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DISENTANGLING AGGLOMERATION ECONOMIES: AGENTS, SOURCES, AND SPATIAL DEPENDENCE*

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ABSTRACT. This paper expands the literature on agglomeration economies in three ways. It disentangles amenity and productivity effects of agglomeration; it decomposes aggregate scale effects into agglomeration factors of interest to policy makers; and it estimates own effects and spillovers to neighbors. It proposes a spatial simultaneous equations model in a spatial equilibrium framework with three agents—workers, consumers, and producers of traded-goods and housing. Results for Ohio counties estimate economies resulting from population size, agglomeration causes, and public service quality and cost on each of the three agents in own and neighboring counties.

1. INTRODUCTION

On the surface, the concept of agglomeration economies is simple enough. As the size of an urban economy increases, its firms become more productive and its consumers enjoy greater amenities. Without agglomeration economies, there could be no trade, and population would distribute itself uniformly over space, except for concentrations in locations with increased resource endowments or higher productivity. However, the mechanisms and causes of agglomeration economies are difficult to model, and without this there are few policies other than direct interventions to change the size of cities or redirect migrants. This paper aims to deconstruct the concept in three ways.

First, it disentangles the effect of agglomeration economies on three agents—consumers and firms in two sectors, a traded-good sector and a sector producing local goods. Size will affect these sectors differently, and possibly, in opposite direction, and only a model that explicitly accounts for the behavior of all three agents will be able to account for their separate role in generating agglomeration economies. Most studies of agglomeration economies, however, look only at either the productivity of firms or the quality of life for consumers.

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Second, it clarifies the role of population size as a source of economies by introducing a bundle of agglomeration factors that are more directly a source of amenity and productivity gains. These include factors identified in the literature as possible sources of economies, such as the sharing of infrastructure, manufacturing localization, the level of human resources, and the quality and cost of public services. It is in the nature of these factors that they both impact the economy and are affected by it. The result is a more detailed understanding of the sources of agglomeration economies, better estimates of the impact of population size, and the availability of policy variables. Many studies instead look only at the effects of agglomeration size. This means that there are few policy implications, as agglomeration size itself is not a policy instrument but the result of factors under a policymaker's control. Moreover, agglomeration factors can have both positive and negative effects, and hence partially offset each other. Measuring the net effect of agglomeration size does not capture the underlying effects individually. Yet it is these individual effects that are of interest in policy decisions.

Third, it identifies spillover effects associated with agglomeration economies. A number of recent estimates show that agglomeration economies have a high rate of spatial decay, and will not have an important effect beyond relatively short neighborhood distances. On the other hand, metropolitan areas all over the world continue to grow, and often extend over distances of 100 km or more, making it likely that at least some agglomeration factors affect neighboring spatial units at some distance. This paper investigates how spatial units impact their neighbors, and in return are impacted by them, changing the productivity and quality of life across borders.

We propose a spatial simultaneous equations model (SEM) and apply it to data for Ohio counties. A single equation model in reduced form would fail to capture the separate effects of agglomeration factors on individuals and firms and hence there is a need for a SEM explaining structural economic forces. In addition, investigating the spatial dependence of these effects requires a spatial framework as well. Thus we incorporate the simultaneous framework into a spatial autoregressive (SAR) model with spatial lags and spatial errors to build a simultaneous system of spatially interrelated equations. The model is estimated using the generalized spatial three-stage least squares (GS3SLS) suggested by Kelejian and Prucha (2004).

The paper is organized as follows. Section 2 motivates the paper and reviews the literature on agglomeration economies. Section 3 develops a theoretical model designed to measure separately the effects of agglomeration size and its factors on both consumers and firms in the traded-good and housing sectors. Section 4 constructs the empirical model designed to measure the spillovers of agglomeration economies, and explains the estimation method. Section 5 shows the estimation results of the model using empirical data of Ohio's regional economy. Section 6 discusses policy implications and the significance of the results. Finally, Section 7 suggests possible paper extensions.

2. LITERATURE REVIEW AND MOTIVATION OF PAPER

Literature on Agglomeration Economies

The concept of agglomeration economies has been at the center of regional science research, as it explains why people and firms concentrate to form a city and why cities of different sizes exist. Since the 1970s, a vast amount of work in urban economics has tried to estimate the size of agglomeration economies and diseconomies. Recent years have seen the emergence of a rather different stream of literature in the form of the new economic geography (NEG), initiated by Krugman's (1991) seminal work. While the former explains agglomeration economies as a location-specific characteristic, the latter explains it as a result of interregional interdependence at a larger spatial scale (Brakman and van Marrewijk, 2009; Brakman, Garretsen, and van Marrewijk, 2009a; Combes, Duranton, and Overman, 2005). Despite differences in focus, both streams of the literature have analyzed sources and magnitudes of (dis)economies in terms of gains (or losses) in productivity and quality of life, though empirical estimates with few exceptions emphasize the production side.

In his excellent survey, Puga (2010) identifies three mechanisms of agglomeration economies bringing productivity gains to firms: the *sharing* of local facilities, intermediate input suppliers, and/or a pool of workers; a better *matching* in goods and labor markets; and *learning* or knowledge spillover. First, the sharing of indivisible facilities has long been recognized as a major source of economies particularly by the public economics literature (Andrews and Swanson, 1995; Munnell, 1990, 1992; Eberts and McMillen, 1999; Morrison and Schwartz, 1996); see Scotchmer (2002) for a review. A large pool of intermediate input suppliers can also reduce transaction costs (Abdel-Rahman and Fujita, 1990; Holmes, 1999; Rosenthal and Strange, 2001), and labor pooling can smooth out idiosyncratic shocks (Overman and Puga, 2009; Dumais, Ellison, and Glaeser, 1997; Francis, 2009; Combes and Duranton, 2006; Rosenthal and Strange, 2004). Second, the probability and quality of matching between employees and employers, and suppliers and buyers increases with market size, though more research is needed to find out its exact mechanism (Helsley and Strange, 1990; Coles, 1994; Coles and Smith, 1998; Gan and Li, 2004; Andersson, Burgess, and Lane, 2007). Third, there is a huge amount of studies, both empirical and theoretical, that suggests that larger agglomerations better develop and faster adopt new technologies and practices (Jacobs, 1969; Fujita and Ogawa, 1982; Ota and Fujita, 1993; Glaeser, 1999; Paci and Usai, 1999; Anselin, Varga, and Acs, 2000; Glaeser and Mare, 2001; Lucas and Esteban Rossi-Hansberg, 2002; Charlot and Duranton, 2004; Lim, 2004; Duranton and Puga, 2004; McCann and Simonen, 2005).

For consumers, a larger agglomeration may raise the quality of life both directly and indirectly, as income grows with greater productivity. Larger markets support a greater variety of goods and services that benefit consumers (Krugman, 1991; Fujita, Krugman, and Venables, 1999; Brakman, Garretsen, and van Marrewijk, 2009b; Stahl, 1982). Greater competition in larger market benefits consumers in the form of lower prices; see for example recent evidence on the price effects of large low-cost retailers (Fu, 2007). Network economies and infrastructure indivisibilities also favor larger over smaller cities or rural areas and the public economics literature provides much evidence that a higher quality of public services raises utility, as reflected in higher housing prices or land rent (Tiebout, 1956; Oates, 1969, 1973; Pollakowski, 1973; Rosen and Fullerton, 1977; Gyourko and Tracy, 1989; Burnell and Galster, 1992; Mozayeni, 1995; Nechyba and Strauss, 1998; Gabriel, Mattey, and Wascher, 2003; Carlsen et al., 2006).

While the above examples all point to the positive effects of a larger agglomeration, there are, of course, also negative effects, such as traffic congestion and pollution (Tabuchi, 1998; Higano and Shibusawa, 1999; Zheng, 2001). Given road capacity, the congestion associated with a greater traffic volume raises firms' transaction costs and decreases individuals' utility. In addition, infrastructure comes at a price, and hence one needs to account for the costs of supplying it. The net effect should be the benefits on the demand side net of the costs on the supply side.

The literature also looks at spatial spillovers of agglomeration economies. In focusing on firms' productivity most studies suggest that spillovers decay rapidly with distance, and are confined to a scale smaller than a city or county. Duranton and Overman (2005) suggest that a majority of U.K. firms are localized in areas of less than 50 km across. Desmet and Fafchamps (2005) maintain that service sectors experience high growth in agglomeration centers but low growth beyond 5 km, and that nonservice sectors grow fast at a distance

20–70 km from the centers. Van Soest, Gerking, and van Oort's (2006) in a study of South Holland suggest that the impact of agglomeration economies on employment growth and the birth of establishments is significant at a scale smaller than a city. Hanink (2006) in a study of the New England region argues that external scale effects do not extend to neighboring counties for most sectors except retailing and services, while other researchers argue for an even smaller scale. Rosenthal and Strange (2003) show that the effect of own two-digit SIC industry employment is 10–1,000 times larger within 1 mile than in an area 2–5 miles away. Fu (2007) also finds that the external effect on wages of human capital depth decays steeply beyond three miles from the work place. But all these studies on spatial spillovers deal only with firms' productivity rather than consumers' amenity. Since the spatial extent of amenity spillovers may differ from that of productivity spillovers, a separate investigation is needed for the former.

Motivation of the Paper

The literature is well aware of the many agglomeration effects on quality of life and productivity. Still empirical studies mostly deal with the latter rather than the former, and very few studies look at both simultaneously. Many researchers in the traditional urban economics investigate production or cost mainly as a function of *city size* (Segal, 1976; Carlino, 1982; Moomaw, 1981, 1983; Henderson, 1986); see Eberts and McMillen (1999) for a review. Recent studies in NEG look at other aspects of agglomeration such as labor market pooling, market potential, and specialization (Gibbs and G.Andrew Bernat, 1997; Wheaton and Lewis, 2002; Hanson, 2005). But NEG studies still focus only on the effects on firms' productivity, not quality of life.

In a different context, Roback (1982) provides a useful framework for analyzing the simultaneous effects of regional attributes on individuals' quality of life and firms' productivity. She provides a spatial equilibrium model to capture the two effects and applies it to U.S. cities, though population size is regarded as an exogenous regional attribute rather than the endogenous variable it should be. As people migrate to a region with good amenities, the size of this region increases, making population size endogenous (Ciccone and Hall, 1996; Henderson, 2003; Koo, 2005). Moreover, some of her empirical results are inconclusive as to the effect of regional attributes on land rent.

Tabuchi and Yoshida (2000) investigate the consumption and production side of agglomeration effects separately, making use of Roback's (1982) framework, as we do in this study. However, there are at least two limitations. First, their study considers the effects of population size, but does not allow for other agglomeration factors. Second, they use land rent rather than housing price as an endogenous variable. This creates a systematic bias, as residents consume housing service rather than land, and thus their utility is affected directly by housing price and not land rent; see Section 3 for a detailed discussion. In the United States, of course, land rent data are typically lacking. Hence, both on theoretical and practical grounds, we turn to housing price data.

This study investigates the effects of various agglomeration factors, considering simultaneously the consumption and production side of the regional economy. It also looks at the spillovers of these agglomeration economies and identifies their neighborhood effects for each agent. In doing so, we determine the implicit values of several policy-driven agglomeration factors related to public service levels including road density, traffic flow, and public expenditure level.

Theoretically, our model follows an urban economics framework rather than NEG. This is appropriate for the problem being addressed, as we deal with economies that are small, relative to the rest of the world and hence, are price takers. As in urban economics, the size of the city is determined based on a postulated spatial equilibrium and the ability of labor to move freely between regions; see Glaeser and Gottlieb (2009) for a review. Trade relations and transport costs are not explicitly modeled, except that different producers must overcome different transportation costs to access world markets. This is appropriate, as a more explicit modeling of interregional linkage trade is more relevant at a large scale than at a smaller urban economy scale (Brakman and van Marrewijk, 2009; Brakman, Garretsen, and van Marrewijk, 2009). However, our model emphasizes spatial linkages in the form of spillovers from agglomeration factors to neighboring areas. Agglomeration (dis)economies are modeled by a shift of total factor productivity as a function of agglomeration characteristics under constant returns to scale. This framework allows us to explain both economies and diseconomies of agglomeration factors, while the NEG framework assumes increasing returns to scale and thus usually neglects diseconomies (Brakman, Garretsen, and van Marrewijk, 2009a). Hence we mainly follow the urban economics framework,[1] though extend this framework by allowing for spatial spillovers and transportation costs to major trade posts, i.e., airports.

3. THE THEORECTICAL MODELING: EFFECTS OF AGGLOMERATION FACTORS

We base our methodology on a study on the impact of agglomeration factors on equilibrium wages and rents. Puga (2010) summarizes three approaches to measure productive advantages of agglomeration: one may show that economic activities are more agglomerated than would be expected; one may estimate the geographical variations of wages and land rents, as amenities and productive advantages of agglomeration are priced by labor and land markets; and one may investigate directly productivity variations across space at the level of individual firms. We follow the second approach as it captures effects on both productivity and quality of life.

Roback (1982) suggests a spatial equilibrium framework that studies geographical variations in wages and rents to evaluate amenity and productivity effects of regional attributes. This approach is based on the assumption that location-specific attributes are priced in the land, housing, and labor markets (Roback, 1982; Knapp and Graves, 1989; Blomquist, Berger, and Hoehn, 1988). Her model tells us that all else being equal, a region's productivity advantages and consumption amenities raise wage rates and land rents, respectively. However, when a regional attribute impacts both productivity and quality of life, the relation becomes more complicated. Still, looking at the systematic spatial patterns in wages and rents enables us to disentangle its impacts on production and consumption.

Assumptions and Model

For the spatial setting, we assume that there are many regions that have different agglomeration factors such as variety, specialization, and provision of infrastructure and public services. Each region is defined by its labor market so that workers do not commute beyond their region on a daily basis, once they determine their location of residence. In the long term, however, capital and labor can move freely across regions, and hence a long-run spatial equilibrium is formed equalizing individuals' utility and firms' unit-cost across regions. The model in the paper deals with this long-run equilibrium.[2]

[1]Combes et al. (2005) also argue that urban economics is more relevant in explaining "spikes" of economic activities at the smaller scale of a city, while NEG is good in explaining broad trends at a larger scale.

[2]We think of the long term as extending beyond 20 years, as infrastructure works often have a design and implementation horizon at least that long, and the effect of localization economies may take even longer to be fully realized.

We follow Roback's (1982) extended model to make the following assumptions: On the production side, each region has two sectors, one producing a traded-composite good, the other nontraded housing. Each sector's production function is described by a representative firm that produces its output under constant returns to scale (CRS) at the firm level but potentially increasing returns to scale (IRS) at the industry level.[3] The traded-good sector produces a composite good with labor, capital, and land as inputs; the housing sector produces housing with the same inputs. Regarding taxation, we assume that representative firms pay all their taxes in the form of a sales tax that varies across regions, and thus the regional price of a good rises with the regional tax rate. On the consumption side, a single worker–consumer represents all individuals' preferences in each region. This worker is employed by one of the two representative firms, and consumes the traded-composite good and housing in competitive markets to maximize her utility. The individual's income consists of her wage and other earnings from factor endowments such as dividends, interest, and rent. Production factors across all regions are equally owned by all worker–consumers of all regions. Particularly, each person has the same portfolio of land ownership across all the regions regardless of her location of residence. Hence, of her income components, only wages vary with her choice of location. Assuming no intersectoral wage difference or free mobility of labor across sectors within a region, one can say that a fraction of a representative worker–consumer's income comes from the traded-good sector and the rest from the housing sector. Regarding taxation, we assume that the representative worker–consumer pays all taxes in the form of a lump-sum tax that varies across regions and thus her disposable income decreases by that amount.

The individual worker–consumer's utility maximizing program gives us an indirect utility function for the representative individual in region i as follows:

$$V(hpric_i, (inc_i - ctax_i); \mathbf{z}_i) = k, \tag{1}$$

where $hpric_i$, inc_i, $ctax_i$, and $\mathbf{z}_i$ are housing price, income, tax payment, and a vector of regional attributes including agglomeration factors that possibly affect the individual's utility in region i. The utility is equalized across regions and thus it has a constant value, k, regardless of regions.

Since the two goods are produced under CRS, the two representative firms' cost minimizing programs give us two unit-cost functions for the two sectors in region i as follows:

$$C(p_K, indr_i, wag_i; \mathbf{z}_i)(1 + trtxrt_i) = 1, \tag{2}$$

$$G(p_K, resr_i, wag_i; \mathbf{z}_i)(1 + hstxrt_i) = hpric_i, \tag{3}$$

where C and G denotes the unit-cost functions for the traded-composite good and housing sectors, respectively; p_K, $indr_i$, wag_i, and $resr_i$ are capital rent, industrial land rent, wage, and residential land rent; and $trtxrt_i$ and $hstxrt_i$ are tax rates for the traded-good and housing sectors, respectively, in region i. Note that $\mathbf{z}_i$ the vector of regional attributes appears again as it possibly affects the firms' productivity. As capital is mobile, the capital rent is constant across regions. The unit-cost of the traded-good is also equalized across regions since the good moves freely across regions. So the good can be regarded as numéraire, and its price is normalized as unity. Housing is not traded and hence its

[3]This Marshall-type approach using a representative firm has some limitations, including the fact that it does not capture the monopolistic characteristic of market competition, which led to the "monopolistic competition revolution" by Chamberlin. We are grateful to the editor for providing information on this issue.

unit-cost differs across regions. The housing price, $hpric_i$, therefore is variable. Note that the vector $\mathbf{z}_i$ has as its elements population size pop_i, a subvector of other agglomeration factors $\mathbf{s}_i$, and another subvector of all other regional attributes $\mathbf{q}_i$. In other words, the vector $\mathbf{z}_i$ is written as $(pop_i, \mathbf{s}_i, \mathbf{q}_i)$.

As to functional forms, we use the Cobb–Douglas function for both the utility and production functions and introduce a shift factor that changes utility or productivity levels depending on regional attributes for a given bundle of consumption. First, the representative worker–consumer's utility is determined by her consumption of the traded-good and housing, and it also is shifted by regional attributes including agglomeration factors. Assuming the separability of population size from other regional attributes in the shift factor, her utility function may be written as

$$U = A(\mathbf{s}, \mathbf{q}) pop^{a_1} g^{\theta} h^{1-\theta},$$

where $A(\cdot)$ represents a utility shift by regional attributes $(\mathbf{s}, \mathbf{q})$ and thus $A(\mathbf{s}, \mathbf{q})pop^{a_1}$ is the utility shift by all regional attributes; g and h are quantities of the traded-good and housing; and parameters a_1 and θ represent the elasticity of utility with respect to population size and the share of expenditure on the traded-good out of total expenditure, respectively. Next, for the production functions of the two sectors, we assume that the representative firm's total factor productivity (TFP) is determined by regional attributes. Assuming the separability of population size, the production functions may be written as

$$g = F(\mathbf{s}, \mathbf{q}) pop^{b_1} L_g^{\alpha_1} N_g^{\beta_1} K_g^{\gamma_1}, \tag{4}$$

$$h = H(\mathbf{s}, \mathbf{q}) pop^{c_1} L_h^{\alpha_2} N_h^{\beta_2} K_h^{\gamma_2}, \tag{5}$$

where $F(\cdot)$ and $H(\cdot)$ represent productivity shifts due to regional attributes $(\mathbf{s}, \mathbf{q})$; N, K, and L indexed by output denote labor, capital and land; and parameters b_1 and c_1 represent the output elasticities with respect to population, while α's, β's, and γ's the output elasticities with respect to the three corresponding inputs as usual. Note that we have assumed Hicks-neutrality in technical changes due to regional attributes. In other words, regional attributes affect the productivities of all the inputs equally and shift outputs neutrally across inputs.

The optimization programs of the three agents give us the indirect utility function and the two unit-cost functions as follows:

$$V = A(\mathbf{s}, \mathbf{q}) pop^{a_1} \theta^{\theta} \left(\frac{1-\theta}{hpric}\right)^{1-\theta} (inc - ctax) = k, \tag{6}$$

$$C = \frac{1}{F(\mathbf{s}, \mathbf{q}) pop^{b_1}} \left(\frac{indr}{\alpha_1}\right)^{\alpha_1} \left(\frac{wag}{\beta_1}\right)^{\beta_1} \left(\frac{p_K}{\gamma_1}\right)^{\gamma_1} = \frac{1}{1 + trtxrt}, \tag{7}$$

$$G = \frac{1}{H(\mathbf{s}, \mathbf{q}) pop^{c_1}} \left(\frac{resr}{\alpha_2}\right)^{\alpha_2} \left(\frac{wag}{\beta_2}\right)^{\beta_2} \left(\frac{p_K}{\gamma_2}\right)^{\gamma_2} = \frac{hpric}{1 + hstxrt}, \tag{8}$$

where the second equalities in the above equations come from Equations (1)–(3). Note that the index i for each region is dropped for simplicity as it is obvious that each equation represents each economic agent's behavior in a specific region. The system of equations is indeterminate because it has only three equations but six unknown variables, *pop*, *inc*, *indr*, *wag*, *resr*, and *hpric*. We deal with this by imposing additional assumptions on people's income, land input in the traded-good sector, and residential land rent. Specifically, the wage variable in (8) is expressed as a function of income as wage is the only income component varying across regions. Using the income share of wages, the wage variable is expressed as an exponential function of the income variable. Second, the share of land input in the traded-good sector is negligible and thus factor returns take the form of wages and capital rent only. Given that capital rent is constant, a productivity increase leads only to an increase in wages and hence all the productivity gains return to regional income. In other words, the factor price index consisting of factor prices, $(indr/\alpha_1)^{\alpha_1}(wag/\beta_1)^{\beta_1}(p_K/\gamma_1)^{\gamma_1}$ in (7) represents regional income coming from the traded-good sector and hence can be expressed as a function of regional income. Third, residential land rent is proxied by other variables and parameters, specifically, population, housing price, and land area. With these three assumptions, the system of simultaneous equations is reduced to a determinate system with three unknowns, *pop*, *inc*, and *hpric*. The three equations can be expressed as explicit functions (9)–(11); see Appendix 1 for a derivation.

$$\log(pop) \approx a_0 - \frac{1}{a_1}\log(inc) + \frac{1-\theta}{a_1}\log(hpric) + \frac{1}{a_1}\cdot\frac{ctax}{inc} - \frac{1}{a_1}\log(A(\mathbf{s},\ \mathbf{q})), \tag{9}$$

$$\log(inc) \approx b_0 + b_1\phi\log(pop) - \phi trtxrt + \phi\log(F(\mathbf{s},\ \mathbf{q})), \tag{10}$$

$$\begin{aligned}\log(hpric) \approx c_0 &+ \frac{\beta_2}{(1-\alpha_2)\varpi}\log(inc) + \frac{\alpha_2 - c_1}{1-\alpha_2}\log(pop) - \frac{\alpha_2}{1-\alpha_2}\log(area)\\ &+ \frac{hstxrt}{1-\alpha_2} - \frac{1}{1-\alpha_2}\log(H(\mathbf{s},\ \mathbf{q})),\end{aligned} \tag{11}$$

where *area* is the area of the region; a_0, b_0, and c_0 are constant parameters; $\boldsymbol{\phi}$ and $\boldsymbol{\varpi}$ are the income share of the traded-good sector and the income share of wages, respectively. One may set $\boldsymbol{\phi}$ as unity, as 96 percent of the region's income comes from the traded-good sector[4] and as it is difficult to extract the per capita income of the traded-good sector alone. Note that the two constants p_K and k are dropped from the system of equations since they can be embedded in the functional forms along with the other constants.

In a nutshell, the model consists of three equations that specify the indirect utility function for the representative consumer (9), and the two unit-cost functions of the two sectors (10) and (11). Equation (9) suggests that human settlements are determined by income, housing price, and other regional attributes including agglomeration factors. Equation (10) tells us that the income coming from the traded-good sector is determined by productivity, as theoretically and empirically validated by the literature (Solow, 1956; Hall and Jones, 1999). The model suggests that the TFP in turn depends on population size and other regional attributes. Equation (11) tells us that the housing price is a function of the income, population density, and productivity, and the productivity in turn depends on regional attributes. Equilibrium population, income, and housing price are obtained through interactions among the three economic agents in the labor and housing markets. The system of equations has population size, income, and housing price as simultaneously determined endogenous variables.

Imputation of a Regional Attribute's Value

The value of a regional attribute is computed as its implicit price for the representative individual and as its effect of cost savings for the two sectors.

First, the effect on individuals' utility of an attribute is measured in terms of its implicit price, that is, the income that the individual is willing to give up for a small

[4]According the REIS data, only 4.3 percent of total income in Ohio comes from the construction sector, and hence the income share taken by the housing sector may be assumed to be too tiny to influence the total income.

attribute increase while maintaining her quality of life (Roback, 1982). Formally, the implicit price $p^*_{z_j}$ of an attribute z_j is computed as

$$p^*_{z_j} = \frac{V_{z_j}}{V_{inc}}, \tag{12}$$

where V_{z_j} and V_{inc} denote the partial derivatives of the indirect utility function with respect to the attribute z_j and income, respectively. Substituting (6) for the indirect utility function in (12) yields the implicit price of the attribute z_j and population size as

$$p^*_{z_j} = \frac{\partial \log(A(\mathbf{s},\ \mathbf{q}))}{\partial \log(z_j)} \cdot \frac{inc}{z_j}, \tag{13}$$

$$p^*_{pop} = a_1 \cdot \frac{inc}{pop}. \tag{14}$$

Equivalently, (13) can be also expressed using the explicit form of the indirect utility function in (9) as follows:

$$p^*_{z_j} = \frac{\partial \log(pop)/\partial \log(z_j)}{\partial \log(pop)/\partial \log(inc)} \cdot \frac{inc}{z_j}. \tag{15}$$

Since (9) suggests that $a_1 = -1/[\partial \log(pop)/\partial \log(inc)]$, the implicit price of population size in (14) is written as

$$p^*_{pop} = -\frac{inc/pop}{\partial \log(pop)/\partial \log(inc)}. \tag{16}$$

If the implicit price is positive, then the factor is an amenity to individuals. Otherwise, it is a disamenity.

The effect on productivity is represented by cost savings or increases incurred by firms to produce the same quantity of goods. Formally, the cost change caused by a regional attribute z_j can be represented in terms of the elasticity of cost as follows:

$$e_{Cz_j} = \frac{\partial \log(C)}{\partial \log(z_j)}, \tag{17}$$

$$e_{Gz_j} = \frac{\partial \log(G)}{\partial \log(z_j)}, \tag{18}$$

where C and G are unit-costs for the two sectors, and e_{Cz_j} and e_{Gz_j} denote the elasticities of cost with respect to the attribute z_j for the two sectors, respectively. Substituting (7) and (8) for the unit cost functions in (17) and (18) yields the elasticities of cost as follows:

$$e_{Cz_j} = \frac{\partial \log(F(\mathbf{s},\ \mathbf{q}))}{\partial \log(z_j)},$$

$$e_{Gz_j} = \frac{\partial \log(H(\mathbf{s},\ \mathbf{q}))}{\partial \log(z_j)}.$$

Equivalently, they can be also expressed using the explicit functions of production costs for the two sectors in (10) and (11). As explained earlier, cost savings in the traded-good sector lead to regional income increases with the elasticity of the income share of that sector, i.e., $\partial \log(inc)/\partial \log(C) = -\phi$. Cost savings in the housing sector obviously lead to housing price decreases with the elasticity of one in competitive housing markets, i.e., $\partial \log(hpric)/\partial \log(G) = 1$. Using these relationships, the cost elasticities in (17) and (18) can be written as

$$e_{Cz_j} = -\frac{1}{\phi} \cdot \frac{\partial \log(inc)}{\partial \log(z_j)}, \tag{19}$$

$$e_{Gz_j} = \frac{\partial \log(hpric)}{\partial \log(z_j)}. \tag{20}$$

If the cost elasticity of a factor is negative, the factor causes a productivity gain, and otherwise a productivity loss.

For policy makers, it is relevant to translate the above cost elasticity to a dollar income change. For the traded-good sector, all the cost savings due to a productivity increase are captured by worker–consumers through wage increases, since the price of the traded-good is given. Using the relation in (19), the cost elasticity with respect to a factor is directly translated into a wage–income change per sector worker, or the latter can be computed directly from the income Equation (10). Formally it is computed as follows:

$$p^C_{z_j} = \frac{1}{\phi} \cdot \frac{\partial inc}{\partial z_j}. \tag{21}$$

For the housing sector, we introduce the notion of "willingness-to-pay-wages" to measure the valuation of an agglomeration factor by a representative housing firm. This is the hypothetical wage–income increase that the firm is willing to pay its workers to compensate for a productivity increase while holding production cost and hence housing price constant. This can be computed as the implicit price of an attribute to a consumer. That is, take the ratio of the partial derivatives of the cost function with respect to the attribute and with respect to wage–income. Equivalently, it can be expressed using the explicit function of housing production cost in (11) as follows:

$$p^G_{z_j} = \frac{G_{z_j}}{G_{inc}} = \frac{\partial hpric/\partial z_j}{\partial hpric/\partial inc}, \tag{22}$$

where $p^G_{z_j}$ denotes the effects on income of an attribute z_j for housing sector. This represents the hypothetical increase in the housing sector's wage–income. To derive the per capita income increase for the whole population, one multiplies the result by the income share of the housing sector, $1 - \phi$.

4. THE EMPIRICAL MODELING

Spatial Econometric Model

The empirical model takes the form of the SEM (9)–(11). This allows us to separate the effects on the three agents of various agglomeration factors but does not capture the spatial dependence of agglomeration economies. This is particularly problematic in geographically contiguous regions, as the arbitrariness of geographical unit of analysis and spatial processes lead to spatial autocorrelation (SAC) problems. To deal with this, we incorporate an SAR model into the three structural equations (9)–(11).

Each equation includes one spatial lag of the dependent variable to capture its spatial spillovers. The auto-regressive spatial lag terms summarize the spillovers of utility and productivities in the two sectors. This is sufficient to measure the order of magnitude of overall spillover effects. The limited number of observations makes it impossible to include the cross-regressive spatial lags and the spatial lags of individual explanatory variables in the model. Spatial errors are introduced to reflect potential spatial dependence in the disturbance process as well. As a result, the model is written as

$$\log(pop_i) = \lambda_1 \overline{\log(pop_i)} + \delta_{10} + \delta_{11}\log(inc_i) + \delta_{12}\log(hpric_i) + \delta_{13} prtxshr_i + \mathbf{s}_i\,\boldsymbol{\eta}_1 + \mathbf{q}_i\zeta_1 + \varepsilon_{1,i}$$
$$\varepsilon_{1,i} = \rho_1\bar{\varepsilon}_{1,i} + u_{1,i} \quad \text{with} \quad u_{1,i} \sim iid\ N(0, \sigma_1^2), \tag{23}$$

$$\log(inc_i) = \lambda_2 \overline{\log(inc_i)} + \delta_{20} + \delta_{21}\log(pop_i) + \delta_{22}\log(indtxr_i) + \mathbf{s}_i\,\boldsymbol{\eta}_2 + \mathbf{q}_i\zeta_2 + \varepsilon_{2,i}$$
$$\varepsilon_{2,i} = \rho_2\bar{\varepsilon}_{2,i} + u_{2,i} \quad \text{with} \quad u_{2,i} \sim iidN(0, \sigma_2^2), \tag{24}$$

$$\log(hpric_i) = \lambda_3 \overline{\log(hpric_i)} + \delta_{30} + \delta_{31}\log(inc_i) + \delta_{32}\log(pop_i) + \delta_{33}\log(area_i) + \delta_{34} indtxr_i + \mathbf{s}_i\,\boldsymbol{\eta}_3 + \mathbf{q}_i\zeta_3 + \varepsilon_{3,i}$$
$$\varepsilon_{3,i} = \rho_3\bar{\varepsilon}_{3,i} + u_{3,i} \quad \text{with} \quad u_{3,i} \sim iidN(0, \sigma_3^2), \tag{25}$$

where $\overline{\log(pop_i)}$, $\overline{\log(inc_i)}$, and $\overline{\log(hpric_i)}$ are the spatial lags of the three dependent variables; $prtxshr_i$ is the share of property tax in income, which is a proxy for the income share of all local taxes in (9); $indtxr_i$ is industrial and commercial property tax rate, which is a proxy for the rates of all local taxes of the two sectors in (10) and (11); δ's are scalar regression parameters, and **η**'s and **ζ**'s are vector parameters with elements of possible zeros; λ's and ρ's are autoregressive parameters for the spatial lags and the spatial disturbances, respectively; ε's are the disturbance terms; and $\bar{\varepsilon}$'s are the spatial lags of the three disturbance terms. The spatial lag of a variable is defined as the mean of the variable over the neighboring observations based on the Rook's definition of contiguity as usual.[5] This can be expressed with a spatial weight matrix **W** that is constructed from a binary $n \times n$ matrix identifying neighbors, standardized by row to sum to unity, where the number of observations is n. Then the spatial lag of a variable y for ith observation is formally defined as $\bar{y}_i = \mathbf{W}_i\,\mathbf{y}$, where $\mathbf{W}_i$ is the ith row of the matrix and $\mathbf{y}$ is the vector of the variable for all observations.

The presence of spatial lag terms complicates the interpretation of model coefficients. LeSage and Pace (2008, 2009)) point out the difference in the interpretation of the coefficients in models with and without spatial lag terms. In the absence of a lag term, there are neither neighborhood effects nor feedbacks from neighbors back to the original spatial unit. They argue that for spatial regression models neighborhood and feedback effects invalidate the conventional interpretation of a regression model. In the autoregressive model, the coefficient of an explanatory variable is no longer the complete partial effect of that variable on the dependent variable—as the complete effect would account for feedback effects. In order to capture the neighborhood and feedback effects appropriately, they suggest estimating the average direct effect (ADE) and average indirect/neighborhood effect (ANE). In addition, we have derived a measure for the effect on nearest neighbors, i.e., the average first-order neighborhood effect (A1NE). This is the effect that a change in one observation unit has on its nearest neighbors on average. It is of interest when thinking about the relationship between central and suburban areas in metropolitan areas, or the relationship between an urban area and its rural neighbors. While ANE captures the total neighborhood effects, i.e., the effect on all the other units, A1NE captures only the average effect on first-order neighbors as defined by the weight matrix.

[5]The spatial weight matrix based on the Rook's definition of contiguity is commonly used to represent geographical connectivity in the spatial statistics literature (Griffith, 2000; Tiefelsdorf and Griffith, 2007; Patuelli et al., 2009).

For notational simplicity of exposition, suppose another simple data-generating process as follows:

$$\mathbf{y} = \lambda \mathbf{W}\mathbf{y} + \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\iota}_n \alpha + \boldsymbol{\varepsilon}, \tag{26}$$

where $\mathbf{y}$ is an $n \times 1$ vector of a dependent variable; $\mathbf{W}$ is an $n \times n$ weight matrix; $\mathbf{X}$ is an $n \times p$ matrix of regressors except the constant term; ι_n is an $n \times 1$ vector of ones; λ is a scalar spatial parameter; $\boldsymbol{\beta}$ is a $p \times 1$ vector of parameters; α is a scalar parameter; and $\boldsymbol{\varepsilon}$ is an $n \times 1$ vector of *iid* normal disturbances. LeSage and Fischer (2008) and LeSage and Pace (2009) define ADE as the average of own effects on the dependent variable of a change of an explanatory variable in an observation unit. For the model in (26), the ADE for the rth explanatory variable is computed as

$$ADE_r = \beta_r \frac{1}{n} tr[(\mathbf{I}_n - \lambda \mathbf{W})^{-1}], \tag{27}$$

where $tr(\cdot)$ is the trace operator and β_r is the rth element of the parameter vector $\boldsymbol{\beta}$. Note that the ADE is the regression coefficient β_r multiplied by the factor $tr[(\mathbf{I}_n - \lambda\mathbf{W})^{-1}]/n$. We call this factor the average direct effect factor (ADEF). We define A1NE as the average of the weighted average effects on the first-order neighbors' dependent variable of a change in an observation unit's explanatory variable. Formally, the A1NE for the rth explanatory variable is computed as

$$A1NE_r = \beta_r \frac{1}{n} tr[W(\mathbf{I}_n - \lambda \mathbf{W})^{-1}], \tag{28}$$

where the matrix $\mathbf{W}$ defines the first-order neighbors and their weights.[6] Note that the A1NE is the regression coefficient β_r multiplied by the factor $tr[\mathbf{W}(\mathbf{I}_n - \lambda\mathbf{W})^{-1}]/n$, which we call the average total effect factor (A1NEF). One can show that this factor is increasing in the spatial parameter $\lambda > 0$, which is reasonable as a high value of λ implies high spillovers. The ratio of A1NEF to ADEF, which we call the average first-order neighborhood effect to direct effect ratio (A1NDR), gives us the relative strength of the first-order neighborhood effect to the direct effect. Formally, it is defined as

$$A1NDR = \frac{tr[\mathbf{W}(\mathbf{I}_n - \lambda \mathbf{W})^{-1}]}{tr[(\mathbf{I}_n - \lambda \mathbf{W})^{-1}]}. \tag{29}$$

Note that this ratio depends on the SAR parameter of the model as well as the exogenous weight matrix, i.e., geographical configuration of observations.

We apply this interpretation of SAR models to the valuation of the effects of agglomeration factors. Since spatial lags in the model bring about the neighborhood and feedback effects, this should be taken into account while computing the values of an agglomeration factor for both worker–consumers and firms. The valuation methods set forth in Section 3 apply in the same way, but the ADE and A1NE of an agglomeration factor should be substituted for the partial derivative of a dependent variable with respect to that factor for the own effects and the first-order neighborhood effects, respectively. When a value is translated to own income equivalent, the reference should be the ADE of income.

Note that the model specification and interpretation methods described above lead to a peculiar result for the neighborhood effect of an agglomeration factor. The strength of the neighborhood effect, relative to the own effect is invariant among agglomeration factors. The ratio of the two effects always equals A1NDR, which varies only with agents, i.e., equations, as we permit a spatial lag of the dependent variable but not of the explanatory variables for each equation. The overall spillovers are captured by only one

[6]It can be derived based on the discussion in Lesage and Fischer (2008) and Lesage and Pace (2009). A derivation is available upon request.

spatial parameter λ, and it represents the overall tendency of spatial processes for the agent represented by each equation. Another factor impacting the neighborhood effect is the geographical configuration of observations as summarized by the weight matrix. As A1NDR is a function of the spatial parameter λ and county adjacencies, it summarizes the overall neighborhood effect for each agent.

Data

The model is applied to 88 Ohio counties in 2000, with each county representing a region and spatial unit of observations. The rationale is that 73 percent of Ohio employers work in the counties of residence according to the 2000 census and thus the county can be roughly defined as the relevant labor market. The county is often used as a unit for measuring regional amenities as well (Carlino and Mills, 1987; Hoehn, Berger, and Blomquist, 1987; Blomquist et al., 1988; Rupasingha and Goetz, 2004). Data availability is also a big advantage in selecting the county as a spatial unit. The remaining error coming from the arbitrariness of the spatial unit is dealt with by taking into account spatial dependence, discussed in the modeling section.

All data are published or open to the public from the following sources: wage, income, and employment from the Regional Economic Information System (REIS) of Bureau of Economic Analysis (BEA); population and median housing value from the 2000 Census of Population and Housing; road density and traffic volumes from the Ohio Department of Transportation (ODOT); taxation data from Ohio Department of Taxation website; unemployment rates from the Ohio Labor Market Information website; and snow fall from the Midwestern Regional Climate Center. County boundaries come from TIGER/Line® 2000, and the coordinates of international airports are obtained from Google Maps. For details of the definition of variables and data sources, see Appendix 2.

Variables for Agglomeration Factors

Agglomeration factors are chosen to reflect three sources. First, where possible they are designed to reflect the mechanisms or causes by which agglomeration economies and diseconomies are transmitted. Second, they are designed to reflect the effect of the agent missing from the structural equations-–government. Third, there are other variables such as the level of human capital, which both impact and are impacted by the size of the agglomeration.

Causes of agglomeration

We follow the sources listed by Puga (2010) but add population size as a catch-all residual factor to proxy congestion, matching, learning, and labor pool sharing associated with agglomeration size, for which better measures did not exist. We treat economies resulting from increased competition (survival of the fittest) as another form of agglomeration economies, as at the aggregate level it is indistinguishable from other economies that raise productivity or reduce consumer’s cost. Hence, the causes of agglomeration economies recognized in the model are as follows:

Specialization in manufacturing. To capture this source, we use a location quotient for manufacturing, *lqman*, at the two-digit SIC level. While it does not capture variety outside manufacturing or at a higher digit level, it provides an estimate of manufacturing variety and degree of specialization at the county level.

Facility sharing. Two indicators are chosen as likely to have a measurable effect on housing productivity and as representative of nonrivalrous public and club goods: road density *rdnt* and the public supply share of domestic water consumption, *water*. Both are suggestive of the ability to socialize development costs that otherwise must be borne by the developer and individual consumer.

Variety. Taste for variety is the dominant source of agglomeration economies modeled in the NEG. We use per capita traffic flow, *pctrf,* as an indicator of variety as it is positively associated with density and thickness of market, and as a result, reduced travel. Of course, per capita traffic flow decreases not only because less travel is required to reach a given level of opportunities, but also because a rising density generates greater congestion for given road investments—and hence, shifts private vehicle travel to public transport. The factor captures both effects.

Advantages from competition. We use retail size, as measured by employment per retail establishment, *szret*, as an indicator of advantages from competition. Firm size increases pricing power, but also scale economies. We would expect larger markets on average to support larger firms, and possibly, several large firms with national marketing and competitive strategies, associated with agglomeration economies.

Government service quality and cost

Second, our agglomeration factors describe the quality and cost of infrastructure and services, to reflect the way government as the agent missing from the structural equations impacts population size. To some extent, there is an overlap with the previous set of factors, including road and water infrastructure factors used to proxy facility sharing, though this is not a problem, as these are two interpretations of the same factors consistent with each other.

The following considers public services for each of the three agents. While a few public services are pure public goods and to some extent used by all three agents, most services are not. This is obvious for service costs, as different agents are subject to different taxes. It is also true for service quality as services have a combination of public good, club, and private good attributes, which varies among agents. Consider each agent in turn.

Public service quality to consumers. This is measured by the residential property tax rate, *restxr*. While neither an output nor traditional input measure, the property tax rate is taken as admission fee for a club and indicator of *preference* for education, or more generally, preference for public services. Those with a preference for services take the fee as an indicator of the level of service they will receive, and pay a premium to be close to others with similar preference. As Tiebout (1956) suggests, a high service fee has to be bundled with a high service level.

Public service cost to consumers. This is proxied by the share of property tax in income, *prtxshr*, i.e., the total property tax collected by all types of local government, divided by the total income of consumer-residents, as property taxes are a key source of funds for services (including sales taxes) used in Ohio.

Quality of public services to traded-good sector. This is proxied by an output and input variable. Educational services are proxied by the 12th grade pass scores 12*gps*, i.e., the average percentage of students who have met the minimum State of Ohio scores in reading, writing, math, science and citizenship. Resource input is proxied by per capita operating expenditures of county governments, *pcexp*.

Cost of public services to traded-good sector. This is approximated by the commercial, industrial, and mineral property tax rate, *indtxr*. Firms across counties are assumed to have the same unit cost structure. However, industrial property taxes alter this structure, by imposing an extra burden on industries, depending on their location.

Quality of public services to housing producers. This is proxied by two variables, *rdnt* and *water.* As already discussed, both are expected to decrease the cost to housing suppliers.

Cost of public services to housing producers. Again, this is approximated by the commercial, industrial, and mineral property tax rate, *indtxr*.

Other agglomeration factors

This includes three variables, two measures of human capital, and the third to proxy factors such as congestion, labor pooling, and improved matching for which no individual proxies are available.

Human capital. Human capital is created in two ways—through local schooling and through migration. The effect of schooling on human capital is measured by 12*gps*, and has already been discussed. The effect of migration is proxied by the percentage of the population 25 years and older with associate's degree or higher. Though local education will have a role, in rural counties without a college in particular, the variable reflects education acquired elsewhere. A higher level of education raises productivity and earnings and conversely, a larger urban economy attracts a better qualified labor force, as its rewards are greater for people with advanced skills and attainment.

Population. Population size, *pop***,** can have positive or negative effects. However, since the positive effects have mostly been modeled while the negative effects (pollution, congestion) have not, population captures, at least to some degree, these negative effects. Hence, we expect population to potentially have negative agglomeration effects on productivity and utility. Agglomeration diseconomies have been largely neglected in the NEG literature, but without them, agglomeration economies are underestimated, and represent only net-effects.

Estimation Method

County adjacency suggests the presence of spatial autocorrelation in the disturbance terms, and presents a challenge in the estimation of simultaneous equations, as the variance–covariance matrix of the disturbance terms is complicated. For single equation models, several methods are used to solve the autocorrelation problem. The spatial econometrics literature widely uses the Cliff-Ord-type SAR model that contains spatial lags in the dependent variable, exogenous variables, and the disturbance term (Anselin, 1988; Kelejian and Prucha, 1998, 1999; Anselin, Florax, and Rey, 2004; Dormann et al., 2007; LeSage and Pace, 2009). The geography literature sometimes uses spatial filtering with eigenvectors of the weight matrix, based on the interpretation that SAC is a result of misspecification (Griffith, 1996, 2000; Getis and Griffith, 2002; Tiefelsdorf and Griffith, 2007; Patuelli et al. 2009). When applied to SEMs, however, these single equation methods lead to multiple complications, as shown in the spatial econometrics literature (Henry, Schmitt, and Piguet, 2001; Rey and Boarnet, 2004; Kelejian and Prucha, 2004).[7] While maximum likelihood (ML) estimators have often been used, their asymptotic properties have not been established until Lee (2004) and they are often not feasible for moderate or large size samples (Kelejian and Prucha, 1999). Kelejian and Prucha (2004) suggest a computationally simpler GS3SLS that combines two (or three) stage least squares with the generalized moments method (GMM) to estimate simultaneous systems with spatial

[7]To our knowledge, spatial filtering has never been used for the estimation of an SEM.

TABLE 1: Structure of the Model

	RHS			
LHS	Endogenous Variables (Structural Sense)	Endogenous Variables (Econometric Sense)	Exogenous Variables	Instrument Variables
log(*pop*)	log(*inc*), log(*hpric*), $\overline{\log(pop)}$	*prtxshr*, log(*szret*), *restxr*, log(*pctrf*)	*snow*, log(*area*), *greatlakes*, *jantemp*	*crime*, log(*crime*), *lqcns*, log(*snow*), *vacn*, *lqret*, *nofreez*, log(*nofreez*) + first- and second-order lag variables of all the exogenous and instrumental variables
log(*inc*)	log(*pop*), $\overline{\log(inc)}$	*educ*, *indtxr*, log(*pcexp*), 12*gps*	*age*, *agesq*, *unemp*, *lqman*, *distair*	
log(*hpric*)	log(*inc*), log(*pop*), $\overline{\log(hpric)}$	log(*rdnt*), *water*, *indtxr*	log(*area*), *hyear*, *hroom*	

lags and spatial errors. Subsequent comparative studies on the ML and GMM estimators show that Kelejian and Prucha's method is better in computational simplicity and applicability than ML estimators (Kelejian and Prucha, 2008; Walde, Larch, and Tappeiner, 2008; Bivand, 2009).

In this paper, we adopt Kelejian and Prucha's (2004) method to estimate the simultaneous system of spatially correlated equations and iterate the procedure to obtain better estimates of spatial error parameters. We iterate the process of GS3SLS until the values of spatial parameter estimates converge.[8]

Regarding the endogeneity, the model includes many endogenous variables in the econometric sense that they are correlated to the disturbance terms. Besides the three simultaneously determined endogenous variables log(*pop*), log(*inc*), and log(*hpric*), agglomeration factors such as infrastructure are all potentially endogenous as they impact the three variables and in turn are influenced by them. The endogeneity of each agglomeration factor is tested using the Durbin–Wu–Hausman test, as applied to a test of a subset of the regressors; see Baum, Schaffer, and Stillman (2003) for technical details. For the 11 agglomeration variables for which we expect to find endogeneity based on theoretical and plausibility arguments, we find endogeneity for 10 in 1 or more equations of the model at the 30 percent level of significance. The 30 percent level of significance is used to be on the conservative side. When using instruments for a variable that was incorrectly classified as endogenous when in reality it was exogenous, we lose efficiency but estimates remain consistent. This is more important than a loss of consistency caused by incorrectly accepting a variable as exogenous, when in fact it is endogenous. Once endogeneity is determined, only exogenous variables are used as instrument variables (IVs).

Table 1 shows the variables used. Three variables are endogenous in the structural sense that each is modeled through a separate structural equation: log(*pop*), log(*inc*), and log(*hpric*). Another 11 variables represent agglomeration factors, of which only the endogeneity of *lqman* proves statistically not significant. All 10 variables are modeled using the same set of instruments. In addition, three variables represent spatial lag variables for the three endogenous variables—$\overline{\log(pop)}$, $\overline{\log(inc)}$, and $\overline{\log(hpric)}$ computed for each county as the average of adjacent counties. The remaining 21 variables are exogenous

[8]We programmed it using Stata® 11 based on the Kelejian and Prucha's (2004). In our estimation, the convergence criterion for the iteration is that the root mean squares of the three parameters is smaller than 0.001

regional attributes, such as snow fall, weather attributes, distance to the nearest airport and others. Some of them are not included in the model but used just as IVs.

The IVs are *crime*, log(*crime*), *lqcns*, log(*snow*), *vacn*, *lqret*, *nofreez*, log(*nofreez*), and the first- and second-order lag variables of all the exogenous and instrumental variables. All these variables are somewhat correlated to the agglomeration factors but are supposedly given exogenously.[9] The lags of all the exogenous and IVs are also included as IVs in order to instrument the three spatial lag terms in the model, as suggested by Kelejian and Prucha (2004).

5. EMPIRICAL RESULTS

Parameter Estimation Results

The final structure of the model consists of three structural equations summarized in Table 1. The first equation represents the individual's consumption behavior, and the second and third the firms' production behavior in the two sectors. The selection of explanatory variables in each equation is a result of plausibility arguments first and empirical confirmation second. The following justifies the selection for variables not already discussed earlier.

First, adjacency to the Great Lakes, *greatlakes*, significantly impacts consumer's utility but not a firm's productivity. The historical advantage of the Great Lakes to the traded-good sector in the form of access to ports and their potential disadvantage in the form of high union wages are no longer important or cancel out. Second, snow and January temperature also appear in the worker–consumer equation only, and proved not significant elsewhere. Third, variables related to human resources, *educ*, 12*gps*, and *age* with its square term, are significant in the traded-good but not the housing sector, which traditionally favor on-the-job training over education. For worker–consumers, education raises income but its effect is already controlled for by including income in the model. Fourth, infrastructure variables, *rdnt* and *water*, are included in the housing but not the traded-good sector equation. Subdivision regulations raise a developer's cost where basic infrastructure is not available, but these systems typically represent a small share of production costs and hence are not significant in the traded-good sector. Fifth, county area is included in the housing and worker–consumer equations, but is not significant in the traded-good sector. After controlling for population, *area* signifies smaller density and decreased congestion but less variety of services, making its sign difficult to determine.

The full results of the iterative GS3SLS are reported in Table 2. The table shows the estimates of the coefficients for the three structural equations with inference statistics.

The parameters of the utility and housing production function provide initial evidence that the model is reasonable and plausible. To estimate the parameters of the housing production function, the share of wages in income is approximated as $\boldsymbol{\varpi} = 0.678$ based on REIS income data for the state of Ohio in 2000. This yields cost share estimates for land, labor, and capital in housing production of 10, 31, and 59 percent, respectively; see Table 3. The capital and housing shares are quite reasonable, while the land cost share is only about half the value suggested in the real estate and urban economics literature (Roback, 1982). This is plausible however, as there is evidence that the Midwestern share

[9]One may think that the variables of crime rate and vacancy rate, *crime* and *vacn*, are endogenous, but an endogeneity test suggest that they endup not being endogenous. This is due to the fact that the two variables are determined by both generation and enforcement, or both supply and demand and thus only one side does not fully determine them. For instance, crime may occur frequently in a highly populated region, but the police service is also good in that region. So the net effect of population size is ambiguous. The same argument can be applied to housing vacancy rate.

TABLE 2: Full Regression Results for the Structural Equations

LHS Variable	RHS Variable	Estimate	Standard Error	t-Value	Pr > |t|
log(*pop*)	log(*pop*)lag	0.3915853	0.091401	4.2843	0.0001
	log(*inc*)	3.129124	0.465856	6.7169	0.0000
	log(*hpric*)	−1.13344	0.348607	−3.2513	0.0017
	prptxshr	−27.73352	11.03123	−2.5141	0.0140
	restxr	0.0882298	0.010298	8.568	0.0000
	log(*szret*)	0.7353888	0.332106	2.2143	0.0298
	log(*pctrf*)	−0.91053	0.205864	−4.423	0.0000
	greatlakes	0.4594739	0.163706	2.8067	0.0064
	log(*area*)	1.311045	0.221379	5.9222	0.0000
	snow	−0.00881	0.003906	−2.2556	0.0270
	tempjan	0.0646903	0.022315	2.899	0.0049
	constant	−30.0268	3.873981	−7.7509	0.0000
	R-squared	0.8604	Adjusted R-squared		0.8401
	$\hat{\rho}_1$	0.1149	$\hat{\sigma}_1$		0.1324
	ADEF	1.0364	A1NEF		0.0931
log(*inc*)	log(*inc*)lag	0.1260172	0.08576	1.4694	0.1458
	log(*pop*)	0.0211475	0.009848	2.1473	0.0350
	indtxr	−0.0036264	0.001119	−3.241	0.0018
	log(*pcexp*)	0.072458	0.041457	1.7478	0.0845
	educ	1.507873	0.131409	11.475	0.0000
	12*gps*	0.0063145	0.001802	3.5035	0.0008
	lqman	0.0376702	0.011665	3.2293	0.0018
	log(*distair*)	−0.0006734	0.000401	−1.6774	0.0976
	age	0.0858956	0.030535	2.813	0.0062
	agesq	−0.0009349	0.00044	−2.1247	0.0369
	unemp	−0.0178829	0.009852	−1.8152	0.0734
	constant	6.137866	0.84879	7.2313	0.0000
	R-squared	0.9117	Adjusted R-squared		0.8989
	$\hat{\rho}_2$	0.1979	$\hat{\sigma}_2$		0.0025
	ADEF	1.0032	A1NEF		0.0256
log(*hpric*)	log(*hpric*)lag	0.1962817	0.078801	2.4909	0.0149
	log(*pop*)	0.1434769	0.028278	5.0738	0.0000
	log(*inc*)	0.5065929	0.098699	5.1327	0.0000
	indtxr	0.0020221	0.001581	1.2787	0.2048
	log(*rdnt*)	−0.3006243	0.066904	−4.4934	0.0000
	water	−0.2188807	0.060489	−3.6185	0.0005
	hyear	−0.0115218	0.001168	−9.8687	0.0000
	hroom	0.191342	0.037453	5.1088	0.0000
	log(*area*)	−0.1150436	0.052531	−2.19	0.0315
	constant	2.902355	1.150041	2.5237	0.0136
	R-squared	0.9137	Adjusted R-Squared		0.9037
	$\hat{\rho}_3$	0.2213	$\hat{\sigma}_3$		0.0045
	ADEF	1.0081	A1NEF		0.0412

TABLE 3: Estimates of Utility and Housing Production Functions' Parameters

$1-\hat{\theta}$	$\hat{\theta}$	$\hat{\alpha}_2$	$\hat{\beta}_2$	$\hat{\alpha}_2$
0.3622	0.6378	0.1032	0.3078	0.5890

is lower than the U.S. average, and 48 of Ohio's 88 counties are nonmetropolitan with small populations and low land rent. These counties account for just 19 percent of the population but 55 percent of county observations. Second, the housing expenditure share is about 36 percent and hence, significantly higher than the share in Ohio. We attribute this to the fact that housing price represents not only housing cost but also the cost of other nontraded-goods and services. Finally, note that the parameters for the production function of the traded-good sector cannot be estimated because its equation combines them into a single income.

Values of Agglomeration Factors

Table 4 shows the effects of an agglomeration factor on an individual's utility and a firm's productivity, based on above parameters and the mean value of the variables. In the case of worker–consumers, implicit prices are expressed as per capita income equivalents. In the case of the traded-good and housing sectors, gains take the form of productivity growth or decline, expressed in terms of compensatory changes in factor payments that leave sector unit cost unchanged. Applying the sector share to sector savings yields the effect on average county income. In addition, Table 4 shows the cost elasticities with respect to agglomeration factors. Table 5 shows the implicit prices of each agglomeration factor for neighboring counties, using the spatial lag term in the three structural equations. These results are not available elsewhere in the literature, though the presence of spatial autocorrelation in similar research elsewhere makes it clear that these effects exist. Again, the effects are expressed as per capita gains to worker–consumers and sector workers, though in this case they are the consumers or sector workers in an average neighboring county. As discussed in the section on the *Spatial Econometric Model*, the values in Table 5 are estimates for which significance is not established individually. They are the product of own-county effects, for which significance has been established, and the neighborhood effect as measured by A1NDR (for each of the three dependent variables), which is also significant. However, establishing significance for each of the products individually would require a spatial lag term for each individual variable. The only exception is the amenity value of population size, for which an individual lag term has been estimated as it is both an agglomeration factor and dependent variable in the model.

Hence, consider the estimated values of individual variables, first for the causes of agglomeration, second the quality and cost of services, third other agglomeration attributes, and lastly neighborhood effect.

Causes of agglomeration

Specialization economies. The average specialization index for manufacturing is 1.22, with a minimum value of 0 and a maximum of 2.72. An increase in the index by 0.1 (an 8 percent increase at the mean) raises productivity in the traded-good sector by 0.4 percent, equivalent to $98.8 per sector worker on average.

Facility sharing. A 1 percent increase in road density raises housing productivity by 0.272 percent, or by $146 per construction worker.[10] A 1 percent increase in the share of public water provision raises housing productivity by 0.153 percent, or by $82 per construction worker. In both cases, the mean effect on county income, of course, is much smaller, $8.3 and $4.7 per resident-respectively, given the 5.7 percent employment share

[10]Even if productivity gain is smaller than in the traded-good sector, the compensatory wage is larger because the labor share in total factor cost is smaller (30.8 percent).

TABLE 4: Own Values of Agglomeration Factors

Factors			Value Imputation of Consumers	Cost Changes for Firms by Sector: Traded Good $/Worker	Traded Good Elasticity	Housing $/Worker	Housing Elasticity
Agglomeration Factors							
Causes of agglomeration	0.1 increase in lq for manufacturing	*lqman*	–	$98.8	−0.402%	–	–
Causes of agglomeration/Services	1% increase in road density	*rdnt*	–	–	–	$146.0	−0.272%
Causes of agglomeration/Services	1% increase in pub. supply share in domestic water	*water*	–	–	–	$82.0	−0.153%
Causes of agglomeration	1% decrease in per capita traffic volume	*pctrf*	$71.6	–	–	–	–
Causes of agglomeration	1% increase in retail size	*szret*	$57.8	–	–	–	–
Quality of services to consumers	1% increase in residential property tax rate	*restxr*	$297.9	–	–	–	–
Cost of services to consumers	1% increase in property tax share in income	*prptxshr*	−$57.5	–	–	–	–
Services/Human capital	1% increase in per capita County gov't expenditure	*pcexp*	–	$19.0	−0.077%	–	–
Quality of services to traded-good sector	1% point increase in 12th grade scores	12*gps*	–	$165.8	−0.674%	–	–
Cost of services to the two sectors	1% increase in industrial property tax rate	*Indtxr*	–	−$45.6	0.185%	−$47.2	0.088%
Human capital	1% point increase in associate's degree	*Educ*	–	$397.7	−1.617%	–	–
Residuals	1% increase in population	*Pop*	−$75.9	$5.54	−0.023%	−$13.81	0.026%
	Doubled in distance to international airport	*distair*	–	$17.6	−0.072%	–	–
	Great Lakes location	*greatlakes*	$3, 613	–	–	–	–
	1% increase in land area	*area*	$103.1	–	–	$55.9	−0.104%
	1% increase in annual snow accumulation	*snow*	−$16.5	–	–	–	–
Other Attributes	1 F increase in January average temparature	*jantemp*	$508.6	–	–	–	–
	One year increase in age	*age*	–	−$435.3	1.769%	–	–
	1% point increase in unemployment rate	*unemp*	–	$463.9	−1.886%	–	–
	One year increase in housing age	*hyear*	–	–	–	$556.6	−1.036%
	1% increase in housing size	*hsize*	–	–	–	−$540.4	1.006%

TABLE 5: Neighbor Values of Agglomeration Factors

				Cost Changes for Firms by Sector			
			Value Imputation of	Traded Good		Housing	
Factors			Consumers	$/Worker	Elasticity	$/Worker	Elasticity
Agglomeration Factors							
Causes of agglomeration	0.1 increase in lq for manufacturing	*lqman*	–	$2.51	−0.010%	–	–
Causes of agglomeration/Services	1% increase in road density	*Rdnt*	–	–	–	$5.97	−0.011%
Causes of agglomeration /Services	1% increase in pub. supply share in domestic water	*water*	–	–	–	$3.35	−0.006%
Causes of agglomeration	1% decrease in per capita traffic volume	*pctrf*	$6.4	–	–	–	–
Causes of agglomeration	1% increase in retail size	*szret*	$5.2	–	–	–	–
Quality of services to consumers	1% increase in residential property tax rate	*restxr*	$26.7	–	–	–	–
Cost of services to consumers	1% increase in property tax share in income	*prptxshr*	−$5.2	–	–	–	–
Services/Human capital	1% increase in per capita County gov't expenditure	12*gps*	–	$4.22	−0.017%	–	–
Quality of services to traded-good sector	1% point increase in 12th grade scores	*pcexp*	–	$0.48	−0.002%	–	–
Cost of services to the two sectors	1% increase in industrial property tax rate	*indtxr*	–	−$1.16	0.005%	−$1.93	0.004%
Human capital	1% point increase in associate's degree	*educ*	–	$10.1	−0.041%	–	–
Residuals	1% increase in population	*pop*	$6.1	$0.14	−0.001%	−$0.56	0.001%
	Doubled in distance to international airport	*distair*	–	−$0.45	0.002%	–	–
	Great Lakes location	*greatlakes*	$324.3	–	–	–	–
	1% increase in land area	*area*	$9.3	–	–	$2.28	−0.004%
	1% increase in annual snow accumulation	*snow*	−$1.5	–	–	–	–
Other attributes	1 F increase in January average temparature	*jantemp*	$45.7	–	–	–	–
	One year increase in age	*age*	–	$11.0	−0.045%	–	–
	1% point increase in unemployment rate	*unemp*	–	−$11.9	0.049%	–	–
	One year increase in housing age	*hyear*	–	–	–	$22.9	−0.043%
	1% increase in housing size	*hsize*	–	–	–	−$22.0	0.041%

of the construction sector. These, values are plausible, given the share of public supply of water.

Variety. A 1 percent decrease in per capita traffic flow raises amenities by $71.6 per worker consumer, though this is a net effect, diminished by the cost of increased congestion and the potentially lower utility associated with switching from private to public transportation-–individual effects that cannot be estimated.

Advantages from competition. A 1 percent increase in retail size generates an increase in amenities of $57.8 per consumer, presumably reflecting the reduced prices and greater in-house variety of national retail chains. This result is in line with Fu's (2007) study on the effect of Wal-Mart noted in Section 2.

Service Quality and Cost

Public services impact residents and firms both through a change in quality and cost. Ideally, this permits calculating net benefits, though the nature of the proxies makes it likely that this would overinterpret the results.

Quality of public services to consumers. A 1 percent rise in service quality is valued at $297.90 per capita, i.e., residents are willing to accept an income decrease of close to $300 when moving into a county with a 1 percent higher service quality. This seems high, particularly when compared to a 1 percent increase in service cost. Most likely, a high property tax rate serves as a sign to potential newcomers of the importance existing residents attach to services including in particular, schooling. In that sense, the high implicit price is suggestive more of a club fee required to enter the area and the preferences of the club including its members, than of service quality alone.

Cost of public services to consumers. A 1 percent increase raises property taxes by $7.65 (noting that average property taxes are 2.64 percent of $24,600 in average per capita income), but residents demand $57.50 in increased income to settle in the county. This seems high, but may be plausible if property tax proxies other local nonproperty tax expenditures, including higher income and sales taxes, or if residents have an aversion to a higher tax share, requiring compensatory income payments exceeding the actual cost of the tax increase.

Quality of public service to traded-good sector. Two variables proxy service quality. First, a 1 percentage point increase in 12th grade scores reduces cost in the traded-good sector by 0.674 percent, or by $165.8 per sector worker. Second, a 1 percent increase in county operating expenditures reduces cost by 0.077 percent or $19.0 per sector worker. Both effects are significant and of the right sign. The impact of county expenditures seems too small to be important to firms. However, this is a macro model, and while the impact is small to the average firm, it may be quite important to some firms or subsectors of the traded-good sector.

Cost of public service to traded-good sector. A 1 percent increase in industrial property taxes raises cost by $45.6 per sector worker. This seems plausible. Given an average income per worker of 24,600, a capital factor share of 32.25 percent, an average mileage rate of 48.1, and assuming for illustration a 5 percent real interest rate and average capital life of 10 years, the capital income per worker is $7,934, capital is valued at 61,264, and annual property taxes would be $2,947. Hence, a 1 percent increase in taxes is $30 per worker per year in line with the estimated cost of $45.6.

Quality and cost of public service to housing sector. The two quality variables have been discussed in the section on facility sharing. The industrial property tax mileage rate as a proxy for cost is not significant.

Other agglomeration factors

Human capital. An increase by 1 percentage point in the associate's degree share improves trade sector productivity by 1.6 percent. This is plausible, given evidence from micro studies in labor economics. A 1 percentage point increase in associate's degrees corresponds to an average 0.076 years rise in years of schooling.[11] This implies that an additional year of schooling raises income by 21.3 percent, or close to the range of 4.0 percent to 18.5 percent in the literature; see Ashenfelter and Rouse (1999) for a review. While our estimate lies above this range, it reflects the aggregate impact of schooling, and hence, includes the effect of increased capital and labor productivity on wages and capital rent; see Breton (2009) for the difference between macro- and micro-effects of schooling.

Population. A 1 percent increase in population generates disamenities equivalent to an annual income decline of \$75.9 per capita. This is much larger or of opposite sign than other estimates in the literature. Roback (1982) estimates that an increase of population by 10,000 results in an amenity loss of \$1.5 per year, equivalent to \$0.19 per year for a 1 percent increase of Ohio counties' average population. However, her estimate represent a net effect, whereas our model controls for other, mostly positive, agglomeration factors. In addition, since population size is endogenous, her OLS estimation must be biased. As discussed in the literature review, Tabuchi and Yochita's (2000) estimate is of opposite sign, which we attributed to the difference between net and gross effect, and possibly, cultural differences between Japan and the United States.

Consider next the impact of population on the traded-good and housing sectors. A 1 percent increase in population leads to savings of 0.023 percent (an income rise of \$5.54 per sector worker) in the traded-good sector and to a cost increase of 0.026 percent (an income decrease of \$13.81 per sector worker) in the housing sector. These estimates are comparable to those in the literature (Eberts and McMillen, 1999; Wheaton and Lewis, 2002) which suggests that doubling city size raises productivity by 2–10 percent, a range that covers our results for the traded-good sector. The negative effect on housing sector productivity is consistent with theory, which tells us that the marginal cost of construction increases with rising building height or increased population density.

Control Variables

All control variables have the expected sign and plausible orders of magnitude. Two variables are discussed further. First, the Great Lakes dummy has a positive impact on individual's utility valued at \$3,613. While this likely reflects the Great Lake's leisure and recreational value, it may also be the result of lingering regional industrial legacies (though income effects are already accounted for). However, a Great Lakes location no longer offers firms any significant productivity gains as the variable was not significant in either of the two production sectors.

Second, distance to the nearest international airport identifies the competitive advantage of counties in national and international markets resulting from differences in transport cost. The variable is significant at the 10 percent level. The average distance is 47 miles, and doubling this distance raises the cost in the traded-good sector by 0.072 percent, equivalent to a compensatory reduction in income of \$17.6 per sector worker. While the effect seems small, this is the result of averaging, with many firms not dependent on airports for either input or output.

[11]This translation comes from a simple regression of the variable *educ* on the average years of schooling in each county with the data set for Ohio. The regression results is summarized as $educ = -1.443 + 0.1316 schyrs + \epsilon$ ($R^2 = 0.8946$), where *shcyrs* is "years of schooling" and ϵ is the error term.

Neighborhood Effects

Neighborhood effects to adjacent counties are specified and tested for significance as a group, by equation. They amount to 9.0 percent of own-county effect for worker–consumers, and 2.6 percent and 4.1 percent for the traded-good and housing sectors, respectively. Since spillover effects cannot be tested individually, estimates in Table 5 must be treated with caution. The only exception is the amenity neighborhood effect of population size, which is 8.0 percent of its own effect. All but the traded-good sector effects are significant.

The high county-level neighborhood effects on the consumption side are remarkable, as the agglomeration literature usually argues that agglomeration economies decay rapidly; see Section 2. This result, however, is consistent with our intuition that for metropolitan residents, county boundaries are not important barriers to commutes for work and shopping. The weak neighborhood effect on the production side, however, is in line with the literature, though in the case of the traded-good sector in particular, it may be affected by the rural nature of many of Ohio's counties noted earlier, and might not be repeated in a sample of metropolitan counties.

Amenity effect of population. The most interesting finding is that the neighborhood effect of a population increase is positive, whereas its "own-county" amenity effect is negative. The average county consumer gains \$6.1 in amenities from a 1 percent population increase in an adjacent county, but the same person dislikes growth in her own backyard and requires \$75.9 in compensation for a similar percent increase in her own county.

To illustrate, take a typical metropolitan area with half its population in a central county and the other half in a ring of eight surrounding counties. Looking at the region in isolation, and disregarding spillovers to rural areas as being an order of magnitude smaller, the amenity losses to central county residents from a 1 percent population increase in their own county are over 12 times as high as the amenity gains experienced collectively by suburban residents. As recent population increases have been mostly in suburban counties while central counties have stagnated or declined, suburban quality of life declined, while central county quality of life increased.

Other amenity effects on worker–consumer. Neighboring counties benefit from other agglomeration factors including an increase in retail size, *szret*, a decrease in traffic volume, *pctrf*, and an increase in the property tax rate, *restxr*. The large size and product variety of shopping centers creates catchment areas that extend beyond county boundaries. Services such as parks, libraries, and well-maintained streets benefit customers from beyond county limits; and safer neighborhoods associated with better policing reduce negative spillovers from crime. The cost of services spills over if people commute to neighboring jobs and are subject to their local income taxes. In addition, exogenous agglomeration attributes have neighborhood effects; see Table 5. Specifically, neighbors to Great Lake counties experience amenities, whether or not they have their own access to the shoreline.

Neighborhood productivity effects on production sectors. The effects are small as already discussed, and in case of the traded-good sector, significant only at the 15 percent level. Individual productivity spillovers cannot be tested, but could plausibly be significant for population size and land area in the case of housing, or for degree of specialization and human capital variables such as the *educ* and 12*gps* in the case of the traded-good sector.

6. POLICY IMPLICATIONS

The empirical estimates suggest several ways to raise firm's productivity or consumer's quality of life–-though the general equilibrium framework, of course, means that all such impacts are fleeting. To remain competitive, local areas must constantly innovate. Any substantial advantage is likely to be eroded over time through migration, business expansion or contraction, and possible feedback effects from agglomeration factors.

Policy results emerge at many levels—in terms of our understanding of the nature of agglomeration economies; at the national level, where policy makers discuss spatial strategies and the type of cities they favor; at the state or regional level where local economic development (LED) planners must identify ways to attract businesses to Ohio; at the level of the county, where planners are asked to reverse decline or strengthen competitiveness; and finally, at the level of the individual firm that must decide where to locate. In general, the same empirical results lend themselves to interpretation at any of these levels.

General findings

Population size. The paper confirms the existence of agglomeration economies, but shows that when agglomeration factors are accounted for, size has negative effects on resident's quality of life and positive effects on firm's productivity. Negative effects far outweigh unexplained positive effects and are much larger than estimates in the literature. While in the past population may have been statistically significant but not important in its size, this is no longer the case. Where voters have a choice, they can be expected to back growth control initiatives, particularly if restrictions are limited to population but exclude the jobs provided by the traded-good sector.

City size strategies. The paper's findings do not support policies that favor migration to either small or large cities. The underlying spatial equilibrium assumptions suggest the coexistence of localities of vastly different sizes, all providing similar utility to households and all allowing firms to compete in national or international markets. The findings show that such a framework is plausible, and that it provides significant parameter estimates. Policy makers must react to this environment by developing a package of policies that temporarily, say for a few years or even a few decades, moves the city ahead of its competitors, and temporarily allows its residents to enjoy higher amenity values than are available elsewhere.

Local economic development (LED) policies. The paper considers a large number of agglomeration factors. Without them, two cities of similar size would be thought to provide similar worker–consumer amenities and productivity. Instead now, one looks at the underlying composition of agglomeration factors and may come to entirely different conclusions. Many of these factors are of interest to LED planners as causes of potential economies. While these causes have been postulated in the literature, empirical evidence of their size is often slim. Planners argue about the importance of manufacturing localization as a source of economies, or about the increased competitiveness and lower prices associated with greater size. The findings here provide additional evidence that these effects exist but also suggest that some are quite small and hence may not be worth pursuing.

Neighborhood effects. The model confirms strong spillover effects, particularly for residents. This can be seen as supporting arguments for state regulatory approaches or intercounty cooperation on efficiency grounds.

Detailed Implications

Public services. Model estimates show that public services matter to the competitiveness of a city. Individuals pay a premium in foregone income to be close to others with similar service preference. On the other hand, the findings also confirm tax aversion, as compensatory income payments exceed property tax cash outlays. An alternative interpretation is that the property tax share in income is a proxy for all local taxes and hence high compensatory payments reflect the cost of all local taxes. Either way, the evidence provides no support for the kind of property tax reductions favored in California.

Firms also benefit from public services, including from good schooling, as suggested by high productivity gains both from county public operating expenditures and 12th grade passing scores. Reducing services in response to economic decline may not be a proper policy response as it raises a firm's production cost. A higher property tax coupled with higher public services contributes both to a friendly business climate and improved quality of life.

Transportation and trade. The only variable related directly to the NEG, distance to the nearest international airport, is significant though only weekly so. This supports the NEG model. However, in the context of Ohio, its impact is small but might well be larger for traded-good subsectors that depend more on trade, which may be tested with additional data.

LED instruments. The model justifies the emphasis placed on human resources as a source of LED. High school performance and educational attainment (percent of associate's degrees and higher) both contribute greatly to trade sector productivity. Both are influenced by local decision making, including support for schools and colleges, and the hiring policies of firms. Policy makers, of course, do not impact hiring directly, but still may raise educational attainment through incentive policies and by attracting firms with high skill and educational requirements.

Model results are ambiguous regarding an LED focus on infrastructure. Investment in roads and public water and sewerage networks raises the productivity of the housing sector but has no effect on the traded-good sector or amenities. However, such investments indirectly raise the quality of life via higher wages and lower housing prices that result from greater productivity. Infrastructure is widely recognized as a key variable of regional productivity in some of the literature (Munnell, 1990, 1992; Andrews and Swanson, 1995; Morrison and Schwartz, 1996; Eberts and McMillen, 1999; McCann and Shefer, 2004). However, several recent articles contradict these findings (Holtz-Eakin, 1994; Crihfield and Panggabean, 1995; Holtz-Eakin and Schwartz, 1995; Haughwout, 1998, 2002). Our results confirm both positions, depending on the sector. In the new economy, traditional infrastructure investments such as roads may have become less important as new types of infrastructure come to the fore such as information networks. However, these have not been modeled in this study.

Localization policies that aim to build a cluster of complementary activities are shown to be significant in raising traded-good sector productivity, though the magnitude of the effect is small. This would likely change in a model with greater sector disaggregation, or with sample counties from a larger geographic area than Ohio.

The sunshine effect is well established in the literature, and is both highly significant and of large size, despite limited intra-Ohio temperature variations (the average January temperature is 26.0°, with a maximum of 31.3 and a minimum of 22.0°). This information is important to policy makers both at the state and local level. While the facts cannot be changed, marketing and promotion can counter negatives and highlight positives. The information can be used to promote the sunshine areas of the state, or increase awareness that the lakeside counties suffer not only from deindustrialization but also from a sunshine effect that makes it difficult to compete with the state's more southern locations. Of course, the region has partly compensating advantages from the Lake's leisure value. So depending on whether a firm looks for sunshine or leisure, the estimates provide some guidance as to where to locate, and the compensating wage variations associated with different locations in Ohio.

Development economists know about the productivity advantage of coastal regions, to which by extension the Great Lakes region belongs. However, perhaps because of its manufacturing decline, the region has no effect on productivity. A future paper may include coastal locations elsewhere in the United States, and hence, provide numerical estimates of the potential size of this advantage.

NIMBY. Some of the more interesting conclusions relate to estimated neighborhood effects. Our findings go beyond the evidence already available in the literature that shows the presence of spatial autocorrelation.

First, the presence of neighborhood effects at the county level suggests that impacts spread over distances beyond those suggested by recent research at the level of the firm. While much depends on the issue, economic planning cannot stop at the county level.

Second, while the model is not yet detailed enough to provide us with testable estimates for individual policy spillovers, it does show that as a group, spillover effects are significant for residents, housing, and traded-good sectors. This includes spillovers from policy decisions on the quality and cost of local services in the case of all three; infrastructure delivery in the case of housing; and airport location and human capital variables in the case of the traded-good sector. As the magnitude of these effects becomes clearer, it may give rise to cooperation and arbitrage among neighbors, including ways to provide voice to affected counties, revenue sharing, compensatory payments, and reciprocity arrangements.

Third, population has both negative own-county effects and positive spillovers. Residents dislike the higher density, congestion and pollution associated with a rise in own-county population, but like the variety, low prices, and opportunities associated with living close to populous neighbors. This asymmetry has implications, particularly in metropolitan areas where suburban counties abut a large central county. While the model does not distinguish between rural and urban, or central and suburban counties, the result suggests a tension between counties of unequal size. Where a central county has many times the population of a neighboring suburban county, its net amenities (own county disamenities plus spillovers from suburban neighbors) will be smaller than those enjoyed by suburban counties. This tension may call for legislation at the state level to enable counties in a metropolitan area to share some of the costs and benefits associated with the provision of services.

Concluding Remarks

This study disentangles agglomeration economies in several dimensions: impacted agents, impacting factors, and spatial dependence. This framework can be extended in a number of ways.

Impacted agents. The three agent–two sector framework can be extended to include government as another agent. Assumptions about typical local government behavior then allows us to model some agglomeration factors through separate structural equations that introduce feedback effects from the local economy to the factors.

Impacting factors. Agglomeration factors so far model positive impacts, leaving negative impacts to be estimated as a residual using population size. It may be possible to find proxies for congestion, pollution, and other diseconomies. This would provide further disaggregation and better estimates of the residual impact of population.

Spatial dependence. Different from the literature, our paper shows that agglomeration economies extend over considerable distances and beyond county boundaries. There are several extensions here. First, with a greater number of observations it should be possible to identify individual neighborhood effects rather than the overall agglomeration effects for each agent as estimated so far. Second, agglomeration effects decay at different rates and it should be possible to estimate these rates. Third, one may focus on metropolitan areas and their rural hinterland. This should make it possible to identify neighborhood effects between a central city and suburban ring, or between the metropolitan area and its rural hinterland. Of particular interests would be possible asymmetries in the neighborhood effects between these three types of areas, as mentioned in Section 6.

REFERENCES

Abdel-Rahman, Hesham and Masahisa Fujita. 1990. "Product Variety, Marshallian Externalities, and City Sizes," *Journal of Regional Science*, 30, 165–183.

Andersson, Fredrik, Simon Burgess, and Julia I. Lane. 2007. "Cities, Matching and the Productivity Gains of Agglomeration," *Journal of Urban Economics*, 61, 112–128.

Andrews, Kim and James Swanson. 1995. "Does Public Infrastructure Affect Regional Performance?" *Growth & Change*, 26, 204–216.

Anselin, Luc. 1988. *Spatial Econometrics: Methods and Models*. Dordrecht; Boston: Kluwer Academic Publishers.

Anselin, Luc, R. J.G.M. Florax, and Sergio J. Rey. 2004. *Advances in Spatial Econometrics: Methodology, Tools and Applications*. Berlin; New York: Springer-Verlag.

Anselin, Luc, Attila Varga, and Zoltan J. Acs. 2000. "Geographic and Sectoral Characteristics of Academic Knowledge Externalities," *Papers in Regional Science*, 79, 435–443.

Ashenfelter, Orley and Cecilia Rouse. 1999. *Schooling, Intelligence, and Income in America: Cracks in the Bell Curve*. NBER Working Papers No. 6902, National Bureau of Economic Research, Inc.

Baum, Christopher F. and Mark E. Schaffer. 2003. "Instrumental Variables and GMM: Estimation and Testing," *The Stata Journal*, 3, 1–31.

Bivand, Roger. 2009. "Fitting and Interpreting Spatial Regression Models: An Applied Survey," paper presented at The 5th Nordic Econometric Meeting, School of Economics and Management, Lund, Sweden.

Blomquist, Glenn C., Mark C. Berger, and John P. Hoehn. 1988. "New Estimates of Quality of Life in Urban Areas," *The American Economic Review*, 78, 89–107.

Brakman, Steven, Harry Garretsen, and Charles van Marrewijk. 2009a. "Economic Geography within and between European Nations: The Role of Market Potential and Density Across Space and Time," *Journal of Regional Science*, 49, 777–800.

———. 2009b. *The New Introduction to Geographical Economics*. New ed. Cambridge, UK; New York: Cambridge University Press.

Brakman, Steven and Charles van Marrewijk. 2009. "Introduction: Heterogeneity at Different Spatial Scales," *Journal of Regional Science*, 49, 607–615.

Breton, Theodore R. 2009. "A Reconciliation of the Macro and the Micro Effects of Schooling on Income," SSRN Working Paper No. 1455161, Social Science Research Network, available at SSRN: http://ssrn.com/abstract=1455161.

Burnell, James D. and George Galster. 1992. "Quality-of-Life Measurements and Urban Size: An Empirical Note," *Urban Studies*, 29, 727–735.

Carlino, Gerald A. 1982. "Manufacturing Agglomeration Economies as Returns to Scale: A Production Function Approach," *Papers in Regional Science*, 50, 95–108.

Carlino, Gerald A. and Edwin S. Mills. 1987. "The Determinants of County Growth," *Journal of Regional Science*, 27, 39–54.

Carlsen, Fredrik, Jørn Rattsø, Bjørg Langset, and Lasse Stambøl. 2006. "*Using Survey Data to Study Capitalization of Local Public Services*," Working Paper No. 8106, Department of Economics, Norwegian University of Science and Technology.

Charlot, Sylvie and Gilles Duranton. 2004. "Communication Externalities in Cities," *Journal of Urban Economics*, 56, 581–613.

Ciccone, Antonio and Robert E. Hall. 1996. "Productivity and the Density of Economic Activity," *The American Economic Review*, 86, 54–70.

Coles, Melvyn G. 1994. "Understanding the Matching Function: The Role of Newspapers and Job Agencies," C.E.P.R. Discussion Papers.

Coles, Melvyn G. and Eric Smith. 1998. "Marketplaces and Matching," *International Economic Review*, 39, 239–54.

Combes, Pierre-Philippe and Gilles Duranton. 2006. "Labour Pooling, Labour Poaching, and Spatial Clustering," *Regional Science and Urban Economics*, 36, 1–28.

Combes, Pierre-Philippe, Gilles Duranton, and Henry G. Overman. 2005. “Agglomeration and the Adjustment of the Spatial Economy,” *Papers in Regional Science*, 84, 311–349.
Crihfield, John B. and Martin P. H. Panggabean. 1995. “Is Public Infrastructure Productive? A Metropolitan Perspective using New Capital Stock Estimates,” *Regional Science and Urban Economics*, 25, 607–630.
Desmet, Klaus and Marcel Fafchamps. 2005. “Changes in the Spatial Concentration of Employment Across US Counties: A Sectoral Analysis 1972–2000,” *Journal of Economic Geography*, 5, 261–284.
Dormann, Carsten F., Jana M. McPherson, Miguel B. Araújo, Roger Bivand, Janine Bolliger, Gudrun Carl, Richard G. Davies, Alexandre Hirzel, Walter Jetz, W. D. Kissling, Ingolf Kühn, Ralf Ohlemüller, Pedro Peres-Neto, Björn Reineking, Boris Schröder, Frank M. Schurr, and Robert Wilson. 2007. “Methods to Account for Spatial Autocorrelation in the Analysis of Species Distributional Data: A Review,” *Ecography*, 30, 609–628.
Dumais, Guy, Glenn Ellison, and Edward Glaeser. 1997. “Geographic Concentration as a Dynamic Process,” NBER Working Paper No. 6270, National Bureau of Economic Research, Inc.
Duranton, Gilles and Henry G. Overman. 2005. “Testing for Localization using Micro-Geographic Data,” *Review of Economic Studies*, 72, 1077–1106.
Duranton, Gilles and Diego Puga. 2004. “Chapter 48 Micro-Foundations of Urban Agglomeration Economies,” in J. Vernon Henderson and Jacques-François Thisse (ed.), *Handbook of Regional and Urban Economics*. Amsterdam: Elsevier, pp. 2063–2117.
Eberts, Randall W. and Daniel P. McMillen. 1999. “Chapter 38 Agglomeration Economies and Urban Public Infrastructure,” in P. Cheshire and E. S. Mills (eds.), *Handbook of Regional and Urban Economics*. Amsterdam: Elsevier, pp. 1455–1495.
Francis, John. 2009. “Agglomeration, Job Flows and Unemployment,” *The Annals of Regional Science*, 43, 181–198.
Fu, Shihe. 2007. “Smart Café Cities: Testing Human Capital Externalities in the Boston Metropolitan Area,” *Journal of Urban Economics*, 61, 86–111.
Fujita, Masahisa, Paul Krugman, and Anthony Venables. 1999. *The Spatial Economy: Cities, Regions and International Trade*. Cambridge, Mass.: MIT Press.
Fujita, Masahisa and Hideaki Ogawa. 1982. “Multiple Equilibria and Structural Transition of Non-Monocentric Urban Configurations,” *Regional Science and Urban Economics*, 12, 161–196.
Gabriel, Stuart A., Joe P. Mattey, and William L. Wascher. 2003. “Compensating Differentials and Evolution in the Quality-of-Life among U.S. States,” *Regional Science and Urban Economics*, 33, 619–649.
Gan, Li and Qi Li. 2004. “*Efficiency of Thin and Thick Markets*,” NBER Working Paper No. 10815, National Bureau of Economic Research, Inc.
Getis, Authur and Daniel A. Griffith. 2002. “Comparative Spatial Filtering in Regression Analysis,” *Geographical Analysis*, 34, 130–140.
Gibbs, Robert M. and G. Andrew Jr. Bernat. 1997. “Rural Industry Clusters Raise Local Earnings,” *Rural Development Perspectives*, 12, 18–25.
Glaeser, Edward L. 1999. “Learning in Cities,” *Journal of Urban Economics*, 46, 254–277.
Glaeser, Edward L. and Joshua D. Gottlieb. 2009. “The Wealth of Cities: Agglomeration Economies and Spatial Equilibrium in the United States,” *Journal of Economic Literature*, 47, 983–1028.
Glaeser, Edward L. and David C. Mare. 2001. “Cities and Skills,” *Journal of Labor Economics*, 19, 316–342.
Griffith, Daniel A. 1996. “Spatial Autocorrelation and Eigenfunctions of the Geographic Weights Matrix Accompanying Geo-Referenced Data,” *Canadian Geographer*, 40, 351–367.
_____. 2000. “A Linear Regression Solution to the Spatial Autocorrelation Problem,” *Journal of Geographical Systems*, 2, 141–156.
Gyourko, Joseph and Joseph Tracy. 1989. “The Importance of Local Fiscal Conditions in Analyzing Local Labor Markets,” *The Journal of Political Economy*, 97, 1208–1231.
Hall, Robert E. and Charles I. Jones. 1999. “Why do some Countries Produce so Much More per Worker than Others?” *Quarterly Journal of Economics*, 114, 83–116.
Hanink, Dean M. 2006. “A Spatial Analysis of Sectoral Variations in Returns to External Scale,” *Journal of Regional Science*, 46, 953–968.
Hanson, Gordon, H. 2005. “Market Potential, Increasing Returns and Geographic Concentration,” *Journal of International Economics*, 67, 1–24.
Haughwout, Andrew F. 1998. “Aggregate Production Functions, Interregional Equilibrium, and the Measurement of Infrastructure Productivity,” *Journal of Urban Economics*, 44, 216–227.
_____. 2002. “Public Infrastructure Investments, Productivity and Welfare in Fixed Geographic Areas,” *Journal of Public Economics*, 83, 405–428.
Helsley, Robert W. and William C. Strange. 1990. “Matching and Agglomeration Economies in a System of Cities,” *Regional Science and Urban Economics*, 20, 189–212.
Henderson, J. V. 1986. “Efficiency of Resource Usage and City Size,” *Journal of Urban Economics*, 19, 47–70.
_____. 2003. “Marshall’s Scale Economies,” *Journal of Urban Economics*, 53, 1–28.
Henry, Mark S., Bertrand Schmitt, and Virginie Piguet. 2001. “Spatial Econometric Models for Simultaneous Systems: Application to Rural Community Growth in France,” *International Regional Science Review*, 24, 171–193.

Higano, Yoshiro and Hiroyuki Shibusawa. 1999. “Agglomeration Diseconomies of Traffic Congestion and Agglomeration Economies of Interaction in the Information-Oriented City,” *Journal of Regional Science*, 39, 21–49.

Hoehn, John P., Mark C. Berger, and Glenn C. Blomquist. 1987. “A Hedonic Model of Interregional Wages, Rents, and Amenity Values,” *Journal of Regional Science*, 27, 605–620.

Holmes, Thomas. 1999. “Localization of Industry and Vertical Disintegration,” *The review of economics and statistics*, 81, 314–325.

Holtz-Eakin, Douglas. 1994. “Public-Sector Capital and the Productivity Puzzle,” *The review of economics and statistics*, 76, 12–21.

Holtz-Eakin, Douglas and Amy E. Schwartz. 1995. “Spatial Productivity Spillovers from Public Infrastructure: Evidence from State Highways,” *International Tax and Public Finance*, 2, 459–468.

Jacobs, Jane. 1969. *The Economy of Cities*. New York: Random House.

Kelejian, Harry H. and Ingmar R. Prucha. 1998. “A Generalized Spatial Two-Stage Least Squares Procedure for Estimating a Spatial Autoregressive Model with Autoregressive Disturbances,” *The Journal of Real Estate Finance and Economics*, 17, 99–121.

———. 1999. “A Generalized Moments Estimator for the Autoregressive Parameter in a Spatial Model,” *International Economic Review*, 40, 509–533.

———. 2004. “Estimation of Simultaneous Systems of Spatially Interrelated Cross Sectional Equations,” *Journal of Econometrics*, 118, 27–50.

———. 2008. “Specification and Estimation of Spatial Autoregressive Models with Autoregressive and Heteroskedastic Disturbances,” CESifo Group Munich.

Knapp, Thomas A. and Philip E. Graves. 1989. “On the Role of Amenities in Models of Migration and Regional Development,” *Journal of Regional Science*, 29, 71–87.

Koo, Jun. 2005. “Agglomeration and Spillovers in a Simultaneous Framework,” *The Annals of Regional Science*, 39, 35–47.

Krugman, Paul. 1991. “Increasing Returns and Economic Geography,” *Journal of Political Economy*, 99, 483–499.

Lee, Lung-Fei. 2004. “Asymptotic Distributions of Quasi-Maximum Likelihood Estimators for Spatial Autoregressive Models,” *Econometrica*, 72, 1899–1925.

LeSage, James P. and Manfred M. Fischer. 2008. “Spatial Growth Regressions: Model Specification, Estimation and Interpretation,” *Spatial Economic Analysis*, 3, 275–304.

LeSage, James P. and R. Kelley Pace. 2009. *Introduction to Spatial Econometrics*. Boca Raton: CRC Press.

Lim, Up. 2004. “Knowledge Spillovers, Agglomeration Economies, and the Geography of Innovative Activity: A Spatial Econometric Analysis,” *Review of Regional Studies*, 34, 11–36.

Lucas, Robert E. and Esteban Rossi-Hansberg. 2002. “On the Internal Structure of Cities,” *Econometrica*, 70, 1445–1476.

McCann, Philip and Daniel Shefer. 2004. “Location, Agglomeration and Infrastructure,” *Papers in Regional Science*, 83, 177–196.

McCann, Philip and Jaakko Simonen. 2005. “Innovation, Knowledge Spillovers and Local Labour Markets,” *Papers in Regional Science*, 84, 465–485.

Moomaw, Ronald L. 1981. “Productivity and City Size: A Critique of the Evidence,” *Quarterly Journal of Economics*, 96, 675–688.

———. 1983. “Is Population Scale a Worthless Surrogate for Business Agglomeration Economies?” *Regional Science and Urban Economics*, 13, 525–545.

Morrison, Catherine J. and Amy E. Schwartz. 1996. “State Infrastructure and Productive Performance,” *The American Economic Review*, 86, 1095–1111.

Mozayeni, Simin. 1995. “A Comparative Analysis of the Output Measures of Local Public Services,” *International Advances in Economic Research*, 1, 173–181.

Munnell, Alicia H. 1990. “How does Public Infrastructure Affect Regional Economic Performance?” *New England Economic Review*, 30, 11–32.

———. 1992. “Policy Watch: Infrastructure Investment and Economic Growth,” *Journal of Economic Perspectives*, 6, 189–198.

Nechyba, Thomas J. and Robert P. Strauss. 1998. “Community Choice and Local Public Services: A Discrete Choice Approach,” *Regional Science and Urban Economics*, 28, 51–73.

Oates, Wallace E. 1969. “The Effects of Property Taxes and Local Public Spending on Property Values: An Empirical Study of Tax Capitalization and the Tiebout Hypothesis,” *Journal of Political Economy*, 77, 957–971.

———. 1973. “The Effects of Property Taxes and Local Public Spending on Property Values: A Reply and Yet further Results,” *Journal of Political Economy*, 81, 1004–1008.

Ota, Mitsuru and Masahisa Fujita. 1993. “Communication Technologies and Spatial Organization of Multi-Unit Firms in Metropolitan Areas,” *Regional Science and Urban Economics*, 23, 695–729.

Overman, Henry G. and Diego Puga. 2009. “Labour Pooling as a Source of Agglomeration: An Empirical Investigation,” C.E.P.R. Discussion Papers.

Paci, Raffaele and Stefano Usai. 1999. "Externalities, Knowledge Spillovers and the Spatial Distribution of Innovation," *Geojournal*, 49, 381–390.
Patuelli, Roberto, Daniel A. Griffith, Michael Tiefelsdorf, and Peter Nijkamp. 2009. "Spatial Filtering and Eigenvector Stability: Space-Time Models for German Unemployment Data," Biblioteca universitaria di Lugano (University Library of Lugano).
Pollakowski, Henry O. 1973. "The Effects of Property Taxes and Local Public Spending on Property Values: A Comment and further Results," *Journal of Political Economy*, 81, 994–1003.
Puga, Diego. 2010. "The Magnitude and Causes of Agglomeration Economies," *Journal of Regional Science*, 50, 203–219.
Rey, Sergio J. and Marlon G. Boarnet. 2004. "A Taxonomy of Spatial Econometric Models for Simultaneous Equations Systems," in L. Anselin, R. J. G. M. Florax and S. J. Rey (eds.), *Advances in Spatial Econometrics: Methodology, Tools and Applications*. Berlin; New York. Springer-Verlag, pp. 99–120.
Roback, Jennifer. 1982. "Wages, Rents, and the Quality of Life," *Journal of Political Economy*, 90, 1257–1278.
Rosen, Harvey S. and David J. Fullerton. 1977. "A Note on Local Tax Rates, Public Benefit Levels, and Property Values," *Journal of Political Economy*, 85, 433–440.
Rosenthal, Stuart S. and William C. Strange. 2001. "The Determinants of Agglomeration," *Journal of Urban Economics*, 50, 191–229.
_____. 2003. "Geography, Industrial Organization, and Agglomeration," *The Review of Economics and Statistics*, 85, 377–393.
———. 2004. "Chapter 49 Evidence on the Nature and Sources of Agglomeration Economies," in J. Vernon Henderson and Jacques-François Thisse (ed.), *Handbook of Regional and Urban Economics*. Amsterdam: Elsevier, pp. 2119–2171.
Rupasingha, Anil and Stephan J. Goetz. 2004. "County Amenities and Net Migration," *Agricultural and Resource Economics Review*, 33, 245–254.
Scotchmer, Suzanne. 2002. "*Local Public Goods and Clubs*," Amsterdam: Elsevier, pp. 1997–2042.
Segal, David. 1976. "Are there Returns to Scale in City Size?" *The review of economics and statistics*, 58, 339–350.
Solow, Robert M. 1956. "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, 70, 65–94.
Stahl, Konrad. 1982. "Differentiated Products, Consumer Search, and Locational Oligopoly," *The Journal of Industrial Economics*, 31, 97–113.
Tabuchi, Takatoshi. 1998. "Urban Agglomeration and Dispersion: A Synthesis of Alonso and Krugman," *Journal of Urban Economics*, 44, 333–351.
Tabuchi, Takatoshi and Atsushi Yoshida. 2000. "Separating Urban Agglomeration Economies in Consumption and Production," *Journal of Urban Economics*, 48, 70–84.
Tiebout, Charles M. 1956. "A Pure Theory of Local Expenditures," *Journal of Political Economy*, 64(5): 416–424.
Tiefelsdorf, M. and D. A. Griffith. 2007. "Semiparametric Filtering of Spatial Autocorrelation: The Eigenvector Approach," *Environment and Planning A*, 39, 1193–1221.
van Soest, Daan P., Shelby Gerking, and Frank G. van Oort. 2006. "Spatial Impacts of Agglomeration Externalities," *Journal of Regional Science*, 46, 881–899.
Walde, Janette, Mario Larch, and Gottfried Tappeiner. 2008. "Performance Contest between MLE and GMM for Huge Spatial Autoregressive Models," *Journal of Statistical Computation and Simulation*, 78(2), 151–166.
Wheaton, William C. and Mark J. Lewis. 2002. "Urban Wages and Labor Market Agglomeration," *Journal of Urban Economics*, 51, 542–562.
Zheng, Xiao-Ping. 2001. "Determinants of Agglomeration Economies and Diseconomies: Empirical Evidence from Tokyo," *Socio-Economic Planning Sciences*, 35, 131–144.

APPENDIX: TECHNICAL DETAILS OF MODEL DERIVATION

Consumers' Utility

The utility maximization of the representative consumer and the spatial equilibrium assumption lead to the indirect utility function in (6). Taking the logarithm on it and letting the constant terms be a_0 yields

$$\log(pop) = a_0 - \frac{1}{a_1}\log(inc) - \frac{1}{a_1}\log\left(1 - \frac{ctax}{inc}\right) + \frac{1-\theta}{a_1}\log(hpric) - \frac{1}{a_1}\log(A(\mathbf{s},\ \mathbf{q})),$$

with $a_0 = [\log(k) - \theta\ \log(\theta) - (1-\theta)\ \log(1-\theta)]/a_1$. But since $\log(1-x) \approx -x$ for a small value of $x \ll 1$, this can be rewritten as (9).

Production in the Traded Good Sector

The profit-maximization problem for the representative firm in the traded-good sector leads to

$$\text{(A1)} \qquad \frac{F(\mathbf{s},\ \mathbf{q})pop^{b_1}}{1+trtxrt} = \left(\frac{indr}{\alpha_1}\right)^{\alpha_1}\left(\frac{wag}{\beta_1}\right)^{\beta_1}\left(\frac{p_K}{\gamma_1}\right)^{\gamma_1}.$$

The right-hand side is the factor price index for the sector with a Cobb–Douglas production function. As explained in reference to (7), the right-hand side also represents the regional income coming from the traded-good sector for a given factor endowment. As we have assumed that all the population has the same factor endowment, the index in fact represents per capita income coming from that sector for a region. Since per capita income consists of the two incomes from the two sectors, a doubling of this index does not lead to a doubled per capita income. Let the share of per capita income coming from the traded-good sector be $\boldsymbol{\phi}$. One can roughly say that per capita income in a region increases with an elasticity of $\boldsymbol{\phi}$ with respect to this index. This relationship can be formalized as

$$\text{(A2)} \qquad cnvf_1\left[\left(indr\alpha_1\right)^{\alpha_1}\left(\frac{wag}{\beta_1}\right)^{\beta_1}\left(\frac{p_K}{\gamma_1}\right)^{\gamma_1}\right]^{\phi} = inc,$$

where $cnvf_1$ is a constant factor for converting the factor price index to per capita income. Substituting (A1) for the factor price index in (A2) and taking the logarithm of both sides yields

$$\log(inc) = b_0 + b_1\phi\log(pop) + \phi\log(F(\mathbf{s},\ \mathbf{q})) - \phi\log(1+trtxrt),$$

with $b_0 = \log(cnvf_1)$. But since log $(1+\ x) \approx x$ for a small value of $x \ll 1$, this can be rewritten as (10).

Production in the Housing Sector

The profit-maximization problem of the representative housing firm leads to

$$\text{(A3)} \qquad \frac{H(\mathbf{s},\ \mathbf{q})pop^{c_1}hpric}{1+hstxrt} = \left(\frac{resr}{\alpha_2}\right)^{\alpha_2}\left(\frac{wag}{\beta_2}\right)^{\beta_2}\left(\frac{p_K}{\gamma_2}\right)^{\gamma_2}.$$

Since wage is the only income component varying across regions, the wage rate variable can be expressed as a function of per capita income. Let the income share of wages be $\boldsymbol{\varpi}$. Then one can say that per capita income increases with an elasticity of $\boldsymbol{\varpi}$ with respect to the wage rate, as the other income components stay almost the same. Formally, it is written as

$$\text{(A4)} \qquad inc = cnvf_2 \cdot wag^{\varpi},$$

where $cnvf_2$ is a constant factor for converting the wage rate to per capita income. Note that this equation would be equivalent to (A2) because $\boldsymbol{\varpi} = \beta_1$ when the traded-good sector occupies almost the whole economy, i.e., $\boldsymbol{\varphi} \approx 1$. Substituting (A4) for the wage variable in (A3) and taking the logarithm of both sides yields

(A5)

$$\log(hpric) = d_0 + \alpha_2\log(resr) + \frac{\beta_2}{\varpi}\log(inc) - c_1\log(pop) + \log(1+hstxrt) - \log(H(\mathbf{s},\ \mathbf{q})),$$

with $d_0 = -\ (\beta_2/\boldsymbol{\varpi})\log(cnvf_2) + \gamma_2\log(p_K) - \alpha_2\log(\alpha_2) - \beta_2\log(\beta_2) - \gamma_2\log(\gamma_2)$ and $\alpha_2 + \beta_2 + \gamma_2 = 1$.

The unit-cost of housing production can be expressed as land rent and the amount of land per housing

$$hpric = \frac{resr \cdot l_y}{\alpha_2}, \tag{A6}$$

where l_y is land input per housing. Let *qhous* and *arhous* denote the total amount of housing and total area of residential land in a region. Then, the unit land input can be written as

$$l_y = \frac{arhous}{qhous} = \frac{1}{hden} \cong \frac{1}{pden} \cong \frac{area}{pop}, \tag{A7}$$

where *area* is the total land area of the region, and *hden* and *pden* denote housing density and population density in the region. In (A7), housing density is approximated by population density. Using (A6) and (A7), land rent can be approximated by

$$resr \cong \alpha_2 hpric \frac{pop}{area}. \tag{A8}$$

Substituting (A8) into (A5) yields

$$\log(hpric) \cong c_0 + \frac{\beta_2}{(1-\alpha_2)\varpi}\log(inc) + \frac{\alpha_2 - c_1}{1-\alpha_2}\log(pop) - \frac{\alpha_2}{1-\alpha_2}\log(area)$$
$$+ \frac{1}{1-\alpha_2}\log(1 + hstxrt) - \frac{1}{1-\alpha_2}\log(H(\mathbf{s},\ \mathbf{q})),$$

with $c_0 = (d_0 + \alpha_2 \log\alpha_2)/(1–\alpha_2)$. Since $\log(1+x) \approx x$ for a small value of $x \ll 1$, this can be rewritten as (11).

DEFINITIONS OF VARIABLES AND DATA SOURCES

Variables	Units	Definitions	Data Sources
Pop	Persons	Total population in the county	2000 Census of population and housing
Inc	\$/person	Per capita income (in 2000 dollar)	REIS (CA05)
Hpric	\$	Median housing value (in 2000 dollar)	2000 Census of population and housing
Prtxshr	percent	Property tax divided by income	Ohio Department of Taxation, Table PD-23 REIS (CA05)
restxr	miles	Residential & agriculture real property tax mileage rate	Ohio department of taxation, Table PR-6
indtxr	miles	Commercial, industrial, mineral real property tax mileage rate	Ohio department of taxation, Table PR-6
pcexp	\$/person	County government's expenditure per capita for operating costs in 2001	2002 Census of Governments
rdnt	mi/sq-mi	Total roads length divided by total land area	Ohio Department of Transportation, RI339
water	percent	Share of public supply in domestic water consumption	Estimated use of water in the United States (USGS)
Educ	percent	Share of population 25 years and older with associate's degree or higher	2000 Census of Population and Housing

Variables	Units	Definitions	Data Sources
12*gps*	percent	Average percentage of students who have met the minimum State of Ohio scores in reading, writing, math, science and citizenship	Ohio Department of Education, Proficiency Test Data
szret	emp./est.	Employees per establishment in construction SIC code 33	REIS (CA25), County business patterns
pctrf	1,000 veh.mi/person	Per capita daily vehicle mile traveled	Ohio Department of Transportation, DVMT reports
lqman		Manufacturing employment share/Total employment share in Ohio	REIS (CA25)
age	year	Median age of population	2000 Census of population and housing
agesq	year^2	age squared	2000 Census of population and housing
unemp	percent	Annual average unemployment rate	Local Area Unemployment Statistics (LAUS) Program
hyear	year	Median housing age as of 2000	2000 Census of population and housing
hroom	room/unit	Median number of rooms	2000 Census of population and housing
area	sq. mi.	Land area of the county	2000 Census of population and housing
snow	inch	Annual average snow fall between 1971 and 2000	Midwestern Regional Climate Center (MRCC)
jantemp	°F	Mean temperature in January between 1971 and 2000	Midwestern Regional Climate Center (MRCC)
greatlakes	1 or 0	1 if a county is adjacent to the Great Lakes	Author
distair	mile	Distance from the county centroid to the nearest international airport	TIGER/Line® 2000, Google Maps
crime	1/100,000	Average number of violent crimes per 100,000 population reported by FBI over the years of 1999, 2000, and 2002	County and City Data Books(1999 Data), Ohio Office of Criminal Justice Services (2000 and 2002 data)
lqcns		Construction employment share/Total employment share in Ohio	REIS (CA25)
lqret		Retail(SIC 52–59) employment share/Total employment share in Ohio	REIS (CA25)
vacn	percent	Vacancy rate of housing	2000 Census of population and housing
nofreez	day	Number of days when the minimum temperature exceeds 32°F	Midwestern Regional Climate Center (MRCC)