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Intra-Urban Wage Variation, Employment Location And Commuting Times

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Abstract

Theory predicts that within a metropolitan area, employers located where there is difficult commuting will have to compensate their workers with appropriately higher wages. This should hold whether one is comparing central city work locations with those at the fringe, or simply differences between suburban "edge cities". In the longer run, if employers are concerned primarily with labor costs, firm mobility should equalize wages or else agglomeration economies must exist to sustain the differences. Using micro-data from the 1990 census for 2 large metropolitan areas in the U.S., wage equations are estimated for urban workers allowing for different wage levels depending on zone of employment. The results show that observationally equivalent workers have wages that vary substantially across employment zones within a metro area, and that this variation is strongly and significantly correlated with the *average* commute time of the workers employed in that zone. These results hold across several different econometric specifications. Wages and average travel times also are found to be highly correlated with the aggregate number of workers in each zone, but are not affected by zone employment specialization. Thus there is inconclusive evidence as to whether wage/commuting cost differences result from equilibrium agglomeration effects or from a disequilibrium distribution of employment.

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I. Introduction.

The capitalization of commuting costs and other location attributes into land rents has long been an established feature of urban economic spatial models (Muth [18] and Mills [16]). More recently, authors have noted that if firms are located at different points within a metropolitan area, then transportation costs must be capitalized into wages as well. As Moses [17] pointed out, if "local" firms employing adjacent workers coexist with firms in a Central Business District, then the wages such local firms pay must decline with distance just as rents do. With differences in both wages and rents it is possible for workers to achieve equal utility across residence zones - regardless of whether they work "locally" or "centrally". In the longer run, whether firms tolerate these wage differences depends on whether their production function generates cost or productivity differences (Wheaton and Sivitanidou [27]).

This paper uses a linear programming model to demonstrate more generally how commuting costs will be capitalized into both labor market wages and land market rents. Specifically, variation in commuting costs of *individual* workers employed at the same location but living at different locations will be capitalized into land rents. Variation in the *average* commuting costs between those employed at different work locations will be capitalized into wages. This paper seeks to empirically validate the conclusions of this model by focusing on three questions. First, do wages vary within metropolitan areas by workplace location? Second, is this variation correlated with commuting times? Third, do larger employment centers have longer average commutes (and hence higher wages)? The paper leaves open the question as to whether (larger) employment locations with longer commutes/higher wages have offsetting agglomeration economies, or whether such differences are simply temporary and eventually will be equilibrated away through firm mobility.

II. Previous empirical work.

Empirical studies of urban wage variation have focused on estimating the wage "gradient" hypothesized by Moses. Early studies, such as Segal [22] and DiMasi and Peddle [3], used average wage levels for certain occupational categories as a means of testing for differences between central city and suburban wages. Using aggregate wage data can lead to bias if other worker characteristics vary systematically across different locations, which they most surely should. Eberts [5] sought to overcome this problem by focusing only on municipal workers, and further, only those within relatively homogeneous occupations, such as firefighters. While an improvement, the problem of using aggregate wage data remained. Later studies, such as Ihlanfeldt [9] , Madden [14] , and McMillen and Singell [12] , avoided the problem by using microdata on individual workers. The advantage of this approach is that a range of human capital factors which determine wage levels, and which may be correlated with location, such as experience, education, occupation, and industry, can be controlled for. This allows for a more precise isolation of the portion of the wage which is due to work place location. The first contribution of this paper then is to use extensive microdata to study intra-urban wage variation.

The studies reviewed so far all have estimated a 1-dimensional wage gradient. This implicitly assumes a single major center of employment, together with "local" employment that uses only a "few" workers. An alternative, but still 1-dimensional specification has employment sharing land with residences while commuting occurs along continuous radial routes. Theoretical models confirm the existence of a wage gradient and show under a wide range of conditions, that employment density is more centralized than that of households, (Ogawa and Fujita [19]). In the real world, however, production economies of scale and the irregularities of regional transportation systems have given rise to "clusters" of local employment – often referred to as "edge cities". Commuting to and around such sub-centers has become a complex 2-dimensional problem, in contrast to the simplistic radial commuting that gives rise to the wage gradient approach (White [28,29], McMillen and McDonald [13]). If large secondary centers develop in the suburbs of an urban area, with smaller centers or dispersed employment located in between the primary and suburban centers, a one dimensional gradient will simply not capture the true variation in wages.

The second contribution of this paper is to treat employment location as discrete within 2-dimensional space: firms and households can reside in one of a finite number of zones, with a commuting cost matrix that is exogenous. This allows for a less restrictive specification of employment location and generates more general patterns of wage and land rent variation. It also matches with the micro data set we will use – which intrinsically treats space as discrete. In all such data sets, individuals and firms are coded to some set of discrete zones (towns, census tracts, etc).

III. Short run spatial equilibrium with multiple employment locations.

Modeling a location equilibrium in discrete space was first described in the bid-rent approach of Alonso [1]. In a competitive market, land or housing units go to the household offering the highest bid, which in turn is based on the net value or utility of the parcel to the household. In addition to this "highest use" condition, a location equilibrium requires that each household is allocated to a parcel , and that the number of households assigned to each parcel cannot exceed its supply or capacity.

Herbert and Stevens [6] developed a linear programming model to mimic an Alonso-type location equilibrium. The objective function sought to maximize the aggregate value of (bid) rent by assigning household types to locations, subject to constraints on the supply of housing and on the number of households of each type. Wheaton [26] and Anderson [2] offered refinements of the Herbert-Stevens model which could guarantee equilibrium. In Anderson's version, bid rent differences across locations will be constant and equal to variations in travel and other spatial costs. Thus, the problem of bid rent maximization under these circumstances is equivalent to one in which the aggregate value of spatially variable costs are minimized. None of this early literature addressed the question of how an equilibrium would be obtained if workers commuted to different work locations. The extension, however, is quite straightforward.

The model we use here is similar to Anderson's in that the only spatially variable costs is commuting and hence maximizing aggregate housing rent is equivalent to minimizing total commuting costs. The city consists of P identical households who can reside in n residential zones (i). Each of these zones has N_i housing units. Workplaces are fixed and in each of m employment zones (j) there are E_j jobs. Each household has a single employed worker, who incurs commuting costs c_{ij}. The following linear program assigns households to zones in a manner which minimizes aggregate commuting costs.

$$Minimize \sum_i \sum_j c_{ij} x_{ij}$$

$$subject\ to \qquad \sum_j x_{ij} \leq N_i \qquad i = 1,\ldots,n$$

$$\sum_i x_{ij} \geq E_j \qquad j = 1,\ldots,m$$

$$x_{ij} \geq 0$$

$$\sum_i N_i = \sum_j E_j = \mathrm{P}$$

where

x_{ij} = commuting flow from residential zone i to work zone j

N_i = number of housing units available in zone i

E_j = total employment in zone j

This formulation of the model is a pure transportation problem in linear programming: shipping workers from their homes to production sites. The constraints ensure that the equilibrium flows from each residential zone will be no larger than the available supply of housing; that equilibrium flows to each employment zone will be no less than the total demand for workers there; and that labor supply will equal labor demand.[2] The solution to the problem will result in workers commuting to the least-cost (nearest) employment center, whenever this is

$$\begin{aligned} \textit{maximize} \quad & \sum_j w_j E_j + \sum_i r_i N_i \\ \textit{subject to} \quad & w_j - r_i \le c_{ij} \qquad i = 1,\dots,n \quad j = 1,\dots,m \\ & w_j \ge 0 \\ & r_i \ge 0 \end{aligned}$$

possible.

More interesting for the purposes of this paper is the dual problem to the above primal form.[3] The objective of the dual programming problem is the following maximization problem.

The variables r_i and w_j are the shadow prices on the supply and demand constraints of the primal problem. In the traditional economic interpretation of transportation problems, these shadow prices are thought of as the value of a commodity (in this case labor) at its production site (work) and its value at the source of supply (home). In the dual problem, the value of labor to the firm must be no greater than its value to the worker plus commuting costs. The shadow prices r_i represent the comparative location advantage to labor of the various source (home) sites; the shadow prices w_j are labor's delivered price. Together, they define a spatial price equilibrium in an economy of competitive labor buyers and sellers (Dorfman, Samuelson, and Solow [4]).

Stevens [24] is credited with interpreting the shadow price at labor's source as location rent. Labor suppliers living closer to production sites will have a commuting advantage over those located further away which they freely bid away in site rent. The shadow price of labor at

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2. This last constraint will also imply that the constraint equations will hold with equality.

3. In matrix form, the dual of the linear program *min cx s.t.* $Ax \geq b$, $x \geq 0$, is *max yb s.t.* $yA \leq c$, $y \geq 0$.

the production site is obviously interpreted as the relative wage rate. To further motivate this interpretation, it is helpful to first recall the rules of complementary slackness, which describe how the solution to the primal problem relates to the constraints of the dual:

$$x_{ij} > 0 \Leftrightarrow w_j - r_i = c_{ij}$$
$$x_{ij} = 0 \Leftrightarrow w_j - r_i < c_{ij}$$

For any flow x_{ij} which is part of the primal solution, the difference in the shadow prices of the origin and destination nodes i and j will exactly equal the commuting costs between the two zones. Thus, in equilibrium, if residential zone i ships workers to employment zones j and k then the wages in zones j and k will be given by:

$$w_j - w_k = c_{ij} - c_{ik} \qquad (3)$$

Similarly, if residential zones i and l ship workers to a common work zones j :

$$r_i - r_l = c_{ij} - c_{lj} \qquad (4)$$

It is well known that in pure transportation problems, there will be at most $m+n-1$ positive origin-destination flows in an optimal solution to the cost minimizing primal problem. Thus, the system of dual constraints which hold with equality will have $m+n-1$ equations in $m+n$ unknowns (the r_i's and w_j's). One of the shadow prices can be normalized to zero, with all other shadow prices calculated relative to this anchor point. This result also implies that there will be at most $m-1$ origins which supply more than one destination.

To illustrate how the shadow prices related to the primal solution consider first a city with a single work center 1 and n residential zones. The dual constraint equations thus become

$$\begin{aligned} w_1 - r_1 &= c_{11} \\ &\vdots \\ w_1 - r_n &= c_{n1} \end{aligned}$$

Since w_1 can be normalized to 0, the shadow prices r_i will simply be the opposite of the transportation costs from each residential zone. They represent the relative commuting cost savings of each zone, which is thought of as location rent

Consider next a city with two employment centers (1 and 2). The set of $n+1$ equality constraints in the dual will have the form

$$\begin{aligned} w_1 - r_1 &= c_{11} \\ \vdots \quad & \quad \vdots \\ w_1 - r_a &= c_{a1} \\ w_2 - r_a &= c_{a2} \\ \vdots \quad & \quad \vdots \\ w_2 - r_n &= c_{n2} \end{aligned}$$

with $n+2$ unknowns to be solved for. The residential zones will be partitioned between the two employment zones, and there will be at most one residential zone (here, zone a) which has positive flows to both employment centers.[4] Thus, the differential between the shadow prices on the employment constraints will be uniquely determined by

$$w_2 - w_1 = c_{a2} - c_{a1} \qquad (5)$$

Normalizing w_1 to zero yields the shadow rents

$$r_i = -c_{i1} \qquad i=1,\ldots,a \qquad (6)$$

$$r_i = w_2 - c_{i2} \qquad i=a,\ldots,n \qquad (7)$$

Thus differences in shadow rents for residential zones serving the same employment center are fully determined by differences in commuting costs between those zones and that center. The shadow wage differential, however, is determined by the commuting cost differential to each employment zone from the marginal residential zone a, which provides workers to both zones.[5]

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4 If there were more than one, then workers could be reassigned to the one with lower shipment costs and the objective function would be improved.

5 It is also possible that there will be less than $m+n-1$ positive flows in the optimal origin-destination system.

When there are many employment centers, the same framework will apply. The set of equality constraints will have *n+m-1* equations, with workers in each (of the n) residential zones either "assigned" exclusively to one of the *m* employment zones, or to one of the *m-1* marginal "tie" zones. By normalizing the shadow wage at the first employment zone to zero, the remaining shadow wages (for each m-1 zones) can be determined recursively – based on the commuting cost difference between its "tie" zone and the commuting cost for the first (employment) zone.

If the transportation and zonal system is relatively uniform, then employment zones that have more workers, ceteris paribus, will have to draw workers from a larger number of residential zones. Since workers will be assigned first to their nearest employment zone, the marginal or "tie" residential zone for larger employment centers will be farther away than for smaller centers. Generally, this will mean larger centers have greater marginal commuting costs, and equation (5) indicates that this implies they also should have higher shadow wages. All of this suggests that *if* employer locations are fixed, then two empirical relationships should exist. In the first (8), relative wages are positively related to marginal or average commuting costs across employment locations. In the second (9), average or marginal commuting costs should be positively related to the size or number of workers at each employment center.

$$W_i - W^0 = F_2(C_i)\ , \quad F_2' > 0 \tag{8}$$

$$C_i = F_1(E_i\ )\ , \quad F_1' > 0 \tag{9}$$

where

C_i = Average commuting cost of workers in employment zone *i*

Under this condition, known as *degeneracy*, there will be more than one free elements in the set of dual equality constraints, and the wage differential cannot be determined. This will generally occur when the supply from each residential zone and the demand at each employment zone are all proportional to some constant, resulting in a commuting flow pattern which is completely separated among the employment centers and thus has no marginal commuting zone. Adjusting the demands from one employment node to another by even one unit alleviate this problem, however.

E_i = Employment in zone i

W_i = Wage rate in zone i

W^0 = Base metropolitan wage rate

IV. Employment location and local agglomeration.

The location of employment has been treated as exogenous in the equilibrium model described above. However, the existence of wage differences within a common labor market is not permanently sustainable in a long run equilibrium where firms must face equal production costs. Firms should redirect employment away from larger or more difficult commuting zones to those with fewer workers and better commuting. In the process, commuting costs would decline at larger existing centers and begin to rise at the newer centers. Eventually, commuting costs – and wages - should equalize between centers of employment (White, [29]). If the distribution of transportation capacity is relatively uniform, then equal wages and commuting costs eventually implies some number of equal-sized employment centers. This seems to be stylistically consistent with spatial structure of newer metropolitan areas in the South and West . In older metropolitan areas, where significantly greater transport capacity has been historically directed towards the center city, larger central employment could co-exist with numerous smaller "edge cities" (Richardson and Kumar [20]). Even in this situation, long run equilibrium still dictates that commuting costs and wages must equalize across (different sized) employment locations.

Thus, one explanation for why wage/commuting cost differentials would be observed in cities is simply that employment locations are not in long-run equilibrium. While the US Census finds that 30% of American households move every year, firms mobility is far less. Firms typically occupy specific production facilities or are committed to locations with long-term leases. Studies using the government's census of firms have found that only a tiny fraction of establishments actually move in any given year (Struyk and James [25]). The creation of new jobs, however, has increasingly been occurring in suburban "edge cities" (Helsley and Sullivan [7]). This suggests that over time, firms have been trying to better match their location to that of their workforce. Perhaps it will simply take several more decades to reach the hypothesized long run equilibrium.

An alternative view is that current employment location patterns do represent an equilibrium, but one in which some form of local agglomeration offsets existing wage differentials. For example, if it were assumed that center size generates some form of "increasing returns", then centers of large, mid, and small size might all coexist within a metropolitan area. In this equilibrium, the advantage to firms of center size would be exactly offset by higher wages, that in turn are necessary because of the increased commuting costs that workers have to expend to get to larger centers. It is important to realize that the "increasing returns" necessary in this case must be specific to each sub-center. Most existing theories of agglomeration, whether based on information exchange (Jaffee[10]), industrial linkages (Henderson [8]) or labor market search (Kim [11]} all hypothesize that these forces operate at a metropolitan-wide level.

The problem with testing these arguments empirically is that they are almost observationally equivalent: both are consistent with a commuting cost – wage relationship across MSA sub-centers. In one case, commuting costs differentials arise from temporary or adjusting employment patterns, which then in turn require wage compensation. In the other case, permanent productivity differences from agglomeration generate wage differences, and in response, labor supply creates offsetting travel costs.

One way to discriminate between these hypotheses would be to examine sub-center wages and employment over time. For example, if the adjustment hypothesis were to hold, then one should expect to see sub-centers with relatively high commuting costs/wages in one period actually grow less (or even contract) in subsequent periods. In turn, the variance in commuting costs and wages across centers would converge over time. Unfortunately, the problems with implementing this test are numerous. First, the Census micro-sample is conducted only every decade, and there is no source of higher frequency local wage data. Secondly, the Census keeps changing the definition of the employment-zones for which it publishes the micro-data. There were no zones defined in Census' prior to 1980, and there is a serious problem of consistency between the 1980 and 1990 area definitions. There is at least the prospect that the 2000 census definitions will be consistent with those in 1990, and this could provide the basis for testing the "convergence" hypothesis.

An alternative would be to look for some direct measure of sub-center agglomeration. One could use such a measure in two ways together with the Census micro-sample data. First, the measure should be positively correlated with the estimated wage and commuting costs differentials across sub-centers. Secondly, if all of the association between wages and commuting truly does originate from equilibrium difference in agglomeration, then controlling for agglomeration should eliminate or seriously weaken the commuting cost - wage association. In this research it is possible to undertake a version of these tests – which we report on with somewhat mixed results.

V. Estimation strategy and data.

To estimate (8), we follow the convention of using a log-linear wage equation. Our innovation is to take account of the worker's job location in one of two forms. In the first approach, we include dummy variables for the location of the individual worker's job. The correlation between the dummy coefficients and commuting patterns is then separately studied. Thus our model estimates a vector of dummy coefficients (α) as well as the traditional human capital coefficients (β):

$$ln(W_j) = \alpha' Xj + \beta' Zj \qquad j=1,\ldots,J \qquad (11)$$

where

W_j = Wage of individual j

X_j = A vector of work zone specific dummy variables

Z_j = A vector of individual characteristics

Our second approach is to directly incorporate the average or marginal reported commuting time of all workers in individual j's work zone as an additional single variable (within

X_j). In this case α (now part of the β vector) becomes a scalar that represents the semi-elasticity of wages with respect to the average commuting costs in individual j's work zone.

The data used in the estimation of the hedonic wage equations come from the 5% Public Use Microdata Sample (PUMS) of the 1990 U.S. Census. By using this rich data base on individual workers, we are able to obtain information about a range of both household and individual characteristics. The following individual characteristics were used as control variables (Zj):

1). Age (entered as a quartic function)

2). Education (dummy variables for highest degree obtained)

3). Race (dummy variables for Black, Asian and Hispanic)

4). Gender dummy

5). Marital Status (also interacted with female)

6). Veteran Status dummy

7). English Ability (dummy variables for 4 different levels)

8). Disability (dummies for 3 types of disability)

9). Industry (see Appendix B)

10). Occupation (see Appendix B)

The individual's wage was obtained by dividing wage and salary income from 1989 by total weeks worked in that year.[6] Regressions were also run using income as the dependent variable on a more restricted sample of full-time workers.[7]

[6] Since the reported workplace and travel times are based on the current (April 1990) job location, while income and hours reported are for the previous year, the computed wages will not correspond to the correct work zone for individuals who change jobs between zones. To partially account for this, the sample was restricted to individuals who reported working at least 35 weeks during the previous year, based on the notion that year-round workers are less likely to have changed jobs than seasonal workers. The sample also excluded part-time workers (those who reported working less than 25 hours per week on average in 1989) for the same reason.

[7] Minimum 48 weeks worked, 35 hours per week. The results for this group are qualitatively and quantitatively similar to those obtained from the wage regressions, and are not reported here.

A particular advantage of the PUMS data is the identification of residence and workplace locations for each household – based on Public Use Microdata Areas (PUMAs). These areas are state-specific and consist of groups of counties or portions of counties with a minimum population of 100,000. The definition of the PUMAs is left to the individual state data centers, using guidelines set by the Census Bureau. Residential PUMAs (RESPUMAs) and place-of-work PUMAs (POWPUMAs) are defined slightly differently, with RESPUMAs forming subsets of POWPUMAs.

According to the Census Bureau guidelines, POWPUMAs below the country level can consist of a city, or a group of cities. As a result of this geographic coding scheme, many metropolitan areas containing very large central city boundaries (such as Los Angeles or Tampa-St. Petersburg) have a limited appeal for empirical work, since much employment is located in a single POWPUMA. Instead, two metro areas were selected which have smaller compact center city jurisdictions and a sufficient number of identifiable suburban work zones. These were the Minneapolis-St. Paul MSA, and the Boston CMSA.[8] Geographic definitions of the PUMAs for each area are given in Appendix A.

VI. Wage results.

The wage equations were estimated separately for private and public sector employees in each city[9]. Within the public sector, the following characteristics are expected *a priori*:

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[8] Unlike the 1% sample, the PUMAs for the 5% sample do not correspond exactly to MSA boundaries; thus, the match between PUMAs chosen and the metro area definitions is not exact. The Boston metro definition used encompasses the region bounded by the New Hampshire border and Interstate 495, including all or most of the Boston, Salem, Lowell-Lawrence, and Brockton MSAs.

[9] The self employed were excluded due to a difficulty in interpreting "wage and salary income" for these individuals (48% of full-time self-employed individuals reported no wage and salary income). Including these individuals did not significantly alter the results from those with the more limited sample.

1). Federal government salaries are set nationally, with some adjustment between metro areas to account for cost-of-living differences. Thus, wages for these workers are not expected to vary within metro areas.

2). Wages for employees of local governments, however, are free to differ across jurisdictions within the metro area. Since local governments must draw their workers from the local labor pool, municipalities with larger employment concentrations might need to draw their workers from further away, leading to higher wages and some positive correlation with commuting times.

3). For state employees, the expected relationship is unclear. If wages are fixed within states, then there will be no correlation with commuting times. If state salaries are allowed tovary between towns, however, there might exist some degree of correlation. Thus, there is little *a priori* expectation for the wages of these workers.

The equations were also estimated separately for each gender, and for eight different private-sector occupational classes. In all cases, the sample was restricted to individuals who live and work within the metropolitan area.[10] Agricultural, mining, and active-duty military were also always excluded.

A. Wage variation.

[10] For Boston, workers were also included who lived in regions adjacent to, and work in, the defined metro area. The definitions of the other areas were sufficiently broad as to realistically include all who work in the urban area.

To determine the wage variation within each metropolitan area, equations were estimated allowing for different intercepts in each POWPUMA through the use of dummy variables. In these equations the adjusted R^2 values range between .41 and .44, with all of the individual variables showing high levels of significance. Such results are quite typical of large sample earnings equations. In Table 1 we present the associated wage premia for each work zone in the two MSAs. The coefficients represent the percentage difference in wages between the center city and various suburban POWPUMA zones. An examination of the table reveals the following:

Boston: Wages are found to be as much as 15% higher in central Boston than in outlying work zones such as numbers 3 and 20. These work zones are located 25 miles north and south respectively. Equally interesting is the observation that several suburban work zones on the region's circumferential highway have wages almost as high as Boston (numbers 11 and 16), while other's not very far away have much lower wages (e.g. zone 6). There is almost as much variation just within the suburban edge cities as there is between the central city and the most distant employment centers.

Minneapolis: Wage differentials of up to 18% are found again between central Minneapolis and the fringe counties to the north (zone 1). Several suburban centers again have wages comparable to central Minneapolis (numbers 3, 7, 10) while two have slightly higher wages (7 and 8). The overall wage variation among this region's suburban edge cities is on the order of 10%.

Thus there appears to be significant wage variation within each metropolitan area. Furthermore this variation is not just between central city and the more fringe employment centers, but also between various suburban centers. In each metropolitan area, several suburban centers have wages as high as the center city. If the center city observations are dropped and the equation re-estimated with one such a suburb as the default zone, the results are essentially identical to Table 1. There is as much wage variation between suburbs as there is between central city and the most distant suburb. The pattern of wage variation simply is much more complex than a one dimensional gradient.

B. Commuting times and zone wages.

The average travel time for employees commuting to each Place-of-Work PUMA is collected by the Census and these are listed in Table 2. As with the wage premia, there is significant variation across work zones. In Boston, average commuting times of workers employed in the central city (34.3 minutes) are nearly double those of workers in some edge cities (e.g. zone 5 at 18.4 minutes). It is also interesting to point out that several suburban centers have average commuting times that are quite close to those of Boston (zones 10, 17, at around 29 minutes). In Minneapolis-St. Paul, the range is from 15.0 minutes at the farthermost employment centers to 25.6 minutes in central Minneapolis. Several suburban employment centers again have average commute times that are statistically indistinguishable from central Minneapolis (zones 8 and 10 at around 24 minutes). The longer commuting times of both center cities may be ascribed to two effects: 1) as the largest employment center, the central city draws workers from the widest region, and (2) traffic congestion tends to be the highest near the center, further lengthening trip times.

In Figure 1, the wage premia for each POWPUMA are plotted against average POWPUMA travel times. The lines in each graph represent the fitted values of a bivariate least squares regression of travel times on wage premia. As evidenced by these figures, the wage premia appear to be strongly and positively correlated with average POWPUMA travel time, precisely as predicted by theory. Note once again, that many suburban POWPUMAs have significantly different average commuting times which are also highly correlated with wage premia. The relationship is not just between the center city and urban fringe. [11]

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[11] In bivariate regressions of average POWPUMA travel times on the wage premia, the coefficients on travel time are significantly positive, with R^2 values of 0.74 for Boston and .63 for Minneapolis. When the center city is omitted from the sample, the R^2 drops slightly in Boston, but rises in Minneapolis. These R^2 values do not account for the fact that the wage premia are estimated values. They overstate the true goodness-of-fit of the bivariate regressions, and provide another reason to include zone-average commuting time directly into the estimated wage equation.

C. The elasticity of wages with respect to zonal commuting times.

The wage equations were next estimated using the average travel time of all commuters in an individual worker's POWPUMA, in place of the dummy variables. Note that this is *not* the travel time of the individual worker. The theory links individual wages to the marginal travel time of *all* workers in the same zone. If residences are located contiguous to their respective employment centers, then average commuting time is a sufficient statistic for the commuting time of the marginal worker. Simulations and research in Small [23] also show that average commuting times closely track marginal times in most situations. Additionally, we felt that in the real world where workers are not contiguously distributed, the average might better capture the competition between centers than the marginal. Thus the primary focus in this analysis will use results based on average commuting times, although the robustness of these results using marginal commuters will be demonstrated.

1. Private/Public sector workers. Table 3 shows the results for private and public sector workers. Heteroscedastic-robust standard errors are in parentheses underneath each coefficient. The coefficients on the average work zone travel time are 0.008 and 0.012 for Boston and Minneapolis, respectively. This coefficient represents the semi-elasticity of the hourly wage with respect to two additional minutes of commuting time (since commuting times are reported as one-way). These two minutes represent a loss of 1/240 of the time spent working in an 8 hour day or 1/210 of the time in 7 hours of actual work. Dividing the estimated coefficients by these fractions gives values of time that range from 1.6 to3.0 times the wage rate. This figure is considerably higher than most of those reported in the value-of-time studies cited in [15] and [23], which rarely find values greater than one.

To reconcile this difference, we must remember that the wage rate variation necessary to compensate workers for added commuting should incorporate not only the time, but also the direct money expenses associated with that additional commute. In most studies, the direct money expenses of commuting (gasoline, parking, auto maintenance and depreciation) are at least the magnitude of the time costs [23]. Thus , if the value of true commuting time is close to the wage rate, then the wage compensation necessary to compensate for added time spent commuting would have to be at least twice the value of time – right in line with the estimates reported here.

The results for government workers are shown for each of the three government levels. A single equation for all government workers was estimated, but allowing for a different average time coefficient for each group. The coefficients exhibit the expected pattern in Boston, with an insignificant correlation for federal workers, an intermediate effect for state workers, and a strong, positive effect for local government employees. In Minneapolis, both state and federal wages are insignificantly related to commuting times. In each case, the hypothesis of no correlation for federal workers and a strong correlation for local workers is supported. The magnitude of the coefficients is in the same range as reported for private sector workers.

2. Gender differences. In Table 4, the results from separate wage regressions for each gender are shown. The first specification uses the travel time of all workers in the POWPUMA. Here, women's wages clearly show a much stronger response to commuting time differences than those of men, with coefficients 1.5 to 2.5 times as large. The second specification uses the average travel times of workers *of the same gender* in the POWPUMA, and this shows much less of a differential between men and women[12]. Thus, there is support for the notion that women value their time lost to commuting more than men do, possibly due to traditionally having a greater share in household responsibilities.

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[12] The appropriate specification depends on the marginal rate of substitution in production of male for female workers. If men and women are perfectly substitutable, then the commuting times of all workers are relevant for both genders. If jobs are gender-specific, then only the travel times of workers in the same gender should affect wages.

3. Marginal –versus- average commuting time. An attempt to compare marginal versus average zonal commuting time was made by using the commuting times of the 75th percentile and the 90th percentile workers in each POWPUMA instead of the average commuting time. The results for each city are shown in Table 5. The travel time coefficients are slightly smaller in magnitude for each city than when the results use averages, but significance levels are roughly comparable. This lends support to the use of average commuting times.

4. Occupational differences. Table 6a presents separately estimated travel time coefficients for groupings of 2-digit occupational categories.[13] The following points can be noted from this table:

1) In only one case (technicians) is the coefficient not significant. We have no explanation for this, although the sample size for this category is small.
2) Excluding technicians, in Boston, the coefficients across occupations (.007 - .011) lie very close to the coefficient estimated for all occupations: .0088.
3) In the Minneapolis area, the coefficients across occupations (.007 - .021) exhibit greater variation around the estimate based on using all occupations: .012.

In Table 6b, we report results for the same regressions , but in this case using the average POWPUMA travel times for only workers in the same occupation, as opposed to all workers. The results are qualitatively quite similar to those in Table 6a.

VII. Zone commuting times, wages and employment: is there agglomeration?

13 . While theory suggests that the absolute value of commuting time should move roughly proportionate to the wage, we know of no argument suggesting a systematic relationship between wages and the value of time – as a *percent* of the wage.

The linear programming model also generated equation (9), wherein average travel times vary closely with the number of workers at each employment zone. As the exact nature of the relationship is unknown, we tested it regressing POWPUMA employment on average commuting times both linearly and in log form. The employment levels of each POWPUMA are listed in Appendix D and results are reported in Table 7. There is a very strong correlation in both log and linear form, although any such regression is heavily influenced by the arbitrariness of the spatial definition of work zones. Zones defined broadly will have more workers, *ceteris paribus*, than small zones, and might also have greater commuting distances simply by construction. An alternative, more direct measure of employment concentration is the import ratio, calculated as the ratio of workers employed in the PUMA to workers residing there. The results (also reported in Table 7) indicate that travel times are strongly correlated with the concentration of employment in each work zone as well as with the absolute magnitude of employment in each zone.

While the programming model generates a relationship between zone size and commuting costs for *any* exogenous distribution of employment, the strength of the relationships in Table (7) is also certainly consistent with the existence of local agglomeration. After all, most theories of increasing returns emphasize the role of sheer employment size or concentration, as well as employment specialization (Henderson [8]).

To further examine the possibility that the current distribution of wages and commuting costs represents an equilibrium distribution of agglomeration advantages, we experimented by including a direct measure of zonal employment specialization in the wage equation. Earlier it was argued that if the correlation between wages and commuting is fully derived from differences in zone agglomeration, then including some direct measure of agglomeration should significantly weaken that correlation. Specialization was measured as the percentage of POWPUMA employment in the *worker's* specific industry relative to the percentage of MSA employment in that same industry.[14] While this variable was significant in the wage equation, the coefficients on average travel times, shown in Table (8), were virtually unchanged from the results in Tables 2 and 6. Thus, the industrial mix of various POWPUMA zones, which often is hypothesized to be a determinant of agglomeration, does not seem to explain away the travel time/wage correlation.

VIII. Discussion: alternative explanations.

The central result presented here is that the observed spatial wage variation of observationally equivalent *individuals* within metropolitan areas is both large and systematically correlated with the *average* commuting time of the individual's zone of employment. Alternative explanations of this effect must rely on finding some omitted variable related to individual ability (and hence wages) which has two other features; it must be spatially correlated as well as correlated with commuting costs. One possible argument that could meet these requirements is based on the recognition that individuals tend to segregate themselves in the housing market according to ability. Furthermore, it is well known that higher ability workers tend to live at lower densities and commute farther. Of course, we have controlled for measured ability, but it might be the case the these relationships continue to exist for the residual (unmeasured) ability in our sample. If firms that employ (unmeasured) high-ability workers choose to locate in areas where those workers live, and vice versa, then one might find a correlation between *average* commuting and (unmeasured) ability that actually reflects worker living preferences rather than employer compensation (Rouwendal [21]).

To explore the possibility of this effect, the wage equations were estimated incorporating dummy variables for the residence zone (RESPUMA) of each individual. Again, our linear programming model clearly indicates that when controlling for residential location (the "tie"

[14]For example, suppose the manufacturing share of total employment in a city is 20%. A POWPUMA with 40% of its workforce in manufacturing would have a specialization index of 2, while a POWPUMA with 10% in manufacturing would have a specialization of .5. In the regressions, each individual worker was assigned the specialization of her industry in her work zone.

zones in the model) workers who commute farther should get paid more. The results from these regressions are reported in Tables 9a and 9b, and in all cases they are quite comparable to those found without the residential zone dummy variables. Thus, it is doubtful that any correlation between omitted ability and residential segmentation in housing markets is accounting for the observed travel time/wage premium correlation.

IX. Conclusion

As employment continues to decentralize and subcenters develop within MSAs , there can be large variations in average commuting time both among suburban centers and between suburban centers and downtown work locations. This paper has conclusively shown that these commuting time differentials will be capitalized into wage differences among competing subcenters. Wages have been found to vary significantly (up to 15%) within metro areas and this variation is significantly related to the average travel times for workers in the various zones. Furthermore the magnitude of the wage premia is consistent with the total travel costs that are associated with the empirically observed differences in commuting times.

Clearly, the next step in this line of research would be to examine more directly whether the commuting time differences between centers are truly temporary. Using the soon to be released 2000 census, it would be of particular interest to test the hypotheses that those zones with higher (relative) wages in 1990 grew less during the last decade, and that employers have been relocating to areas where commuting is easier and wages lower. In the process, one would expect to see commuting times and wages gradually converging.

The alternative to this hypothesis would have to be an explanation in which permanent difference in wages and commuting costs are sustained by differences in local agglomeration economies. Testing for this, however, involves developing some direct measure of these economies and seeing if it is both highly correlated individually with wages and commuting costs, and in turn causes the correlation described in this current research to largely vanish. We have found here that employment specialization, a sometimes hypothesized revealed measure of agglomeration, does not have this effect in our sample, but further work is clearly needed.

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Appendix A: POWPUMA Definitions

Boston

	PUMA	Primary Cities/Counties
1	1400	Lowell
2	1500	Chelmsford-Tewksbury-Dracut
3	1600	Lawrence-Haverhill
4	1700	Methuen-North Andover-Newburyport
5	1800	Salem-Beverly-Marblehead
6	1900	Peabody-Danvers-Gloucester
7	2000	Boston
8	2100	Revere-Everett-Chelsea
9	2200	Malden-Medford
10	2300	Cambridge-Somerville
11	2400	Waltham-Belmont-Lexington-Arlington
12	2500	Newton-Brookline
13	2600	Quincy-Milton
14	2700	Lynn-Saugus-Lynnfield
15	2800	Woburn-Melrose-Stoneham-Winchester
16	2900	Burlington-Reading-Wakefield
17	3000	Acton-Maynard-Concord
18	3100	Natick-Needham-Wellesley
19	3200	Framingham-Marlboro-Sudbury
20	3300	Milford-Franklin-Foxboro
21	3400	Dedham-Norwood-Westwood
22	3500	Braintree-Randolph-Stoughton
23	3600	Weymouth-Hingham-Hanover
24	3700	Brockton-Whitman

Minneapolis-St. Paul

1	900	Chisago-Isanti-Wright-Benton-Sherburn Cos.
2	1100	Carver Co.-Scott Co.
3	1200	Coon Rapids-Fridley-Columbia Hts
4	1300	Anoka Co.(part)
5	1400	Washington Co.
6	1500	Minneapolis
7	1600	Bloomington-Richfield
8	1700	Plymouth-Minnetonka-Edina-Eden Prairie
9	1800	Brooklyn Park-Brooklyn Center-Champlin
10	1900	St. Louis Park-Crystal-New Hope
11	2000	Hennepin Co.(part)
12	2100	St. Paul
13	2200	Ramsey Co.(part)
14	2300	Burnsville-Eagan-Apple Valley
15	2400	Dakota Co.(part)

Appendix B: Industries and Occupations

Private Sector

Occupations

1 Managers
2 Management Related
3 Engineers & Scientists
4 Doctors
5 Nurses & Therapists
6 Teachers
7 Social Scientists
8 Lawyers
9 Artists, etc.
10 Technicians
11 Sales Representatives
12 Sales Workers
13 Clerical
14 Secretaries & Receptionists
15 Other Service Workers
16 Mechanics & Repairers
17 Craftsmen
18 Precision Production
19 Operators
20 Fabricators
21 Transportation & Material Movers
22 Laborers

Industries

1 Construction
2 Manufacturing
3 Transportation, Communications, and Public Utilities
4 Wholesale
5 Retail
6 Finance, Insurance, and Real Estate
7 Business and Repair Services
8 Personal Services
9 Professional Services

Government

Industries

1 Postal Service
2 Other Transp, Comm, Pub Utilities
4 Health Services
5 Education
6 Executive, Legislative, & Public Finance
7 General Administration
8 Justice
9 N.E.C.

Occupations

1 Managers
2 Engineers & Scientists
3 Other Professionals
4 Elementary School Teachers
5 Secondary School Teachers
6 Technicians
7 Clerks
8 Secretaries & Receptionists
9 Protective Service Workers
10 Other Service Workers
11 Craftsmen and Laborers

Appendix C: Full-Time Employment Levels by POWPUMA

POWPUMA	Boston	Minneapolis
1	29691	32250
2	53832	26947
3	31372	44879
4	62197	16977
5	33624	28127
6	47495	224095
7	362963	83159
8	26448	112800
9	24102	23409
10	95853	73179
11	88301	22938
12	44377	136707
13	34881	84375
14	33556	45317
15	36438	35274
16	59599	
17	55935	
18	53189	
19	70333	
20	28061	
21	44991	
22	53675	
23	43276	
24	25539	
Total	1439728	990433

Table 1
Wage Premia for Each Work Zone
Full-Time, Private Sector Employees

POWPUMA	Boston	Minneapolis
1	**-.073**	**-.176**
2	**-.040**	**-.053**
3	**-.149**	-.009
4	**-.057**	**-.089**
5	**-.130**	-.038
6	**-.119**	
7		.013
8	**-.101**	**.026**
9	**-.084**	-.038
10	**-.045**	-.006
11	-.013	**-.063**
12	**-.060**	-.015
13	**-.080**	**-.025**
14	**-.066**	**-.031**
15	**-.045**	**-.070**
16	**-.027**	
17	**-.028**	
18	**-.034**	
19	**-.029**	
20	**-.146**	
21	**-.060**	
22	**-.051**	
23	**-.114**	
24	**-.104**	
Adj-R2	.419	.443
Obs	53979	27831

Values in **bold** are significantly different from zero at the 5% level

Table 2
Average Commuting Times for Workers in Each Zone

POWPUMA	Boston	Minneapolis
1	22.8	15.0
2	25.3	17.8
3	19.3	22.4
4	22.8	19.9
5	18.4	18.0
6	20.4	25.6
7	34.3	22.8
8	22.7	24.1
9	21.9	21.5
10	29.1	23.4
11	27.6	19.9
12	26.3	22.9
13	25.6	21.0
14	21.1	20.7
15	24.1	17.8
16	27.2	
17	28.6	
18	27.1	
19	25.6	
20	20.7	
21	24.4	
22	25.0	
23	20.6	
24	19.4	
Mean	26.9	22.5
Std. Dev	5.0	2.8

Table 3
Travel Time Coefficients
Public and Private Sectors

Private Sector

	Boston	Minneapolis
	.0079 (.0005)	.0120 (.0012)
Adj-R^2 Obs	.418 53979	.442 27831

Public Sector

[illegible]	[illegible] (.0015)	[illegible] (.0065)
State	.0072 (.0022)	-.0006 (.0077)
Local	.0117 (.0020)	.0141 (.0072)
Adj-R^2 Obs	.345 9751	.392 4388

Standard errors in parentheses

Table 4
Separate Regressions for Men and Women

	Boston		Minneapolis	
	(1)	(2)	(1)	(2)
Males	.0060	.0072	.0066	.0090
	(.0007)	(.0007)	(.0017)	(.0020)
Females	.0095	.0078	.0178	.0134
	(.0006)	(.0005)	(.0016)	(.0012)

Heteroscedastic-robust Standard Errors in parentheses

Column (1) uses the average commuting time of all workers in the same POWPUMA
Column (2) uses the average commuting time of workers in the same POWPUMA and Gender

Table 5
Travel Time Coefficients
75th and 90th Percentiles

	Boston	Minneapolis
75th Pctile	.0058	.0138
	(.0003)	(.0013)
90th Pctile	.0045	.0083
	(.0003)	(.0008)

Standard errors in parentheses

Table 6a
Travel Time Coefficients by Occupation*

	Boston	Minneapolis
Managers	.0098 (.0011)	.0160 (.0036)
Professionals	.0069 (.0011)	.0215 (.0035)
Technicians	.0014 (.0017)	-.0070 (.0053)
Sales	.0114 (.0015)	.0156 (.0037)
Admin Support	.0091 (.0009)	.0127 (.0022)
Service	.0088 (.0015)	.0073 (.0039)
PPCR	.0071 (.0013)	.0109 (.0028)
OFL	.0068 (.0015)	.0090 (.0027)

Standard Errors in Parentheses
*Using Average Travel Time of All Workers in the POWPUMA

PPCR=Precision Production, Craft, and Repair
OFL=Operators, Fabricators, and Laborers

Table 6b
Travel Time Coefficients by Occupation*

	Boston	Minneapolis
Managers	.0085 (.0010)	.0130 (.0031)
Professionals	.0087 (.0013)	.0206 (.0038)
Technicians	.0031 (.0017)	-.0040 (.0051)
Sales	.0111 (.0015)	.0142 (.0032)
Admin Support	.0077 (.0008)	.0087 (.0016)
Service	.0111 (.0018)	.0074 (.0045)
PPCR	.0073 (.0014)	.0092 (.0024)
OFL	.0072 (.0016)	.0080 (.0025)

Standard Errors in Parentheses
*Using Average Travel Time for Workers in the same POWPUMA and Occupation

Table 7
POWPUMA Employment and Commuting Times

Dependent Var.: Mean Commuting Times

Independent Variable	Boston	Minneapolis
Emp(x10^4)	.399	.368
	(.084)	(.095)
R^2	.51	.52
Log(emp)	5.36	2.76
	(.79)	(.71)
R^2	.65	.51
Import ratio	9.86	5.20
	(1.35)	(1.15)
R^2	.71	.61
Log(imp rat)	9.90	4.36
	(1.52)	(1.09)
R^2	.66	.55

Standard errors in parentheses

Table 8
Travel Time Coefficients
Zonal Industry Specialization Ratios Included

	Boston	Minneapolis
(1)	.0079 (.0004)	.0123 (.0011)
(2)	.0100 (.0005)	.0142 (.0012)

Standard errors in parentheses, all other variables as in Table 3.

Specification (2) also includes residential PUMA dummies.

Table 9a
Travel Time Coefficients with Residence Zone-Specific Effects

Private Sector

	Boston	Minneapolis
	.0101	.0138
	(.0005)	(.0013)
Adj-R^2	.424	.450

Public Sector

Federal	.0035	.0040
	(.0016)	(.0067)
State	.0094	.0033
	(.0021)	(.0078)
Local	.0148	.0184
	(.0020)	(.0072)
Adj-R^2	.353	.399

Table 9b
Travel Time Coefficients by Occupation
Residence Zone-Specific Effects

	Boston		Minneapolis	
	(1)	(2)	(1)	(2)
Managers	.0100	.0091	.0136	.0127
	(.0012)	(.0010)	(.0038)	(.0032)
Profess	.0086	.0097	.0213	.0206
	(.0012)	(.0014)	(.0038)	(.0041)
Technical	.0050	.0062	-.0031	-.0018
	(.0020)	(.0019)	(.0058)	(.0056)
Sales	.0130	.0132	.0136	.0128
	(.0017)	(.0016)	(.0043)	(.0037)
Admin Support	.0122	.0104	.0151	.0104
	(.0010)	(.0009)	(.0026)	(.0018)
Service	.0120	.0146	.0074	.0076
	(.0020)	(.0025)	(.0054)	(.0054)
PPCR	.0086	.0092	.0141	.0117
	(.0014)	(.0016)	(.0031)	(.0026)
OFL	.0105	.0115	.0144	.0114
	(.0018)	(.0020)	(.0029)	(.0027)

Standard Errors in Parentheses

Column (1) uses Average Travel Times of all workers in the same POWPUMA
Column (2) uses Average Travel Times of workers in the same POWPUMA and Occupation