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Suburban Subcenters and Employment Density in Metropolitan Chicago*

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A detailed data set covering every quarter section in suburban Chicago is used to identify employment subcenters and to determine their influence on employment density. Proximity to the 20 identified subcenters is used to explain employment density in 1980 and 1990. We argue that density functions are subject to selection bias, and we find significant correlations between employment density and selection equation errors. Subcenter proximity has a significant influence on expected density independent of distance from the Chicago central business district, O'Hare Airport, highway interchanges, and rail lines, suggesting that subcenters offer significant advantages beyond simple access to the transportation network.

1. INTRODUCTION

Recent research on employment subcenters in urban areas focused on the definition and the identification of employment subcenters, the effects of subcenters on land values or real estate values, and the effects of subcenters on the spatial distribution of employment and population in urban areas. This paper makes two distinct contributions to research on the causes and effects of suburban employment subcenters. First, the underlying reasons for the existence of employment subcenters are discussed, and an econometric test is formulated and is used to distinguish between two types of agglomeration economies. Internal scale economies

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lead to large individual establishments, while agglomeration economies cause establishments to locate together. Agglomeration economies can arise from causes internal to the group of establishments in close proximity (e.g., reduction in shopping costs for customers). We test separately for the effects on employment density of access to transportation *and* for proximity to an employment subcenter. This paper is unique in providing a detailed assessment of the nature of the agglomeration economies that cause employment concentration.

Second, a model of employment density is introduced that uses bid-rent theory. The model explicitly includes a selection process that determines whether a small zone in the urban area contains any employment. This modeling approach permits us to distinguish the probability that a zone contains any employment from the density of employment in those zones that do contain employment. The paper presents the first model of this type. Our results indicate that standard ordinary least squares (OLS) estimates of density functions are subject to selection bias, which calls into question a large body of existing empirical work.

The next section presents the bid-rent model of employment density and formulates the implied maximum-likelihood estimation procedure. The following two sections discuss the data sources examined in the study and discuss the approach used to identify employment subcenters. The study uses data on employment density by quarter section for the Chicago metropolitan area in 1980 and 1990. Section 5 presents the econometric results. Several measures of access to transportation are statistically significant in both functions. Proximity to an employment subcenter is also an important determinant of both employment probability and employment density. These findings suggest that agglomeration economies arising from shared facilities and agglomeration economies internal to the proximate group of establishments determine subcenter formation.

Twenty suburban subcenters are identified, and they can be classified as follows:

- Old satellite cities—3
- Old industrial suburbs—3
- Post World War II industrial suburbs—6
- Newer industrial/retail suburbs—2
- Edge Cities—3
- Service and retail centers—3

The five employment centers in the newer industrial/retail and Edge City categories had the largest employment growth rates over the 1980–1990 decade. The growth record for the other types of subcenters is mixed.

2. BID-RENT FUNCTIONS AND EMPLOYMENT DENSITY

Scale economies cause the spatial concentration of employment. The standard textbook analysis (e.g., O'Sullivan [20]) delineates two primary types of scale economies—internal scale economies at a single location and agglomeration economies. Agglomeration economies normally refer to three types of economies: (1) localization economies, which are external to individual firms and which arise from the size of the local industry in the urban area; (2) urbanization economies, which are external to the local industry and which arise from the size of the urban economy; and (3) interindustry linkages, which arise from transportation cost savings in the purchase of intermediate inputs. While internal scale economies can cause pockets of high employment density within an urban area, they do not lead directly to the formation of employment subcenters. Cost advantages associated with size are confined to the establishment and offer no particular advantage to others.

As the previous listing suggests, agglomeration economies normally refer to forces that operate over an entire urban area. In this paper, we argue that there are agglomeration economies that can generate concentrations of employment at certain locations *within* an urban area. A location well served by highways, rail lines, etc. may attract many firms even when the firms have no interest in locating near one another. This line of reasoning suggests that a suburban subcenter may form near transportation centers, but accessibility rather than mutual attraction leads to the employment concentration. If such is the case, only the accessibility measures are statistically significant in an employment density regression that includes as explanatory variables both accessibility measures and a variable representing proximity to suburban subcenters. Beginning with White [23], a large number of theoretical studies and urban simulation models used this idea.

Another form of agglomeration economy occurs when firms enjoy cost advantages from locating near one another. Proximity to other firms may lower production costs by simplifying personal communication or may help customers reduce their shopping costs. The initial location of a suburban subcenter may be the result of access to the transportation network, but this added agglomeration economy can provide an independent motivation for firm location. If proximity to other firms lowers costs, then a firm may bid more for sites in suburban subcenters, independent of the other advantages the subcenter location offers. The critical distinction for employment subcenters is between economies that arise purely from access to common infrastructure, and agglomeration economies that are internal to the group of establishments within the subcenter. The ability of proximity to a subcenter, holding accessibility constant, to explain employment density provides a means to discriminate between these two forms of agglomeration economies at particular locations within an urban area.[1]

The effect of suburban subcenters on employment density can be formalized using bid-rent functions. A bid-rent function represents the maximum amount a firm or an individual will pay for a unit of land as a function of the parcel's characteristics. In the standard monocentric urban model, the bid rent is a simple function of distance from the city center because all economic activity is assumed to take place there (Fujita [3]). This approach is inadequate for modeling modern suburban areas that have many employment subcenters. The city center continues to affect employment patterns even in such decentralized cities as Los Angeles, but suburban employment is influenced more directly by access to expressway interchanges and other features of the transportation network. Such accessibility measures are represented by the vector **A**. If agglomeration economies are important, then bid rents also are affected by proximity to the employment subcenters, independent of the vector **A**. Let the vector of subcenter access measures be represented by **S**. Potential employment sites also may have idiosyncratic characteristics that influence bid rents. For example, some sites may be swampy and ill-suited for employment, while others are level and clear, reducing the costs of construction. Measurable idiosyncratic characteristics are represented by the vector **C**, while unobservable characteristics are represented by the error term u. We follow the empirical literature on bid-rent functions and we assume the following simple functional form for non-residential land rents,

$$\ln R_1 = \boldsymbol{\beta}'_1 X + u_1, \tag{1}$$

where R_1 represents bid rent for land use 1 (non-residential), $\mathbf{X} = (\mathbf{A}, \mathbf{S}, \mathbf{C})$, $\boldsymbol{\beta}_1$ is a vector of coefficients, and u_1 is a normally distributed error term.

Non-residential firms compete with households for sites. To reduce their transportation costs, households also prefer to be near suburban employment centers. Also, include in the vector **C** measurable idiosyncratic site characteristics that influence residential bid rents. The residential bid-rent function is

$$\ln R_2 = \boldsymbol{\beta}'_2 \mathbf{X} + u_2, \tag{2}$$

where u_2 is the normally distributed error term for residential bid rents.

[1]Some theoretical work on polycentric urban areas is based on this idea. For example, Fujita and Ogawa [4] introduce non-pecuniary production externalities, Anas and Kim [1] assume intermediate inputs and interindustry transactions, and Ogawa and Fujita [19] base their model on an interfirm communication requirement. See Anas and Kim [1] for a more thorough summary of this literature.

By definition, employment density is the ratio of labor to land, both of which are inputs to production. Density is a function, therefore, of land rent, wages, other input prices, and output prices. Output prices and input costs other than land are unlikely to vary greatly over urban areas so density simplifies to a function of land rent alone,[2]

$$\ln\left(\frac{E}{L_e}\right) = \alpha \ln R_1 + \eta_1 = \alpha \boldsymbol{\beta}_1' \mathbf{X} + \eta_1 + \alpha u_1, \tag{3}$$

where E is employment and L_e is land devoted to employment use.

While data on E and $\mathbf{X}$ are readily available, data on L_e are usually unavailable and often imprecise. Most previous research focused on gross employment density, which is the ratio of employment to the *total* amount of land in a small urban zone, rather than on the theoretically preferred net density of Eq. (3). The natural log of gross employment density can be written

$$\ln D = \ln\left[\left(\frac{E}{L_e}\right)\left(\frac{L_e}{L}\right)\right] = \ln\left(\frac{E}{L_e}\right) + \ln\left(\frac{L_e}{L}\right), \tag{4}$$

where L is the total amount of land in the zone. The key to moving from net to gross density is the specification of $\ln(L_e/L)$, which is the natural log of the proportion of the zone's land area used for employment. This variable is determined in part by market forces, but also is influenced by zoning practices. We assume that the following expression applies for $\ln(L_e/L)$ when $L_e > 0$,

$$\ln\left(\frac{L_e}{L}\right) = \theta(\ln R_1 - \ln R_2) + \boldsymbol{\tau}'\mathbf{W} + \eta_2, \tag{5}$$

where $\mathbf{W}$ is a vector of variables that influence land use, and η_2 is another normally distributed error term. The first term in Eq. (5) measures the response of land use to market rents. No other variables would determine land use in a competitive market, but zoning officials may alter market outcomes in predictable ways. Sites along major roads may all be zoned for commercial use, and other areas may be zoned exclusively for residential uses. Such non-market results are captured in $\mathbf{W}$. McMillen and McDonald [17] provide empirical support for the specification of Eq. (5).

[2] While several studies suggest that wages vary spatially within urban areas (Eberts [2], Ihlanfeldt [13], McMillen and Singell [18]), there is no evidence of variation in other input prices or output prices. Most of the spatial variation in wages is accounted for by a central city–suburban differential. Within suburban areas, potential wage variation can be represented by site-specific factors such as distance from the city center.

Combining terms, $\ln D = \alpha \boldsymbol{\beta}_1' \mathbf{X} + \theta(\boldsymbol{\beta}_1 - \boldsymbol{\beta}_2)' \mathbf{X} + \tau' \mathbf{W} + \eta_1 + \eta_2 + \alpha u_1 + \theta(u_1 - u_2)$, which after obvious substitutions becomes

$$\ln D = \boldsymbol{\lambda}' \mathbf{Z} + u, \qquad L_e > 0. \tag{6}$$

The error term in Eq. (6) is a composite of errors from the residential and non-residential land rent functions (Eqs. (1) and (2)), the net employment density function (Eq. (3)), and the land use Eq. (5). All error terms are assumed to be normally distributed, which implies that u is normally distributed also.

Employment density is a function of the same variables that determine land rents, although other factors may also matter. The relationship between non-residential land rent and gross employment density need not be a simple one, however. While other inputs are substituted for acreage as land rent rises, labor may be a substitute or a complement to land. Intuition suggests that net density increases when non-residential land rent rises, but theory provides ambiguous predictions for multiple-input production processes. On the other hand, an increase in residential land rent (holding constant non-residential land rent) will decrease the amount of land allocated to employment (L_e/L) and, thus, tend to reduce gross density.

Equation (6) applies only for the minority of zones that have employment. Zoning officials can be expected to base the decision to have any employment in a zone on the same factors that influence the proportion of land zoned for employment given that $L_e > 0$. Thus, a zone is more likely to have some employment when R_1 is high relative to R_2, and the same "other factors" ($\mathbf{W}$) influence zoning decisions, but the decision to have some employment is likely to have a different structure than Eq. (5). The equation that determines whether there is some employment in a zone is

$$\text{Prob}(I = 1) = \text{Prob}(\boldsymbol{\gamma}' \mathbf{Z} + v > 0) = \Phi\left(\frac{\boldsymbol{\gamma}' \mathbf{Z}}{\sigma_v}\right), \tag{7}$$

where I is a variable that equals one when a zone has employment ($I = 0$ otherwise), v is a normally distributed error term, and $\boldsymbol{\gamma}$ is a vector of coefficients that help determine land use, with $\boldsymbol{\gamma} \neq \boldsymbol{\lambda}$.

Note that v is correlated with u because the same factors influence the proportion of land used for employment when $L_e > 0$ and the decision to have any employment at all. For example, a site with a large error in the non-residential land rent function (u_1) will be more likely to have some employment and will have more land devoted to employment when $L_e > 0$. The correlation between v and u implies that employment density functions are subject to selection bias, and OLS estimates of Eq. (6) are biased.

A tobit specification is inappropriate because employment probability and employment density, though related, are determined by different processes. The typical data set has observations on employment density for many sites and characteristics of the sites, such as distance from the city center and proximity to suburban subcenters. Typically, many sites have no employment, implying zero density. OLS estimates using only non-zero densities are biased, while tobit estimates impose inappropriate structure on the equations.

Heckman [11] two-stage estimates are consistent: the first stage is probit estimation of Eq. (7) using all observations, followed in the second stage by selection bias corrected OLS estimates of Eq. (6) for non-zero densities. The Heckman procedure is inefficient and often unreliable (Hartman [10]), but maximum-likelihood estimation is not difficult. The likelihood functions is $\prod_{i=1}^{n}(\int_{-\boldsymbol{\gamma}'\mathbf{Z}_i}^{\infty} g(\ln D_i - \gamma'\mathbf{Z}_i, v_i)\,dv_i)^{I_i}(\int_{-\infty}^{-\boldsymbol{\gamma}'\mathbf{Z}_i} f(v_i)\,dv_i)^{1-I_i}$, where g and f are the bivariate and univariate normal density functions, $I_i = 1$ if the ith site includes non-residential use while $I_i = 0$ for residential sites, and n is the number of observations. Letting $\sigma_u^2 = \mathrm{var}(u)$, $\sigma_v^2 = \mathrm{var}(v)$, and $\rho\sigma_u\sigma_v = \mathrm{cov}(u, v)$, and using u_i as shorthand for $\ln D_i - \boldsymbol{\lambda}'\mathbf{Z}_i$, the log-likelihood function is

$$\sum_{i=1}^{n} I_i\left(\ln\phi\left(\frac{u_i}{\sigma_u}\right) - \ln\sigma_u\right) + \sum_{i=1}^{n} I_i \ln\Phi\left(\frac{\boldsymbol{\gamma}'\mathbf{Z}_i/\sigma_v + \rho u_i/\sigma_u}{\sqrt{1-\rho^2}}\right) + \sum_{i=1}^{n}(1 - I_i)\ln\Phi\left(\frac{-\boldsymbol{\gamma}'\mathbf{Z}_i}{\sigma_v}\right). \quad (8)$$

The standard normal density and distribution functions are represented by ϕ and Φ, respectively. Identified parameters are $\boldsymbol{\lambda}$, $\boldsymbol{\gamma}/\sigma_v$, σ_u, and ρ. The normalization $\sigma_v = 1$ is imposed because only the ratio $\boldsymbol{\gamma}/\sigma_v$ is identified.

Estimating the model by maximizing Eq. (8) provides estimates simultaneously of the gross employment-density function (Eq. (6)) and the probability that a site has employment (Eq. (7)). Selection bias complicates the interpretation of employment-density function estimates. Expected log density for sites with employment is given by

$$E(\ln D \mid I = 1) = \boldsymbol{\lambda}'\mathbf{Z} + \rho\sigma_u\phi(\boldsymbol{\gamma}'\mathbf{Z})/\Phi(\boldsymbol{\gamma}'\mathbf{Z}). \quad (9)$$

Equation (9) provides a convenient means to evaluate the effect of a variable on employment density. Consider the effect of distance from a suburban employment subcenter. In a random sample, increasing distance lowers non-residential bid rents if agglomeration economies exist, which is likely to lower employment density. This relationship implies a negative coefficient on distance in the vector $\boldsymbol{\lambda}$. Distance from a suburban subcenter is likely to have a greater effect on non-residential than on residential bid rents, so the coefficient on distance in the vector $\boldsymbol{\gamma}$ is likely to be negative if land use is predominantly market driven, and increasing distance lowers the probability that a site is non-residential. Thus, the farther a non-residential $(I_i = 1)$ site is from the suburban subcenter, the greater v_i must be for the site to be non-residential. This argument implies that more distant non-residential sites have relatively large values of v.

The effect of this selectivity on employment density depends on the correlation between u and v. If $\rho < 0$, then positive employment probability errors (v) are associated with negative errors in the density equation. The large positive values of v at more distant non-residential sites are then associated with negative u, which tends to lower expected employment density below its value in a random sample. But if $\rho > 0$, large values of v are associated with positive u, which raises expected employment density. Equation (9) combines the effects of the explanatory variables on random sample bid rents and sample composition. The combined marginal effect is calculated directly as the derivative with respect to a component of $\mathbf{Z}_i$.

Bid-rent theory imposes no restrictions on the sign of ρ. The error term in the gross density equation is a composite of land rent and of net employment density errors, while the error term in the selection equation includes land rent errors and unobserved zoning practices. An unobserved site characteristic that raises non-residential land rents tends to increase density, suggesting a positive correlation between u and v. The site also may be non-residential because of a negative error in the residential land-rent equation or of a positive error in the land-use equation. For example, sites near polluted rivers may have low land rents in all uses, but they will not be residential in a competitive market if pollution matters more to homeowners than to firms. The low land rent leads to low density. Pollution is an unobserved variable that enters the model as a positive error in the land-use equation and as a negative error in the density equation, leading to a negative value for ρ.

3. DATA

The data set was provided by the Northeastern Illinois Planning Commission (NIPC). NIPC uses U.S. Census data to provide employment figures for every quarter section of suburban Chicago. Quarter sections formally are a quarter square mile (160 acres), but do not always contain exactly 160 acres because of geographic irregularities. The 1980 survey provides a measure of land area for each quarter section, measured in acres. Accurate employment estimates are available for 1980 and 1990. Gross employment density is simply the ratio of employment to land area.

The data cover suburban Cook County and five other counties in northeastern Illinois (DuPage, Kane, Lake, McHenry, and Will).

The theory presented in the previous section suggests that employment density and the probability of employment depend primarily on factors that influence bid rents. Our explanatory variables include standard measures of accessibility, with all distances measured in straight-line miles from the quarter-section midpoint. The first explanatory variable is distance from the Chicago central business district (the CBD). Chicago remains a highly centralized city, so accessibility to the CBD raises both residential and non-residential bid rents even in the suburbs. A cubic function proved necessary to adequately account for the CBD's effects. The second explanatory variable is distance to O'Hare Airport. McDonald [14] and McDonald and Prather [16] identify O'Hare Airport as the primary suburban employment center in the Chicago area, and ample evidence suggests that proximity to O'Hare raises land values (McDonald and Prather [16], McMillen and McDonald [17]). O'Hare is also a center of Chicago's expressway system: the Tri-State Tollway (which circles the city), the Kennedy Expressway (which provides access to the CBD), and the North-West Tollway (providing access to the northwest suburbs) intersect near the entrance to the airport. Distance to this intersection measures accessibility to O'Hare, and statistical tests suggest that higher order terms are unnecessary for this variable.

Chicago has an extensive commuter rail system, and access to the rail stations is valued both by homeowners and businesses. Thus, distance to the nearest commuter rail station is included as an explanatory variable. Chicago also has a system of expressways, tollways, and major limited-access highways. Distance to interchanges on these roads (all of which will be referred to as highways) is used as another explanatory variable. Distances to commuter train stations and to highway interchanges are entered in inverse form because the effects of these sites are expected to decline quickly with distance.

NIPC's land-use measures provide another set of explanatory variables. Much of Chicago's industry still relies on rail for shipping. The proportion of the quarter section devoted to railroad rights of way is a convenient measure of a site's accessibility to rail service. Suburban Chicago has lakes that are attractive for homes, but also has swampy areas that are unattractive for any use. Thus, quarter sections with a greater proportion of water are unlikely to have much employment.

The proportion of the quarter section that is accounted for by parks or by open space (NIPC does not distinguish between them) may help explain employment density. Parks lower gross employment density by adding unused land area to the denominator. Open space also is unused land under NIPC's definition. Large proportions of parks and open space reduce the probability of employment and lower gross employment density. Parks include small-scale suburban parks and large forest preserves. Forest preserves probably account for most non-zero observations of the variable. All of the forest preserve and most of the park location decisions were made long ago, and we can take them as exogenous. Agriculture is a separate category, so open space is either land that is currently vacant but held for speculative purposes or unusable lots (e.g., flood plains or irregular lots near expressways and rail lines). The geographic features that make land unusable are exogenous, but the decision to hold land vacant for speculation is endogenous in our model. We expect few quarter sections to include speculative unused land, so any endogeneity bias should be insignificant.

There are 14,290 quarter sections in suburban Chicago (or 3572 square miles), of which 4239 had employment in 1980. There was a large increase in the number of sites with employment in 1990, to 4887 quarter sections. Average employment density rose somewhat over time, from 3.048 per acre in sites with employment in 1980 to 3.261 per acre in 1990.

4. SUBCENTER IDENTIFICATION

While the location of an urban area's CBD is obvious, determining when a suburban employment site is large enough to be classified as a subcenter generally is difficult. Pockets of employment exist throughout a city, but a site is a subcenter only when it has an influence on overall employment patterns, population density, and land rents. Most studies define subcenters very simply. In an early study, Greene [8] defines employment centers as areas with double the average employment density. Working with large tracts, McDonald [14] and McDonald and McMillen [15] define potential subcenters as zones with higher gross employment density than all contiguous tracts. This approach is adequate for large tracts, but may identify small zones as subcenters when they are surrounded by others with little or no employment. Thus, Small and Song [22, p. 297] define employment centers as "a contiguous set of zones, each with gross employment density above some cutoff $\overline{D}$, that contains total employment above another cutoff $\overline{E}$." Large values of $\overline{D}$ and $\overline{E}$ produce a small set of subcenters, while small values do the opposite. This approach also was used by Giuliano and Small [6] and Sivitanidou [21].

In contrast to these more informal approaches, Gordon *et al.* [7] use t-values on distance measures in population and employment regressions to determine subcenter locations. Similarly, Heikkila *et al.* [12] use stepwise regression in an analysis of land values. McDonald and Prather [16] begin with a monocentric analysis of employment density, and define subcenters as locations with significantly positive residuals. Employment density was found to be a function of distance to these subcenters. These methods are better than informal approaches at analyzing subcenters with agglomeration economies because they recognize that the effects of a subcenter potentially are spread over a large area. However, they may overlook fairly large subcenters populated by firms with large internal scale economies because the employment effects may be highly localized.

The approach taken in this paper is based on the theory outlined in Section 2. The first step is to identify potential subcenters. We follow Giuliano and Small [6] and define as potential centers a set of nearby tracts that each have at least 10 employees per acre in either 1980 or 1990 and together have an average over the two sample years of at least 10,000 employees.[3] The subcenter ‘‘peak’’ is the quarter section with the greatest employment in the set of contiguous tracts. The second step is to include distances from subcenter peaks as explanatory variables in the employment density and in the employment probability equations. The distance measures enter the estimated models in inverse form. Those sites adding significant explanatory power to expected employment (Eq. (9)) form our final list of subcenters.

Using endogenously identified employment subcenter sites to explain employment density may bias our results. By definition, the subcenter site is a location with higher density than nearby tracts, which leads to a tendency toward negative gradients even in a falsely identified subcenter. The potential bias is the reason testing for significance is important. The testing procedure reduces the probability of identifying false subcenters, but the possible bias suggests that a lower than conventional significance level be used. A further check on the validity of the subcenters is the extent to which they correspond with prior knowledge of Chicago’s employment patterns. The identified subcenter locations are all reasonable, and generally are highly significant in our estimated models.

We identify 15 potential subcenters for suburban Chicago. While most subcenter sites are reasonable, two are too large to be consistent with the notion of a subcenter. The first of these is centered near O’Hare Airport and has more than 400,000 employees, while the other is centered near Evanston and has more than 100,000 employees. In these two areas, we raised the cutoff for the minimum employment density to 20, which produced more reasonable results. The large center near O’Hare then

[3]‘‘Nearby’’ is defined as within 1.5 miles rather than as contiguity because quarter sections are small, with pockets of low employment in areas with high density otherwise. Quarter sections are one-half mile square, so contiguous quarter sections are a half mile apart when adjoining north−south or east−west, and 0.707 miles apart when adjoining on the diagonal.

separates into 5 subcenters, while the Evanston center divides into 2. Our final list includes 20 subcenters.[4]

Table 1 provides some detail on the subcenters. The subcenters are identified by the municipality in which they are located; these municipalities are shown in Fig. 1. The 20 subcenters listed in Table 1 can be grouped informally into six fairly distinct categories based on age, location, and industrial composition. At the turn of the century, the Chicago metropolitan area consisted of the city of Chicago (with roughly its current boundaries) and immediately adjacent suburbs, other residential suburbs along rail lines, and satellite cities located about 30–35 miles from the Chicago CBD. Six of the current subcenters existed at the time; three (Aurora, Elgin, and Waukegan) are old satellite cities created in the 19th century by the intersection of the outer radial and the circumferential rail lines, and another three (Chicago Heights, Harvey, and McCook) are old industrial suburbs of Chicago that reached some prominence around the turn of the century. Manufacturing dominates all six of these subcenters still. Six additional subcenters (Addison, Des Plaines, Franklin Park, Niles, Norridge, and O'Hare) are centers of industrial activity that have emerged since World War II and since the opening of O'Hare Airport in 1962. All six are dominated by manufacturing and TCUW (transportation, communications, utilities, and warehousing) employment. Two subcenters (Northbrook and Palatine) are rather new centers of industry *and* retail trade that have grown to prominence since 1970. Indeed, Northbrook has a diverse employment base and rapid growth, so it may be emerging as the next "Edge City". Garreau [5] identifies three subcenters (Naperville, Oak Brook, and Schaumburg) as Edge Cities. These subcenters include a large business service sector and substantial amounts of office space available in the rental market. Finally, three (Burbank, Evanston, and Maywood) are centers of services and retail trade. Burbank and Maywood specialize in health services, while education (Northwestern University) dominates Evanston.

The five subcenters with the most rapid employment growth rates over the 1980–1990 period are the two newer industrial/retail suburbs and the three Edge Cities. Each of the other four categories of subcenters includes

[4] The subcenter labeled "O'Hare" is just north of the airport near Des Plaines, and should not be confused with the "distance to O'Hare" variable. The subcenter site is in Cook County just north of the airport, and is about 2 miles from the airport's major access point. Although one is in level form and the other is an inverse, the two O'Hare variables are highly correlated. Nevertheless, Table 5 demonstrates that the estimated models can distinguish between the variables, as both are significant.

TABLE 1
Subcenter Employment

Subcenter municipality	1980 Employment	1990 Employment	Percentage of 1980 employment in subcenter					
			Govt.	Manuf.	Retail	Service	TCUW	Other
Old satellite cities								
Aurora	13,766	10,689	3.52	58.86	8.29	14.64	8.03	6.65
Elgin	10,198	13,095	6.62	35.86	11.37	37.69	2.34	6.11
Waukegan	10,562	11,506	28.35	64.40	0.16	1.26	0.00	5.83
Old industrial suburbs								
Chicago Hts.	10,516	10,862	4.14	62.18	1.82	21.72	4.50	5.65
Harvey	11,755	9,880	6.74	42.59	4.48	25.15	14.47	6.57
McCook	45,002	31,109	1.13	64.32	3.60	4.89	19.89	6.18
Post World War II industrial suburbs								
Addison	15,641	23,409	1.83	61.81	4.30	5.15	15.31	11.60
Des Plaines	22,633	27,653	0.00	30.88	3.42	3.81	51.08	10.81
Franklin Park	28,155	27,462	10.02	55.80	17.73	1.06	8.25	7.14
Niles	44,152	40,040	0.75	65.40	3.74	5.68	15.53	8.90
Norridge	9,565	10,457	5.89	43.22	17.28	20.88	6.29	6.44
O'Hare	23,270	32,681	4.76	21.39	5.48	27.22	30.74	10.41
New industrial/retail suburbs								
Northbrook	28,451	43,030	1.95	30.60	21.37	22.90	10.50	12.68
Palatine	3,514	19,385	0.00	18.73	45.33	8.96	8.22	18.75
Edge Cities								
Naperville	9,001	35,168	7.30	19.92	12.21	51.58	1.90	7.09
Oak Brook	54,196	111,550	1.19	12.52	21.98	36.53	19.38	8.39
Schaumburg	23,640	40,295	4.81	13.12	35.98	26.24	12.17	7.68
Service and retail centers								
Burbank	10,783	14,028	2.84	0.86	23.00	65.25	1.96	6.09
Evanston	20,491	19,551	4.34	4.14	13.38	69.38	2.64	6.12
Maywood	23,873	26,749	25.53	6.76	10.56	39.15	11.78	6.22

some subcenters with positive growth and others with negative growth. Of the fifteen subcenters in these four groups, nine had positive employment growth and six declined over the decade. The two subcenters in these groups with the greatest growth rates are Addison and O'Hare, two centers immediately adjacent to O'Hare Airport.

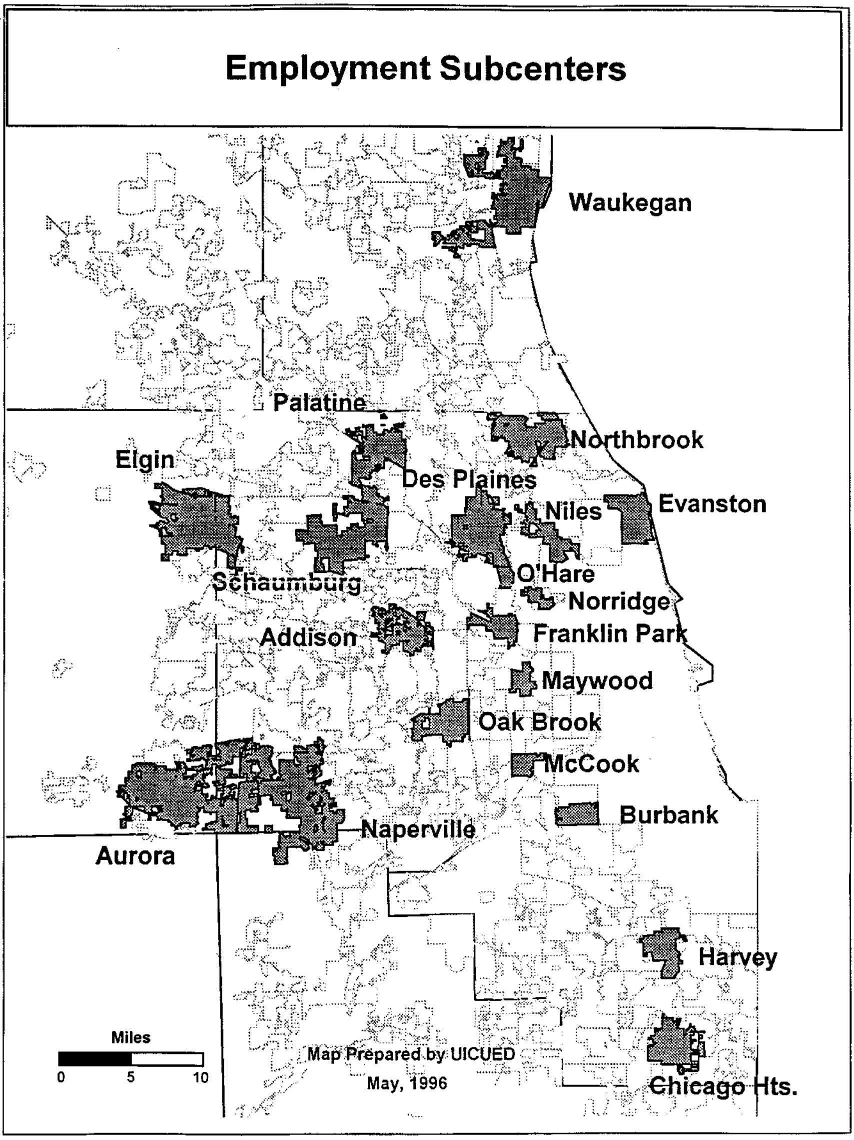
Employment Subcenters
Waukegan
Palatine
Northbrook
Elgin
Des Plaines
Niles
Evanston
O'Hare
Schaumburg
Norridge
Addison
Franklin Park
Maywood
Oak Brook
McCook
Burbank
Naperville
Aurora
Harvey
Miles
0
5
10
Map Prepared by UICUED
May, 1996
Chicago Hts.

FIGURE 1

5. EMPLOYMENT PROBABILITY AND EMPLOYMENT DENSITY

Employment density and probability functions are estimated jointly by maximizing Eq. (8). The models are estimated separately for the 1980 and 1990 data. The scale of distance to the CBD is changed to provide similar units for the estimated coefficients. Models are estimated separately for sites within 15 miles of O'Hare Airport and for those farther away. Estimated functions may differ because the area around O'Hare has greater average employment density and more subcenters than any other part of the urban area. The choice of 15 miles is somewhat arbitrary, but is reasonable and experimentation suggested that the results are not sensitive to small changes in the radius.

Modeling the effects of proximity to subcenters causes some difficulties. Including a separate variable for distance from each subcenter causes severe multicollinearity and implies somewhat unreasonably that the influence of various subcenters is complementary, in that adding a new center at a site lowers densities even far away. Small and Song [22] overcome this problem by modeling density (D) using the following functional form,

$$D_m = \sum_{n=1}^{N} A_n e^{-b_n r_{mn}} + v_m, \qquad m = 1, \dots, M, \tag{10}$$

where N is the number of centers, M is the number of zones, and r_{mn} is the distance between zone m and center n. This additive form proved intractable in our selection approach, either producing extremely high standard errors or more commonly failing to converge altogether.

We take two approaches to modeling the effects of subcenter proximity. In both, the natural logarithm of gross employment density is the dependent variable in Eq. (6), which has a long and successful tradition. Also, we use the inverses of subcenter distances as our proximity measures to reduce multicollinearity problems and because this specification implies that the effects of subcenters, albeit not disappearing altogether, approach zero quickly.[5] In our first approach, subcenter proximity is measured as the inverse of distance to the *nearest* subcenter site. This approach has several advantages: it minimizes multicollinearity problems, it does not imply that adding a subcenter affects densities far away, and it provides a simple and a direct means to determine whether subcenters have any influence on densities after controlling for other variables. To save space, we present detailed results only for this approach.

[5] At subcenter sites the inverse of distance is arbitrarily set to 4 rather than to ∞.

The first approach imposes that a subcenter's influence ends at a site that is equidistant to another center, even when one subcenter has much more employment. While this constraint may not be severe if the effects of all subcenters are as localized as we expect, it may be preferable not to impose it *a priori*. Our second approach relaxes the constraint by including separately the inverse of distance from each subcenter site that is within the sample area (i.e., within 15 miles of O'Hare and beyond 15 miles from O'Hare), allowing us to determine which subcenters have significant effects on expected density.

The estimated models for 1980 are presented in Table 2, and 1990 results are presented in Table 3. Every variable adds significant explanatory power to at least one equation in each year. The correlation coefficient (ρ) is highly significant in the equations for sites more than 15 miles from O'Hare Airport, and the correlation coefficient (ρ) is significant at the 10% level in the 1980 equation for sites near O'Hare. This result is consistent with the theory presented in Section 2, and the result suggests strongly that standard OLS density estimates are subject to significant selection bias.

Most coefficients have the same sign in the employment density and probability equations, but interpretation of the results is easier when the two equations are combined using the expected log-density Eq. (9). Table 4 presents estimates of the marginal effects of the variables on expected log density. The estimates are averages across all observations with employment. Standard errors are estimated using the delta method (see Greene [9]), and the implied absolute asymptotic t-values are presented in Table 4.

On average for a randomly drawn site, access to O'Hare Airport has a pronounced effect on expected employment density in the region within 15 miles of the airport, with an estimated gradient of −7.9% per mile in 1980 and −7.2% per mile in 1990. O'Hare Airport had no effect on expected employment density in 1980 for sites beyond 15 miles from O'Hare, but by 1990 the gradient is significant at −1.7%. The 1990 result suggests that O'Hare's influence is extending to a larger area over time. Table 4 also indicates significant gradients for distance from the CBD, although the rates of decline are smaller than for O'Hare.

Distance to a commuter train station has no effect on expected density in the region near O'Hare Airport where stations are numerous, but has a significant effect farther away where stations are more sparse. The decline in expected density is sharp: −25.0 and −20.0% per mile on average in 1980 and 1990, respectively. For all four estimated models, expected employment density declines significantly with distance to the nearest highway interchange.

Table 4 indicates that expected employment density is higher on average in quarter sections with a higher proportion of land devoted to rail lines,

TABLE 2

Log-Employment Density and Probability Functions, 1980

Variable	Within 15 miles of O'Hare: Probability	Within 15 miles of O'Hare: Density	More than 15 miles from O'Hare: Probability	More than 15 miles from O'Hare: Density
Constant	4.889	5.628	0.898	1.754
	(3.453)	(4.055)	(2.812)	(4.083)
Distance to O'Hare airport	−0.055	−0.081	−0.016	0.002
	(4.628)	(3.798)	(6.861)	(0.402)
Distance to CBD ÷ 10 (DCBD)	−5.516	−7.364	−1.024	−1.815
	(2.368)	(2.936)	(3.745)	(4.320)
$DCBD^2 \div 10$	26.807	35.774	1.840	5.528
	(2.150)	(2.581)	(2.433)	(4.365)
$DCBD^3 \div 100$	−44.436	−57.566	−1.225	−4.947
	(2.080)	(2.292)	(1.864)	(4.125)
Inverse of distance to commuter train station	0.251	0.135	0.789	0.081
	(4.813)	(1.591)	(27.813)	(1.640)
Inverse of distance to highway interchange	−0.024	0.091	0.214	0.046
	(0.563)	(2.006)	(8.185)	(0.995)
Proportion rail	−0.363	1.950	6.961	1.539
	(0.476)	(2.840)	(15.065)	(3.615)
Proportion water	−3.429	0.038	−0.012	−1.220
	(3.109)	(0.021)	(0.068)	(3.043)
Proportion parks and open space	−1.091	−1.162	−0.614	−0.366
	(8.287)	(2.471)	(7.501)	(2.004)
Inverse of distance to nearest subcenter	0.272	0.687	1.473	0.502
	(2.644)	(6.247)	(19.305)	(5.098)
σ_u	1.352		1.341	
	(1.655)		(35.712)	
ρ	0.088		−0.465	
	(1.660)		(7.274)	
Log likelihood	−3,722.6		−9,206.6	
Number of observations	2,100		12,190	
Number of observations with employment	1,559		2,680	

Note. Absolute asymptotic t-values are in parentheses.

and it is lower in those with more water, parks, and open space. A site with more rail lines is attractive to manufacturing, in particular, and significantly increases the probability of employment in the area more than 15 miles from O'Hare, as can be seen in Tables 2 and 3. Tables 2 and 3 also show that having more land devoted to rail lines significantly increases employment density, which suggests that firms using rail tend to be large, perhaps with significant internal economies of scale. In contrast, sites with

TABLE 3

Log-Employment Density and Probability Functions, 1990

Variable	Within 15 miles of O'Hare: Probability	Within 15 miles of O'Hare: Density	More than 15 miles from O'Hare: Probability	More than 15 miles from O'Hare: Density
Constant	2.664	3.408	1.121	1.700
	(2.368)	(2.851)	(3.648)	(3.994)
Distance to O'Hare airport	−0.019	−0.072	−0.026)	−0.006
	(1.543)	(4.766)	(11.646)	(1.434)
Distance to CBD ÷ 10 (DCBD)	−2.785	−3.818	−0.759	−1.349
	(1.468)	(1.564)	(2.930)	(3.422)
$DCBD^2 \div 10$	15.575	19.504	1.131	3.854
	(1.490)	(1.397)	(1.587)	(3.265)
$DCBD^3 \div 100$	−29.038	−32.865	−0.623	−3.220
	(1.585)	(1.268)	(1.007)	(2.920)
Inverse of distance to commuter train station	0.155	0.065	0.737	0.060
	(2.803)	(0.767)	(29.894)	(1.234)
Inverse of distance to highway interchange	0.006	0.086	0.230	0.116
	(0.127)	(2.070)	(8.895)	(2.813)
Proportion rail	0.234	1.559	4.495	1.322
	(0.311)	(2.035)	(12.191)	(2.451)
Proportion water	−3.402	−0.976	0.132	−1.239
	(3.241)	(0.385)	(0.861)	(3.474)
Proportion parks and open space	−1.463	−1.158	−0.785	−0.158
	(10.780)	(1.139)	(9.578)	(0.913)
Inverse of distance to nearest subcenter	0.291	0.734	1.354	0.549
	(2.789)	(4.425)	(18.640)	(5.097)
σ_u	1.351		1.365	
	(0.962)		(34.220)	
ρ	0.062		−0.492)	
	(1.026)		(7.471)	
Log likelihood	−3,820.0		−10,620.4	
Number of observations	2,100		12,190	
Number of observations with employment	1,672		3,215	

Note. Absolute asymptotic t-values are in parentheses.

more water, parks, and open space tend to be unattractive to all uses.[6] Land is inexpensive in such locations, reducing density.

The most important variable for our purposes is the last, representing access to employment subcenters. In all four estimated models, the inverse of distance to the nearest subcenter is highly significant in both the

[6] This result may sound counter-intuitive, but Chicago is built on low-lying land that often floods. Water is not necessarily a good thing in such an area. Similarly, forest preserves and other open space tend to be located in areas that are not desirable for development.

TABLE 4

Marginal Effects for Expected Log-Employment Density

Variable	Within 15 miles of O'Hare 1980	Within 15 miles of O'Hare 1990	More than 15 miles from O'Hare 1980	More than 15 miles from O'Hare 1990
Distance to O'Hare airport	−0.079	−0.072	−0.005	−0.017
	(3.705)	(4.750)	(1.123)	(4.550)
Distance to CBD	−0.055	−0.026	−0.007	−0.008
	(2.604)	(1.372)	(2.270)	(2.481)
Distance to commuter train station	−0.239	−0.110	−0.250	−0.200
	(1.506)	(0.727)	(5.771)	(5.324)
Distance to highway interchange	−0.134	−0.131	−0.083	−0.138
	(2.032)	(2.068)	(2.734)	(5.045)
Proportion rail	1.968	1.552	4.272	3.180
	(2.898)	(2.033)	(7.288)	(5.450)
Proportion water	0.202	−0.870	−1.225	−1.184
	(0.114)	(0.345)	(3.095)	(3.406)
Proportion parks and open space	−1.110	−1.113	−0.608	−0.482
	(2.382)	(1.103)	(3.490)	(3.057)
Distance to nearest subcenter	−0.339	−0.351	−0.126	−0.117
	(6.219)	(4.415)	(7.902)	(7.783)

Note. Absolute asymptotic *t*-values are in parentheses.

employment probability and the density equations. Table 4 indicates that the gradients are steep: average expected employment density declines by 33.9% per mile with distance to the nearest subcenter in the region within 15 miles of O'Hare Airport in 1980 and it declines by 35.1% per mile in 1990. The decline is less steep in the region farther from O'Hare where subcenters are less numerous, but the decline is still high at 12.60% per mile in 1980 and at 11.7% per mile in 1990. These results are particularly significant because we have controlled for access to O'Hare, the Chicago CBD, highway interchanges, and commuter train stations. Access to the transportation network is a prime consideration in locating firms with internal scale economies. The importance of other kinds of agglomeration economies to firm location is suggested by the significance of subcenter access after controlling for other forms of accessibility.

Table 5 presents a portion of the results of our second specification, in which individual subcenters are entered separately. Only those subcenters located within the sample area are included as explanatory variables, which reduces the number of subcenters to 13 in the region near O'Hare and to 7 in the region farther away. Despite the multicollinearity that is expected when many distance variables are included as explanatory variables, the large number of significant coefficients suggests that the results

TABLE 5
Marginal Effects for Expected Log-Employment Density:
Distance from Individual Subcenters

Within 15 miles of O'Hare			More than 15 miles from O'Hare		
Subcenter	1980	1990	Subcenter	1980	1990
Addison	−0.028	−0.025	Aurora	−0.020	−0.018
	(1.940)	(2.028)		(2.206)	(2.400)
Des Plaines	−0.048	−0.032	Burbank	−0.014	−0.012
	(2.895)	(1.779)		(1.790)	(1.951)
Evanston	−0.043	−0.038	Chicago Hts.	−0.020	−0.019
	(3.962)	(3.949)		(3.125)	(2.101)
Franklin Park	−0.052	−0.042	Elgin	−0.014	−0.016
	(2.784)	(2.009)		(2.736)	(3.600)
Maywood	−0.011	−0.020	Harvey	−0.009	−0.004
	(0.813)	(1.596)		(1.648)	(1.022)
McCook	−0.029	−0.018	Naperville	−0.009	−0.018
	(3.214)	(1.378)		(2.323)	(4.415)
Niles	−0.051	−0.046	Waukegan	−0.020	−0.018
	(3.476)	(3.307)		(4.128)	(3.714)
Norridge	−0.011	−0.016			
	(0.737)	(1.008)			
Northbrook	−0.042	−0.034			
	(3.061)	(2.925)			
Oak Brook	−0.044	−0.064			
	(3.360)	(4.142)			
O'Hare	−0.044	−0.043			
	(3.558)	(2.785)			
Palatine	0.007	−0.025			
	(0.591)	(2.131)			
Schaumburg	−0.050	−0.063			
	(3.069)	(6.216)			

Note. Absolute asymptotic t-values are in parentheses.

are quite precise. The only average expected employment density gradients that are clearly insignificant in both years are Maywood, Norridge, and Harvey. Norridge is the smallest subcenter and is close to others, so it is the prime candidate for elimination from our subcenter list. Other gradients hover near a decline of 3–4% per mile in the region near O'Hare, and they hover under 1% per mile farther away. Overall, Table 5 is strong evidence that subcenters exert a powerful influence on employment patterns in the Chicago area.

The subcenter with the largest gradient across the years is Schaumburg, which is one of the three Edge Cities. The rapid growth of employment in the Schaumburg subcenter produced a steeper gradient (−6.3% per mile) in 1990 than in 1980 (−5.0% per mile). The gradients for the other two

Edge Cities (Naperville and Oak Brook) became steeper over the 1980–1990 period as well. The gradient for Palatine, which is one of the two newer industrial/retail suburbs, also became steeper. The gradients for the remaining subcenters changed very little or they became flatter over the decade. These results suggest that one measure of the strength of the agglomeration economies of a subcenters is the *change* in the employment density gradient as measured here. A subcenter that produces a *steeper* gradient over time very likely had strong agglomeration economies.

Our results confirm bid-rent theory's prediction of selection bias, but we have not yet demonstrated the severity of the bias. Table 6 presents OLS log-employment density estimates using observations with employment. The results in Table 6 are directly comparable to the columns labeled

TABLE 6

Ordinary Least Squares Log-Employment Density Estimates

Variable	Within 15 miles of O'Hare 1980	Within 15 miles of O'Hare 1990	More than 15 miles from O'Hare 1980	More than 15 miles from O'Hare 1990
Constant	5.518	3.381	1.507	1.442
	(5.381)	(3.351)	(3.671)	(3.624)
Distance to O'Hare airport	−0.079	−0.072	−0.006	−0.019
	(6.294)	(5.816)	(1.488)	(4.998)
Distance to CBD ÷ 10 (DCBD)	−7.153	−3.730	−1.968	−1.347
	(3.917)	(2.097)	(4.969)	(3.578)
$DCBD^2 \div 10$	34.662	18.986	5.557	3.458
	(3.293)	(1.871)	(4.680)	(3.070)
$DCBD^3 \div 100$	−55.520	−31.847	−4.903	−2.820
	(2.889)	(1.737)	(4.437)	(2.682)
Inverse of distance to commuter train station	0.125	0.061	0.299	0.273
	(3.033)	(1.503)	(9.264)	(8.484)
Inverse of distance to highway interchange	0.092	0.085	0.118	0.193
	(2.050)	(2.010)	(2.850)	(5.195)
Proportion rail	1.968	1.556	2.373	1.921
	(3.233)	(2.570)	(4.763)	(3.733)
Proportion water	0.216	−0.854	−1.266	−1.212
	(0.137)	(0.567)	(3.380)	(3.743)
Proportion parks and open space	−1.098	−1.098	−0.614	−0.490
	(5.567)	(5.383)	(3.701)	(3.057)
Inverse of distance to nearest subcenter	0.677	0.727	0.780	0.813
	(9.170)	(9.996)	(10.238)	(10.782)
R^2	0.191	0.149	0.139	0.144
Number of observations	1,559	1,672	2,680	3,215

Note. Absolute *t*-values are in parentheses.

“density” in Tables 2 and 3. Consider the 1990 equation for the area more than 15 miles from O’Hare Airport. The selection-bias corrected results indicate that distance to the airport does not have a significant effect on density in a random sample, whereas OLS indicates a highly significant coefficient of -0.019. OLS uniformly produces larger coefficients in this equation, with higher t-values. The selection bias is severe.

6. CONCLUSION

This paper accomplished two tasks. First, a bid-rent model of employment location was formulated that makes the distinction between small zones that contain no employment and those that do contain employment. Separate equations are specified for the probability that a small zone contains any employment and for gross employment density given that employment exists in the zone. We show that the method of maximum-likelihood estimation can be used to estimate these two equations jointly. Evidence of significant correlations between employment density and employment probability errors implies that OLS estimates are subject to selection bias, and the bias alters the results significantly.

Second, we formulated an empirical test that distinguishes between two types of agglomeration economies that might be exhibited by an urban site. The first type of agglomeration economy is based on access to infrastructure shared by many firms. Transportation facilities, such as limited-access highways, waterways, railways, and airports, are subject to economies of scale. Therefore, a location near these facilities permits a firm to make use of scale economies to a greater degree. Firms will cluster near transportation facilities even if there are no direct benefits of locating near one another. The second type of agglomeration economy stems from causes that are internal to the group of establishments, and may consist of information, communications, or shopping externalities.

The empirical study is based on employment density data for the suburbs of Chicago for the years 1980 and 1990. Suburban subcenters (in addition to O’Hare Airport) were identified using the procedure outlined by Giuliano and Small [6]. Twenty subcenters were identified, and they can be classified into distinct categories as (1) old satellite cities, (2) old industrial suburbs, (3) post World War II industrial suburbs, (4) newer industrial/retail suburbs, (5) Edge Cities, and (6) service or retail centers.

The empirical results show that the measures of access to the transportation systems are highly statistically significant determinants of both employment probability and employment density. The results also show that, holding access to transportation constant, proximity to an employment subcenter is a statistically significant variable in both equations as well. These findings are general confirmation of the existence of both types of agglomeration economies as previously discussed. Estimation of the model for 1980 and 1990 permits us to determine whether the effect of proximity to an employment subcenter increased. In general, this effect did not change very much, but the employment density gradient for four of the twenty subcenters clearly became steeper. These four subcenters include the three that are called Edge Cities by Garreau [5]—Schaumburg, Naperville, and Oak Brook.

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