THE WAGE GRADIENT IN A MULTI-NUCLEATED CITY

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Introduction

Urban price gradients are fundamental components of spatial location theory. Unfortunately, the empirical verification of such gradients has been a difficult task that has yielded at best mixed results. Nowhere is this more apparent than the disappointing and sparse empirical results regarding intraurban wage gradients.[1] One reason may be that it is quite difficult to obtain firm wage data by location.[2] Empirical studies of wage gradients can, however, also suffer from specification problems.

Urban spatial location theory argues that wages should decline as accessibility to an employment center decreases. Workers who accept local employment have reduced commuting costs and so would be willing to accept a wage lower than that found in the employment center. In empirical specifications of the familiar monocentric model this translates into an inverse relationship between the wage and distance to the central business district (CBD). Typically, accessibility is measured as the linear distance to the CBD. This formulation is inappropriate in the presence of multiple employment centers and/or nonlinear transportation costs.

This paper focuses on the application to intraurban wage equations of a generalized accessibility measure introduced by Jackson [2]. From a theoret-

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1. One of the few studies that finds expected results in Eberts [1]. Negative wage gradients with respect to the Chicago CBD were found for four of five groups of municipal employees. In a more recent paper, Madden [3] finds evidence of negative wage gradients using data across urban areas on individual worker job and residence changes.

2. Eberts [1] overcame this problem, however, by restricting attention to public employment in municipalities in an urban area for which the wage and other relevant data were available.

ical perspective this measure is appealing. First, the measure does not require the researcher to know or to specify the location of the employment center (or centers). Second, the measure provides a flexible functional form which allows the researcher to choose an appropriate polynomial approximation of the accessibility surface through application of a statistical test. We find this accessibility measure to have significant explanatory power with respect to intraurban wage variation and to offer superior results to those for the conventional unidimensional accessibility measure.

The plan of the paper is as follows. Section 2 provides a discussion of the accessibility measure and the wage equation to be estimated. Section 3 presents results for statistical estimation of the wage surface for the Boston metropolitan area. Finally, Section 4 offers some concluding remarks.

Wage Equations and Accessibility

Moses [4], Muth [5], and White [10] present theories of intraurban spatial location in which equilibrium wage rates for employees with similar skills and the same occupation vary systematically by employer location within an urban area. Specifically, it is determined that in a monocentric region the wages of workers employed locally will decline with distance from the CBD. If employment subcenters exist, the wages will first decline with a movement away from one concentration of employment and then rise as another concentration is approached. It is our intent here to specify an equation to be estimated which is consistent with the theory of wage gradients and which explains a significant portion of the variation of wages within an urban area. Details of the underlying theory can be found in the above mentioned sources.

Real world transportation networks are not laid out densely enough nor with sufficient uniformity in capacity for worker accessibility to employment centers to be precisely measured by straight-line distance. Thus, even if multiple employment centers are considered, wage equations which use a linear measure of accessibility may be misspecified. In addition, estimation with a particular functional form for accessibility which is chosen a priori requires foreknowledge of the locations of the employment centers. In a multinucleated region this may be difficult.

In an empirical investigation of housing price gradients, Jackson [2] employs trend surface analysis to eliminate the problems of a priori choice of the functional form for accessibility and of the sites to which access is valued. We adapt this methodology to the problem of providing a measure of worker accessibility to employment centers. In particular, a double power series form with unknown coefficients is used as an approximation of the true accessibility surface.

The unit of observation is taken to be a community within a given metropolitan area. A coordinate system with an arbitrary origin is embedded in a map of the metropolitan area. Coordinates are then determined for the mid-points of the communities. Accessibility is defined in terms of these (X,Y) coordinates. Specifically, the true accessibility to employment centers of a worker residing in community t is given by:

$$A_t = g(X_t, Y_t) \quad (1)$$

This surface can be represented by the following Taylor Series expansion of $g(X_t, Y_t)$ about the origin:

$$A_t = g(X_t, Y_t) = g(0,0) = \frac{\partial g}{\partial X_t} . X_t + \frac{\partial g}{\partial Y_t} . Y_t + \sum_{j=1}^{n} \sum_{i=1}^{n} g_{ij} \cdot X_t^i \cdot Y_t^j + R_n \quad (2)$$

where $i+j \leq n$, the g_{ij}'s are terms involving constants and the partial derivatives of g evaluated at the origin, and R_n is the remainder term.

Dropping the remainder term, the right-hand side of [2] may be placed in a wage equation and the partial derivative terms estimated as unknown regression coefficients. Thus, an approximation of the true accessibility surface may be obtained. The appropriate degree of the approximating polynomial is determined by the data. Jackson [2] describes a joint F test that can be used to determine if increasing the degree of the polynomial adds significant explanatory power to the regression. An alternative criterion, based upon inspecting the residuals for spatial autocorrelation, is also discussed by Jackson.

In addition to accessibility, there should also be worker and community characteristics which help to explain the wage of a given class of workers in a community. As a result, the following general equation is estimated:

$$w_t + \beta . Z_t + \sum_{i+0}^{n} \sum_{j+0}^{n} \Upsilon_{ij} . X_t^i . Y_t^j + u_t \quad (3)$$

where $i+j \leq n$, w_t is the wage rate of a given type of worker in community t, β is a vector of coefficients, Z_t is a vector of worker and community characteristics (the variables in this vector are specifically defined in the Appendix to this paper, the Υ_{ij}'s are coefficients, and u_t is a stochastic error term.[3]

Ideally, the equation would be estimated with data on individual worker characteristics and wages paid by individual firms. Unfortunately, privacy considerations precluded obtaining such disaggregated data. All of the data used for this study are at the community level. The class of workers focused on is that of manufacturing production workers in the various communities of the Boston SMSA in 1977. Wage rates are community averages for these workers.[4]

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3. A constant term for the regression is included in this formultion. It is given by Υ_{00}.

4. Wage rates can vary by manufacturing industry. Thus, the mix of manufacturing industries in communities might have an important impact on the average manufacturing wage rates for the various communities. Unfortunately, data on separate manufacturing industries by community was available only for those 2-digit industries which employed at least 450 workers in the community. Attempts were made to dummy out the effects of those reported 2-digit industries which paid wages that were

Worker characteristics should be related to wage payments. In particular, profit maximization implies that worker productivity is positively related to the wage rate. To capture this effect, manufacturing value added per production worker in a community is used as an independent variable.

If a community is unable to provide enough manufacturing workers to meet the demands of the firms within it, then workers must be attracted from outside the community. It is expected then that wages in such communities will be higher than if labor demands are met locally. Additionally, the more workers to be attracted from an outside area the higher the wage will have to be. This effect is modelled in the wage equation by including an employment concentration variable: the ratio of manufacturing production workers to population in the community.

Following Eberts [1], a housing price measure is included as an explanatory variable. The rationale underlying this choice is the notion that workers may have to be paid higher wages in a community with high housing prices to compensate them for the cost of living in the community or commuting to it from elsewhere. A housing price variable, defined in [2], that is a weighted average of rents and unit values for owner-occupied housing in a community is used in the wage equation.

The tightness of the local labor market might also affect community wages. In particular, labor surpluses permit firms to satisfy, to a large extent, their demands for labor locally. Thus, we would expect wages in such communities to be lower. To proxy for the excess supply of labor the rate of population change in the community is used. As noted in Eberts [1], a better proxy would be a measure of the change in employment demand relative to supply, but data on firm migration are not available. It is also argued there that, in any case, firms relocate at a much slower pace than households.

Finally, demographic variables were considered.[5] In a study of low-income job applicants, Phillips and Meyers [6] find that high wages are concentrated in primarily white census tracts, regardless of the census tracts of worker residences. Consequently, racial variables were included in the regressions. The precentage of blacks in a community did not prove to be a statistically significant explanator of wages. On the other hand, the percentage of Hispanics in a community was shown to be significant with the expected sign. Only results with the Hispanic variable are reported below.

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significantly above or below the manufacturing average for the given urban area. None of the dummy variables, however, were shown to be statistically significant explanators.

5. Community income and education variables were tried but were not found to have any explanatory power. Since there seems to be no compelling reason why these characteristics of the communities should be highly correlated with the corresponding characteristics of workers in these same communities, the outcome observed is not too surprising.

Because there was no clear indication of what the form of the relationship between the wage rate and the worker and community characteristics should be, the Box-Cox transformation was utilized. In particular, various combinations of linear, logarithmic, and exponential forms for the dependent variable and the non-accessibility independent variables were tried.[6] Results were not very sensitive to the transformation used but appeared best for the double log form.

Results

Four regressions from the heart of our empirical analysis. Results for them are reported in Table 1. Equation I represents a run of the model using a conventional linear distance measure, while equations II, III, and IV use a first degree, second degree, and third degree polynomial approximation of generalized accessibility, respectively. Several points are suggested by the results.

All of the models seem to offer significant cumulative explanatory power as measured by the adjusted R^2 statistic. However, we observe a notable increase in its value as the second and third degree polynomials are considered. With respect to the non-accessibility variables we observe relatively stable results in terms of the signs and magnitudes of the coefficients.

The housing price variable, though theoretically well justified, fails to ever reach even marginal significance and is unstable in the sign of its coefficient. However, the other non-accessibility variables are much more stable in the signs and magnitudes of their coefficients across the four equations. PHISP80 consistently enters with a negative and significant coefficient. Aside from general prejudice, one could conjecture that the reason might be in the notion, held by some, that the Hispanic population in the Boston SMS contains a fairly large proportion of illegal aliens who receive below market wages. How significant this effect would be in the manufacturing sector is certainly subject to debate. There does appear, however, to be a significant correlation here between low manufacturing wages and a high Hispanic populaion in communities. A more satisfactory explanation of this phenomenon encourages further investigation and insight.

LCON277 is an employment concentration variable. According to theory, sub-centers of employment should offer higher wages than communities with only local employment. The results support this theory. Although the coefficients for PDIF are statistically insignificant, they do have the right sign. Finally, we observe the expected significant positive relationship between productivity and wages in the results for LPROD77.

Although the aforementioned results are very encouraging, the focus of our investigation remains the appropriate consideration of accessibility. As a baseline, equation I uses the linear distance to the CBD, i.e. the conventional

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6. The polynomial form for accessibility approximates any accessibility surface. Thus, there is no need to apply transformations to the coordinate variables.

TABLE 1

LNWAGE77 REGRESSION RESULTS
(t statistics in parentheses)

Variable	EQUATION I	EQUATION II	EQUATION III	EQUATION IV
CONSTANT	1.7787 (4.9392)	1.7283 (5.0704)	1.8776 (5.9609)	2.0210 (5.9580)
PHISP80	-1.7023 (-1.7963)	-1.7136 (-1.8758)	-2.2368 (-2.6248)	-2.3457 (-2.5968)
LCON277	.04014 (1.7309)	.03821 (1.6406)	.05931 (2.6912)	.06423 (2.5681)
LPROD77	.2171 (3.9346)	.2350 (3.7375)	.2548 (4.4124)	.2695 (4.0393)
LRENT2	.01685 (.4499)	.02193 (.6339)	- .00205 (-.05933)	- .00678 (-.1802)
PDIF280	- .06251 (-.4426)	- .05979 (-.4323)	-.0457 (-.3567)	- .02138 (-.1598)
X		-.001272 (-.2731)	- .03693 (-2.0398)	- .04995 (-.9513)
Y		-.003813 (-1.0013)	.05866 (2.6542)	-.01855 (-.2720)
XY			-.001319 (-1.7045)	.000546 (.09969)
XSQ			.002308 (2.6436)	.004261 (.6565)
YSQ			-.03018 (-2.7851)	.006596 (.8618)
XCU				-.0001075 (-.4497)
YCU				-.0003106 (-1.1633)
XYSQ				-.0002148 (-.8901)
YXSQ				.0000787 (.4511)
DCBD	.001280 (.1584)			
	$R^2_{adj} = .3122$	$R^2_{adj} = .3124$	$R^2_{adj} = .4476$	$R^2_{adj} = .4303$
		$F_{3,40} = 4.5691$		$F_{4,36} = .6457$

accessibility measure. DCBD enters with the wrong sign and is insignificant at any reasonable level.

Equation II utilizes a first degree formulation of the generalized accessibility measure and provides no notable improvement over the conventional measure other than slightly more precise coefficient estimates with respect to accessibility. A second degree accessibility polynomial was then constructed and used to estimate equation III. An F test was performed to determine whether the second degree formulation was statistically superior to the first degree formulation. The value of the appropriate F statistic is reported in the table between equations II and III. To check for spatial autocorrelation an examination and a test of the residuals of the equations were also conducted. Using the criteria outlined in [2], the second degree formulation was found to be superior on all counts. Observation of the results for equation III indicates that significant explanatory power can be attributed to accessibility, a conclusion not justified by the results from equations I and II.

Equation IV reports the results for a third degree polynomial formuation. Neither the F test (the F statistic is listed between equations III and IV) nor examination of the residuals supported utilization of the third degree formulation.

The coefficient estimates of the coordinate variables for equation III yield an approximately accessibility surface which, when considered as an unconstrained surface in 3-dimensional Euclidean space, has a saddle point and no local extrema. The saddle point is given at (X,Y) + (10.14, 7.50), which is about 6.22 miles west and 3.47 miles south of the city of Boston. The Boston SMSA, however, is not an isolated circular region. On the east it is bordered by the Atlantic Ocean and at some points west, north, and south it runs contiguous with other smaller metropolitan areas. Thus, even if centers, defined in terms of accessibility, in a region such as this exist, they may not appear as local maxima for an estimated surface if they are located close to the boundaries of the metropolitan area that is investigated.

Wage gradients in a multi-nucleated area with nonlinear accessibility are not easy to characterize. The change in the wage rate for small changes in distance varies with the slope of the accessibility surface. One can get a sense, however, for how wages vary with distance in the area by computing changes in wages between distant points in parts of the region where wages are uniformly rising or falling.

For example, for the accessibility surface given by equation III, average per mile changes in the wage rate can be obtained for east-west or north-south movements from the saddle point. Specifically, other things equal, the average per mile percentage increase in the wage rate for a fourteen mile move eastward from the saddle point (approximately as far east as the metropolitan area extends from the saddle point) is .87%. For a northward (or southward) move of the same distance from the saddle point wages declined at an average of 1.01% per mile.[7]

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7. Because of changing slopes, the calculated average percentage wage

Conclusion

This paper investigated the wage gradient in a multi-nucleated city through application of a generalized accessibility measure. The measure was found to offer results superior to those using the conventional linear measure, and indicated significant explanatory power for accessibility in the determination of urban wages.

Application of the generalized accessibility framework allowed us to identify a saddle point of the approximating accessibility surface and to investigate the sensitivity of wages to changes in accessibility. In particular, over significant portions of the Boston SMSA wage rates for manufacturing production workers were found, ceteris paribus, to vary on average at rates that were in the neighborhood of 1% per mile. More reliable estimates may be obtained with more disaggregated worker and firm data, but it seems evident that a flexible functional form for accessibility can be profitably used in estimating intraurban wage equations.

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change depends on the extent of the movement away from the saddle point. For example, for a 7 mile move eastward (or westward) from the saddle point wages increase by an average of .42% per mile, while a 7 mile move northward (or southward) entails a .53% per mile decrease in wages.

The Data

Data was gathered for communities in the Boston SMSA. Primary sources for the data were the 1977 *Census of Manufactures* and the 1977 and 1982 editions of the *County and City Data Book*. A total of 51 communities from all sections of the SMSA had sufficient manufacturing activity to be reported in the *Census of Manufactures*, representing more than 60 percent of the total communities in the SMSA and all of the larger cities and towns. Data from these 51 communities constitute our sample. The variables are defined as follows:

LNWAGE77	= Log of total manufacturing production worker wages per production worker in a community in 1977
PHISP80	= Percent of 1980 population that was Hispanic
LCON277	= Log of the ratio of manufacturing production workers to community population in 1977 (i.e., employment concentration
LPROD77	= Log of value added per production worker in 1977
LRENT2	= Log of mean price for housing services, calculated as in Jackson (2)
X	= Distance west from arbitrary origin (1X = 1.98 miles)
Y	= Distance north from arbitrary origin (1Y = 1.98 miles)
XY	= X^*Y
XSQ	= X^2
YSQ	= Y^2
XCU	= X^3
YCU	= Y^3
XYSQ	= X^*Y^2
YXSQ	= Y^*X^2
DCBD	= Airline distance to Boston central business district

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