , \tag{21}$$

where $\frac{\partial^2 b}{\partial s \partial r} = \frac{(p u_d'' - p^r u_d')(f^s + 1) + p^r u_e' + (1-p)u_e''}{u_1' y_1^b - p u_d' y^b - (1-p)u_e' y^b}$, which is negative if u_d'' is small in absolute value relative to the other terms in this expression.

The solution to the maximization problem (MP3) represents a mapping from $(N, w, k, \theta, l, p_0, \alpha, \beta)$ to s and one from it to r which may be represented by

$$s^* = s(N, w, k, \theta, l, p_0, \alpha, \beta) ,$$

and

$$r^* = r(N, w, k, \theta, l, p_0, \alpha, \beta) .$$

Given this solution, the equilibrium outer boundary in the risky region can be written as

$$b^* = b(N, w, k, \theta, l, p_0, \alpha, \beta) .$$

Using equations (16)-(18), we can easily find that $\frac{\partial b^*}{\partial \alpha} > 0$ and $\frac{\partial b^*}{\partial \beta} > 0$ which suggest that the productivity level of self-insurance and/or the productivity level of self-production have positive effects on outer boundary in the risky region when both of them are available. Appendix C presents a number of comparative statics about the effects of changes in exogenous variables on optimal expenditure on self-insurance and self-protection when both of them are available.

If $u^{''}$ is small enough in absolute value such that $pu_d^{''} - p^r u_d^{'} \geq 0$[14] and $f^{s\alpha}$ is large enough[15] in absolute value, then we have that $\frac{\partial s^*}{\partial \alpha} > 0$ and $\frac{\partial r^*}{\partial \alpha} < 0$,[16] which indicates that an increase in the productivity level of self-insurance increases the optimal expenditure on self-insurance and reduces that on self-protection.

Using the two assumptions made in previous sections that $u^{''}$ is small enough in absolute value such that $pu_d^{''} - p^r u_d^{'} \geq 0$ and $p^{r\beta}$ is large enough in absolute value, we can determine that $\frac{\partial r^*}{\partial \beta} > 0$ and $\frac{\partial s^*}{\partial \beta} < 0$ which suggest that an increase in the productivity of self-protection increases the optimal expenditure on self-protection and decreases that on self-insurance. Hence, self-insurance and self-protection can be seen as substitutes.

The effects of changes in variables such as wage, population, land area share of the risky region, and unit commuting cost are easily derived when both self-insurance and self-protection are available. The effects depend on preferences and production functions for self-insurance and self-protection. We have the following lemma.

Lemma 3. If $\frac{\partial[ARA(g)]}{\partial g} < (=,>)0$ and $p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''} < (=,>)0$, then $\frac{\partial s^*}{\partial w} > (=,<)0$ and $\frac{\partial r^*}{\partial w} < (=,>)0$, $\frac{\partial s^*}{\partial N} < (=,>)0$ and $\frac{\partial r^*}{\partial N} > (=,<)0$, and $\frac{\partial s^*}{\partial \theta} < (=,>)0$ and $\frac{\partial r^*}{\partial \theta} > (=,<)0$ when both self-insurance and self-protection are available.

Proof: See Appendix C.

4.4 Concluding remarks

This paper considers the optimal decisions on designing and implementing mandatory building codes for regulating land development in a disaster-prone area. The roles of self-insurance and self-protection played by building codes to improve community welfare are analyzed in a simple urban economics model.

The design of building codes should response to changes in socioeconomic characteristics of the area as well as productivity levels of self-insurance and self-protection. The net effects of these variables on optimal building codes depend on preferences and the production functions for self-insurance and self-protection. Competition on the land market amplifies or reduces the direct effects of changes in wage, population, and land area share of the risky region on the amount of optimal expenditure on self-insurance and self-insurance required by the mandatory building codes. The model proposed here produces a number of analytical comparative statics results. Our analysis allows us to identify optimal building codes at the community level where location play fundamental roles.

In this paper, we assumed there are no interdependencies between households such as the likelihood of a fire occurring in one's house is affected by her neighbor's investment in protective measures. It is not difficult to extend the model proposed in this paper by allowing such interdependencies (Muermann and Kunreuther, 2008). That extension may require more complex spatial structure for the model analyzed. As a result, the optimal building codes are location-specific. We also assumed that an individual inhabit one unit of land. While analyzing a model with space in the utility function (as in Frame 2000 and Wheaton 1977) would present formidable technical challenges, it is clearly an interesting direction for future work.

4.5 Endnotes

[1] A set of mandatory building codes was managed to be passed by the Governor and the state legislature in Louisiana in 2006.

[2] The interactions between market insurance, self-insurance, and self-protection are studied by Ehrlich and Becker (1972). We apply their methods in the context of urban economics to analyze building codes.

[3] Base Flood Elevation defined by Federal Emergency Management Agency is the one associated with the flood having 1% annual chance of being equal or exceed in any given year.

[4] The "1%" annual chance is chosen by many regulation agencies in the US, at least for regulating development in some regions which are subject to disasters such as floods (Green, et al., 2000) and storms (Dehring, 2006).

[5] We do not intend to analyze in this paper why individuals underinvest in voluntary self-protection and self-insurance.

[6] The assumption of one unit of land for each individual seems somewhat restrictive. But it is a compromise between this restrictiveness and the attainability of analytical results. In an earlier version, we let the agents in our model the freedom to choose the quantity of land. It is not easy to get the analytical results of comparative statics presented later in this paper. However, the assumption we adopted here does not prevent us analyzing the major questions raised in this paper.

[7] An equilibrium in the land market requires that all households to spend the same amount on rent, $R(v)$, plus commuting costs, kv, for any distance v from the CBD ($v \leq b$). At the city edge at a radius of v in the risky region, it is true that $R(v) + kv = kb$ since $R(b) = 0$ in this area. Thus, $R(v) = k(b - v)$ and then total land rents collected from the risky region equal to $k\theta\int_0^b (b - v)vdv$. Using similar logic, we can find land rents collected from the risk-free region. Note that the both the value of b and that of b_1 are endogenously determined in the model which are presented and analyzed later in the present paper.

[8] Equation (5) can be rewritten as $\frac{\partial S^*}{\partial \alpha} = \frac{(1-p_0)u_e'' y^b \frac{\partial b^*}{\partial \alpha} - p_0(f^s + 1)u_d''[f^\alpha - y^b \frac{\partial b^*}{\partial \alpha}] + p_0 f^{s\alpha} u_d'}{p_0(f^s + 1)^2 u_d'' - p_0 f^{ss} u_d' + (1-p_0)u_e''}$. Note that the denominator is negative and $(1 - p_0)u_e'' y^b \frac{\partial b^*}{\partial \alpha} - p_0(f^s + 1)u_d''[f^\alpha - y^b \frac{\partial b^*}{\partial \alpha}] > 0$ since $f^\alpha - y^b \frac{\partial b^*}{\partial \alpha} < 0$ by equation (4).

[9] The latter case is examined by Ehrlich and Becker (1972).

[10] This statement can be proved by contradiction. If $1 + y^b \frac{\partial b^*}{\partial w} < 0$, then $\frac{\partial b^*}{\partial w} > 0$ given $y^b < 0$. If the equation $(1 + y^b \frac{\partial b^*}{\partial w})(p_0 u_d' + (1 - p_0)u_e') = (1 + y_1^b \frac{\partial b^*}{\partial w})u_1'$ holds, it requires that $1 + y_1^b \frac{\partial b^*}{\partial w} < 0$, which further requires that $\frac{\partial b^*}{\partial w} < 0$ because $y_1^b > 0$. Though change in wage may change net profits from the land market, $1 + y^b \frac{\partial b^*}{\partial w} < 0$ implies that the sum of wage and profit is increasing in wage in equilibrium.

[11] Though the production function for self-insurance does not appear explicitly in equation (10), it affects the quantities of composite good consumed by individuals because the function has impacts on net profits from land market.

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12 $p_0 u_d^{"}(f^s+1)+(1-p_0)u_e^{"}=[p_0(f^s+1)+(1-p_0)u_e^{"}/u_d^{"}]u_d^{"}$. If $-u_e^{"}/u_e^{'}>-u_d^{"}/u_d^{'}$ then $p_0(f^s+1)+(1-p_0)u_e^{"}/u_d^{"}>0$ given $p_0(f^s+1)+(1-p_0)u_e^{'}/u_d^{'}=0$ from condition (2).

13 To relate this condition to that in Lemma 1, we note that $p^r(u_d^{'}-u_e^{'})-pu_d^{"}-(1-p)u_e^{"}<0$ if $\frac{\partial[ARA(g)]}{\partial g}>0$ and $\frac{p^r}{p(1-p)f^s}>-\frac{u^{"}}{u^{'}}$.

14 Or if $-\frac{u_d^{"}}{u_d^{'}}\leq-\frac{p^r}{p}$. Hence, $\frac{\partial^2 b}{\partial s\partial r}<0$. Another sufficient condition for $\frac{\partial^2 b}{\partial s\partial r}<0$ to hold is that $\frac{\partial[ARA(g)]}{\partial g}>0$. Given this condition, we have that $\frac{\partial^2 b}{\partial s\partial r}<0$ since $(pu_d^{"}-p^r u_d^{'})(f^s+1)+p^r u_e^{'}+(1-p)u_e^{"}=[pu_d^{"}(f^s+1)+(1-p)u_e^{"}]-p^r u_d^{'}(f^s+1)+p^r u_e^{'}$.

15 It is assumed as that in section 3.1.1.

16 To prove, we note first that $f^{\alpha}-y^b\frac{\partial b^*}{\partial\alpha}<0$.

4.6 References

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Table 4.1: Comparative-statics results

Variable	Productivity level of self-insurance, α	Productivity level of self-protection, β	Endowed probability of disaster, p_0	Endowed loss from disaster, l	Wage, w	Population, N	Land area share of the risky region, θ
Outer boundary in the risky region, b^*	+	+	–	–	±	±	±
Equilibrium utility, or expected utility	+	+	–	–	+	–	–
Net profit received by an individual in the risky region from the land market, y^*	–	–	+	+	±	±	±
Net profit received by an individual in the safe region from the land market, y_1^*	+	+	–	–	±	±	±
Optimal self-insurance, s^*	±		±	+	±	±	±
Optimal self-protection, r^*		±	±	±	±	±	±

Notes: The signs in the table indicate the effect of a change in the exogenous variable at the top of the column on the row variable.

Appendix A Comparative-Static Results: Self-Insurance

The following comparative statics results are obtained by differentiating equations (1) and (2) with respect to corresponding exogenous variables.

The effects of a change in population are given by

$$\frac{\partial S^*}{\partial N} = \frac{[p_0(f^s+1)u_d'' + (1-p_0)u_e''](\frac{\partial y^*}{\partial N} + y^b \frac{\partial b^*}{\partial N})}{p_0(f^s+1)^2 u_d'' - p_0 f^{ss} u_d' + (1-p_0)u_e''}, \tag{A1}$$

where

$$\frac{\partial y^*}{\partial N} + y^b \frac{\partial b^*}{\partial N} < 0, \tag{A2}$$

and

$$\frac{\partial b^*}{\partial N} = \frac{p_0 u_d' y^N + (1-p_0)u_e' y^N - u_1' y_1^N}{u_1' y_1^b - p_0 u_d' y^b - (1-p_0)u_e' y^b}. \tag{A3}$$

The effects of an increase in land area share of the risky region:

$$\frac{\partial S^*}{\partial \theta} = \frac{[p_0(f^s+1)u_d'' + (1-p_0)u_e''](\frac{\partial y^*}{\partial \theta} + y^b \frac{\partial b^*}{\partial \theta})}{p_0(f^s+1)^2 u_d'' - p_0 f^{ss} u_d' + (1-p_0)u_e''}, \tag{A4}$$

where

$$\frac{\partial y^*}{\partial \theta} + y^b \frac{\partial b^*}{\partial \theta} < 0, \tag{A5}$$

and

$$\frac{\partial b^*}{\partial \theta} = \frac{p_0 u_d' y^\theta + (1-p_0)u_e' y^\theta - u_1' y_1^\theta}{u_1' y_1^b - p_0 u_d' y^b - (1-p_0)u_e' y^b}. \tag{A6}$$

The effects of a change in unit commuting cost:

$$\frac{\partial S^*}{\partial k} = \frac{[p_0(f^s+1)u_d'' + (1-p_0)u_e''](\frac{\partial y^*}{\partial k} + y^b \frac{\partial b^*}{\partial k})}{p_0(f^s+1)^2 u_d'' - p_0 f^{ss} u_d' + (1-p_0)u_e''}, \tag{A7}$$

where the sign of $\frac{\partial y^*}{\partial k} + y^b \frac{\partial b^*}{\partial k}$ is ambiguous. However, if the boundaries, b_1 and b, are such that $y^k \leq 0$ (e.g. if $b_1 \leq 3b$) then $\frac{\partial y^*}{\partial k} + y^b \frac{\partial b^*}{\partial k} < 0$.

$$\frac{\partial b^*}{\partial k} = \frac{-p_0 u_d^{'} y^k - (1-p_0) u_e^{'} y^k + u_1^{'} y_1^k}{p_0 u_d^{'} y^b + (1-p_0) u_e^{'} y^b - u_1^{'} y_1^b} . \tag{A8}$$

Equations (A1) and (A4) show that both an increase in population and an increase in the land area share of the risky region would reduce the amount of the composite good because net profits from the land market decrease. An increase in unit commuting cost would have similar effect on consumption if the boundary in the safe region is not so further away from the CBD relative to that in the risky region.

A special case is that $\frac{\partial s^*}{\partial w} = \frac{\partial s^*}{\partial N} = \frac{\partial s^*}{\partial \theta} = \frac{\partial s^*}{\partial k} = 0$ and $\frac{\partial b^*}{\partial w} = \frac{\partial b^*}{\partial N} = \frac{\partial b^*}{\partial \theta} = \frac{\partial b^*}{\partial k} = 0$ if marginal utility of the composite good is constant.

Appendix B Comparative-Static Results: Self-Protection

Totally differentiating (12) with respect to β and using condition (13) we obtain that

$$p^{\beta}(u_d - u_e) + (pu_d^{'} + (1-p)u_e^{'}) y^b \frac{\partial b^*}{\partial \beta} = u_1^{'} y_1^b \frac{\partial b^*}{\partial \beta} , \tag{B1}$$

which suggests that $\frac{\partial b^*}{\partial \beta} > 0$. Furthermore, totally differentiating (13) with respect to β gives that

$$\frac{\partial r^*}{\partial \beta} = -\frac{[p^r(u_d^{'} - u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}] y^b \frac{\partial b^*}{\partial \beta} - p^{\beta}(u_d^{'} - u_e^{'}) + p^{r\beta}(u_d - u_e)}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'} - u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}} . \tag{B2}$$

The above comparative-statics results show the effects of technological improvements in self-protection. As technology of self-protection advances, more land development occurs in the risky region and then the equilibrium level of welfare achieved in the city increases.

The effects of changes in endowed probability of and loss from natural disaster, wage, population, land area share of the risky region, and unit commuting cost are described by the following derivatives, all of which are obtained by differentiating (12) and (13) with respect to respective variables.

The effects of a change in endowed probability of natural disaster:

$$\frac{\partial r^*}{\partial p_0} = -\frac{[p^r(u_d^{'}-u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}]y^b \frac{\partial b^*}{\partial p_0} + p^{rp_0}(u_d - u_e)}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'}-u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}, \tag{B3}$$

where

$$\frac{\partial b^*}{\partial p_0} = \frac{\frac{\partial p}{\partial p_0}(u_d - u_e)}{u_1^{'}y_1^b - pu_d^{'}y^b - (1-p)u_e^{'}y^b} < 0 \tag{B4}$$

The effects of a change in endowed loss from natural disaster:

$$\frac{\partial r^*}{\partial l} = -\frac{[p^r(u_d^{'}-u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}]y^b \frac{\partial b^*}{\partial l} + p^r u_d^{'} + pu_d^{''}}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'}-u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}, \tag{B5}$$

where

$$\frac{\partial b^*}{\partial l} = -\frac{pu_d^{'} + (1-p)u_e^{'}}{u_1^{'}y_1^b - pu_d^{'}y^b - (1-p)u_e^{'}y^b} < 0 \tag{B6}$$

The effects of a change in wage:

$$\frac{\partial r^*}{\partial w} = -\frac{[p^r(u_d^{'}-u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}](1 + y^b \frac{\partial b^*}{\partial w})}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'}-u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}, \tag{B7}$$

where

$$1 + y^b \frac{\partial b^*}{\partial w} > 0, \tag{B8}$$

and

$$\frac{\partial b^*}{\partial w} = \frac{pu_d^{'} + (1-p)u_e^{'} - u_1^{'}}{u_1^{'}y_1^b - pu_d^{'}y^b - (1-p)u_e^{'}y^b}. \tag{B9}$$

The effects of population growth:

$$\frac{\partial r^*}{\partial N} = -\frac{[p^r(u_d^{'}-u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}](\frac{\partial y^*}{\partial N} + y^b \frac{\partial b^*}{\partial N})}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'}-u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}, \tag{B10}$$

where

$$\frac{\partial y^*}{\partial N} + y^b \frac{\partial b^*}{\partial N} < 0, \tag{B11}$$

and

$$\frac{\partial b^*}{\partial N} = \frac{pu_d^{'} y^N + (1-p)u_e^{'} y^N - u_1^{'} y_1^N}{u_1^{'} y_1^b - pu_d^{'} y^b - (1-p)u_e^{'} y^b}. \tag{B12}$$

The effects of an increase in land area share of the risky region:

$$\frac{\partial r^*}{\partial \theta} = -\frac{[p^r(u_d^{'}-u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}](\frac{\partial y^*}{\partial \theta} + y^b \frac{\partial b^*}{\partial \theta})}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'}-u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}, \tag{B13}$$

where

$$\frac{\partial y^*}{\partial \theta} + y^b \frac{\partial b^*}{\partial \theta} < 0, \tag{B14}$$

and

$$\frac{\partial b^*}{\partial \theta} = \frac{pu_d^{'} y^\theta + (1-p)u_e^{'} y^\theta - u_1^{'} y_1^\theta}{u_1^{'} y_1^b - pu_d^{'} y^b - (1-p)u_e^{'} y^b}. \tag{B15}$$

The effects of an increase in unit commuting cost:

$$\frac{\partial r^*}{\partial k} = -\frac{[p^r(u_d^{'}-u_e^{'}) - pu_d^{''} - (1-p)u_e^{''}](\frac{\partial y^*}{\partial k} + y^b \frac{\partial b^*}{\partial \theta})}{p^{rr}(u_d - u_e) - 2p^r(u_d^{'}-u_e^{'}) + pu_d^{''} + (1-p)u_e^{''}}, \tag{B16}$$

where the sign of $\frac{\partial y^*}{\partial k} + y^b \frac{\partial b^*}{\partial k}$ is ambiguous and depends on the relative magnitude of b and b_1, and

$$\frac{\partial b^*}{\partial k} = \frac{pu_d^{'} y^k + (1-p)u_e^{'} y^k - u_1^{'} y_1^k}{u_1^{'} y_1^b - pu_d^{'} y^b - (1-p)u_e^{'} y^b}. \tag{B17}$$

A special case is that $\frac{\partial r^*}{\partial w} = \frac{\partial r^*}{\partial N} = \frac{\partial r^*}{\partial \theta} = \frac{\partial r^*}{\partial k} = 0$ and $\frac{\partial b^*}{\partial w} = \frac{\partial b^*}{\partial N} = \frac{\partial b^*}{\partial \theta} = \frac{\partial b^*}{\partial k} = 0$ if marginal utility of the composite good is constant.

Appendix C Comparative-Static Results: Joint Determination on Self-Insurance and Self-Protection

To see the effects of technological improvement in self-insurance on expenditures on self-insurance and self-protection, we totally differentiate the two first-order conditions, (17) and (18), with respect to α and solve them for the following two partial derivatives:

$$\frac{\partial s^*}{\partial \alpha} = \frac{\Delta^{-1}}{u_1' y_1^b - p u_d' y^b - (1-p) u_e' y^b} \left\{ \frac{\partial^2 b}{\partial s \partial r} \mathrm{E} - \frac{\partial^2 b}{\partial r^2} \Phi \right\}, \tag{C1}$$

and

$$\frac{\partial r^*}{\partial \alpha} = \frac{\Delta^{-1}}{u_1' y_1^b - p u_d' y^b - (1-p) u_e' y^b} \left\{ \frac{\partial^2 b}{\partial s \partial r} \Phi - \frac{\partial^2 b}{\partial r^2} \mathrm{E} \right\}, \tag{C2}$$

where $\mathrm{E} \equiv (p u_d'' - p^r u_d')(f^\alpha - y^b \frac{\partial b^*}{\partial \alpha}) - (p^r u_e' + (1-p) u_e'') y^b \frac{\partial b^*}{\partial \alpha}$ and

$\Phi \equiv p(f^s + 1) f^\alpha u_d'' - p f^{s\alpha} u_d' - (p(f^s + 1) u_d'' + (1-p) u_e'') y^b \frac{\partial b^*}{\partial \alpha}$.

The effects of an increase in the productivity of self-protection are demonstrated by

$$\frac{\partial s^*}{\partial \beta} = \frac{\Delta^{-1}}{u_1' y_1^b - p u_d' y^b - (1-p) u_e' y^b} \left\{ \frac{\partial^2 b}{\partial r^2} \Gamma - \frac{\partial^2 b}{\partial s \partial r} \mathrm{H} \right\}, \tag{C3}$$

and

$$\frac{\partial r^*}{\partial \beta} = \frac{\Delta^{-1}}{u_1' y_1^b - p u_d' y^b - (1-p) u_e' y^b} \left\{ \frac{\partial^2 b}{\partial s^2} \mathrm{H} - \frac{\partial^2 b}{\partial s \partial r} \Gamma \right\}, \tag{C4}$$

Where $\Gamma \equiv p^\beta (f^s + 1) u_d' - p^\beta u_e' + (p(f^s + 1) u_d'' + (1-p) u_e'') y^b \frac{\partial b^*}{\partial \beta}$ and

$\mathrm{H} \equiv p^\beta (u_d' - u_e') - p^{r\beta} (u_d - u_e) - (p^r (u_d' - u_e') - p u_d'' - (1-p) u_e'') y^b \frac{\partial b^*}{\partial \alpha}$.

The effects of a change in income on self-insurance and self-protection when both are available:

$$\frac{\partial s^*}{\partial w} = \Lambda(1 + y^b \tfrac{\partial b^*}{\partial w}) , \tag{C5}$$

and

$$\frac{\partial r^*}{\partial w} = -\mathrm{M}(1 + y^b \tfrac{\partial b^*}{\partial w}) , \tag{C6}$$

where

$$\Lambda \equiv \frac{\Delta^{-1}}{u_1' y_1^b - p u_d' y^b - (1-p) u_e' y^b} \left\{ \frac{\partial^2 b}{\partial r^2} [p(f^s + 1) u_d'' + (1-p) u_e''] + \frac{\partial^2 b}{\partial s \partial r} [p^r (u_d' - u_e') - p u_d'' - (1-p) u_e''] \right\}$$

and

$$\mathrm{M} \equiv \frac{\Delta^{-1}}{u_1' y_1^b - p u_d' y^b - (1-p) u_e' y^b} \left\{ \frac{\partial^2 b}{\partial s \partial r} [p(f^s + 1) u_d'' + (1-p) u_e''] + \frac{\partial^2 b}{\partial r^2} [p^r (u_d' - u_e') - p u_d'' - (1-p) u_e''] \right\} .$$

The effects of a change in population:

$$\frac{\partial s^*}{\partial N} = \Lambda(\tfrac{\partial y^*}{\partial N} + y^b \tfrac{\partial b^*}{\partial N}) , \tag{C7}$$

$$\frac{\partial r^*}{\partial N} = -\mathrm{M}(\tfrac{\partial y^*}{\partial N} + y^b \tfrac{\partial b^*}{\partial N}) . \tag{C8}$$

The effects of a change in land area share of the risky region:

$$\frac{\partial s^*}{\partial \theta} = \Lambda(\tfrac{\partial y^*}{\partial \theta} + y^b \tfrac{\partial b^*}{\partial \theta}) , \tag{C9}$$

$$\frac{\partial r^*}{\partial \theta} = -\mathrm{M}(\tfrac{\partial y^*}{\partial \theta} + y^b \tfrac{\partial b^*}{\partial \theta}) . \tag{C10}$$

CHAPTER 5

5 GENERAL CONCLUSION

This research focuses on the interdependencies between environment and the spatial distribution of economic activities. The three essays suggest that they affect each other in many ways and both of them have important effects on social welfare. The interdependencies should be taken into account by government when making related regulation policies.

The first essay develops a theoretical model to understand the major determinants of urban development patterns and the process in which an economy evolves from partial to full urbanization of population. Theoretical results show that urban development patterns are strongly influenced by the spatial distribution of amenities. The effects of amenities are reinforced by the increasing returns derived from scale economies and knowledge spillovers. This paper also analyzes how the spatial distribution of amenities and increasing returns affect the trajectories of human capital accumulation and economic growth. Locations with higher environmental amenities attract workers and thus tend to have a higher level of human capital. Workers in those amenity locations are more productive because of scale economies and knowledge spillovers. In particular, our result suggests that an economy with few environmental amenities will have a very low growth rate or even shrink if the effect of increasing returns is not large enough. The decentralized equilibrium is not optimal because of the externalities associated with human capital investments made by individual workers. The efficiency can be improved by public policies encouraging human capital investments. Such policies also increase the pace of urbanization and economic growth. To test some of the theoretical findings, we assemble a data set at the metropolitan area level from 1900-1990 and conduct empirical tests. Empirical evidence supports the argument that the spatial distribution of amenities and the level of accumulated human capital are major determinants of urban development patterns.

The second essay empirically estimates the effects of natural disasters on population growth across U.S. counties during the period of 1960-2000. Our results differ substantially from those in some previous studies which use country-level data and find significant effects of natural disasters on economic growth. Results from the present paper suggest that except earthquakes and most serious hurricanes, the risks of natural disasters have no statistically significant effects on population growth. We also estimate the effects of natural disasters on county socioeconomic and demographic characteristics, including human capital, age and ethnic composition of population, industrial composition, and income inequality. The insignificance of those effects indicates that natural disasters have no indirect effects on population growth, either. It is also found that those states affected by natural disasters differ in the overall net effects of natural disasters on population growth.

The third essay considers the roles of mandatory building codes for regulating land development in a natural disaster-prone area as self-insurance and self-protection. To find the optimal building codes, a simple urban economics model is constructed for the analysis of the government's decision under uncertainty. The design of building codes should response to changes in socioeconomic characteristics of the city as well as productivity levels of self-insurance and self-protection. A number of comparative statics results are presented to describe how optimal building codes are affected by the endowed probability of the disaster, the expected loss, productivity levels of self-insurance and self-protection, and socioeconomic characteristics of the area such as wage, population, and the share of land area in the risky region. In general, the properties of preferences and the production functions for self-insurance and self-protection determine those effects. Competition in the land market amplifies or reduces the direct effects of changes in socioeconomic variables of the area.

This research could be extended in a variety of ways. Based on the first essay, it is desirable to model different mechanisms of knowledge spillovers among cities, workers' human capital investment decisions and attainment. Test of these mechanisms with the distribution of amenity advantages and their effects on city formation would also be helpful for understanding the issues handled in that paper. The second essay finds that states affected by natural disasters differ in the overall net effects of natural disasters on population growth. However, data collected in this paper could not uncover the sources, which is left for future research. To extend the research presented in the third essay, it is useful to consider multi-period problems which allow government to adjust the mandatory building codes when exogenous conditions change and there is uncertainty regarding investment levels.

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