Measuring the Regional Economic Impact of Transportation Access Improvements in the Context of a Large Metropolitan Region

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Abstract. Transportation planners are increasingly recognizing the importance of access in enabling employment growth and better paying job opportunities for residents. Although regional economic impact analysis is often an important element of transportation investment evaluation by state departments of transportation, it can be particularly challenging for metropolitan area planners because existing economic modeling methods do not fully account for the multifaceted roles that transportation links play in affecting access within large, polycentric metropolitan areas. This article examines these issues and presents information from a study of the Chicago region, to evaluate statistical relationships of employment cluster size and wage levels to zonal differences in business-to-business connectivity and population connectivity. It presents elasticities of employment and wage impact associated with various access measures for different sectors of the economy. These findings point to the importance of transportation planners considering the impacts on connectivity to both population markets and employment centers when evaluating the potential economic implications of proposed transportation system improvements in large, polycentric metropolitan areas. The article then lays out directions for future research and practice to improve transportation project evaluation and planning.

Transportation planning agencies in the United States and Canada frequently consider economic development impacts as a factor in planning, prioritization, project selection, and funding decision processes for road and rail infrastructure. These impacts may be viewed in relation to growth in jobs, wages, gross domestic product (GDP), and export base. To capture these effects, many transportation agencies rely on regional macroeconomic forecasting and simulation models that represent the dynamics of economic growth and the role of transportation in affecting regional economic productivity and competitiveness. These models are sensitive to two outcomes of transportation improvement: (a) reducing travel times and transportation costs for existing travelers and (b) expanding markets to enable scale economies and corresponding productivity gains for businesses (*1*, *2*). To address the latter effect, they typically build on the field of economic geography that ties the competitive advantage of cities and regions to agglomeration benefits. However, these methods may not fully account for the multifaceted market access roles of transportation links within large, polycentric metropolitan areas that feature multiple business activity clusters. This paper examines these issues with regard to how population and employment access can affect the economic productivity of zones within a large metropolitan area, as measured by differences in industry wage rates. The results could be useful in enabling transportation planners to recognize how various kinds of access improvements can affect some industries more than others.

Research Literature

Traditionally, the fundamental basis for linking transportation access and regional economies was built on the concept that cities start as economic activity centers that serve a surrounding “hinterland.” The inference is that improving the transportation connections of an urbanized area to surrounding areas can expand market access and productivity through agglomeration economies, thus leading to more jobs and wages at the metropolitan level. However, this narrative does not really address the more complex issue of how changes in connectivity and access within a metropolitan area can affect its economy.

There are two lines of research on how transportation effects productivity and economic growth, which focus on different levels of spatial impact. New economic geography builds on the concept of market potentials and returns to scale (3 –5). It draws on comparisons among regions or metropolitan areas, finding that larger labor and customer markets enable economies of scale that enhance economic productivity, competitiveness, and growth. This is attributed to greater matching of workforce skills to business needs in a larger labor market, and scale economies in production and distribution to serve a larger customer market (6). These effects tend to be wide, occurring at the level of a metropolitan area that may extend across a distance of 60 km or more.

The other line of research focuses on effective density or production agglomeration of zones within an urban area. This reflects the proximity and connectivity among firms as a further source of productivity that is attributable to input sharing and information sharing among firms (7 –9). These effects tend to be strongly localized with a sharp decay function, such that effects are most dominant within an area under 10 km (10). Thus, the two lines of research reflect different spatial scales of agglomeration economies.

The most commonly used regional economic simulation models for regional-scale (state department of transportation and metropolitan planning organization [MPO]) transportation planning within the United States and Canada draw most on the regional market potentials aspect, showing how a proposed road or rail corridor improvement can be modeled as a connectivity improvement that reduces transportation costs between a business activity center and a surrounding market, thus expanding the scale of the available labor force, delivery opportunities, or both. In these models, transportation market access improvement is commonly measured in relation to market size and travel time changes. This may be a market-size-weighted measure of access time improvement (referred to as “effective distance”), or a measure of expansion in market size within a time threshold, such as the labor market being accessible within 45 min of a central employment district (11). The time threshold reflects commuting demand patterns. It also helps to explain the effective limits of the size of urbanized areas before they evolve from a monocentric to a polycentric form that features multiple business activity clusters. The existence of polycentric cities is itself evidence of market-size thresholds and further agglomeration economies at a sub-metropolitan level (12).

Challenges for Considering Economic Impacts in Transportation Planning

The research on both market scale and effective density of business clustering provides insight into how regional economies and cities develop and how productivity effects occur. However, for transportation planners, there is a further need to ensure that research information is applied appropriately to assess the potential future economic impact of proposed projects. This is important as not all historical processes can be applied forward, particularly as land use and the built environment of cities evolve.

Transportation planners typically see projects that involve differing mixes of trip types, including work-related travel, commuting, truck delivery, and tourism/recreation travel. Improvements for any of these trip types may lead to business scale economies and productivity impacts, though they occur at different spatial levels and affect different industries (13, 14). Truck delivery and recreational trips typically involve travel behavior that occurs at a broader intercity level. Commuting and work-related travel, which both occur at the metropolitan level, are the focus of this paper.

One issue that makes the metropolitan planning context more problematic is that as urbanized areas evolve into a polycentric form, there can be diminishing returns from greater intrazonal connectivity. This is a particular concern for cases in which multiple activity centers compete for the same workers and customers within a single labor market (metropolitan area). In such cases, capacity increases for roads or rail connections within the region may expand areas of overlapping markets rather than grow the scale of the metropolitan agglomeration (as would occur with improved access to a previously underserved hinterland). The net effect on productivity may depend on the mix of activities occurring within these centers and the extent to which they complement or compete with each other. This means that the time-based measure of market size, which works well for connecting urban centers to each other or to a wider hinterland, could potentially misstate the net agglomeration gains of a new or expanded highway or rail line when it is located fully within a single metropolitan area.

The solution is to adopt a more aggregate, regionwide measure of effective accessibility (or agglomeration) that (a) accounts for the finer networks connecting broad sets of points within a metropolitan region and (b) allows for diminishing returns to scale of additional connectivity within such a region. Research by Graham for the UK Dept. for Transport (8, 15) develops the concept of "effective density" as a measures of the scale and proximity of jobs in a region; this measure is then shown to be a predictor of productivity per worker (as measured by output or wages per employee). It is calculated using a gravity model formulation that counts total employment in each zone and in all surrounding zones but gives greater weight to closer zones. This measure is then aggregated for all zones in a region.

The effective density concept can be interpreted as a composite reflection of (a) localization benefits: the size and density of employment clusters, and (b) proximity and connectivity between similar and complementary employment clusters, while implicitly also reflecting (c) other urbanization effects such as the accessibility to a surrounding population base (representing workforce and customer markets). This approach has been shown to be a theoretically valid and statistically significant predictor of variation in zonal productivity (8).

However, the effective density measure does not decompose the relative roles of the aforementioned "a," "b," and "c," which limits its practical application for transportation planning. It assumes that transportation can provide access that both generates density and effectively offers a substitute for physical proximity. Although that may be true in the long run, transportation planners today need to consider the incremental impact of proposed projects, recognizing that they can directly enhance connectivity and access but not necessarily change the physical density or spatial proximity of existing employment centers. Furthermore, effective density calculations change with improved connectivity between employment locations, but not connectivity among population locations. As a result, the effective density measure is sensitive to a transportation project that connects between employment centers but may not change if a transportation project improves connectivity from an isolated or poorly connected residential area to a major employment center.

Further supporting this concern is the observation that multiple activity centers develop as a metropolitan area, and its economy grows as a way to access the market agglomeration economies of a metropolitan labor pool while avoiding the agglomeration diseconomies of rising congestion and land prices in the urban core (16, 17). This point reinforces the need for metropolitan transportation agencies to consider transportation project impacts on population and workforce connectivity in addition to the impacts on business connectivity (18).

Our review thus suggests that the economic benefits of proposed transportation improvements within a polycentric metropolitan area can be mis-estimated if they are based on incremental increases in either (a) time-based market access measures or (b) effective density measures of accessibility. The former approach is limited by its inability to adjust for overlapping markets. The latter approach is limited by its inability to distinguish between localization and urbanization effects, or the incremental effects of population and employment connectivity gains (that are enabled by transportation projects) from the effects of physical density and location siting (that are not directly changed by transportation projects).

Research Design: Untangling Effects That Can and Cannot Be Changed by Transportation Projects

The Goal

Transportation planners operating at the metropolitan level need methods that will allow them to assess the economic impacts of proposed transportation infrastructure investments at that same metropolitan level. This calls for economic impact methods that are relevant to project contexts and types, which can include freight corridors, commuting corridors, and connections among business centers. Neither business connectivity measures such as effective density, nor market access measures (such as effective population market size) can capture impacts across this full range of contexts. This indicates a need to recognize multiple or composite measures of access impacts.

To address this issue, we conducted research to identify opportunities, limitations, and approaches for linking business activity and wage rates (an indicator of productivity) to measures of transportation access. Our work focused on the statistical relationships of employment cluster size and wage levels to zonal differences in business-to-business (employment) access and population market access. At the outset, we identified the roles of three behavioral processes affecting zonal employment and wages for a given economic sector, drawing on prior NCHRP research on transportation and productivity (14):

- Scale of local business activity: a “localization effect” in which there are economies of scale for business activity at a given physical location, reflecting density (enabling information sharing) and shared location advantages for operations.
- Business-to-business connectivity: reflecting connectivity between business locations, to enable better buyer–supplier matching and complementarity (for supply chains).
- Population market size: reflecting an “urbanization effect” in which there are economies of scale for serving a broader customer market and attracting a broader labor market.

The distinctions between these three behavioral factors is not merely academic, for they matter for transportation planning decisions. On the one hand, they can explain how investment in freight corridors and connector routes can incrementally improve business connectivity and facilitate greater industry productivity, whereas enhancement of public transportation and expansion of commuter road routes can incrementally expand labor and customer markets to facilitate further commercial growth. On the other hand, the size and density of existing economic clusters is accepted as given, since that reflects the historical development of the city (which may have been based on location proximity to waterways, railroads, and historical trade routes, as well as municipal land development policies).

Data Analysis

To improve the ability of regional economic impact analysis to be relevant for metropolitan-level transportation planning, we sought to demonstrate the relative economic roles played by business cluster density, business connectivity, and population market size factors within a metropolitan area. We applied regression analysis to measure how each of those factors helps explain business activity levels and wage rates for various industries within the metropolitan area. Our data set was the Chicago metropolitan area, drawing on a database developed by the Chicago Metropolitan Agency for Planning (CMAP). This analysis drew data for 1,711 traffic analysis zones (TAZs) in the Chicago planning region, with a matrix of travel times and volumes for 2,927,521 origin–destination pairs. However, for this study, TAZs that had no employment (i.e., vacant land, parks, and purely residential areas) were excluded from analysis. That left 1,694 TAZs (2,867,942 origin–destination pairs) for further analysis.

Information on TAZ-level employment and wages by industry was provided to CMAP by the Illinois Dept. of Employment Security. Information on population and commuting patterns was derived from the Longitudinal Employment–Household Dynamics (LEHD) database. LEHD data is available at the census tract level and was transferred to TAZs. Employment and wage rates were classified into four industry groups: producer services (finance, insurance, management, and other office-type jobs), retail and consumer services (also including lodging, restaurants, and wholesale), manufacturing, and other industries (including construction, utilities, government, education, and health care). Inter- and intrazonal travel times (referred to as impedance factors) were developed by the CMAP travel model and were computed as a normalized weighted average of auto and transit commute times between all zones during the AM peak period. The transit travel times included walk access as well as in-vehicle times.

In contrast to most other studies of agglomeration effects, which examine differences in output or wages per worker across multiple labor markets, this study analysis focused on differences among zones within a single labor market that had multiple business activity centers. It explored the separate effects of population access and business-to-business access, by estimating regressions that relate these zonal access measures to zonal differences in wage rates by industry.

Location and Spatial Clustering of Business Activities

We measured wages and employment by zone separately for each industry group and then mapped them to show the location of employment clusters (Figure 1). The resulting bubble diagrams show the CMAP study area, primary roads, and the zones with highest employment in major sectors of the regional economy. The maps show the polycentric nature of the metropolitan area and the economic differences between locations, consistent with earlier studies (19, 20). Key findings follow:

There were distinct clusters (centers of concentration) for producer services, retail/consumer services, and manufacturing. They tended to occur in different places within the metropolitan area, though all appeared to locate along or near major highway links—which is a clear indicator that transportation access matters. (Of course, land use regulation also plays a role.)

Producer services were clustered strongly in the downtown core and secondarily on outlying northern and western suburb circumferential highway routes. Manufacturing clusters tended to locate along highways away from the city core, indicating an aversion to more congested central city locations and a preference for more peripheral highway locations along interstate highway routes. Retail and consumer services clusters covered both the core and outlying areas with spacing that appeared to maximize access to population patterns. The zones with highest wages generally corresponded with the locations of producer service offices.

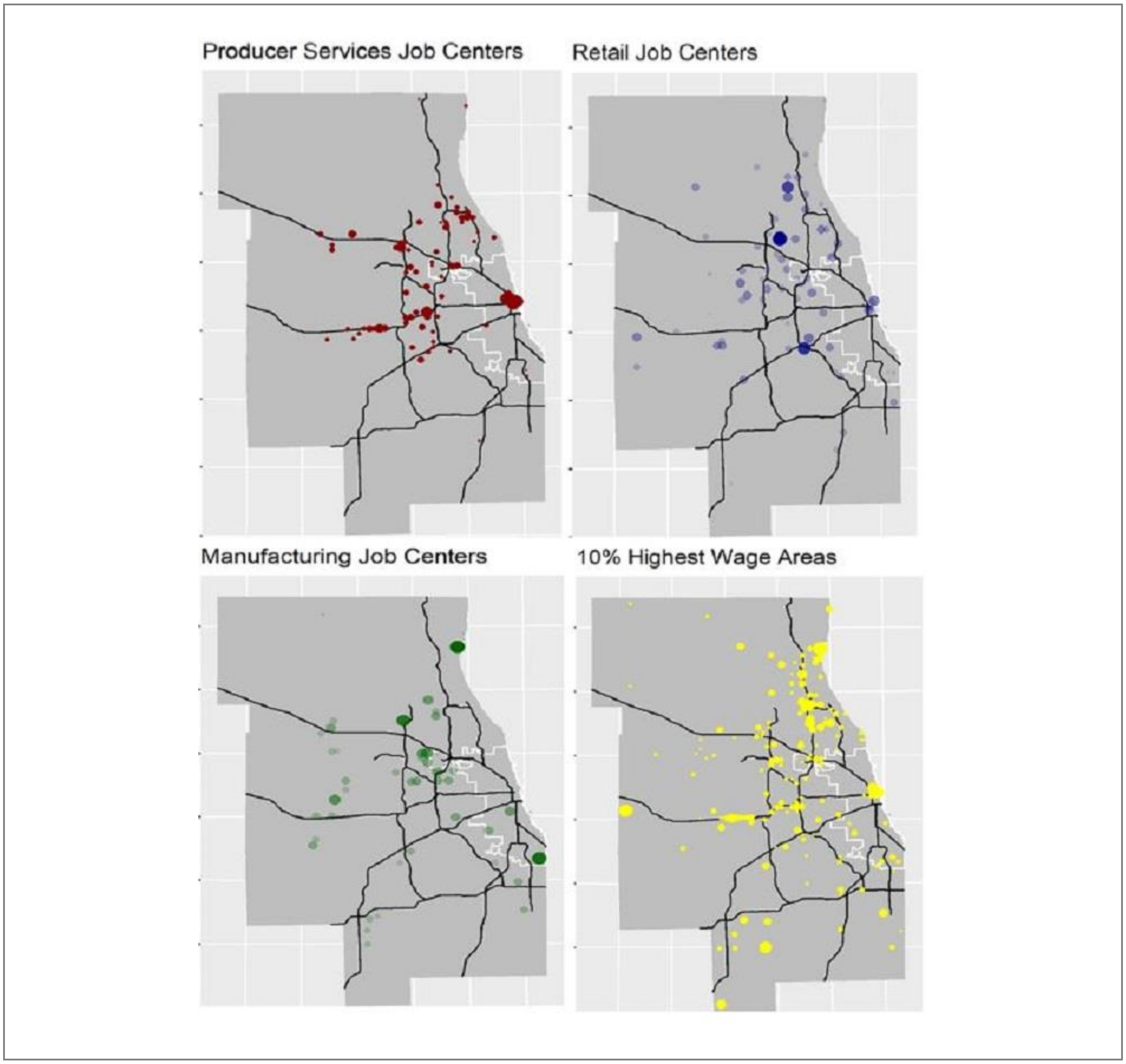

Figure 1. Clusters within the Chicago metropolitan area.

Note: White line shows Chicago city boundary. Black lines show primary roads. Circles represent areas where employment in the specified industry exceeds population. (Circle size is proportional to employment.).

These visual observations of industry location and wage patterns pointed to a need to examine economic impact factors differently by industry group, including both urbanization or market connectivity effects (which appeared to drive the spacing of these clusters) and localization or business-to-business connectivity effects (which appeared to drive the intensity of these clusters). Next, we examined measures of each effect and their interaction, drawing on a statistical analysis of the Chicago region.

Connectivity Among Businesses

We adopted the widely used measure of effective density, splitting it into two segments: the local zone scale effect and the measure of accessibility of surrounding zones,

$$(1) \qquad Effective\ Density = \frac{E_i}{{d_{ii}}^{a}} + \sum_{j}^{i\neq j} \frac{E_j}{{d_{ij}}^{a}}$$

$$= Local\ Scale + Access\ Factor$$

where

$E_{i,}$ = employment in zone i,

d_{ij} = interzonal impedance (travel time between zones i and j),

d_{ii} = intrazonal impedance (travel time from center to border of zone i), and

α = decay parameter.

The local scale effect captures the existing "mass" of economic activity in a zone. The access factor measures the surrounding employment, weighted by a decay function that reflects proximity to the local zone in relation to travel time.

Recognizing that past studies have found the decay factor to vary by industry and region, we initially identified the decay factor (α) for each industry group through a grid search for the values that could best explain wage variation among zones in this region (in relation to maximizing regression R^2 for the formula below). Our findings ($\alpha = 2.0$ for producer services, 1.9 for retail, 1.1 for manufacturing, and 1.6 for other industries) were close to the findings of Graham et al., though they indicated slightly higher decay factors for producer services and retail (15). We applied these decay factors in a log-log regression for each industry category to calculate the elasticity of wage change with respect to both the local scale of activity and the accessibility factor for each zone. This formulation provides a constant percent impact on wages in response to a constant percent change in the explanatory factors, which means it provides a diminishing absolute change in wages from additional absolute changes in the measure of explanatory factors.

Table 1.
Regression of Wages as a Function of Business Connectivity

Coefficients	All industries	Producer services	Retail + consumer services	Manufacturing	Other
Intercept	10.183 (84.689)***	10.218 (128.68)***	9.979 (116.275)***	10.252 (54.831)***	10.432 (100.369)***
Local scale (LS)	0.077 (10.97)***	0.094 (10.319)***	0.027 (3.25)***	0.132 (17.04)***	0.059 (8.201)***
Access factor (AF)	0.017 (1.09)	0.065 (4.022)***	0.077 (4.62)***	0.0131 (0.768)	–0.014 (–0.934)
R-squared	0.13	0.18	0.05	0.20	0.05

Note: Values in parenthesis represent t-statistics.
***Indicates statistical significance, $p < 0.001$.
See Appendix for range of variable values.

$$(2) \qquad ln(W_{c,i}) = B_0 + B_1 ln(LS_{c,i}) + \; B_2 \ln{(AF_{c,i})}$$

where
$W_{c,i}$ = average wage for industry c in zone i,
$LS_{c,i}$ = local Scale factor for industry c in zone i, and
$AF_{c,i}$ = access factor for industry c in zone i.

The regression findings (Table 1) indicated that the local scale of business activity (LS) within a zone was a strong indicator of higher wages among all industry categories. The findings also showed that access to the same industry in the surrounding area (AF) also mattered for producer services and retail, though the explanatory power of this factor was less important for retail. For manufacturing, the low decay factor and the low economic significance of AF indicated that access to other nearby businesses was not a predictor of higher wages. This was consistent with findings of other studies that manufacturing, as an export industry, has its productivity driven by location in industrial parks (captured by the LS factor) along with access to wider-scale intercity supply chains—a factor not captured in this analysis (21, 22).

Differences in the explanatory power of these equations (R2) were also notable. The value was quite low for the retail and other industry groups, but notably higher for producer services and manufacturing, indicating that the local scale and access effects were of more importance for the latter groups. The value for those groups (around 0.2) is typical of cross-sectional analysis findings that focus on intra-metropolitan zone differentials without further information on spatial zoning differences or worker socioeconomic characteristics (e.g., see Hensher et al. [23]).

Connectivity to Population Markets

In the United States and Canada, a metropolitan area is commonly defined by a labor market and commuting shed, with the requirement that a high share of commuting from peripheral areas goes to the core city or county. The U.S. Bureau of Economic Analysis definition of "labor market areas" is coterminous with metropolitan areas. These definitions are consistent with North American commute patterns in which workers seek to find the best available jobs within what they consider to be a reasonable commuting time threshold. Thus, the most applicable model for labor market access is defined by the size of the population base within a time range, rather than by a continuous time decay function, as is applicable for connectivity among businesses. This is supported by data from the Chicago region that most commute trips fall within a wide 10- to 50-min range, though a somewhat longer commute is common for outlying areas where reliance on commuter rail is common.

Recognizing the pattern of commute times, we applied a log-log regression for each industry category to calculate the elasticity of both zonal employment scale and zonal average wage to the scale of market access. We tried measures of accessibility within 20-, 30-, 40-, 45-, and 50-min travel time thresholds. For all industry groups, the highest explanatory power (R2) came from the 45-min threshold.

$$(3) \qquad ln(W_{c,i}) = B_0 + B_1 ln(PM_{c,i}), \qquad ln(E_{c,i}) = B_2 + B_3 ln(PM_{c,i})$$

where
$W_{c,i}$ = average wage for industry c in zone i,
E_{ci} = average employment for industry c in zone i, and
$PM_{c,i}$ = population market size for industry c in zone i (based on 45 min travel time).

The regression findings (Table 2) indicate that the wide area measure of population market access was a strong locational predictor of zonal cluster (employment) for producer services and retail, but a much weaker predictor of zonal wage rate (based on the difference in R2 values for these equations). The finding on zonal employment reflects the role of population market size as a factor affecting access to skilled workers for producer services, and access to customers for retailing. Owing to the wide reach of the population market size variable, there was much less variation in that measure within a metropolitan area than between metropolitan areas.

Table 2.
Regression of Employment and Wages as a Function of Population Market Connectivity

(a) Zonal employment

Coefficients	All industries	Producer services	Retail + consumer services	Manufacturing	Other
Intercept	6.764 (189.2)***	4.699 (112.57)***	5.181 (135.03)***	3.877 (66.976)***	5.836 (150.96)***
Population market within 45 min	0.931 (21.68)***	0.972 (18.37)***	0.776 (16.06)***	0.406 (5.627)***	0.878 (18.63)***
R^2	0.218	0.173	0.138	0.023	0.173

(b) Zonal wages

Coefficients	All industries	Producer services	Retail + consumer services	Manufacturing	Other
Intercept	10.66 (1012)***	10.72 (747.05)***	10.48 (849.39)***	10.67 (602.18)***	10.529 (957.48)***
Population market within 45 min	0.103 (8.173)***	0.188 (10.33)***	0.104 (6.734)***	0.101 (4.59)***	0.074 (5.516)***
R^2	0.038	0.062	0.027	0.016	0.018

Note: Values in parenthesis represent t-statistics.
***Indicates statistical significance, $p < 0.001$.
See Appendix for range of variable values.

There was a reason for the appearance of a low predictive power of the population market size variable as a predictor of wage differences. That was its failure to capture the relative access advantages of the downtown in relation to transportation capacity and service options. Downtown Chicago has the highest density of employment and the highest wage rates in the metropolitan area, but it does not appear to be unique when viewed in relation to the population market accessible within 45 min. The maps that follow (Figure 2) show that downtown as well as many zones to the west all have excellent access to a high portion of the regional population. However, there is an additional factor not captured by this observation, which is that areas to the west have limited capacities for both highway ramps and the rail transportation system compared with downtown's massive infrastructure of converging highways and rail lines that serve a high volume of commuters.

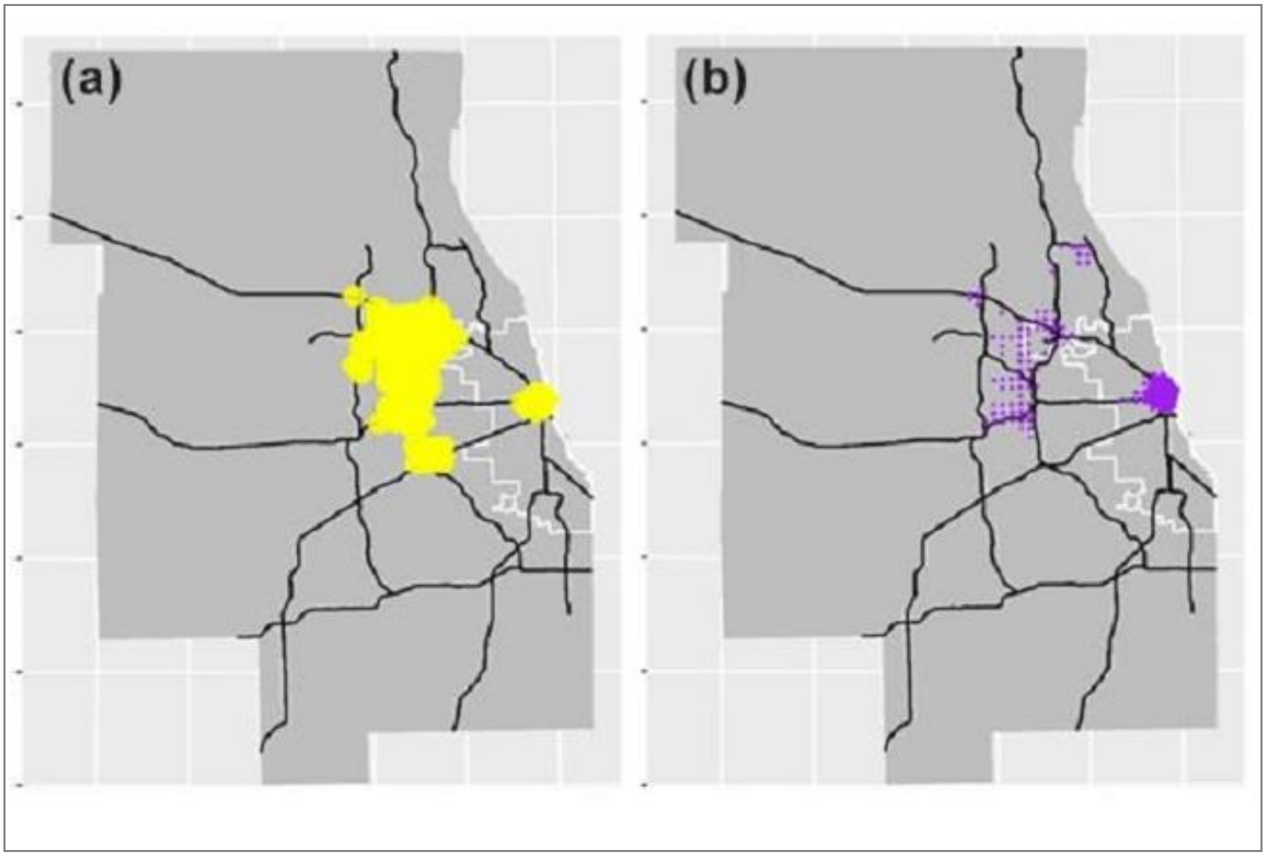

Figure 2. Population market connectivity and business connectivity patterns: (*a*) top 10% of zones for 45-min population market and (*b*) top 10% of zones for effective density.

Historically, downtown Chicago developed along Lake Michigan, where intercity and regional railroad lines converged. Later highways and transit lines were built to serve the area. These transportation capacity investments enabled the development of the downtown business area, but as commuter and visitor volumes grew, so did congestion, which slowed travel times for cars and buses. In addition, the location of downtown on the lake means that there can be no growth to the east. As a result, over time, places to the west have come to appear close to downtown in relation to market access travel times even though they clearly lack the highway and transit capacity of downtown. (This capacity difference is reflected in a land value premium for downtown locations, which is not captured by our statistical analysis.)

In contrast to the population market access map (Figure 2a), the effective density measure of business-to-business (employment) connectivity appears more concentrated at and around the downtown core (Figure 2b), though that is partially because of the pattern of historical growth.

Combining Measures of Business Connectivity and Population Market Connectivity

The parallel existence of urbanization and localization agglomeration economies makes it important, though not easy, to distinguish between market access (urbanization type effects) and connectivity (localization type effects)—a point emphasized by Ellison et al. in their analysis of polycentric cities (24) . Yet when considering the relative roles of the two kinds of connectivity addressed in this paper, we were immediately confronted with evidence that the two were very highly correlated; for all industries there was a 0.68

correlation between the business connectivity and the population market connectivity measures shown in Figure 2. This occurred because their effects were intertwined in the development of urban spatial form. Urban development theory indicates that the scale of population market access plays an initial role in providing scale economies (productivity benefits) that attract producer services to what becomes the core of a metropolitan region and later the secondary business centers of a polycentric economy. However, as that occurs, secondary and complementary businesses locate nearby, which provides further business-to-business connectivity. As a result, both the population access and business access effects tend to evolve together over time.

Although there is simultaneity of localization and urbanization effects affecting the business location and metropolitan growth patterns, that does not help transportation planners who need to assess potential economic impacts of proposed new projects. For them, there is still a need to assess the likely incremental impact of projects on productivity and its economic development consequences. For regional economic impact modeling, we thus needed to assess productivity impacts in a way that recognized project effects on population market connectivity, business connectivity, or both.

Given the relatively high (0.68) correlation of business connectivity (AF in Equation 2) and population market (PM in Equation 3), there was a need to reduce multicollinearity in the regression estimates. We therefore defined a regression equation that combines the measures of existing employment clusters (LS), surrounding business connectivity (AF), and a weighted population market measure (WPM) that was defined as the population within 45 min of each zone weighted by that zone's employment base. This interaction term reduced multicollinearity between component elements (as the correlation of WPM and AF was 0.57), and it also emphasized the particular importance of wide population markets for the larger business centers.

$$(4) \quad ln(W_{c,i}) = B_0 + B_1 ln(AF_{c,i}) + B_2 \ln(LS_{c,i}) + B_3(WPM_{c,i})$$

where $WPM_{c,I}$ is PM (population market within 45 min) of each zone, weighted by the employment of that same zone, for each industry *c* and zone *i* (expressed in millions).

The coefficient results (Table 3) indicated that, for our evaluation of wage rate impacts, population market connectivity (WPM variable) mattered most for retail as it reflects the scale of the potential customer base. Business connectivity (AF variable) mattered most for producer services and retail, as it reflects the productivity benefits of location near similar and complementary businesses. These findings confirmed expectations, noted earlier by Giuliano et al., that "population serving activity (e.g., general retail) places a high value on access to customers, who are more widely distributed across the metro area than employment. Professional services, on the other hand, value access to existing and potential clients and should be more likely to cluster" (19).

Table 3.
Regression of Wages as a Function of Business Connectivity + Population Market Connectivity

Coefficient (and *t*-statistic)	All industries	Producer services	Retail + consumer services	Manufacturing	Other
Intercept	10.290 (83.23)***	10.233 (127.82)***	10.003 (118.314)***	10.169 (54.503)***	10.468 (99.796)***
Local scale (LS)	0.068 (9.239)***	0.0869 (9.16)***	0.0065 (0.710)	0.144 (16.058)***	0.0589 (7.828)***
Access factor (AF)	0.007 (0.451)	0.0618 (3.81)***	0.0723 (4.4.19)***	0.0265 (1.106)	–0.0201 (–1.292)
Weighted population market (WPM)	0.007 (4.492)***	0.0015 (2.50)*	0.0782 (5.551)***	–0.055 (−1.955)	0.0055 (2.071)*
R^2	0.14	0.20	0.08	0.22	0.06

Note: Values in parenthesis represent t-statistics.
*Statistical significance p < 0.05.
***Statistical significance, p < 0.001.
All VIF values <2.3.
See Appendix (Table 4) for range of variable values.

This hybrid equation did not change the earlier finding from Table 1 about the importance of the business connectivity (AF) impact for both producer services and retail activities. For manufacturing, neither business connectivity (AF) nor population connectivity (WPM) had a statistically significant effect, but the local clustering effect (LS) was important. That is not surprising for, as noted earlier, manufacturers often prefer locating in peripheral industrial parks that minimize congestion and maximize access to wider interstate highway routes. The Appendix provides the range of values for dependent and independent variables used in these regressions, which can be used to better interpret the relative impacts of these elasticities in the Chicago context. Although these results clearly need to be further validated for other cities, they do appear generally consistent with past studies of transportation connectivity and market access impacts on industry productivity.

Conclusions

From this study, we can draw a set of findings about the application of agglomeration–productivity relationships for a large metropolitan area, and their implications for regional economic models of transportation impact. This information could potentially aid MPOs in using economic models to improve their assessment of proposed projects.

- *Project Type*—Although all types of transportation enhancements can provide user benefits, wider productivity benefits are most likely for projects that expand system connectivity by broadening metropolitan labor or customer markets, or enhancing interactions among similar and complementary businesses. This kind of outcome is clearly relevant for new highway or rail connectors that link isolated areas to a metropolitan market. However, the situation is more complex for new projects within a metropolitan area, as the very existence of the metropolitan area and its business clusters represents an agglomeration outcome of the existing transportation network. Further agglomeration effects and economic development consequences will be likely only insofar as an additional network improvement is expected to tangibly enable further scale economies in business access to labor, to needed materials and services, or to customers. Most other types of projects—including safety enhancements, congestion delay reduction, and preservation projects—may generate time, cost, and safety benefits for users but are unlikely to bring broader productivity gains. A project that expands capacity to avoid or minimize future congestion may preserve existing agglomeration economies relative to other areas.

- *Scale of Impact*—Transportation system enhancements can occur at different spatial scales. A major new rail transit line or highway may have regionwide consequences for expanding labor market access, whereas a new truck route may enhance longer intercity supply chains. In contrast, an urban connector road may merely enhance the connectivity of businesses around a given cluster. For this reason, it makes sense for transportation analysts to categorize the type of project and its expected consequences in relation to a primary category of intra-metropolitan connectivity impact (i.e., population/labor market connectivity, local business connectivity, or both). Then, depending on the applicable project category, the corresponding elasticities of labor productivity (wage rate impact) from Table 3 might then be applied within the broader context of a regional economic impact simulation and forecasting model. If the project supports a broader intercity freight or intermodal travel connectivity that affects trips beyond the metropolitan area, then applicable productivity impact elasticities will need to be drawn from other studies (e.g., [*13*]).
- *Applicability for Economic Impact Analysis*—This research focused on the identification and application of productivity impact measures that can drive broader changes in metropolitan and regional economic competitiveness and associated job and income growth. It is possible to directly extrapolate the wage rate impact to imply a regional GDP effect without using a regional economic model. However, that approach would be misleading because it would ignore other aspects of GDP impact associated with user cost savings as well as longer-term labor supply/demand, business competitiveness and investment, export base, and workforce migration impacts. A regional economic impact simulation model could address those other impacts, differentiated by industry. In that case, the form of impact (on labor market connectivity versus business-to-business connectivity) matters, as these factors affect different sectors of the economy. To correctly pursue that line of analysis, an MPO also needs to sort out the difference between (a) access factors that cannot be easily changed such as historical building concentrations and land development patterns, (b) factors that can be improved such as accessibility for specific population subgroups and business activity clusters that currently have access limitations or deficiencies, and (c) actions intended to avoid future degradation of transportation benefits, thus preserving existing agglomeration benefits.

Need for Further Research

Although the general results of our Chicago analysis were consistent with broader studies conducted elsewhere, there is a clear need to develop more robust measures of elasticities to link transportation investments within a metropolitan area to expected productivity gains. Further improvement in impact prediction could be achieved by developing (a) broader access measures covering walk/bike options, goods movement, and connectivity to intermodal terminals; and (b) improved measures of car and transit access to account for tolls/fees, modal availability, capacity and service performance for off-peak as well as peak period travel. To improve model accuracy and explanatory power, it could also be valuable to include (c) broader zonal variables representing worker age and education as well as business occupational skill needs, (d) more detailed industry categories, and (e) application of nonlinear model estimation methods. There is further need to validate the elasticity findings by (f) analyzing other metropolitan areas that have different patterns of density, spatial development, and transportation systems. Finally, (g) applications of time series data and geographic information systems might also yield insights about temporal causality and spatial lags.

Appendix: Data Characteristics

To interpret the relative magnitude of impact effects, it is helpful to understand the mean and median values of the dependent and independent (explanatory) variables as shown in Table 4.

Table 4. Range of Variable Values

Variable	Industry group	Minimum value	Median value	Mean value	Maximum value	Number of observations
Local scale (LS)	All industries	0	72	218	27,403	1,694
	Producer services	0.01	4	49	9,214	1,615
	Retail services	0.01	10	27	1,282	1,624
	Manufacturing	0.07	7.43	40.4	1,243	1,324
	Other	0.04	34	116	20,369	1,662
Access factor (AF)	All industries	483	5,516	6,631	87,247	1,694
	Producer services	8	206	527	38,747	1,694
	Retail services	17.4	318	445	7,393	1,694
	Manufacturing	306	3,021	3,173	7,591	1,694
	Other	130	2,189	2,671	51,332	1,694
Weighted population market (WPM)	All industries	0.0001	0.8497	2.491	143.56	1,687
	Producer services	0.000047	0.0918	0.673	51.75	1,608
	Retail services	0.000031	0.195	0.522	15.53	1,617
	Manufacturing	0.000041	0.0377	0.292	7.736	1,317
	Other	0.0001	0.367	1.142	102.7	1,655
Average wages	All industries	2,330	41,191	46,282	378,325	1,694
	Producer services	2,000	43,740	51,692	482,136	1,615
	Retail services	2,000	34,500	39,794	245,030	1,621
	Manufacturing	476	44,301	49,415	241,434	1,321
	Other	1,227	37,241	40,262	194,179	1,661
Zonal employment	All industries	1	901	1,794	69,379	1,694
	Producer services	1	100	424	23,894	1,615
	Retail services	1	212	401	8,883	1,624
	Manufacturing	1	45	238	5,599	1,324
	Other	1	378	839	49,782	1,662
Pop45 (millions)		0.0206	1.0283	1.0585	2.5077	1,694

Note: Industry categories are defined by North American Industry Classification System (NAICS) codes: Producer Services (51, 52, 53, 54, 55, 56), Retail & Consumer Services (42, 44, 45, 48, 71, 81), Manufacturing (11, 21, 31, 32, 33), Other (All other NAICS).

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