ESSAYS IN URBAN ECONOMICS AND LOCAL LABOR MARKETS: THE ROLE OF CONCENTRATIONS OF EMPLOYMENT

A Dissertation

Presented to

The Faculty of the Department

of Economics

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Philosophy

By

Adam W. Perdue

May, 2012

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Abstract

This dissertation consists of two essays exploring the often noted dispersion of economic activity within cities. Focusing in particular on the phenomenon of polycentricity, these essays explore the relationship between employment centers and spatial and economic outcomes of cities.

The first essay explores the implications of two common proposed criteria for identifying an employment center. Does the area represent a local concentration of employment? Does the area affect the local population density of the city? Using data on both place of employment and place of residence, I propose a new method for testing the relationship between concentrations of employment and population density within a metropolitan area. First a recently developed statistical method is used to identify concentrations of employment using data on place of employment. Second, I propose two methods for estimating the extent of the radius of influence for an employment center, using the relationship between tract of employment and tract of residence. Third, I propose a new specification for the entrance of distance into the polycentric regression. This new specification allows the impacts of the concentrations of employments on density to be positive, following the theoretical hypothesis. I use this new specification to jointly estimate the local gradients of 21 identified concentrations of employment in the Houston metropolitan area on their local population density. I find that not all identified employment concentrations have the expected significant positive gradients, and thus do not qualify as employment centers. I also find that the estimated gradients are sensitive to

estimates for the radius of influence for each employment concentration, and that the level of employment in an employment concentration, alone, is not a strong predictor of significant local impact on population density or on the size of the estimated gradient.

The second essay tests for the theoretically predicted relationships between the number of employment centers in a city, and the city's transport costs and wages. Urban area vehicle miles travelled rise with an increase in the number of employment centers in an urban area, while commute times are unaffected. These findings contradict the common hypothesis that additional employment centers lower transport costs by allowing workers to live closer to work. Instead, it appears that if transport costs are falling they do so through a fall in per unit distance price. I find that urban area average wages fall with an increase in the number of employment centers. I also find that average wages increase as a larger share of employment locates within employment centers. These two findings support the belief in the presence of agglomeration economies within employment centers that increases in concentration. In a competitive equilibrium the formation of additional employment centers have externalities in both the costs and benefits, thus it is not clear if the efficient number of employment centers will be formed within an urban area. This is explored through an investigation of the determinants of the share of urban area employment that locates in employment centers. I find that the predicted employment share maximizing number of employment centers increases with urban area size.

Contents

1 Employment centers: Their radius of influence and relationship to local population densities

2 Wages, travel and the number of employment centers in urban areas

Employment centers: Their radius of influence and relationship to local population densities

1.1 Introduction

The goal of this paper is to empirically identify employment centers based on two theoretically derived criteria. First, employment centers should represent local concentrations of employment. Second, proximity to employment centers should be related to increases in local population densities. There exists a broad literature identifying employment centers as local concentrations of employment (Giuliano and Small (1991); McDonald and McMillen (1998); Craig and Ng (2001); McMillen (2001); and Redfearn (2007))Furthermore, there are some studies of the impacts of the concentrations on land prices, and population or employment densities (Sivitanidou (1996); McDonald and McMillen (1998); and Small and Song (1994)) using a set of three standard functional forms of the polycentric density function (Anas et. al. (1998)).

In this paper I propose a modification of the functional forms that relaxes their strict assumptions of area of influence and allows them to better match the theoretical models of the relationship between employment centers and population densities. Using data tying location of employment to location of residence, I estimate radii of influence for each of the employment centers. Estimating the radii of influence negates the need to choose between the assumptions about the extent of influence of the earlier functional forms. The estimates of the employment center gradients are found to be sensitive to the estimated radii of influence. To my knowledge this is the first paper to attempt to estimate radii of influence for concentrations of employment.

As a second modification to the existing functional form I enter distance as movement away from the previously estimated radius of influence and towards the employment concentration. That is, my distance variable increases upon approach towards a concentration of employment. This allows proximity to an employment concentration to increase population density above some underlying value, which would be fixed by the influence of the remaining concentrations. Modeling distance as distance away from an employment center would predict a fall in density below the estimate underlying density.

21 concentrations of employment are identified as local statistically significant concentrations of employment. Then four procedures are used to estimate radii of influence for each employment concentration. The modified functional form is used to estimate a polycentric density function under each set of estimated radii. Finally employment centers are identified as concentrations of employment that have an estimated significantly positive local gradient. Not all concentrations of employment are identified as employment centers. Both the significance and the point estimates of the gradients are sensitive to the estimated radii of influence.

The remainder of the paper is organized as follows. Section 2 provides an overview of the literature exploring polycentric urban areas. Section 3 presents the data and its sources. Section 4 provides an overview of methods for identifying employment centers and presents the chosen method for this paper. Section 5 presents the proposed method of identifying the radius of influence of the employment centers. Section 6 presents the new specification of the multiplicative model used in this paper. Section 7 presents the results of the estimation of the radii of influence of the employment concentrations and identifies employment centers using a modified multiplicative model. Section 8 concludes the paper.

1.2 Polycentric Urban Areas

Fujita and Ogawa (1982) and Anas and Kim (1996) explore urban polycentric static equilibrium in the presence of transport costs and agglomeration economies. Berliant and Wang (2008) explores a dynamic equilibrium with formation of employment centers as a consequence of urban area growth.[1] In these models with local agglomeration economies and sufficiently low transport costs, employment concentrates within one location, the CBD. An employer then faces a tradeoff between the positive production externalities and the transport costs associated with increasing concentration. With increases in transportation costs the urban form eventually supports a new stable equilibrium, with multiple employment centers. The dispersion of employment lowers worker productivity, but lowers transport costs and thus the compensating wages employers must offer workers. The models also include workers who seek to maximize their utility by minimizing their commuting cost. Workers trade off proximity to their employment for lower housing prices and/or density.

Two common testable criteria for identifying employment centers are drawn from these models. First, the employers' attempts to recapture local agglomerations will lead to local concentrations of employment within urban areas. Second, workers' attempts to lower commuting costs will lead to increasing land prices and density with proximity to these concentrations of employment.

[1] The growth of the urban area leads to increases in transportation costs.

Early attempts at identifying employment centers used local knowledge (Bender and Wang (1985)), or simple local peaks in employment density (McDonald (1987)). One common method uses cutoffs in employment density and level (Giuliano and Small (1991) and McDonald and McMillen (1998)). An initial statistically based method was Craig and Ng (2001), which used local peaks in the 95th percentile splines of the monocentric gradient to identify rings around the employment center with statistically significant concentrations of employment. Recently methods have been developed that allow the density gradient to vary locally and independently of direction from the CBD (McMillen (2001); Redfearn (2007)). These three methods identify what can best be called locally statistically significant concentrations of employment.

Empirical measurements of the impact of concentrations of employment typically follow one of three functional forms (Anas et. al. (1998)).[2]

$$D_i = Max_j\left[A_j exp\left(-\beta_j d_{ij}\right)\right] \quad (1)$$

$$D_i = A \prod_{\mathbf{j-1}}^{\mathbf{J}} exp\left(-\beta_j d_{ij}\right) \quad (2)$$

$$D_i = \sum_{\mathbf{j-1}}^{\mathbf{J}} A_j exp\left(-\beta_j d_{ij}\right) \quad (3)$$

Where D_i is the density at location i, d_{ij} is distance from location i to employment concentration j, $A_j$and A are constant terms, and $\beta_j$is the gradient. Equation 1 assumes the employment concentrations act as perfect substitutes, so that each worker only has a preference for proximity to one of the J employment centers. Sivitinadou(1995) identifies concentrations of service employment in the Los

[2] The empirical literature largely identifies concentrations of employment as employment centers, then tests the hypothesis that distance from the employment centers has a negative relationship to density or prices. Here and in McMillen(2001) employment centers are identified as concentrations of employment that have the predicted relationship to density. It is an important distinction, but the estimation procedures are similar.

Angeles region, then performs a series of tests of the relationship between distance from the concentrations and office land rents. The first of these tests is an approximation of equation 1. Sivitinadou assumes that the CBD affects the whole of L.A. and that the bid rent function of a secondary concentration dominates at all locations for which that concentration is the nearest. Under these assumptions, Sivitinadou finds that "on average" land prices are negatively related with distance from the nearest concentration.

Equations 2 and 3 drop the assumption of the perfect substitutability between employment concentrations. By allowing employment concentrations to impact density across the whole of the city, the underlying assumption is that each worker has some preference for each and every employment center. The multiplicative model, equation 2, assumes that the employment concentrations act as perfect complements. While the multiplicative model is rather straight forward to estimate, after taking logarithms, it has one extreme property. Large distance from even one employment concentration can prevent development at a tract. The additive model, equation 3, is an intermediate case. The value of a location is affected by its proximity to each employment center, but here the cost of large distances from an employment center approaches zero.

Sivitanidou's (1996) second and third models adopt equation 2. Sivitanidou finds that simultaneous proximity to multiple employment centers increases values, suggesting that employment centers do not act as perfect substitutes. Sivitanidou reports mixed results for center specific gradients when entering distance from each concentration. McDonald and McMillen (1998) also apply the multiplicative model, to explore the relationship between proximity to employment concentrations and employment density in Chicago. They find significant relationships between distance from all but one identified employment concentration and employment density. Small and Song (1994) apply the additive model, equation 3, in Los Angeles. Using high cutoffs to identify ten concentrations in L.A. they find mixed results for the relationship between distance from the concentrations and local employment and population densities.

1.3 Data

This study uses employment and population data at the tract level for the Houston Metropolitan Statistical Area as defined in the year 2000. Houston was selected as the area of study based on the existence of previous work identifying employment centers (McMillen (2001) and Craig and Ng (2001)) and the City of Houston's status as a relatively free market city. While the City of Houston does have significant government involvement in land use decisions, it retains a unique status as the only large American city without zoning or a "plan". Its remaining regulations are on the whole no more restrictive or prescriptive than those in any other major American city (Lewyn (2005)).

Data on employment was obtained from the Census Transportation Planning Package 2000 Part 3 Journey to Work. The Journey to Work data estimates place of residence and place of work for all workers using data from a sample of residents compiled from the census long form. [3] Place of work data, is used to identify the employment centers. Place of work and place of residence is then used to identify

[3] Respondents reporting either place of employment or place of residence outside of the metropolitan area were dropped.

the tract of residence of workers working in each employment center, in order to estimate the radius of influence of the employment center. Data from the 2000 decennial census gives the total population for each tract. Tigerline files from the Geography division of the Census Bureau gives geographical data for each census tract such as latitude and longitude of the centroid, and land area.

1.4 Identification of Concentrations of Employment

Early attempts to analytically identify employment centers and their extent include employment density and level cutoffs, as can be seen in Giuliano and Small (1991) and McDonald and McMillen (1998). This method is arbitrary and requires local knowledge to set appropriate cutoffs for different cities. These drawbacks can readily be seen upon inspection of McDonald and McMillen (1998). Investigating the Chicago region and starting with the working cutoff definitions from Giuliano and Small (1991), they find an “unreasonably large” employment center near O’Hare Airport. They then change the cutoffs in order to obtain more reasonable results.

An early attempt at defining employment centers as statistically significant concentrations of employment can be seen in Craig and Ng (2001). The authors locate employment subcenters in the Houston region using quantile smoothing splines. They define rings equidistant from the CBD where the 95th percentile of employment density has a local maximum. Once these rings are identified they then inspect the census tracts within a certain bandwith to find the employment subcenters. Disadvantages to this method are that it assumes a monocentric density gradient that is independent of direction from the city center and requires manual inspection to identify the employment centers located on each ring.

McMillen (2001) and Redfearn (2007) both propose localized nonparametric methodologies to identify employment centers. They all weaken the need for strong assumptions about the form of the city, for local knowledge, and increase the objectivity and consistency of measurement across cities. All three methods allow the density gradient to vary locally and indentify employment centers that can be characterized as locally statistically significant concentrations of employment.

The methodology used in this paper to identify employment centers is an adaptation of the first stage of McMillen (2001). The first stage of this adapted methodology uses a locally weighted regression (LWR) on the natural log of employment density of each observation in a Metropolitan area as in McMillen (2001). [4] The observations for each regression are those that fall within a given distance or bandwidth from the current tract of interest.[5] Once the tracts that fall within the bandwidth are identified they are weighted using a tricube kernel, which is a negative function of distance from the tract of interest. Each LWR produces a predicted value of the natural log of employment density $\hat{y}$ for each observation. Candidate employment centers are then defined as tracts or sets of contiguous tracts whose true value of y falls above the 95% confidence interval of $\hat{y}$.

Figure 1 shows the 21 locally statistically significant concentrations of employment identified as candidate employment centers, using the above method,

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[4] The units of observation in this paper is are the census tracts in the Houston Metropolitan Area as defined by the Census Bureau.
[5] McMillen(2001) uses the 50% of tracts out of the set that are nearest neighbors. A thirty mile bandwidth is used here.

in the Houston Metropolitan area. Table 1 presents the list of employment centers identified, their number of workers, employment density, and the percentage of urban area employment locating in that employment center. The names come from local names, the primary political unit, or the intersection of major highways associated with the employment center. Total employment in the identified employment centers is 484,629, which is 24% of the total metropolitan area employment of 2,023,871. 0.65% of total land area is located in the identified employment centers. Employment totals range from 155,105 workers in the two tracts that are identified as Downtown Houston[6], to 739 workers in the tract in the City of Cleveland. The percentage of urban area employment ranges from 7.7% in Downtown to 0.037% in Cleveland.

1.5 Estimation of the Radius of Influence

Each of the three functional forms described previously make assumptions about the area of influence of the employment concentrations. Equation 1 assumes that a concentration only affects that area for which its bid rent function is dominant, but offers no clues as to how to delineate the boundary, except that there cannot be overlap in the areas of influence. Equations 2 and 3 operate on the assumption that each employment center has some influence on the whole city. This leads to the case where a small outlying concentration can either influence, under equation 3, or deny the development completely, under equation 2, of a location on the extreme opposite side of the city. This seems implausible.[7]

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[6] 1 tract comprises the traditional CBD. The second tract is contiguous with the CBD tract, lies to the south and encompasses an area locally known as Midtown.

[7] Consider the employment concentration identified earlier as Cleveland, with employment of 739, or 0.037% of the metropolitan area workers, and located in the far northeast section of the Houston MSA. The

Equation 4 shows the modification of the multiplicative functional form that restricts the influence of employment concentration to some radius.

$$D_i = A \prod_{\mathbf{j-1}}^{\mathbf{J}} exp(-\beta_j d_{ij} I_{ij}) \quad (4)$$

$$I_{ij} = 1 \; if \, d_{ij} \leq r_j, 0 \; otherwise$$

Where I_{ij} is a dummy that equals one if tract i falls within r_j, the radius of influence of employment concentration j, and zero otherwise. [8] With this modification β_j is the estimate of the density gradient of the employment concentration within its radius of influence.

The estimate of the gradient will be sensitive to the radius of influence specified. The true radius of influence delineates the area where there exists a relationship between distance from the employment center and density, and the area where that relationship no longer exists. If r_j is greater than the true radius of influence, the first order effect would be to bias the estimated gradient toward zero, due to the inclusion of an area where there is no existing relationship between distance and density.[9] There would exist no first order bias in the estimated gradient associated with r_j being less than the true radius of influence, assuming that an employment concentration's gradient is constant within its radius of influence. As a second order effect, the misspecification would leave an increase in density associated with an employment concentration to be explained by the constant term

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assumption that each employment concentration impacts the whole of the metropolitan area implies that the existence of Cleveland is influencing the density of tracts on the opposite side of the area (across central Houston) up to 100 miles away.

[8] The functional forms represented by equations 1 and 3 can be modified similarly. In equation 1 the r_j would represent a delineation of the intersections of the bid rent functions.

[9] I use first order here because in the polycentric regression a biased estimate of the radius of influence will impact the estimate of the concentration's gradient. The biased estimate of one gradient and one radius of influence will then bias the estimates of the constant term and the gradients of neighboring concentrations.

and the estimated gradients of its neighbors. The assumed radius of influence thus appears to be likely to affect the estimated impacts of employment concentration on local population densities.

To my knowledge there does not exist any literature exploring methods to explicitly estimate the area of impact of employment centers within an urban area. I propose using data on workplace and residence locations from the Census Transportation Planning Package: Journey to Work. The Journey to Work data links residence and work place location for workers.

As my estimates of an employment concentration's radius of influence, I use two separate measures. First, I use a visual estimate of the extent of the relationship between proportion of workers living in a tract and working at the employment concentration of interest, and the distance between the tract and the employment concentration. Figure 2 contains the graphical representation of this relationship for each of the 21 identified concentrations of employment. For the visual estimate I attempt to select the distance beyond which there is no longer any apparent relationship between distance from a concentration and the proportion of a tracts residents working in the concentration. The second estimate of the radius of influence is selected as that distance from a concentration within which 95% of the concentration's workers reside.

As further estimates of the radius of influence, I apply a procedure by Kohlhase (1991) but limit analysis to within the ranges identified in the first stages and estimate the relationship between proportion of workers, distance and distance squared.

$$\frac{workers\ residing\ in\ tract_j\ working\ at\ EC_i}{workers\ residing\ in\ tract_j} = \alpha + \beta_1 d_{ij} + \beta_2 (d_{ij})^2 + \varepsilon_j \ \forall\, i \qquad (5)$$

The quadratic formulation allows for an estimation of the range wherein distance has a negative effect on proportion of workers working within the employment center of interest. The estimated marginal radius of influence is then the distance at which the estimated marginal effect on the proportion of employment center workers of an increase in distance from the employment center is zero.

$$estimated\ marginal\ radius\ of\ influence = \frac{-\beta_1}{2\beta_2} \qquad (6)$$

Previous literature has typically identified the extent of the radius of influence of employment centers in two ways, as exemplified in both Sivitanidou (1996) and McDonald and McMillen (1998). First, the area of impact is left unaddressed and employment centers are implicitly assumed to affect the whole of the area being studied. The assumption that employment centers affect the whole of the area will likely be incorrect for smaller employment centers lying on the outskirts of a region. Second, an employment center is sometimes assumed to affect only the tracts for which that employment center is the closest. This assumption follows models such as Fujita and Ogawa (1982) and Berliant and Wang (2008), which assume that workers only care about proximity to their employment center of work. Other models have shown that workers from different employment centers might mix if given preferences for multiple employment centers, such as through a preference for amenities (Ng (2008)) or potential locations of work (Crane (1996)). The method in this paper explicitly tests for the radius of influence with no a priori assumptions about the extent of an employment center's influence or separation between employment centers' areas of influence.

1.6 Multiplicative Specification and the Measurement of Distance

The functional forms previously present enter distance, as distance away from an employment concentration. Entering distance into the equation this way will lead to biased estimates because of the implicitly assumed city form. The estimated gradients for all of the remaining employment centers will fix estimated densities at and around the location of the employment concentration of interest. Then for an employment concentration to have a negative gradient it would need to be causing population density to fall below the underlying estimate from the other employment concentrations and that decrease in population density would grow larger with movement away from the employment concentration. The thick dashed line in figure 3 shows the implicitly assumed local effects of an employment center on population density when distance enters as distance from an employment center.

The prediction of the polycentric models is that population density increases from some base level upon approach toward an employment center, as shown with the solid line in figure 3. Thus it becomes necessary to change the specification in the multiplicative model in some way to change the implicit assumption from a loss of population density with movement away from an employment center to the assumption that moving toward an employment increases population density above an otherwise predicted level. [10] Using the estimated radius of influence discussed previously I propose estimating the model

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[10] A third functional form would be $\ln(D_i) = \alpha + \sum_j^{j=n} I_{ij}(\beta_j^I + \beta_j^d d_{ij}) + \gamma X$ where I_{ij}=1 if tract i lays within the area of influence of employment center and 0 otherwise. This specification would test for an increase in population density and a gradient separately. Analysis is forthcoming.

$$D_i = A \prod_{\mathbf{j-1}}^{\mathbf{J}} exp(\beta_j m_{ij} I_{ij}) \quad (7)$$

$$m_{ij} = r_j - d_{ij}, \; if \; d_{ij} \leq r_j$$

m_{ij} is calculated as distance from the estimated radius of influence of employment center j to tract i if tract i is within the radius of influence. For each employment center this new specification will fix the underlying estimated densities based on proximity to the remaining employment centers and then allow the estimation of the increase in population density caused by moving closer to the employment center of interest.

1.7 Results

Table 2 shows the estimated radii of influence for each employment concentration. The first column represents an estimate, from visual inspection by the author, of the extent of the relationship between distance from each employment concentration and proportion of workers in each tract working in the concentration. The selection criterion is that distance at which the apparent visual relationship between distance from an employment concentration and proportion of employment concentration workers disappears. The third column reports the distances within which 95% of a concentration's workers reside.

To estimate the marginal radii of influence in the second and fourth columns of table 2, I first restrict the data set to within their respective initially estimated distances, the visual estimate and then the 95% distance. To derive the estimates of the marginal radius of influence, I then estimate the relationship between proportion of workers that live in a tract and its distance from the employment concentration and its square term, equation 5. The estimated marginal radius of influence is found by taking the derivative of equation 5, with respect to distance from the concentration, and setting it equal to zero and solving for the distance at which the estimated marginal impact of distance from the concentration is zero. Table 3 shows the results of the regressions used to estimate the marginal radius of influence when distance is restricted to within the initial visual estimation.[11]

Estimating the polycentric multiplicative model is straight forward. Taking the natural logarithm of both side of equation 7 yields

$$\ln(D_i) = lnA + \sum_{j-1}^{J} exp(\beta_j m_{ij} I_{ij}) + \varepsilon_i \quad (8)$$

Table 4 shows the estimates of the employment concentrations local population gradients from the regression of natural log of population density on distance from each employment center with the influence of each employment concentration limited to their estimated market areas. The first column reports the results when the market area is set by visual inspection. Eleven employment concentrations have the predicted positive impact on population density with proximity, and thus define both criteria of an employment center. The second column in Table 4 shows the estimates of the regression restricting the market areas to the visual marginal radii of influence, with twelve identified as employment centers. The regression restricting the radius of influence to the 95% percentile distance has seven concentrations identified as employment centers, and the final regression has twelve concentrations with the predicted relationship to local population density.

[11] The fourth column of Table 2 was estimated using the same method, but restricting the data to that distance within which 95% of the concentration's workers reside.

The results in table 4 show the sensitivity of employment center identification to the estimated market areas. Restricting the employment concentrations' radii of influence to their visual estimates yields 11 employment centers and one significant negative gradient. Estimating the regression with the visual marginal estimates of radii of influence yields three additional employment centers, fails to identify two of the employment centers from the first regression, and changes the employment concentration that receives the significant negative gradient. The regression restricting the radii of influence to the distances within which 95% of the employment concentration's workers reside identifies 7 concentrations as employment centers and one concentration is estimated to have a negative impact on local population density. The final regression, limiting the radii to the 95% marginal estimates, identifies 12 employment centers. The minimum number of employment centers identified in any one regression is 7, but 15 employment centers are identified in at least one regression.

Table 5 lists the employment concentrations their size, in terms of total employment, employment density, proportion of metropolitan workers, and estimated gradients from the specification presented in table 4 column 2. Four of the five largest, by level or density, employment concentrations do not have positive significant estimated gradients. Galleria, the second largest by level and the third largest by employment density, has a significant negative gradient. The Medical Center, Greenway Plaza, and Allen Parkway all have insignificant estimated gradients. The common link between these four employment centers is their proximity to downtown and to each other. They all lie within 6.2 miles of downtown and within 5.13 miles of each other. Their estimated areas of influence have significant overlap which leads to issues of multicollinearity in measurement of distance from each of these close in employment concentrations. Beyond the question of the presence of significant local gradients lies the question of the determinants of the size of the gradients. Upon inspection a relationship between the size of the employment center and the level of its estimated gradient is not apparent.

1.8 Conclusion

In this paper I explore the relationship between Houston Metropolitan area employment concentrations and their local population densities. Employment centers are identified as local concentrations of employment proximity to which has a positive relationship on local population density. To test for the positive relationship between proximity to an employment concentration and population density, I propose modifications to the multiplicative polycentric density function.

First, I propose a method for delineating the radius of influence of each of the employment centers. Previous research has largely left the question of the extent of local economic impact of spatial phenomenon largely unexamined. I estimate radii of influence, using four different proposed procedures, for identified concentrations of employment using data tying place of employment to place of residence. To my knowledge this paper represents the first attempt to estimate the extent of influence of employment concentrations. The impact of improper specification of radius of influence is explored, and it is found that the significance and estimated gradients of employment concentrations are sensitive to the estimated radii.

I also propose a new specification for the entrance of distance, which enters negatively as approaching an employment center. This new specification changes underlying implicit assumptions and allows proximity to a concentration of employment to increase population density above the underlying density.

In the end I find that a majority of the identified employment concentrations do appear to have some local positive effect on population density. 15 of the 21 employment concentrations have significant estimated positive gradients under at least one of the proposed radii of influence.

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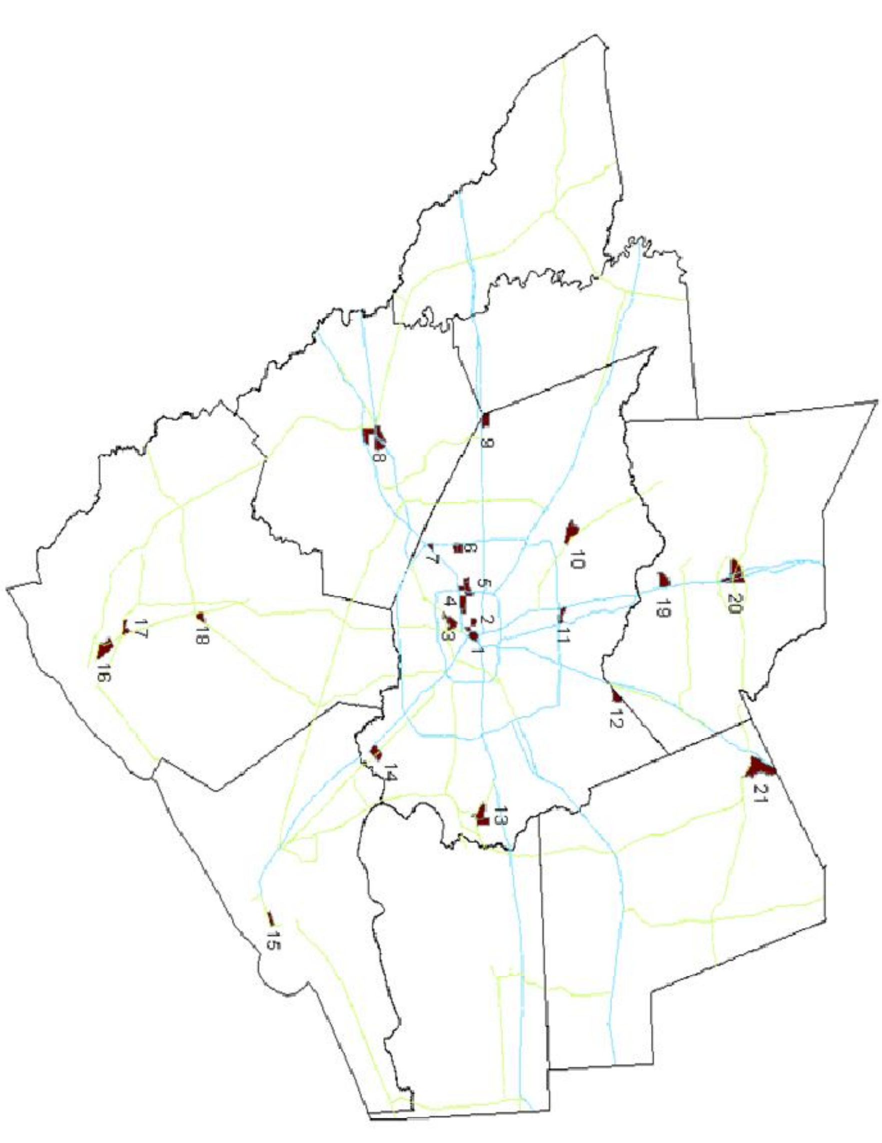
1.10 Tables and Figures

Figure 1- Employment Centers in the Houston Metropolitan Area[1,2]



Employment Centers[3]

1 CBD
2 Allen Parkway
3 Medical Center
4 Greenway Plaza
5 Galleria
6 Westpark
7 US 59 / BW 8
8 Richmond
9 Katy
10 SH 249 / FM 1960
11 Greenspoint
12 Kingwood
13 Baytown
14 Webster
15 Galveston
16 Freeport
17 Lake Jackson
18 Angleton
19 Woodlands
20 Conroe
21 Cleveland

1 Metropolitan Statistical Area as defined by the Office of Management and Budget.
2 Employment Centers defined as locally statistically significant concentrations of employment following first stage of McMillen (2001). Employment data from Census Transportation Planning Package Part 3 Journey to work.
3 employment centers identified using local names, major highway intersection, or political jurisdiction.

Table 1- Employment Concentration summary

Employment Concentration[1,2]	Workers[3]	Workers/ sq mile	Proportion of Metropolitan Area Workers[4]	Proportion of Concentration Workers
Downtown	155105	84032.8094	0.077	0.32
Galleria	68067	27707.8023	0.034	0.14
Medical Center	58067	30072.8902	0.029	0.12
Greenway Plaza	53057	28542.6045	0.026	0.11
Galveston	16509	15996.6844	0.0082	0.034
Greenspoint	16502	11835.5735	0.0082	0.034
249_1960	16361	5233.97435	0.0081	0.034
Westpark	15538	11196.7156	0.0077	0.032
Conroe	13048	2358.25421	0.0064	0.027
Webster	10520	5889.52134	0.0052	0.022
Woodlands	10306	4819.92597	0.0051	0.021
Freeport	10015	3176.9074	0.0049	0.021
Allen Parkway	9578	19340.6262	0.0047	0.02
Baytown	8475	2303.90363	0.0042	0.017
Richmond	6752	1258.17872	0.0033	0.014
59_bw8	5277	9528.71349	0.0026	0.011
Lake Jackson	4453	3582.86713	0.0022	0.0092
Katy	2310	1246.10442	0.0011	0.0048
Angleton	2101	1577.39279	0.0010	0.0043
Kingwood	1836	1371.2366	0.00090	0.0038
Cleveland	739	117.486462	0.00037	0.0015
Total	484629		0.24	

1 Employment Centers defined as locally statistically significant concentrations of employment following first stage of McMillen (2001). Employment data from Census Transportation Planning Package Part 3 Journey to work.
2 employment centers identified using local names, major highway intersection, or political jurisdiction.
3 workers working within employment center and residing within the Houston Metropolitan Area.
4 Proportion of total metropolitan employment contained within the employment center.

Table 2 - Estimates of the Radius of Influence

Employment Center[1,2]	Visual[3]	Visual-marginal[5]	95 percentile[4]	95 percentile-marginal[5]
CBD	60.00	50.00	30.30	23.18
Galleria	25.00	16.97	28.30	19.23
Medical Center	20.00	14.97	26.00	19.82
Greenway Plaza	25.00	19.35	27.27	21.32
Galveston	25.00	24.18	31.71	30.15
Greenspoint	30.00	23.09	28.37	21.73
249_1960	20.00	15.50	25.91	19.50
Westpark	20.00	14.52	28.28	19.66
Conroe	25.00	20.48	27.32	21.97
Webster	20.00	15.42	33.50	23.82
Woodlands	30.00	23.37	33.04	25.32
Freeport	35.00	48.73	40.93	42.16
Allen	30.00	20.48	27.08	18.61
Baytown	20.00	16.86	33.15	24.34
Richmond	20.00	15.78	24.14	18.35
59_bw8	25.00	18.29	24.73	18.09
Lake Jackson	25.00	26.58	41.12	35.44
Katy	20.00	15.38	37.24	25.49
Angleton	20.00	15.60	34.18	26.24
Kingwood	15.00	11.20	35.23	24.69
Cleveland	25.00	20.63	37.52	29.20

1 Employment Centers defined as local statistically significant concentrations of employment following first stage of McMillen (2001). Employment data from Census Transportation Planning Package Part 3 Journey to work.
2 Employment centers identified using local names, major highway intersection, or political jurisdiction.
3 The distance at which the apparent, by visual inspection, relationship between distance and proportion of workers ends
4 The distance within which 95% of the employment center's workers reside
5 The distance at which the estimated marginal impact of a change in distance on proportion of workers is zero. Estimated using quadratic regression restricted to within Visual or 95 percentile distances.

Figure 2

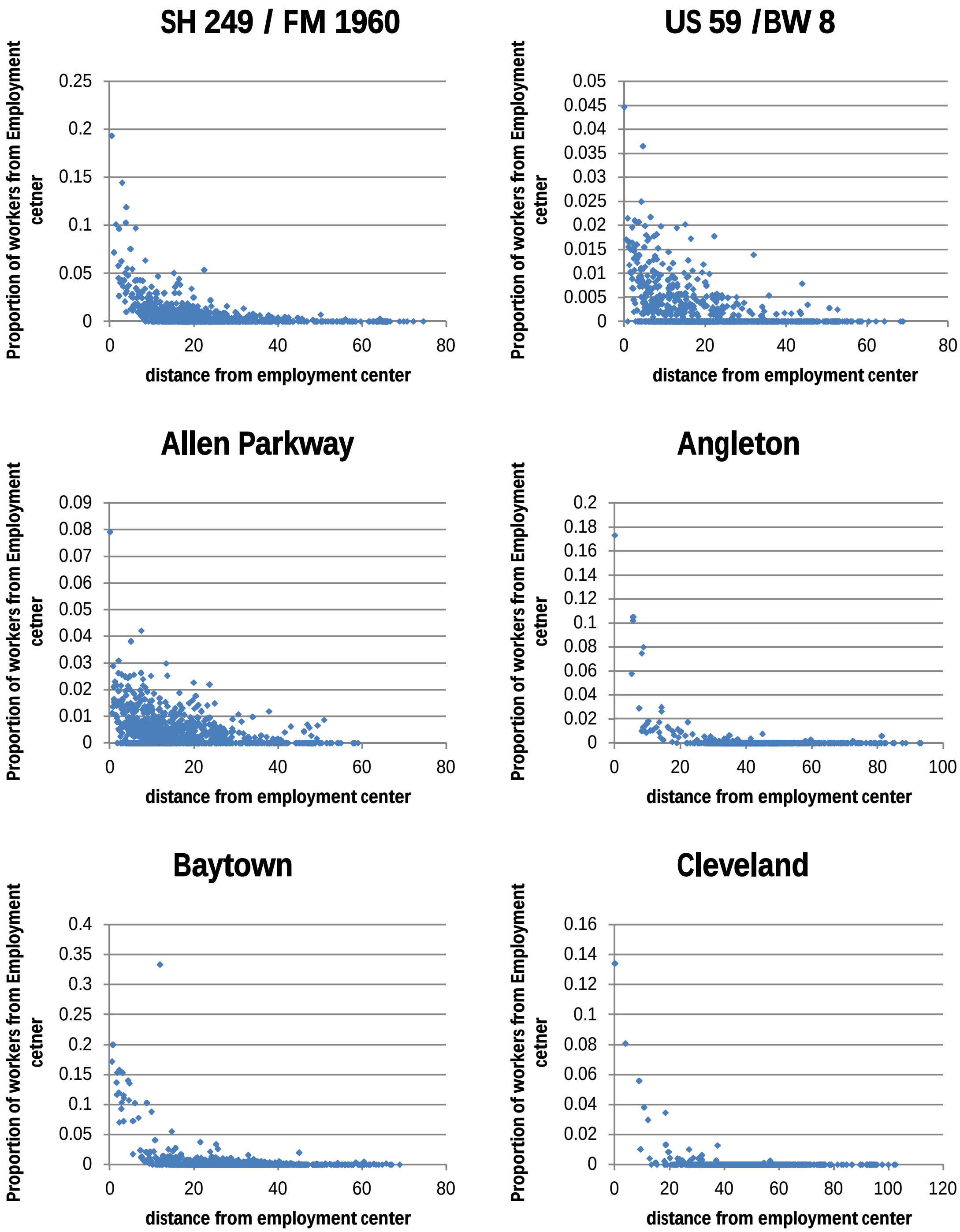

SH 249 / FM 1960
Proportion of workers from Employment cetner
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
distance from employment center
US 59 /BW 8
Proportion of workers from Employment cetner
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20
40
60
80
distance from employment center
Allen Parkway
Proportion of workers from Employment cetner
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
distance from employment center
Angleton
Proportion of workers from Employment cetner
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
distance from employment center
Baytown
Proportion of workers from Employment cetner
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
distance from employment center
Cleveland
Proportion of workers from Employment cetner
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
120
distance from employment center

Figure 2 cont.

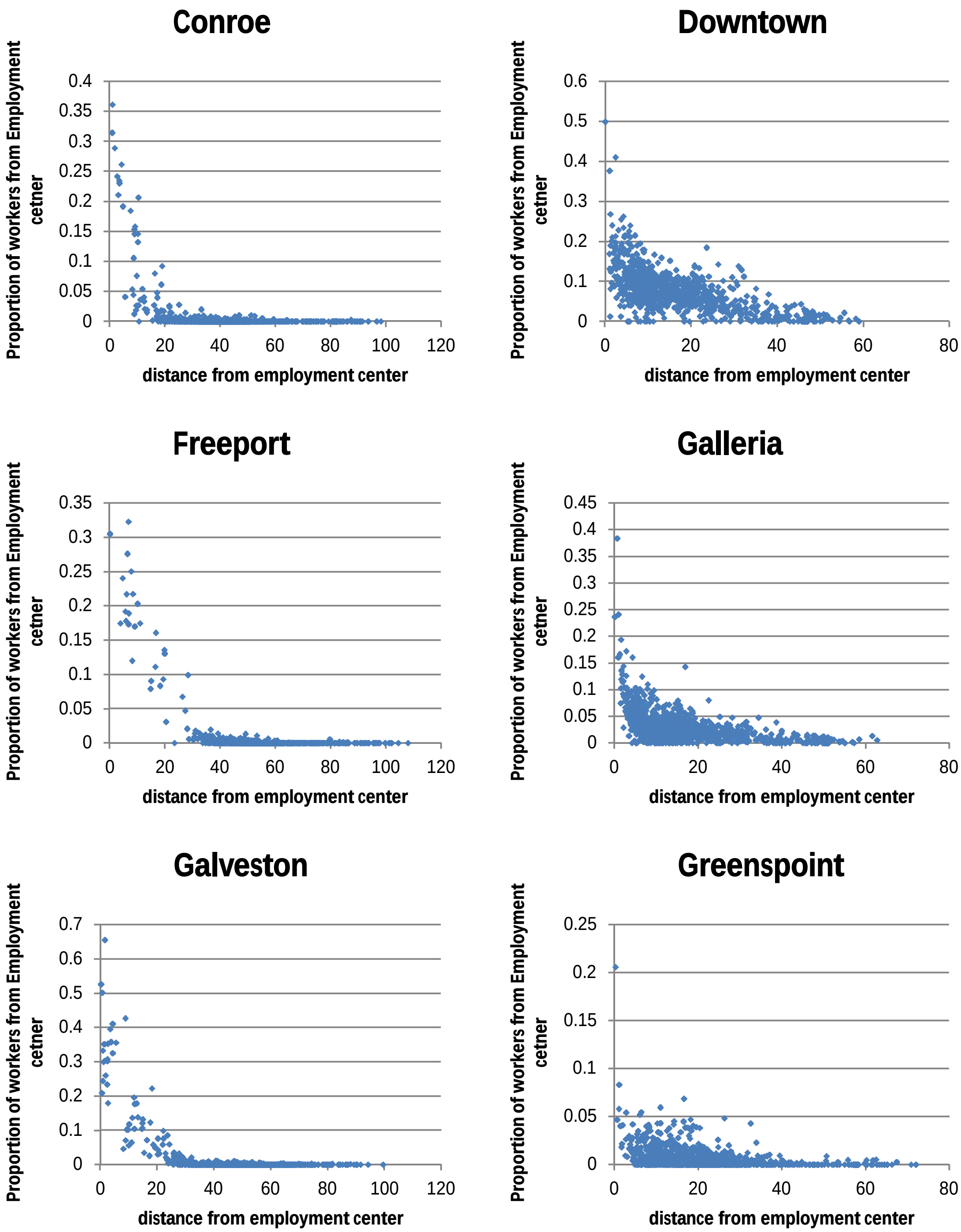


Figure 2 cont.

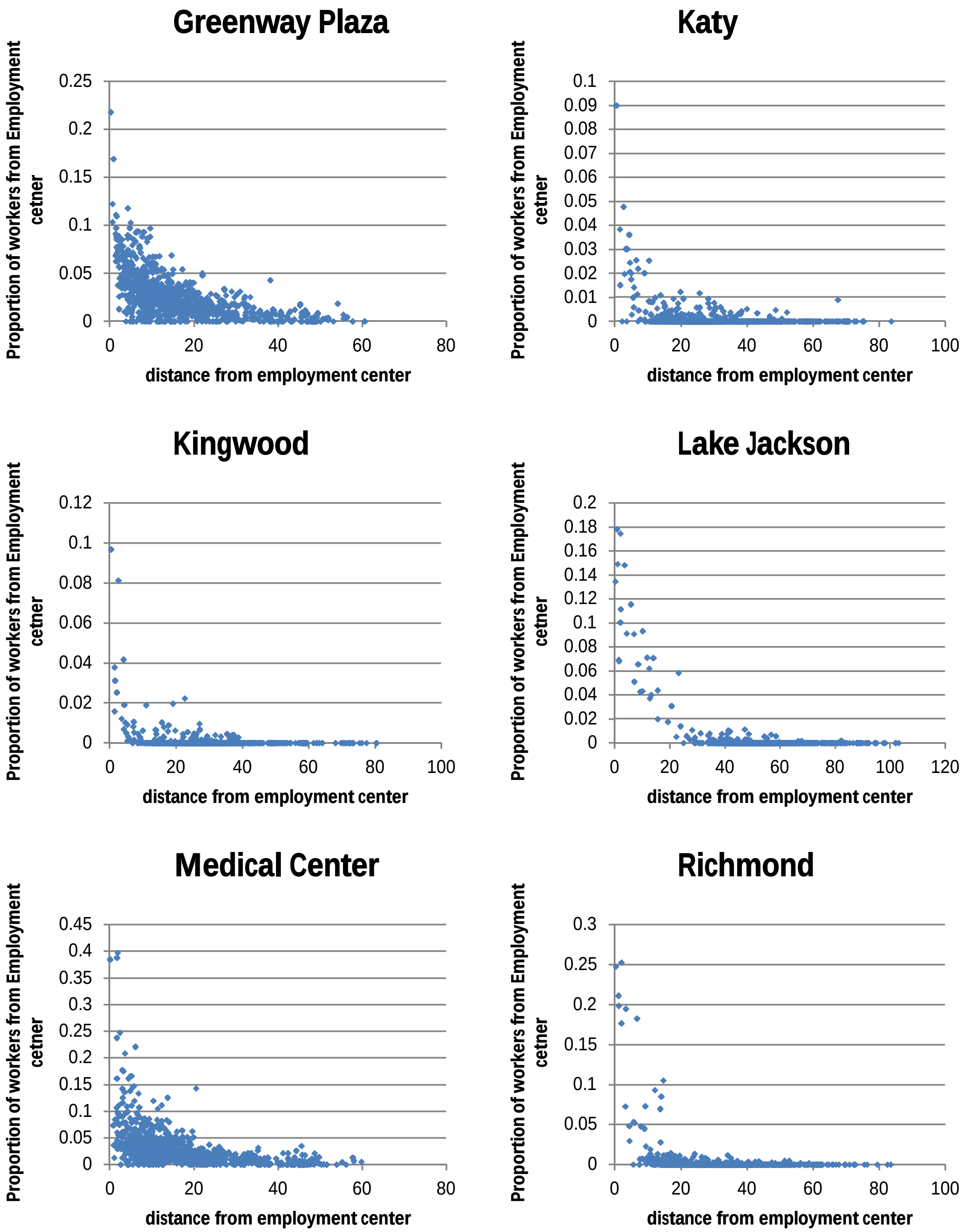


Figure 2 cont.

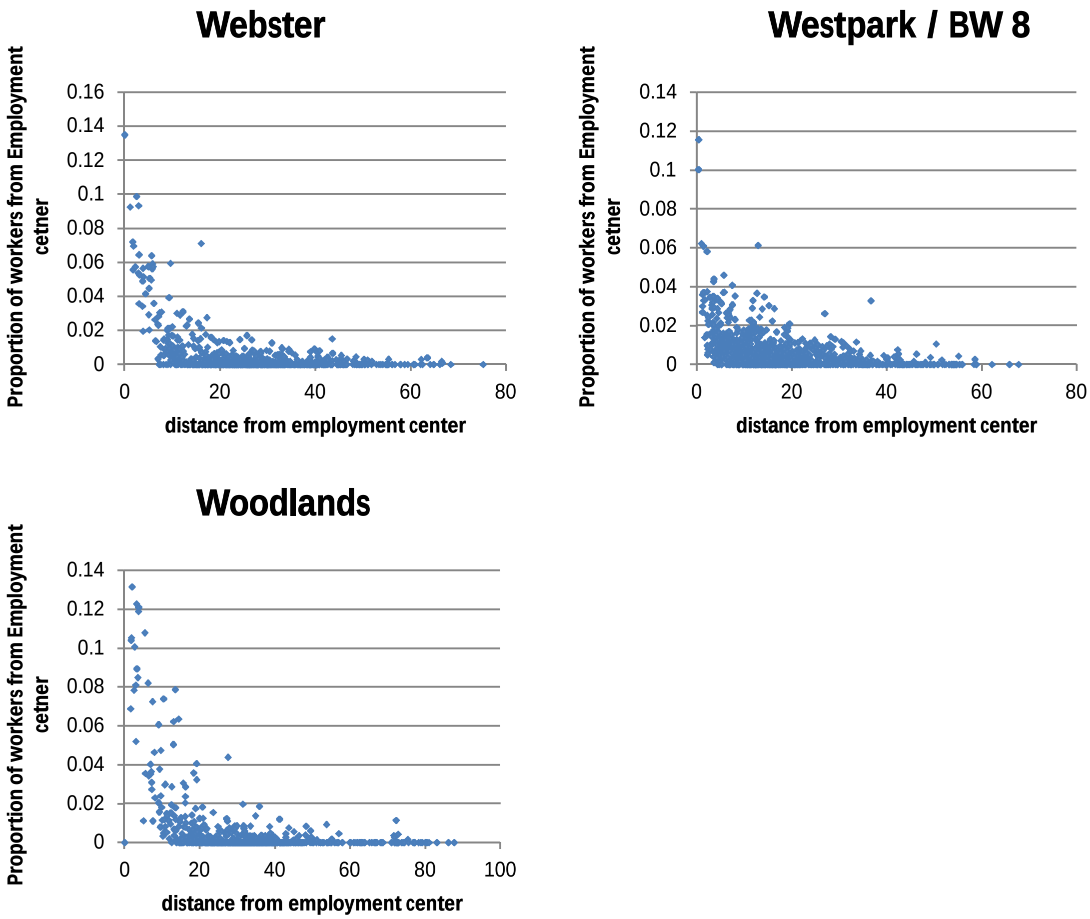
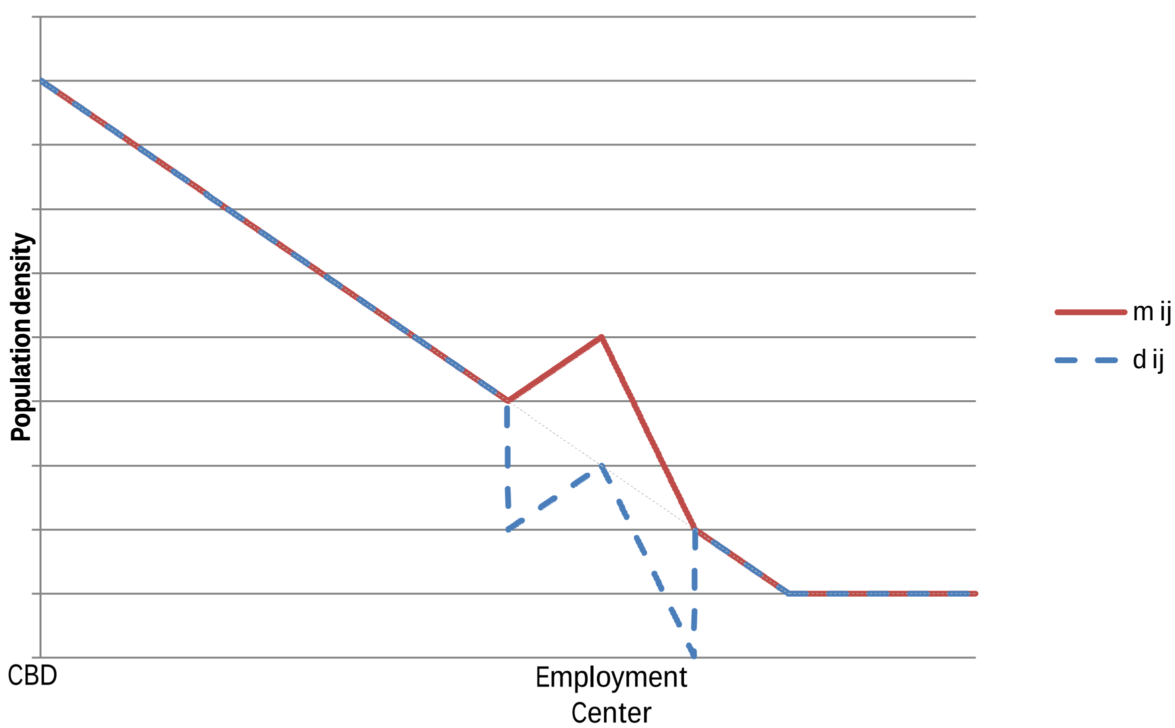


Figure 3- Implicitly Assumed Urban Form of the Multiplicative Model



d_{ij} – a multicentric model using distance away from an employment center. Estimating the multicentric additive model will fix the underlying estimated population density in the area around an employment center. Movement away from that employment center is predicted to lower population density.

m_{ij}- a multicentric model using distance away from the edge of influence of an employment center. Movement away from the edge of influence and towards the employment center is predicted to increase population density.

Table 3 – Proportion of employment concentration workers and distance-Visual[1,2]

	Proportion of workers working in tract						
	249_1960	59_bw8	allen	angleton	baytown	cleveland	conroe
distance	-0.011***	-0.0014***	-0.00093***	-0.022***	-0.020***	-0.012***	-0.031***
	(-5.87)	(-7.14)	(-4.28)	(-13.33)	(-9.00)	(-12.44)	(-13.07)
distance^2	0.00035***	0.000037***	0.000023***	0.00069***	0.00058***	0.00030***	0.00077***
	(5.15)	(5.94)	(3.49)	(9.93)	(6.18)	(8.46)	(9.69)
constant	0.086***	0.013***	0.012***	0.17***	0.17***	0.13***	0.32***
	(7.51)	(10.07)	(7.90)	(15.63)	(15.74)	(19.02)	(18.09)
observations	402	614	739	32	181	38	99
Calculated Radius of influence[3]							
	15.50	18.29	20.48	15.60	16.86	20.63	20.48

Table 3 – Proportion of employment concentration workers and distance-Visual[1,2]

	Proportion of workers working in tract						
	downtown	freeport	galleria	galveston	greenspoint	greenway	katy
distance	-0.0052***	-0.013***	-0.012***	-0.029***	-0.0025**	-0.0061***	-0.0060***
	(-9.55)	(-5.06)	(-7.97)	(-4.73)	(-3.08)	(-7.71)	(-4.33)
distance^2	0.000052***	0.00013*	0.00034***	0.00060**	0.000053*	0.00016***	0.00020***
	(5.68)	(2.21)	(6.83)	(2.72)	(2.47)	(5.75)	(3.91)
constant	0.15***	0.29***	0.11***	0.40***	0.032***	0.076***	0.046***
	(23.02)	(13.02)	(12.67)	(10.81)	(4.85)	(15.26)	(5.08)
observations	878	44	663	60	712	670	204
Calculated Radius of influence[3]							
	50.00	48.73	16.97	24.18	23.09	19.35	15.38

Table 3 – Proportion of employment concentration workers and distance-Visual[1,2]

	Proportion of workers working in tract						
	kingwood	jackson	medical	richmond	webster	westpark	woodlands
distance	-0.011***	-0.0091**	-0.011***	-0.027***	-0.012***	-0.0040***	-0.0090***
	(-3.62)	(-3.63)	(-4.36)	(-8.98)	(-10.85)	(-4.92)	(-11.94)
distance^2	0.00048**	0.00017	0.00039***	0.00086***	0.00038***	0.00014***	0.00019***
	(3.31)	(1.88)	(3.61)	(8.31)	(9.25)	(4.13)	(10.73)
constant	0.058***	0.14***	0.11***	0.21***	0.091***	0.033***	0.10***
	(4.18)	(8.87)	(7.37)	(9.60)	(14.00)	(7.67)	(13.60)
observations	78	30	579	174	252	537	380
			t statistics in parentheses				
			* p<0.05 ** p<0.01 *** p<0.001				
Calculated Radius of influence[3]							
	11.20	26.58	14.97	15.78	15.42	14.52	23.37

1 Relationship between the proportion of workers in a tract working in an employment center and that tract's distance from the employment center. Restricted to the distance within Visually estimated distance.
2 Employment Centers defined as local statistically significant concentrations of employment following first stage of McMillen (2001). Employment data from Census Transportation Planning Package Part 3 Journey to work.
3 Distance at which the estimated marginal impact of change in distance on proportion of workers is zero. Estimated using quadratic regression restricted to within Visual distance.

Table 4 - Multicenteric Multiplicative Model [1]

Employment Concentrations[2]	ln(population density) Visual[3]	Visual -marginal[5]	95 percentile[4]	95 percentile - marginal [5]
mcbd	0.0248	0.0833***	0.320***	0.0416
	(1.72)	(7.19)	(5.04)	(0.82)
mgalleria	0.198	-0.208**	0.0702	-0.141
	(1.81)	(-3.18)	(0.65)	(-1.55)
mmedical	0.0908*	0.0180	0.0784	0.173*
	(2.42)	(0.50)	(1.20)	(2.55)
mgreenway	-0.297*	0.140	0.0178	0.118
	(-2.38)	(1.70)	(0.12)	(1.27)
mgalveston	0.207***	0.234***	0.146***	0.165***
	(16.71)	(16.94)	(9.20)	(15.00)
mgreenspoint	0.0238	0.0261	-0.0383	0.0417
	(1.01)	(1.40)	(-1.38)	(1.43)
m249_1960	0.0323	0.0972***	0.0701*	0.110***
	(1.56)	(6.51)	(2.39)	(4.15)
mwestpark	-0.0409	0.0748*	0.0472	0.0463
	(-1.18)	(2.06)	(0.85)	(0.90)
mconroe	0.0631*	0.109***	0.0603*	0.0816**
	(2.13)	(4.77)	(2.10)	(2.89)
mwebster	0.137***	0.162***	0.0342*	0.106***
	(8.81)	(8.28)	(2.03)	(10.05)
mwoodlands	0.0561	0.0370	0.0544	0.0601*
	(1.84)	(1.91)	(1.64)	(2.38)
mfreeport	-0.0413	-0.0406*	0.0445	-0.0865
	(-0.97)	(-2.36)	(0.64)	(-1.88)
mallen	0.116**	0.0227	-0.397***	-0.0651
	(2.83)	(0.43)	(-4.36)	(-1.23)
mbaytown	0.112***	0.0979***	0.0517*	0.112***
	(5.54)	(4.05)	(2.19)	(7.97)
mrichmond	0.0618**	0.0858**	0.0774**	0.109***
	(2.82)	(3.00)	(3.10)	(4.63)
m59_bw8	0.113***	0.0977***	0.0245	0.114**
	(4.14)	(3.81)	(0.68)	(2.83)
mjackson	0.209***	0.227***	0.106	0.183**
	(3.64)	(5.73)	(1.13)	(3.08)
mkaty	0.0447*	0.0922***	0.0144	0.0917***
	(2.47)	(3.60)	(1.01)	(4.96)
mangleton	-0.00850	-0.0353	-0.100	0.00171
	(-0.14)	(-0.45)	(-1.53)	(0.03)
mkingwood	0.0674*	0.133***	0.0192	0.0862***
	(2.49)	(3.74)	(0.69)	(3.87)
mcleveland	0.0304	0.0527	0.0223	0.0178
	(1.34)	(1.68)	(0.99)	(0.83)
_cons	3.226***	3.254***	3.183***	3.636***
	(9.78)	(14.27)	(9.63)	(17.58)
N	878	878	878	878
Number of Employment Centers[6]	11	12	7	12

t statistics in parentheses *** p<0.01, ** p<0.05, * p<0.1

1 multicentric additive regressions of population density on employment center distance. Distance enters in as distance from the edges of the employment concentrations' radius of influence.

2 Employment concentrations defined as local statistically significant concentrations of employment following first stage of McMillen (2001). Employment data from Census Transportation Planning Package Part 3 Journey to work.

3 Employment centers' radii of influence as the distance at which the apparent relationship, from visual inspection, between distance from the employment concentration and proportion of workers ends

4 Employment concentrations' radii of influence as the distance within which 95 percent of the employment concentrations workers reside.

5 Employment concentrations' radii of influence as The distance at which the estimated marginal impact of a change in distance on proportion of workers is zero. Estimated using quadratic regression restricted to within Visual or 95 percentile distances.

6 Employment Centers identified as local statistically significant concentrations of employment, proximity to which is estimated to have a positive impact on population density

Table 5- employment center characteristics and estimated gradient

Concentrations of employment	Workers	Workers/ sq mile	Proportion Metropolitan Area Workers	Estimated Gradient Table 4 Column 3
Downtown	155105	84032.81	0.077	0.0833***
Galleria	68067	27707.80	0.034	-0.208**
Medical Center	58067	30072.89	0.029	0.018
Greenway Plaza	53057	28542.60	0.026	0.14
Galveston	16509	15996.68	0.0082	0.234***
Greenspoint	16502	11835.57	0.0082	0.0261
249_1960	16361	5233.97	0.0081	0.0972***
Westpark	15538	11196.71	0.0077	0.0748*
Conroe	13048	2358.25	0.0064	0.109***
Webster	10520	5889.52	0.0052	0.162***
Woodlands	10306	4819.93	0.0051	0.037
Freeport	10015	3176.91	0.0049	-0.0406*
Allen Parkway	9578	19340.63	0.0047	0.0227
Baytown	8475	2303.90	0.0042	0.0979***
Richmond	6752	1258.18	0.0033	0.0858**
59_bw8	5277	9528.71	0.0026	0.0977***
Lake Jackson	4453	3582.87	0.0022	0.227***
Katy	2310	1246.10	0.0011	0.0922***
Angleton	2101	1577.39	0.0010	-0.0353
Kingwood	1836	1371.24	0.00090	0.133***
Cleveland	739	117.49	0.00037	0.0527
Total	484629		0.24	

Wages, travel and the number of employment centers in urban areas

2.1 Introduction

Increasing recognition of the limitations of monocentric models, in explaining urban form, has led to the development of a polycentric literature (Anas and Kim, 1996; Berliant and Konishi, 2000; Berliant and Wang, 2008; Fujita et. al., 1997, 1999; Fujita and Ogawa 1982; Helsley and Sullivan, 1991; Henderson and Mitra, 1996; Konishi, 2000; Wieand, 1987; Yinger, 1992). In a polycentric city, dispersion of employment away from the Central Business District (CBD) takes the form of secondary employment centers located throughout an urban area.[12] This dispersion of employment is thought to involve a tradeoff between lower productivity, caused by the loss of agglomeration externalities, and lower transport costs.

Thus far, the empirical polycentric literature has focused primarily on establishing standards for defining employment centers (Craig and Ng, 2001; Giuliano and Small, 1991; McDonald, 1987; McMillen, 2001; Redfearn, 2007) and measuring their localized spatial impacts on rent and density gradients (Bender and Hwang, 1985; Dowall and Treffeisen, 1991; Greene, 1980; Griffith, 1981; McDonald, 1987; McDonald and Prather, 1994; McMillen and McDonald, 1997, 1998; Shukla and Waddell, 1991; Small and Song, 1994) in urban areas. Testing for the urban area wide economic effects of the number of employment centers has been limited. McMillen and Smith (2003) finds that the number of employment centers is positively correlated with the Texas Transportation Institute's Travel Time Index.

In this paper, I explore the relationship between the number of urban area employment centers, and urban transport costs and average wages. In the

[12] Employment centers are local concentrations of employment within an urban area. The central business district is a special case, as the primary, and generally the initial, employment center within an urban area.

polycentric models the dispersion of employment into new employment centers is assumed to benefit an urban area by lowering the total transport costs. There exist two separate proposed mechanisms by which additional employment centers might lower transport cost. First, they make it possible for workers to locate closer to their place of employment. Second, they might lower the per unit distance costs of travel by decreasing congestion through the dispersion of travel patterns. The Travel Time Index produced by the Texas Transportation Institute is a common metric used to measure transport costs. I reject the use of this measure, and instead I use a measure of implicit demand for travel. This analysis shows that the number of employment centers affects transport decisions and appears to increase the implicit quantity of travel demanded. I also find that commute times are unaffected by the number of employment centers. The combination of increased distance travelled with unchanging commute times provides support for the hypothesis that additional employment centers lower the per unit distance congestion costs in urban areas, while leaving the change in total costs indeterminate.

The relationship between the number of employment centers and urban area average wages is also explored in this paper. It is predicted, that the formation of new employment centers will lower wages in an urban area, through two mechanisms. First, the predicted fall in transport costs will allow firms to offer lower wages. Second, the loss of agglomeration economies, through dispersion, is expected to lower productivity. I find that an increase in the number of employment centers is associated with lower urban area average wages. I also find that an increase of the share of urban area employment that locates within employment centers is associated with an increase in urban area wages. To my knowledge, this is the first paper to test for the predicted consequences of the number of employment centers on urban area wide economic measures.

The transport costs and the agglomeration economies in an urban area can be characterized by the presence of externalities. Thus, it is likely that a competitive equilibrium will not produce the efficient number of employment centers, and it is unclear whether urban areas will have more or fewer than the social optimum. I explore this by investigating the number of employment centers that maximizes the employment center share of urban area employment. I find that the employment share maximizing number of employment centers increases with the urban area size.

The first concern when attempting to empirically study the assumptions and predictions of the polycentric model is the identification of employment centers within urban areas. The methods proposed to identify employment centers have progressively required less local knowledge, arbitrariness, manual inspection, and require fewer a priori assumptions on urban form, while becoming more statistically based. Initial methodologies relied significantly on local knowledge and manual inspection. Then density and level measures or cutoffs were suggested (McDonald, 1987; Guiliano and Small, 1991), still requiring local knowledge to select appropriate measures or cutoffs. An initial statistical method identified employment centers as perturbations in the monocentric rent gradient (Craig and Ng, 2001). The most recent methods use locally weighted regressions (LWR) that allow the rent gradient to vary in direction from the CBD to identify locally statistically significant areas of employment concentration (McMillen, 2001; Redfearn, 2007).

Using a LWR method to identify employment centers, data on urban transportation characteristics, and urban wages, this paper explores the relationship between employment center formation, and urban area wages and transport costs. This paper goes farther than any previous research, known by the author, by testing the predicted effects of employment center formation on transport costs and urban area wages, testing for the presence and mechanics of agglomeration economies, and proposing and testing a proxy for the efficiency of the number of employment centers.

The rest of this paper is organized as follows. Section 2 outlines the reduced form specifications to be tested and the predictions from the polycentric models. Section 3 presents the method used in this paper to identify employment centers within urban areas. The data sources are explained in Section 4. Section 5 presents the analysis. Section 6 discusses the empirical finding's implications for the use of the Travel Time Index as a measure of per unit distance cost of congestion. Section 7 concludes the paper.

2.2 Specification

Polycentric models such as those presented by Fujita and Ogawa (1982), Anas and Kim (1996), and Berliant and Wang (2008), show the formation of employment centers as a trade-off between agglomeration economies and transport costs and yield two straight forward predictions. The models predict that the formation of additional employment centers will lower both urban area transport costs and wages. The analysis in this paper tests the reduced form relationship between the number of employment centers and the economic characteristics of interest.[13] I start by testing the reduced form relationship between the number of employment centers on transport costs, using a measure of implicit demand for travel, then test for the relationship with urban area average wage. I will continue this line of research by testing for the urban form determinants of the share of urban area employment that locates in employment centers.

The first effect of employment centers that this paper explores is their effect on transport costs within the urban area. The travel time index produced by the Texas Transportation Institute is a commonly used metric for measuring transportation costs within urban areas. McMillen and Smith (2003) and Gleaser and Kohlhase (2004) show typical treatments of the travel time index as an urban area transport cost measure. The travel time index is meant to measure per unit distance congestion costs within an urban area by giving the ratio of travel time in peak hours to free flow travel time. It is a function of both endogenous, vehicle miles travelled, and exogenous, infrastructure supply, measures of expected transport costs within a city. It is a general approximation of unit distance congestion costs as long as certain assumed travel patterns are constant across cities. For this line of research, employment center formation is expected to affect travel patterns. Therefore, the travel time index is not an appropriate measure of differences in transport costs

[13] In the long run, the agglomeration economies, transport costs, wages, and urban form of an urban area are expected to be determined simultaneously. In the short run I expect that average wages and the implicit demand for travel would be more responsive than the number and location of employment centers and public policy responses in the supply of transport infrastructure. Therefore the reduced form equations can best be thought of as short term responses of average wages and the implicit demand for travel to a given number of employment centers, and to infrastructure and other urban area characteristics.

across urban areas.[14] Instead I separate the measures of transportation characteristics in urban areas. In the short run, per capita vehicles miles travelled is an endogenous measure of the implicit demand for travel, while transportation infrastructure supply is exogenous.

In this paper I estimate the reduced form equation of the effects of urban form and available infrastructure effects on the per capita vehicles miles travelled on freeways. The primary urban form characteristic of interest, in this regression, is the number of employment centers. The polycentric models produce two opposing predictions of employment center's effect on per capita vehicle miles travelled. First, if the formation of employment centers reduces total transportation costs solely by allowing workers to live closer to their place of employment, as in Fujita and Ogawa (1982) and Berliant and Wang (2008), then we would expect to see a decrease in the implicit demand for travel. On the other hand, if employment centers decrease unit distance transport costs by lowering congestion costs through dispersion of travel patterns, as allowed for in Anas and Kim (1996), then the per unit distance cost of travel falls leading to an expectation of an increase in the implicit quantity of travel demanded.

This reduced form equation also explores the effects of the supply of transport infrastructure and urban area size on per capita freeway vehicle miles travelled. Per thousand population lane miles of freeway is a measure of the expected cost of travel on the urban area freeways with congestion increasing in usage. So, an increase in the availability of freeway lane miles should lower the unit distance cost and raise the implicit demand for travel on freeways. Travel along

[14] Texas Transportation Institute updated their methodology for the 2010 Urban Mobility Report.

arterials acts as a substitute for travel on the freeways. An increase in the availability of lane miles of arterials per population lowers the price of travel along the arterials and lowers the expected implicit demand for travel along freeways. It is unclear what effect on per capita vehicle miles travelled to expect from a change in population and employment in an urban area. Congestion costs are expected to increase with population which is expected to decrease the implicit demand for travel. On the other hand the increase in total demand for space could cause an increase in the extent of the urban area, possibly leading to higher per capita travel.

As a second test of the effect of the number of employment centers on transportation decisions, I estimate a reduced form equation using the average commute times of workers and residents as a proxy of total transport costs. I control for the number of employment centers, infrastructure availability and urban area size. As explained above each of the controls is related to changes in the per unit distance costs of transportation. In a city where unit distance transport costs can change it is unclear what effect changes in per unit distance costs will have on travel time and is dependent on the elasticity of the implicit demand for travel.

To the extent that travel time and distance travelled are good proxies for total variable costs of travel, the results from these first two regressions will allow me to test the relationship between the number of employment centers and total travel costs. If the number of employment centers has a positive association with both travel time and vehicle miles travelled it is likely that additional employment center is raising the total costs of travel within an urban area. A negative association with both vehicle miles travelled and travel time would suggest additional employment centers are lowering total transport costs.

In the polycentric model, wages fall with additional employment centers due to the lower compensating wages that firms must offer once workers' transport costs fall. Also, the dispersion of employment into additional employment centers is thought to reduce agglomeration economies and therefore lower productivity. This fall in productivity associated with the loss of agglomeration economies reinforces the expectation that an increase in the number of employment centers will lead to a fall in urban area wages. Urban area wide agglomeration economies are expected to be increasing in concentration so that average wages are expected to rise with urban area population. Given the sharp local attenuation of agglomeration economies found by Rosenthal and Strange (2003) and Soest et al (2006), it is also expected that concentration of employment within employment centers would increase productivity and thus wages.

I test the reduced form equation exploring the effects of the number of employment centers, urban area size, and share of employment located in employment centers on the average wage. Both the expected fall in workers' transport costs and the loss of agglomeration economies caused by dispersion of employment lead to the expectation that an increase in the number of employment centers would cause a fall in urban area average wages. The increase in agglomeration economies with concentration leads to the expectation that average wages will increase with urban area population. The sharp attenuation of agglomeration economies implies that firms located in employment centers will be more productive, which should cause average wage to increase with the share of firms located in employment centers.

Both of the expected effects of employment center formation can be characterized by the presence of externalities. In a competitive equilibrium, firms would not be expected to consider the fall in transport costs for other firm's employees due to the decision to form a new employment center. They also would not take into account the loss of agglomeration economies to the firms that remain in the existing employment centers. Given these opposing externalities it is possible that the optimal number of employment centers is not being formed, and it is not certain whether any urban area would have more or less than this optimal number of employment centers. Because there is a tradeoff between lower transport costs and higher agglomeration economies, the optimal number of centers might be that which maximizes the difference between benefits and costs for firms locating in, and workers commuting to, employment centers. Then the optimal number of employment centers would maximize the attractiveness, for firms, of locating in an employment center. As a proxy for the efficiency of the number of employment centers, I propose finding the number of employment centers that maximizes the share of urban area employment that locates within the employment centers.

I test the reduced form equation of the urban form's effects on share of urban area employment located within employment centers. The descriptive variables are the number of employment centers normalized by urban area employment, dispersion of employment center employment, transportation infrastructure, urban area population, and controls for bias in selecting employment centers. The number of employment centers is expected to increase with urban area size. If there are decreasing net returns to employment center formation it might be expected that there exists a number of employment centers that maximizes the share of urban area employment locating in the centers. If there are agglomerative interactions between employment centers, then greater dispersion of employment centers would be expected to decrease the total agglomeration economies within the employment centers. A priori, it is unclear what effect to expect from a more robust transport network. Decreasing transport costs to the employment centers might make them more attractive. On the other hand, they might decrease the rate of attenuation of agglomeration economies, lowering the increase in benefits associated with locating in employment centers.

2.3 Subcenter Identification

To empirically test polycentric models of urban areas, a definition of employment centers is needed. Early attempts to analytically identify employment centers and their extent include employment density and level cutoffs, as can be seen in Giuliano and Small (1991) and McMillen and McDonald (1997). This method is arbitrary and requires local knowledge to set appropriate cutoffs for different cities. These drawbacks can readily be seen upon inspection of McMillen and McDonald (1997). Investigating the Chicago region and starting with the working cutoff definitions from Giuliano and Small (1991), they find an unreasonably large employment center near O'Hare Airport. They then change the cutoffs in order to obtain more reasonable results.

An early attempt at defining employment centers as statistically significant concentrations of employment can be seen in Craig and Ng (2001). The authors locate employment subcenters in the Houston region using quantile smoothing splines. They define rings equidistant from the CBD where the 95th percentile of employment density has a local maximum. Once these rings are identified, they then inspect the census tracts within a certain bandwidth to find the employment subcenters. Disadvantages to this method are that it assumes a monocentric density gradient that is independent of direction from the city center and requires manual inspection to identify the employment centers located on each ring.

McMillen (2001) and Redfearn (2007) both propose localized nonparametric methodologies to identify employment centers. They all weaken the need for strong assumptions about the form of the city, for local knowledge, and increase the objectivity and consistency of measurement across cities. All three methods allow the density gradient to vary locally and indentify employment centers that can be characterized as locally statistically significant concentrations of employment.

The methodology used in this paper to identify employment centers is an adaptation of McMillen (2001) and Giuliano and Small (1991) as presented in McMillen and Smith (2003). The first stage of this adapted methodology uses a locally weighted regression (LWR) on the natural log of employment density of each observation[15] in an urban area as in McMillen (2001). Each LWR produces a predicted value of the natural log of employment density $\hat{y}$ for each observation.

[15] The units of observation in this paper is are the census tracts in the urban areas as defined by the Census Bureau

Tracts are identified as a potential employment center site if the true value of y falls above the 95% confidence interval of $\hat{y}$.

The adapted second stage uses a minimum level cutoff, as in Giuliano and Small (1991), to analyze the candidacy of potential employment centers. The total employment for each independent tract or cluster of contiguous tracts, identified as employment center candidates, is measured. If the total employment is greater than or equal to 10,000, then the candidate site is considered an employment center under this method. This allows for the identification of employment centers that do not have trivial levels of employment and allows for the identification of the geographical extent of the employment centers. The introduction of a minimum cutoff reintroduces an element of arbitrariness, but increases the simplicity of identification and analysis.

2.4 Data

The data for this paper was collected on 50 large urban areas in the United States for the year 2000. To find employment centers within each urban area I obtained employment data by census tract, from the Census Transportation Planning Package[16] Part 2 from the Bureau of Transportation Statistics. The geographical information[17] for urban area census tracts came from the geographical department of The Census Bureau. The average wage for 45 metropolitan areas comes from the National Compensation Survey by the Bureau of Labor Statistics.[18] The transportation characteristics and total population for each urban area were obtained from the Texas Transportation Institute 'Urban Mobility Report' (UMR)

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[16] http://www.transtats.bts.gov/Tables.asp?DB_ID=630
[17] http://www.census.gov/geo/www/tiger/
[18] http://www.bls.gov/ncs/ncspubs_2000.htm

(Lomax and Schrank, 2009). The UMR contains data on the infrastructure (i.e. lane miles of freeway, arterial), vehicle miles travelled, the travel time index, and other urban area characteristics. Table 1 shows the summary statistics of variables from these data sets and used in this paper.

The number of employment centers is calculated using the methodology from McMillen and Smith (2003) as explained previously. The left hand side variables are per capita daily vehicle miles travelled on a freeway, average commute times, average wage, and the percent of urban area employment located in employment centers. There are three dispersion metrics. The dispersion of employment center employment from the CBD measures the average distance from the CBD of all the jobs located in all employment centers. The dispersion of employment center employment measures the average distance between jobs in the employment centers. The Herfindahl index measures the distribution of employment between the employment centers, where a lower measure indicates more equal sharing of employment among the employment centers and, in general, dispersion of employment away from the center. The remaining variables are urban area characteristics obtained from the UMR.

2.5 Results

The first test is on the reduced form regression of per capita freeway vehicle miles travelled on the number of employment centers, urban area population or employment, the urban area’s land area, and per thousand population lane miles of freeway and arterials. Table 2 shows the results of the regression. The transportation characteristics of an urban area all have the expected sign and are significant in each case. Per capita vehicle miles travelled on freeways increases with per thousand population freeway lane miles. Changes in the availability of substitute infrastructure, arterials, have a negative relationship with freeway vehicle miles travelled. Controlling for the per thousand population availability of transportation infrastructure, the total population and employment of the urban area have an insignificant effect on vehicle miles travelled.[19]

There are two hypothesized non-exclusive mechanisms through which the formation of an additional employment center decreases urban area transport costs: allowing workers to live closer to their place of employment or by lowering unit distance transport costs. The significant positive effect of employment centers on vehicle miles travelled shows that an increase in the number employment centers is associated with an increase in the vehicle miles travelled, at a decreasing rate. This is inconsistent with the hypothesis that an additional employment center lowers transport costs by allowing workers to live closer to their place of employment, as it appears that travel is increasing. Thus, if employment centers reduce transport cost, it appears that they are doing so primarily by decreasing unit distance cost of travel and leading to an increase in the implicit demand for travel.

The results of the second test of the effects that the number of employment centers has on transportation decisions are presented in Table 3. Here, I regress urban area workers' and residents' average commute times on the number of employment centers, urban area population or employment and area, and per

[19] Regressions using arterial and total vehicle miles travelled have substantially the same results. Additional employment centers increase vehicle miles travelled at a decreasing rate. Per capita levels of infrastructure have the expected sign, and urban size is insignificant.

thousand population lane miles of freeway and arterials.[20] The number of employment centers has an insignificant effect on the average commute times of both workers and residents. Per thousand lane miles of freeway does not appear to effect commute times while an increase in per thousand lane miles of arterials is associated with a significant decrease in average commuting times. Population and employment levels are insignificant predictors of commuting times. The land area contained by an urban area significantly increases commute times for residents, but is insignificant for workers' commuting times.

The lack of a relationship between the number of employment centers and commute times, combined with the positive relationship with vehicle miles travelled appears to confirm the hypothesis that the per unit distance price of travel is falling. The dispersion of travel patterns related to the formation of additional employment centers appears to be allowing urban area residents and workers to be driving longer distances without increasing the time of their commutes. The relationships make it unclear if total costs are changing. In as much as travel distance and travel time are good proxies for all of the variable costs of travel, the findings of these two regressions suggest that, in the long term, additional employment centers increase the total travel costs in an urban area. On the other hand, if the fall in congestion is allowing the miles driven to be driven at a more efficient speed, the total costs may be falling.

The third regression of interest is on the reduced form equation of average urban area wages on urban area population or employment, the number of

[20] Regressing on commute times for solo drivers and carpoolers, yields results that are substantially similar and are the same in terms of significant effects.

employment centers, and share of urban area employment that locates within the employment centers. Table 4 shows the results of the regression on the above reduced form equation. The results support the predictions that an increase in the number of employment centers is associated with a fall in the urban area average wage. The exact mechanism that links the number of employment centers to the fall in wages is not determined within the scope of this paper. Within the literature there are two possible non-exclusive explanations, lower productivity due to the loss of agglomeration economies and lower compensating wages due to a fall in transport costs. The results also show the expected effects of the agglomeration economies within urban areas. Average wage is positively associated with urban area population and employment, as well as concentration of urban area employment within the employment centers.

Above, I find evidence that congestion costs and wages fall with the formation of new employment centers. This supports the hypothesis that the formation of new employment centers is faced with a tradeoff between agglomeration economies, and congestion costs. Each new employment center in an urban area is expected to lower the agglomeration economies in the already existing employment centers, but is also expected to lower congestion costs. The loss of productivity is expected to lower the benefits of locating in an employment center, for firms. On the other hand, the lower congestion costs will lower the costs of locating in an employment center, for firms. Therefore it is possible that the share of urban area employment locating in employment centers is a good measure of the suitability of the tradeoff being made. If an urban area has “too many” employment centers then agglomeration economies will disappear and there will be no reason form firms to locate in them, as opposed to other locations in the urban area. “Too few” and congestion costs and thus wages will outweigh the benefits of locating in the employment center. In the following I explore the number of employment centers that will maximize the difference between productivity in the employment centers and congestion costs by exploring the determinants of the share of urban area employment that locates in the employment centers.

Table 5 presents the results of the regression of the share of urban area employment locating in employment centers on the urban form characteristics. In columns 1-4 I normalize the number of employment centers by urban area employment. This allows me to explore the employment center employment share maximizing number of employment centers for a given urban area size. The last two controls are the percentage of urban area tracts identified as part of employment centers and the percentage of the urban area identified as being included in an urban area. This controls for the bias in selection of additional employment centers which would always increase the share of employment in the employment centers.

The first column shows a typical result when using a simple normalization. The normalized number of employment centers, its squared term, and the other explanatory variables are all insignificant. Columns 2-4 of Table 5 show the regressions where the number of employment centers is normalized by the natural log of urban area employment. The significance of this specification suggests that the employment center employment share effects of employment center formation are not linear in urban area employment. As urban area employment grows the employment center employment share maximizing number of employment centers grows at a slower rate. Also, holding urban area population constant, the results imply that there are decreasing returns to employment center formation, and that the number of employment centers that maximizes the employment center share of urban area employment is dependent on urban area size. The negative and significant result on the employment center employment dispersion indexes supports the proposition that there exist agglomeration economies between employment centers which decrease as employment center employment disperses away from the central business district and away from each other. The positive and significant result on the Herfindahl index has the same interpretation.

Columns 5-7 of Table 5 show an alternative specification to determine urban form's effect on the employment center employment share maximizing number of employment centers. I regress employment center employment share on the number of employment centers, its squared term, and the interaction between the number of employment centers and urban area employment along with other determinants. Here, again, I find decreasing returns in employment share with the addition of employment centers. This specification suggests that the urban area size shifts the employment maximizing number of employment centers. While, the ln normalized specification suggests that changes in urban area size change the rate of return of each employment center.

Taking the results from the two specifications of interest in Table 5 it becomes possible to develop predicted estimates of the employment center employment share maximizing number of employment centers. For the ln normalized specification taking

$$EC\ emp\ share\ =\ \hat{\beta}_1 \frac{Number\ of\ EC}{\ln UAemp} + \hat{\beta}_2 \left(\frac{Number\ of EC}{\ln UAemp}\right)^2 + X \qquad (1)$$

and given that it is expected that employment center employment share to be related to the number of employment centers, and that the employment center employment share maximizing number is expected to change with urban area employment, we find.

$$\frac{\partial \frac{\partial EC\ emp\ share}{\partial\ Number\ of\ EC}}{\partial \ln UA\ emp} = -\hat{\beta}_1 \frac{1}{lnUAemp^2} - 4\hat{\beta}_2 \frac{Number\ of\ EC}{lnUAemp^3} \qquad (2)$$

Setting the Cross derivative equal to zero and solving for number of employment centers that maximizes employment share given the ln of urban area employment provides,

$$EC\ employment\ share\ maximizing\ Number\ of\ EC\ = \frac{\hat{\beta}_1}{4\hat{\beta}_2} lnUAemp \qquad (3)$$

The second specification does not allow the rate of return of employment centers to change with urban area size so starting with,

$$EC\ emp\ share\ =\ \hat{\beta}_1 Number\ of EC + \hat{\beta}_2 Number\ of\ EC^2 \qquad (4)$$

$$+\hat{\beta}_3 Number\ of\ EC * UAemp +\ X$$

and taking the derivative with respect to the number of employment centers,

$$\frac{\partial EC\ emp\ share}{\partial\ Number\ of\ EC} = \hat{\beta}_1 + 2\hat{\beta}_2 Number\ of\ EC + \hat{\beta}_3 UAemp \qquad (5)$$

and setting it equal to zero provides the formula for the predicted employment center employment share maximizing number of employment centers with respect to urban area size.

$$Number\ of\ EC = -\frac{\hat{\beta}_1 + \hat{\beta}_3 UAemp}{2\hat{\beta}_2} \quad (6)$$

Table 6 shows the number of employment centers, the predicted share maximizing number of employment centers under each specification, and whether the urban area has fewer than or more than the predicted employment share maximizing number of employment centers. The table shows a very clear pattern when the urban areas are sorted by employment. The smaller urban areas presented have fewer than the predicted employment center employment share maximizing number of employment centers. The likelihood of an urban area having more than the predicted employment center employment share maximizing number of employment centers increases as urban area population increases.

2.6 Implications for the Travel Time Index as a Measure of Transportation Costs

> **Travel Time Index**
> The ratio of the travel time during the peak period to the time required to make the same trip at free-flow speeds. A value of 1.3, for example, indicates a 20-minute free-flow trip requires 26 minutes during the peak period.

The Travel Time Index (TTI) produced by Lomax and Schrank (2009) through the Texas Transportation Institute is devised to measure the ratio of the estimated time it takes to complete a trip during the peak period to the time it takes to complete that trip under free-flow conditions. As such, it appears that it is best interpreted as an attempt to estimate the percentage increase in peak period unit distance travel prices due to congestion costs in an urban area.

The development of the TTI variable has characteristics that make its use as a congestion price variable in an analysis across urban areas unsuitable. First they calculate a Roadway Congestion Index (RCI) that is a ratio of vehicle miles travelled and lane-miles of roadway.

$$RCI = \frac{\frac{Freeway\ VMT}{Ln{-}Mi\ Freeway} X\ Freeway\ VMT + \frac{Arterial\ VMT}{Ln{-}Mi\ Arterial} X\ Arterial\ VMT}{14{,}000\ X\ Freeway\ VMT + 5{,}000\ X\ Arterial\ VMT} \qquad (7)$$

The RCI is then used to estimate congested speeds in the peak direction for each roadway type.[21] These estimated congested speeds are then compared to assumed roadway free-flow speeds to develop estimated travel delay due to congestion.[22] Then the TTI is developed as a ratio of estimated peak travel time to assumed free flow travel time, where peak travel time is free flow travel time plus delay due to congestion.

$$TTI = \frac{Peak\ Travel\ Time}{Free\ Flow\ Travel\ Time} \qquad (8)$$

The RCI measure, and thus the TTI, interprets any change in vehicle miles travelled without an associated change in infrastructure availability as a change in congestion, and thus per unit distance congestion costs. Therefore, if anything besides a change in infrastructure changes the per unit distance price of travel, viewing the TTI as a price measure would imply a price change in the opposite direction. Or, something that causes the unit distance price of travel to increase would cause a fall in vehicle miles travelled, causing the TTI to fall. That fall in the TTI would then naively be viewed as implying that the unit price of travel had actually fallen. Employment centers might be expected to lower unit distance travel costs by

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[21] Speeds are estimated using an assumed travel volume distribution, given average daily volume, for each road type across all cities. Additional employment centers are expected to change travel patterns. The RCI does not take these differences into account.

[22] Starting in 2010, and with data for 2007-09, the authors of the Urban Mobility Report use real time speed data for each roadway section in an urban area. It is possible that this change will increase the viability of TTI as a measure of actual congestion costs across urban areas and time.

dispersing travel patterns by allowing for reverse or cross commuting, or by substituting travel on congested inner roadways for travel on less congested outer roadways. If this is the case the falling congestion costs associated with an additional employment center would be expected to increase vehicle miles travelled, increasing the travel time index. Thus if the formation of employment centers do lower the unit distance congestion price of travel, use of the TTI as the measure of price would actually cause the finding that they increase the congestion price of travel.

Table 2 shows that controlling for infrastructure availability, additional employment centers are associated with an increase in vehicle miles travel. Table 7 shows the results from a regression of the TTI on the same variables. In this regression TTI and the number of employment centers exhibit a positive relationship when controlling for infrastructure availability. If the TTI is then naively interpreted as a per unit distance congestion cost measure, one would expect the combination of increased travel and a higher per unit distance price of travel to lead to longer travel times. Table 3 shows that controlling for infrastructure availability additional employment centers are not significantly associated with a change in commute times. Therefore, it is not likely that the TTI is an appropriate measure of per unit distance travel congestion costs in across urban areas.

2.7 Conclusion

Using reduced form equations this paper finds that the number of employment centers in an urban area affects transportation decisions, average wages, and the share of urban area employment that locates within employment centers. I find that the number of employment centers is positively related to per capita vehicle miles traveled and insignificantly related to commute times. The increase in vehicle miles travelled leads to the rejection of the hypothesis that additional employment centers lower total transport cost by allowing workers to live closer to their place of employment. On the other hand, the increase in vehicle miles travelled together with no change in commute times supports the hypothesis that an additional employment center lowers the unit distance price of travel. It appears that the lower unit price of travel allows workers to forego the opportunity to move closer to work, and instead move towards locational amenities other than place of employment. The change in total travel costs associated with an additional employment center remains unclear.

I find support for the theoretical hypothesis that increases in the number of employment centers lower the average wage within an urban area. Thus far I have not been able to determine the exact cause of the fall in wage. Theoretically there exist two nonexclusive explanations, a fall in productivity due to the loss of total agglomeration economies, or a fall in the wage needed to compensate workers for their congestion costs. I also find support for the presence of agglomeration economies within employment centers through localized concentration's effect on average wages in an urban area, supporting the hypothesized reason for the creation of employment centers.

To my knowledge this has been the first paper to test the theoretical predictions of the predicted economic consequences of employment center formation within an urban area. It is likely that the reduced form equations presented in this paper should be estimated simultaneously, and future research would be able to further our understanding of the effects of employment centers by searching for likely instruments. Redfearn (2010) has found that the location of employment centers in Los Angeles seem to qualitatively be better described by early roadway networks than by the current network. This suggests that a time series type analysis might be a productive branch of research for at least questions about the relationship between transport costs and the number of employment centers. Some of the determinants of urban area wages, such as industry mix, might also have effects on both wages and the number of employment centers.

Given that there are external costs and benefits associated with the formation of employment centers, it is possible urban areas do not have the efficient number of employment centers. To my knowledge, this is the first paper to attempt to measure the efficiency of the number of employment centers and does so by proposing a proxy measure, the share of urban area employment locating within employment centers. If the efficient number of employment centers maximizes the total benefit minus the total costs of locating within an employment center, then this could be an appropriate measure. I find that the employment center employment share maximizing number of employment centers varies with urban area size. The analysis done in this paper allows me to predict the number of employment centers that maximizes the employment centers' share of urban area employment given the urban area population. There is a clear pattern when inspecting the data, as to whether an urban area has more or less than the predicted employment center employment share maximizing number of employment centers. The small urban areas in my dataset have less than the predicted employment share maximizing number. The likelihood that an urban area has more than the predicted employment center employment share maximizing number increases as population increase, with the largest two urban areas having significantly more.

The employment center employment share seems to be an appropriate measure of the tradeoff being made between transport costs and agglomeration economies given the current understanding of location decisions in urban areas. Certain questions that would give us a better understanding remain to be explored in the literature. The relationship between export and local employment and their respective locational distribution in an urban area would have a large impact on the understanding on the efficiency aspect of urban form. Also the use of an open economy model might make it possible to explore whether the employment that is most likely to locate in employment centers is also most likely to locate in the larger urban areas. This might explain the pattern of differences from the predicted share maximizing number of employment centers. Glaesar and Kohlhase (2004) find that county density is related to industry mix suggesting that this would be a productive line of research. Models with fixed costs associated with the formation and in the location of employment centers might also help in understanding this pattern given Redfearn's (2010) finding showing the relationship between initial transport investment and the formation and persistence of employment centers.

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2.9 Tables and Figures

Table 1-Summary statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Number of employment centers[1]	50	6.68	5.61	1	28
Per capita daily vehicle miles travelled freeway[2]	50	9.43	2.44	4.99	13.6
Average commute time of urban area residents	50	25.21	3.18	19.49	34.64
Average commute time of urban area workers	50	27.04	3.18	21.22	35.93
Travel Time Index	50	1.22	0.088	1.06	1.46
Average wage	45	17.33	2.02	13.29	22.06
Urban Area employment (1000's)	50	1305.02	1358.02	397	8119.5
Urban Area population (1000's)	50	2561.2	2948.5	650	17090
Lane miles freeway per 1000 pop[3]	50	0.64	0.21	0.33	1.21
Lane miles arterial per 1000 pop[3]	50	1.74	0.39	1.025	3.013
Urban Area land area	50	1020.6	776.79	290	4400
Proportion of Urban Area employment in Employment Centers	50	0.22	0.065	0.079	0.36
Dispersion of Employment Center employment from CBD[4]	50	5.91	4.039	0	19.055
Dispersion of Employment Center employment[4]	50	8.42	5.27	0	25.25
Employment Center Herfindahl index[5]	50	0.44	0.23	0.1	1
Proportion of Urban Area tracts in Employment Centers	50	0.037	0.012	0.015	0.061
Proportion of Urban Area land area in Employment Centers	50	0.026	0.019	0.000041	0.1
Number of Employment Centers per 1Mil Urban Area employment	50	5.51	2.17	1.62	11.15
Number of Employment Centers per Ln of Urban Area employment	50	0.47	0.36	0.076	1.76

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)
[2]per capita daily vmt is a measure of the implicit demand for travel
[3]Per thousand population lane miles represent expected costs of utilizing transport infrastructure with price per distance increasing in population and decreasing in lane miles. Travel along arterials is a substitute for travel along freeways
[4]the dispersion metrics measure the average distance of employment center employment from the CBD and from all other employment center employment, respectively
[5] Herfindahl index measures the dispersion of employment among employment centers,with lower values representing more equal sharing of employment among employment center and in practice dispersion of employment center employment away from the CBD

Table 2 - Effects of the number of employment centers on the implicit demand for travel in an urban area

	Dependent variable: per capita vehicles miles travelled by freeway			
VARIABLES	(1)	(2)	(3)	(4)
Number of employment centers[1]	0.390***		0.415***	
	(0.0926)		(0.0926)	
Number of employment centers squared	-0.0103*		-0.0128*	
	(0.00595)		(0.00643)	
Ln of the number of employment centers		1.247***		1.235***
		(0.313)		(0.309)
lane miles of freeway per thousand population[2]	11.33***	11.02***	11.51***	11.08***
	(1.112)	(1.082)	(1.150)	(1.093)
lane miles of arterials per thousand population[2]	-1.087**	-0.978**	-1.021**	-0.958**
	(0.455)	(0.427)	(0.423)	(0.416)
Urban Area employment (1000's)	0.000150	-5.12e-05		
	(0.000841)	(0.000510)		
Urban Area population (1000's)			0.000193	1.98e-05
			(0.000370)	(0.000204)
Urban Area total land area	-0.000748	-0.000521	-0.000917	-0.000654
	(0.000930)	(0.000801)	(0.000807)	(0.000707)
Constant	2.811**	2.686**	2.476*	2.649**
	(1.291)	(1.159)	(1.233)	(1.152)
Observations	50	50	50	50
R-squared	0.773	0.756	0.775	0.756

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)

[2]Per thousand population lane miles represent expected costs of utilizing transport infrastructure with price per distance increasing in population and decreasing in lane miles, travel along arterials is a substitute for travel along freeways

Table 3 - Effects of the number of employment centers on average commute time

VARIABLES	Urban area worker average commute (1)	(2)	(3)	(4)	Urban area resident average commute (5)	(6)	(7)	(8)
Number of employment centers[1]	0.343		0.301		0.162		0.161	
	(0.220)		(0.215)		(0.205)		(0.179)	
Number of employment centers squared	-0.0127		-0.00720		-0.00479		-0.00453	
	(0.0108)		(0.0106)		(0.00937)		(0.00722)	
Ln of the number of employment centers		0.935		0.988		0.391		0.391
		(0.700)		(0.726)		(0.621)		(0.633)
Lane miles freeway per thousand population	0.897	0.501	0.599	0.382	-1.873	-2.046	-1.884	-2.061
	(1.703)	(1.603)	(1.790)	(1.649)	(1.440)	(1.310)	(1.411)	(1.301)
Lane miles arterial per thousand population	-1.523*	-1.546*	-1.709**	-1.600**	-1.991***	-1.992***	-2.001***	-1.995***
	(0.838)	(0.803)	(0.809)	(0.789)	(0.694)	(0.656)	(0.653)	(0.643)
Urban Area employment(1000's)	0.00111	0.000514			8.33e-05	-3.97e-05		
	(0.00121)	(0.000579)			(0.000885)	(0.000416)		
Urban Area population (1000's)			0.000130	0.000104			1.82e-05	-2.36e-05
			(0.000447)	(0.000179)			(0.000293)	(0.000139)
Urban Area total land area	0.000571	0.000991	0.00130	0.00141	0.00211**	0.00227***	0.00215***	0.00229***
	(0.00147)	(0.00115)	(0.000957)	(0.000840)	(0.00104)	(0.000815)	(0.000671)	(0.000599)
Constant	25.75***	26.23***	26.51***	26.30***	26.88***	27.09***	26.92***	27.10***
	(2.126)	(1.908)	(2.074)	(1.891)	(2.223)	(1.920)	(1.937)	(1.885)
Observations	50	50	50	50	50	50	50	50
R-squared	0.523	0.513	0.514	0.508	0.630	0.625	0.630	0.625

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)

Table 4 - Effects of the number of employment centers on average wage in an urban area

VARIABLES	Average urban area wage (1)	(2)	(3)	(4)
Number of employment centers[1]	-0.48**	-0.47**		
	(0.202)	(0.225)		
Number of employment centers squared	0.013**	0.011*		
	(0.00577)	(0.00617)		
Ln number of employment centers			-1.61*	-1.47
			(0.937)	(1.017)
% Urban Area employment in Employment Centers	9.68	13.49**	10.56	13.27*
	(6.099)	(6.107)	(6.930)	(7.276)
Ln Urban Area employment	3.46***		3.35***	
	(0.975)		(0.995)	
Ln population		2.76***		2.55***
		(0.910)		(0.939)
Urban Area land area	-0.0011	-0.00059	-0.00082	-0.00045
	(0.000824)	(0.000703)	(0.000760)	(0.000690)
Constant	-29.26**	-22.58*	-27.85**	-19.59
	(12.60)	(12.60)	(12.88)	(12.90)
Observations	45	45	45	45
R-squared	0.354	0.352	0.339	0.332

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)

Table 5 - Determinants of the employment center share of urban area employment

	Percentage of urban area employment located in employment centers						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Number of ECs[1] per UA employment (1000000s)	-0.0098						
	(0.0104)						
(Number of ECs per UA employment (1000000s)) ^2	0.0011						
	(0.000743)						
Number of ECs per Ln of UA employment		0.23***	0.25***	0.23***			
		(0.0500)	(0.0640)	(0.0718)			
(Number of ECs per Ln of UA employment)^2		-0.10**	-0.13**	-0.096*			
		(0.0422)	(0.0514)	(0.0485)			
Number of employment centers					0.015***	0.017***	0.020***
					(0.00398)	(0.00427)	(0.00570)
Number of employment centers ^2					-0.00053	-0.00066**	-0.00091***
					(0.000326)	(0.000279)	(0.000315)
Number of employment centers* UA employment					4.61e-10	7.36e-10	2.01e-09**
					(1.21e-09)	(1.05e-09)	(9.26e-10)
Average EC employment distance from CBD	0.0013	-0.0054***			-0.00495**		
	(0.00127)	(0.00151)			(0.00221)		
EC employment dispersion			-0.0049**			-0.0042*	
			(0.00185)			(0.00238)	
EC Herfindahl index[2]				0.082*			0.075*
				(0.0411)			(0.0401)
Per thousand population lane miles of freeway		0.046	0.048	0.055	0.045	0.046	0.046
		(0.0344)	(0.0346)	(0.0346)	(0.0352)	(0.0357)	(0.0360)
UA population		5.53e-09	8.74e-09	1.89e-09	2.81e-09	4.22e-09	-8.89e-09
		(7.21e-09)	(7.54e-09)	(7.84e-09)	(1.07e-08)	(1.19e-08)	(1.06e-08)
Proportion of UA area in employment centers	1.11***	1.29***	1.24***	1.32***	1.31***	1.26***	1.33***
	(0.213)	(0.256)	(0.280)	(0.249)	(0.256)	(0.279)	(0.249)
Proportion of UA tracts in employment centers	2.93***	1.79***	2.0***	2.26***	1.84***	2.03***	2.13***
	(0.695)	(0.646)	(0.616)	(0.623)	(0.660)	(0.642)	(0.679)
Constant	0.092***	0.037	0.027	-0.048	0.041	0.034	-0.029
	(0.0315)	(0.0506)	(0.0498)	(0.0591)	(0.0517)	(0.0513)	(0.0585)
Observations	50	50	50	50	50	50	50
R-squared	0.644	0.747	0.742	0.729	0.744	0.740	0.740

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)

[2]Herfindahl index measures the dispersion of employment among employment centers,with lower values representing more equal sharing of employment among employment center and in practice dispersion of employment center employment away from the CBD

UA-urban area, EC-employment center

Table 6 – Predicted employment center employment share maximizing number of employment centers

Urban Area	Urban Area employment(1000's)	number of EC[1]	share maximizing number of EC (predicted Table 4 column 3)		share maximizing number of EC (predicted Table 4 column 7)	
Birmingham	397	1	6.4	-	11.5	-
Rochester	412.5	3	6.5	-	11.5	-
Oklahoma City	422	2	6.5	-	11.5	-
Jacksonville	476.5	2	6.5	-	11.6	-
Buffalo	484.5	1	6.5	-	11.6	-
New Orleans	489	2	6.6	-	11.6	-
Richmond	492.5	3	6.6	-	11.6	-
Salt Lake City	495	2	6.6	-	11.6	-
Louisville	500	4	6.6	-	11.6	-
Memphis	504.5	3	6.6	-	11.6	-
Nashville	531.5	3	6.6	-	11.6	-
Charlotte	540	3	6.6	-	11.6	-
Hartford	546	2	6.6	-	11.7	-
Riverside	550.5	2	6.6	-	11.7	-
Austin	585	4	6.6	-	11.7	-
Providence	596.5	2	6.6	-	11.7	-
Las Vegas	613.5	2	6.7	-	11.7	-
San Antonio	654	5	6.7	-	11.8	-
Sacramento	689	3	6.7	-	11.8	-
Columbus	693.5	7	6.7	+	11.8	-
Orlando	697	5	6.7	-	11.8	-
Milwaukee	714.5	2	6.7	-	11.8	-
Virginia Beach	717.5	8	6.7	+	11.8	-
Indianapolis	720.5	3	6.7	-	11.9	-
Kansas City	804	3	6.8	-	11.9	-
Cincinnati	857	5	6.8	-	12.0	-
Portland	896.5	6	6.9	-	12.0	-
San Jose	930.5	8	6.9	+	12.1	-
Pittsburgh	954	3	6.9	-	12.1	-
Cleveland	973	6	6.9	-	12.1	-
Tampa	1005.5	7	6.9	+	12.2	-
Baltimore	1068.5	9	6.9	+	12.2	-
Denver	1081	6	6.9	-	12.3	-
St. Louis	1129.5	6	7.0	-	12.3	-
San Diego	1278.5	11	7.0	+	12.5	-
Phoenix	1387.5	11	7.1	+	12.6	-
Minneapolis	1466.5	8	7.1	+	12.7	-
Seattle	1514.5	12	7.1	+	12.7	-

San Francisco	1683	6	7.2	-	12.9	-
Houston	1858.5	12	7.2	+	13.1	-
Detroit	1908	16	7.2	+	13.2	+
Atlanta	1998.5	15	7.3	+	13.3	+
Miami	2114	9	7.3	+	13.4	-
Dallas	2281	11	7.3	+	13.6	-
Boston	2332.5	6	7.3	-	13.6	-
District of Columbia	2368.5	14	7.3	+	13.7	+
Philadelphia	2468.5	4	7.4	-	13.8	-
Chicago	4031	15	7.6	+	15.5	-
Los Angeles	5219	23	7.7	+	16.8	+
New York	8119.5	28	8.0	+	20.1	+

+/- the urban area has more/fewer than the employment center share of urban area employment maximizing number of employment centers as predicted from the results in Table 4

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)

Table 7 – Effect of the number of employment centers on the Travel Time Index

	Dependant variable: Travel Time Index			
VARIABLES	(1)	(2)	(3)	(4)
Number of employment centers[1]	0.019***		0.021***	
	(0.00380)		(0.00385)	
Number of employment centers squared	-0.00062***		-0.00078***	
	(0.000224)		(0.000244)	
Ln of the number of employment centers		0.06***		0.06***
		(0.0136)		(0.0133)
Lane miles of freeway per thousand population	-0.11***	-0.13***	-0.094***	-0.12***
	(0.0291)	(0.0294)	(0.0308)	(0.0300)
Lane miles of arterials per thousand population	-0.06***	-0.058***	-0.057***	-0.057***
	(0.0158)	(0.0163)	(0.0147)	(0.0158)
Urban Area employment (1000's)	3.55e-05	1.31e-05		
	(2.85e-05)	(2.20e-05)		
Urban Area total land area	-4.72e-05	-3.05e-05	-5.19e-05*	-3.46e-05
	(3.40e-05)	(2.94e-05)	(3.02e-05)	(2.59e-05)
Urban Area population (1000's)			2.25e-05*	7.54e-06
			(1.33e-05)	(8.69e-06)
Constant	1.31***	1.31***	1.29***	1.31***
	(0.0369)	(0.0359)	(0.0378)	(0.0349)
Observations	50	50	50	50
R-squared	0.716	0.691	0.732	0.696

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

[1]Employment centers are identified by the Author as statistically significant concentrations of employment identified using locally weighted regressions and employment level cutoff based on methodology from McMillen and Smith (2003)