The Relationship of Transportation Access and Connectivity to Local Economic Outcomes: A Statistical Analysis

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ABSTRACT
Transportation system improvements can affect economic growth and productivity by changing access to markets and connectivity to intermodal terminals. This paper demonstrates these relationships through a two step process. First, it defines seven types of market access and intermodal connectivity measures that vary widely across the US. Then, it develops econometric models of the relationship between access/connectivity characteristics of local areas and relative levels of business productivity, job concentration and export base. These relationships are estimated using simultaneous, non-linear equations that allow access threshold effects to be recognized, and for different relationships to apply among 54 industry sectors. The findings are discussed in terms of how they relate to broader productivity and agglomeration research, along with their implications for estimating the wider economic benefits of specific transportation investment.

1. INTRODUCTION

Background: Policy Implications of Access, Connectivity and Economic Development.

The relationship of market access and connectivity to local economic growth is an important research topic for two reasons: (1) many transportation system expansion or improvement projects are justified in part on their ability to enhance this relationship, and (2) treatment of access and connectivity in transportation benefit assessment is very inconsistent; these factors are usually ignored but occasionally given very high value. It is thus useful to review relevant policy, theory and past research, and then conduct new statistical analysis to further understand the nature of this relationship.

In basic economic theory, essentially all economic activities are seen as depending on access to workers, input materials and customers. Consequently, it is not surprising that the economic development literature is replete with surveys finding that workforce and customer "market access" are both among the most important factors in business location and expansion decisions (*1*), (*2*). Business location magazines (e.g., *Site Location, Area Development* and *Business Facilities*) reinforce this point via advertising by regional agencies that frequently feature market access as a prominent element of their sales pitch to attract business. The implication is that having access to broad labor and customer markets makes a location more attractive by providing productivity or profitability benefits that are in addition to having attractive unit costs for workforce and facilities operations.

Legislators, governmental leaders and planners also frequently cite economic growth as a motivation and justification for major transportation investments, based on the potential for many forms of transportation (including highway, transit, rail, airport marine port and intermodal) investments to enhance the connection between intercity business markets or expand local labor and delivery markets. And indeed, a recent study of the US Strategic Highway Research Program developed case studies of 100 major highway and highway/rail intermodal projects and classified the motivations for those projects. It found that 59% had cited some form of access improvement, including 30% citing labor market access, 32% citing truck delivery market access, and over 35% citing highway access to an intermodal terminal such as an airport, rail terminal, or marine port (*3*).

Analysis of Wider Economic Benefits

In program evaluation and project appraisal, recognition that transportation investments can benefit non-travelers is not new. In the US, there has been a continuing series of highway project evaluation studies dating back to 1991 that have recognized and incorporated some form of business attraction or productivity benefit attributed to market access and connectivity improvement (*4*), (*5*), (*6*), (*7*), and more recently this has extended to public transportation benefit studies (*8*), (*9*). In the UK, market access benefits have been recognized in a series of studies of urban agglomeration and productivity, and the effects of transportation access on effective labor market density (*10*), (*11*).

Clearly, then, there is both public perception and analytic recognition that transportation impacts on an area's access characteristics can affect productivity and economic growth. That makes it particularly important for both researchers and planners to better understand the dimensions of transportation access and the extent to they can actually affect economic productivity and growth.

Objectives of this Paper

This paper seeks to clarify the relationship of access and economic development, in two ways. First, it examines past research to better define the elements of access and ways in which they can affect a local or regional economy. Second, it describes the specification and results of a set of statistical models that relate access and connectivity characteristics of 3,100 locations across the US with their observed patterns of business output, concentration and productivity. These relationships are estimated using simultaneous, non-linear equations, with different relationships estimated for each of 54 industry sectors. Findings are discussed in terms of both implications for broader productivity and agglomeration research, and applications for estimating wider benefits of transportation investment.

2. DEFINITION OF TERMS.

It is useful to establish a common understanding of how (a) transportation access, (b) connectivity and (c) economic productivity are defined, before discussing the nature of their behavioral relationship. Definitions of those terms, as used in this paper, are as follows.

"Market Access," in the context of transportation planning, refers the ability of transportation facilities and services to provide households and businesses with access to opportunities that they desire. In the economic development literature, businesses desire access to three basic kinds of markets:

- *labor market*: the workforce with required skills that a business can draw from to obtain its employees,
- *input material market*: the sources of specialized materials that a business can acquire (or specialized services that it can use) to produce its output, and
- *customer market*: the buyers whose specific needs can be reasonably and competitively served by a business. (This can include shoppers, tourists or freight delivery recipients.)

From the viewpoint of households (rather than businesses), transportation can alternatively be viewed as providing worker access to employment and shopping opportunities that match to their skills and needs. Transportation investments can potentially expand any of these forms of market access. Market access is often measured through the concept of "effective density," which refers to the magnitude of surrounding market opportunities (e..g., workers to be utilized or customers to be served) from a specific location. This is in contrast to the traditional concept of "spatial density," which refers to the number of market opportunities that exist within a specific spatial area.

"Connectivity", in the context of transportation planning, refers to the ease, time or cost of traveling between different transportation route systems or modal systems. The most common use is in terms of connectivity of local roads to specific multi-modal access points, such as: (a) ramps onto the interstate highway system, (b) local public transit stations, (c) railroad terminals, (d) airports, (e) marine ports, (f) international gateway terminals or (g) border crossings. One could similarly define measures of the connectivity of feeder transit, rail or air services to long-haul or high speed lines.

In a strict language sense, "connectivity" represents a form of "access" that is between two systems. However, in practice it is useful to distinguish market access and connectivity. Whereas "market access" refers to a surrounding *area* or region comprising the market, connectivity commonly refers to characteristics of the *link* to terminals or interchanges. Both can enhance productivity, and intermodal transportation connectivity improvements also tend to extend the range of workers, materials and/or customers that are accessible to a business.

"Productivity" refers to the ratio of [business output] / [production cost], where the denominator is the total cost of all input factors including labor, materials, utilities, transportation and other services. In the context of transportation economics, an improvement in the performance of transportation facilities and services can enhance productivity in two ways. The first way is by reducing time and/or expense costs incurred in the continuing operation of businesses. That effectively raises productivity by decreasing the denominator of the ratio. The second way is by enlarging market access or connectivity, which grows the numerator while the denominator either remains constant or grows proportionally less than the numerator. This can occur as long as there are scale economies or other business operating efficiencies enabled by access to a larger market. (These effects are described further in the literature review which follows.)

A Simple Example.

The difference between transportation cost savings and transportation-induced changes in market access can be illustrated by considering two projects: (1) adding a lane to a congested highway and (2) building a bridge across a river that has divided two parts of a region.

For the first project, the vast majority of benefits (and ensuing economic impacts) arise from reduced transportation costs. In this case, reduced costs of travel time and reliability, combined with lower vehicle operating costs, translate to lower business operating expenses. Benefits for this project are relatively easy to measure because the high volumes on the congested roadway provide a rich source of information on transportation costs, and how those are likely to change with the investment. Moreover, unless the project's congestion relief is dramatic, the pattern of trip-making is not likely to change, as the facility links basically the same origins and destinations as before. The project will primarily reduce costs to existing patterns of trip-making activity.

For the second project, which creates a new link between two economies, benefits (and ensuing economic impacts) arise in a totally different manner. This is because patterns of trip-making activity are very likely to change after the project is finished. Rather than reduce costs for *existing* travelers, the facility enables *new* trip-making activity. These new trips reflect new economic activity between the two regions – which were previously functionally separate. Capturing benefits simply as travel cost savings would yield only small benefits because prior trip-making activity across the river has been limited by the lack of a nearby bridge. Moreover, measuring benefits in this manner misses the point of the investment, which is to enable new economic linkages. With the new bridge investment, affected areas may become more productive for business activity as they gain access to broader consumer markets for their goods, an expanded pool of suppliers and potential business partners, and a new pool of potential employees. Area households may similarly gain as they find access to new goods and services as well as a greater variety of potential jobs. In all cases, the expanded market scope provides the opportunity for new economic connections and net productivity growth.

PAST RESEARCH

Agglomeration and Effective Density

The relationship between market scale and economic productivity goes back nearly a century to Marshall (*12*). However, it was the Nobel prize winning work of Krugman (*13*) that showed that, with imperfect competition, regions naturally develop differentiated industry mixes that reflect "agglomeration economies." The agglomeration is reflected in a disproportionately

large concentration (or cluster) of some activities. It is typically enabled by access to larger markets, which in turn brings demand for greater product variety, and enables firms to realize increasing returns to scale. This effect can reflect not only production scale economies (spreading fixed cost over a wider base to reduce unit cost), but also further operating economies associated with greater access to differentiated inputs (i.e., cost and quality benefits associated with greater ability to acquire specialized labor and materials) and potential knowledge spillovers (technology enhancement associated with clustering). The effect is driven by inter-industry linkages which create demand for specialized suppliers that varies by industry (*14*).

Ultimately, a variety of behavioral mechanisms (including enhancement of specialized product/service sharing, specialized input requirement matching and specialized knowledge spillovers) can enable business clusters or agglomerations to serve this demand for specialized inputs. The result -- greater worker productivity in larger and more diverse markets that drive industry clustering -- is ultimately reflected in higher worker income.

An approach for empirical measurement of industry response elasticities was laid out in a 1998 paper which showed how local productivity for various industries varied by accessibility as measured by inter-regional trade flows (*15*). A 2001 NCHRP study measured productivity impacts of reducing urban traffic congestion based on the relationship of productivity to travel times for commuting trips and truck deliveries (*16*), (*17*). The study concluded that labor markets and truck delivery markets had very different time/distance patterns that reflected differing needs for specialized worker/job skill matching and product/buyer feature matching among various industries. A series of further studies in the US documented how industry location patterns and clustering vary systematically by access factors ranging from intermodal freight gateways (*18*) to regional market scale (*19*), (*20*).

Dimensions of Access and Connectivity

In recent years, a growing body of evidence has shown that accessibility measures need to be multi-faceted to reflect a number of different dimensions, including labor market, customer market and intermodal connectivity impacts. These include studies addressing the relationship of business growth and/or productivity to:

- *access to broader labor markets with diverse worker skills*: NCHRP Report 463 (*16*), (*21*), (*22*) and studies of the effects of transport access and cost on wage gradients (*23*), (*24*), (*25*), (*26*)
- *access to broader customer markets* (*27*), (*20*)
- *new route connectivity*, enabling wider trade between market centers (*28*), (7), (*29*)
- *intermodal connectivity (air/sea/rail)* (*30*), (*31*), (7)

The range of access and connectivity elements being studied is consistent with the overarching view that economic benefits of transportation enhancement emanate from a combination of (a) cost, (b) quality and (c) scale effects that all have economic value (32), (33).

EMPIRICAL ANLYSIS: DATASET DEFINITION

Past research studies indicate that business clusters and the associated benefits of agglomeration emerge out of interactions across a number of important access elements relating to different business functions (including labor markets, industry product delivery markets, and connectivity to modal facilities). And the roles of these access elements vary widely by industry. To estimate the nature of these effects for both urban and rural regions, the authors developed a database of economic and locational access measures for county locations across the US. The

dataset features are described in terms of (a) spatial unit of measurement, (b) access and connectivity features and (c) economic outcomes.

Spatial Unit of Measurement

For each of 3,141 counties in the US, a GIS system was used to identify the population-weighted centroid location. For most rural and small metro counties, this generally matched or was close to the location of the dominant population and trade center. For larger, multi-county metro areas, this generally corresponded to the most densely-built area which also represented a trade and employment center. From that location, a transportation network model was used to identify areas accessible within average travel times ranging from 40 minutes to 180 minutes, and to calculate average travel times to major intermodal terminals. These measures of market access and connectivity were then statistically related to measures of county-level economic activity (output, GDP) as well as per-capita income and labor productivity.

Access and Intermodal Connectivity Features

A series of access measures were defined, representing both local and regional scale market areas and connectivity to key intermodal transfer terminals:

- *Local Market Access* – The total population within a 40 minute travel time was selected as a proxy for variation in "local" labor market potential, since more direct measures of available labor force were not available for this study. The 40 minute time represents the 80th percentile for average commute time in the US, and roughly corresponds to the typical characteristics of BEA-defined labor market areas. (Note that this market potential measure may be totally within a county, but more often extends beyond its borders.) Expanding the size of the labor force accessible within that market area can reflect agglomeration factors that increase labor skill matching, final good (consumer market) matching, and knowledge spillovers.
- *Regional Delivery Market* – The total employment located within a 3 hour drive time was selected as a proxy for the scale of "regional" business activity occurring within a same-day delivery area. The 3-hour threshold was chosen to represent the effective limit within which a business can make same-day outbound and inbound deliveries, with allowance for a delay buffer and load/unload time. The magnitude of business activity occurring within that area can reflect opportunities for enhanced product matching, inter-industry complementarity and supply chain integration consequences of industry supplier/delivery markets.
- *Access to a domestic airport* – this serves as a proxy for inter-regional connectivity, which is an important component of innovation networks, knowledge spillovers, and high-value supply chains. It is measured as average ground access time to the nearest commercial airport with scheduled air carrier operations, weighted by the scale of airport activity (air carrier takeoffs + landings). In many cases, that airport is located outside the county border.
- *Access to an intermodal rail facility* – many manufacturing sectors are highly dependent on rail shipping, both for production inputs and output. This variable measures the average drive time to a public intermodal yard with scheduled daily COFC/TOFC rail service.
- *Access to major seaport* – this measures the drive time to major freight export seaports, weighted by the tonnage of goods exported per year. It therefore captures one facet of international supply chain access.
- *Access to major international airport* – this captures another facet of international supply chain access, as it measures drive time to major international air cargo gateways, weighted by value of goods exported per year.

• *Access to major international land border* – this captures drive time to active Canada or Mexico border crossings, weighted by annual export value.

All of these access measures are defined on the basis of travel times. That is critical because transportation improvements can effectively expand market areas and shrink the connection time to specific (terminal) locations. These changes can occur as new routes or services are established to between locations and regions, or as changes to facilities or their operations reduce delays. With appropriate calculation, cost savings to existing travelers can be separated from the productivity gains associated with location access enhancement.

The two (local and regional) market access measures are defined on basis of travel time boundaries. This differs from some past studies that have defined market access by gravity models – i.e., as the sum of surrounding population or employment weighted by a selected time or distance decay function (which may be linear or exponential). In this case the boundary-based calculation was selected to better reflect the threshold (drop-off) effects found in past research on ranges of commuting times for skilled labor, limits of labor markets and just-in-time delivery practices (17, 19). However, a less acute boundary might be preferred for future studies as it could be less susceptible to random disparities causing large market access changes to be calculated from small travel time shifts.

Table 1 shows the correlation among these seven access and connectivity metrics for the 3,131 locations studied. Not surprisingly, it shows that proximity to larger airports is correlated with larger urban markets, while intermodal road/rail container terminals tend to be located away from the most dense urban areas. However, even the highest correlations are on the order of 0.4 to 0.6, which are sufficiently low to not be problematic in multiple regressions. This allows for simultaneous estimation of the economic impact of all seven dimensions of access and connectivity.

TABLE 1 Correlations between the Seven Access and Connectivity Metrics

	Local Pop Market	Delivery Market	Airport	Rail Term.	Seaport	Border	Intl. Gateway
Local Pop Market	1	0.635	0.617	-0.649	-0.570	-0.074	-0.51
Delivery Market	0.635	1	0.390	-0.505	-0.589	-0.021	-0.575
Airport	0.617	0.390	1	-0.533	-0.421	-0.105	-0.361
Rail Terminal	-0.648	-0.505	-0.533	1	0.496	0.080	0.407
Seaport	-0.567	-0.589	-0.421	0.496	1	0.060	0.494
Border	-0.074	-0.021	-0.105	0.0798	0.060	1	0.095
Intl. Air Gateway	-0.505	-0.575	-0.361	0.407	0.494	0.095	1

Economic Outcome Measures

The effect of increasing market access and intermodal connectivity can lead to agglomeration effects with a wide variety of economic consequences, which may be reflected in local changes in of business output, productivity, worker income, labor force participation, household location choice, land development and/or import/export activity. From the standpoint of national macroeconomic growth, many of these local effects may be dismissed as inter-regional "shuffling." And yet, at the local level, this "shuffling" is tremendously important for two reasons. First, it can make the affected local area more competitive for business attraction. Even where this business attraction does not increase productivity *within* an industry, it can shift the mix of industrial activity away from low-productivity sectors to high-productivity sectors.

Second, there is reason to believe that industry dynamics and productivity growth are, in fact, two outcomes of a single underlying process of economic transformation (*20*). That is, productivity gains are achieved through changes in industry and employment mix. Therefore, estimating productivity outcomes without considering the underlying processes of industry change limits the scope of economic impacts.

In an attempt to capture a broad set of economic consequences of market access changes, we calculate the relationship of economic activity to variation in worker skills and accessibility via three equations:

- *Industry Employment Concentration.* Equation 1 relates the seven access variables, as well as worker skill (a control variable) to the concentration of employment in a single specific industry (relative to a county's total population). This measures industry concentration relative to other industries. Using a cross-sectional perspective across all 3,141 US counties, Equation 1 reveals how access measures affect industry concentration "i" in county "c." Using county population in the denominator also allows for the effects of labor participation, household location, and land use change.

Eq. 1 $\left(\frac{Employment_c^i}{Population_c}\right) = f(WorkerSkill_c, Access_c)$ *...where i=industry and c=county*

- *Industry Labor Productivity.* Equation 2 relates access measures and worker skill to labor productivity for a single industry and reflects the industry's unique wage and skill mix.

Eq. 2 $\left(\frac{Output_c^i}{Employment_c^i}\right) = f(WorkerSkill_c, Access_c)$

- *Foreign Export Proportion.* Equation 3 relates "gateway" access measures to the portion of an industry's output (sales) generated from international demand. This provides an additional mechanism of industry growth beyond domestic access measures.

Eq. 3 $\left(\frac{Exports_c^i}{Output_c^i}\right) = f(Access_c)$

STATISTICAL MODEL SPECIFICATION AND RESULTS

Model Specification

Through logarithmic transformations, Equations 1-3 can be transformed into the following three log-linear econometric equations, estimated separately for each of 54 industries:

$$Empl_c^i = \alpha_0^1 + \alpha_1^1 Pop_c + \alpha_2^1 Skill_c + \beta_1^1 Pop40_c + \beta_2^1 Empl180_c + \beta_3^1 \left(\frac{DomAirOps_c}{DomAirTime_c}\right) + \beta_4^1 RailTime_c + \beta_5^1 SeaTime_c + \beta_6^1 IntlAirTime_c + \beta_7^1 LandBdrTime_c$$

$$Output_c^i = \gamma_1^2 Empl_c^i + \alpha_0^2 + \alpha_1^2 Skill_c + \beta_1^2 Pop40_c + \beta_2^2 Empl180_c + \beta_3^2 \left(\frac{DomAirOps_c}{DomAirTime_c}\right) + \beta_4^2 RailTime_c + \beta_5^2 SeaTime_c + \beta_6^2 IntlAirTime_c + \beta_7^2 LandBdrTime_c$$

$$Export_c^i = \gamma_1^3 Output_c^i + \alpha_0^3 + \beta_3^3 \left(\frac{DomAirOps_c}{DomAirTime_c}\right) + \beta_5^3 SeaTime_c + \beta_6^3 IntlAirTime_c + \beta_7^3 LandBdrTime_c$$

where…

$Empl_c^i$ = Employment in county *c* and industry *i*
$Output_c^i$ = Total Output (sales) in county *c* and industry *i*
$Export_c^i$ = International exports from county *c* in industry *i*
α = Calibration model parameter (constant or control variable)
β = Access concept model parameter (used to estimate scenario impacts)
γ = Simultaneous equations model parameter (used to calibrate equation
$Skill_c$ = Worker skill level in county c (percent of workers with college degree)
$Pop40_c$ = County *c*'s access to population within 40 minute drive*
$Empl180_c$ = County *c*'s access to employment within 3 hour (180 minute) drive
$DomAirOps_c$ = Number of annual operations at County *c*'s closest commercial airport
$DomAirTime_c$ = Drive time to County *c*'s closest domestic commercial airport
$RailTime_c$ = Drive time to County *c*'s closest intermodal rail terminal
$SeaTime_c$ = Drive time to County *c*'s closest "major" marine port*
$IntlAirTime_c$ = Drive time to County *c*'s closest "major" international freight airport
$LandBdrTime_c$ = Drive time to County *c*'s closest border to Canada or Mexico*

Note that the employment equation controls for population base, so it effectively represents the effect of access on industry employment concentration. Similarly, the output equation controls for local employment so that it effectively explains labor productivity. And the export equation controls for output level, so it effectively explains export proportions.

Some of the *dependent variables* (to the left of "=") also appear as *explanatory variables* (to the right of "=") in other equations. This effectively ties the three equations into a system that is estimated "simultaneously", ensuring no double-counting among the three types of outcomes. Furthermore, note that the market access measures are included simultaneously. Therefore, the effect of each measure is incremental in nature. When it comes to applying the result of this statistical, we can then be sure that there is no double-counting between (e.g., between the effect from population access and domestic airport access). Each measure's contribution is in the context of the county's entire baseline accessibility landscape. The statistical coefficients for these equations were then estimated using a two-stage, least squares technique for simultaneous equations, run separately for each of 54 industry groups.

Results.

The explanatory power of these regressions, which incorporate access and connectivity metrics as explanatory variables, is shown in Figure 1. It shows that this specification accounts for a relatively large share of the county-to-county variance in industry employment concentration for trade and service industries (with R^2 typically in the 50% to 85% range) but a substantially smaller share for manufacturing and resource sectors of the economy (with R^2 typically in the 20% to 55% range). However, the model specification accounts for a substantially greater share of the variance in concentrations among manufacturing industries, when measured in terms of output or employment (with R^2 typically in the 65% to 95% range). Since the output equation reflects the growth in output relative to employment in a given industry and area, these regression results also reflect the relative importance of access variables in explaining productivity.

Since the system of simultaneous equations has 514 distinct parameter estimates (equations 1-3 estimated for each of 54 industry sectors), space limitations preclude presentation of all of them. Instead, we summarize the coefficient findings in Table 2, via a ten-point scale that reflects the statistically significance of individual access metrics for each industry. The scale is designed so that a value of 10 is assigned if that variable was statistically significant at the 99% level for all three equations, a value of 5 if that variable was statistically significant at the 95% level for all three equations. These results show several key findings:

- *The local, 40-minute market size* (a measure of effective labor market or shopping market scale) is a consistently strong factor in all three equations for the trade and service industries. However, it is generally less strong as a factor affecting manufacturing, construction and utilities sectors, as they also depend to a larger extent on access to supply chain factors such as incoming materials and outgoing deliveries, as well as utility availability and cost.
- *The regional, 3-hour market size* (a measure of same-day delivery market scale) is generally most important for manufacturing , and also important for agricultural industries. But it is seldom a statistically significant factor for trade and service industries.
- *Commercial airport access* is generally most important for professional, scientific and administrative businesses that require employee travel, as well as recreation industries that depend on tourism and manufacturers of specialized products that tend to rely on air cargo services (such as electronics, textiles and printed matter). It is generally less important for most other industries.
- *Intermodal freight terminal access* is generally most important for industries that send or receive coal or other mining products, wood and paper products, or retail products. It is generally not important for most other industries.

The regression coefficient values can be transformed into elasticities that reflect the effects of labor market scale (agglomeration) on labor productivity by industry. They indicate an elasticity of productivity with respect to changes in labor market scale that typically ranges from 0.01 to 0.04 for manufacturing industries, and 0.05 to 0.10 for professional service industries. These results are generally in line with prior research (10,11).

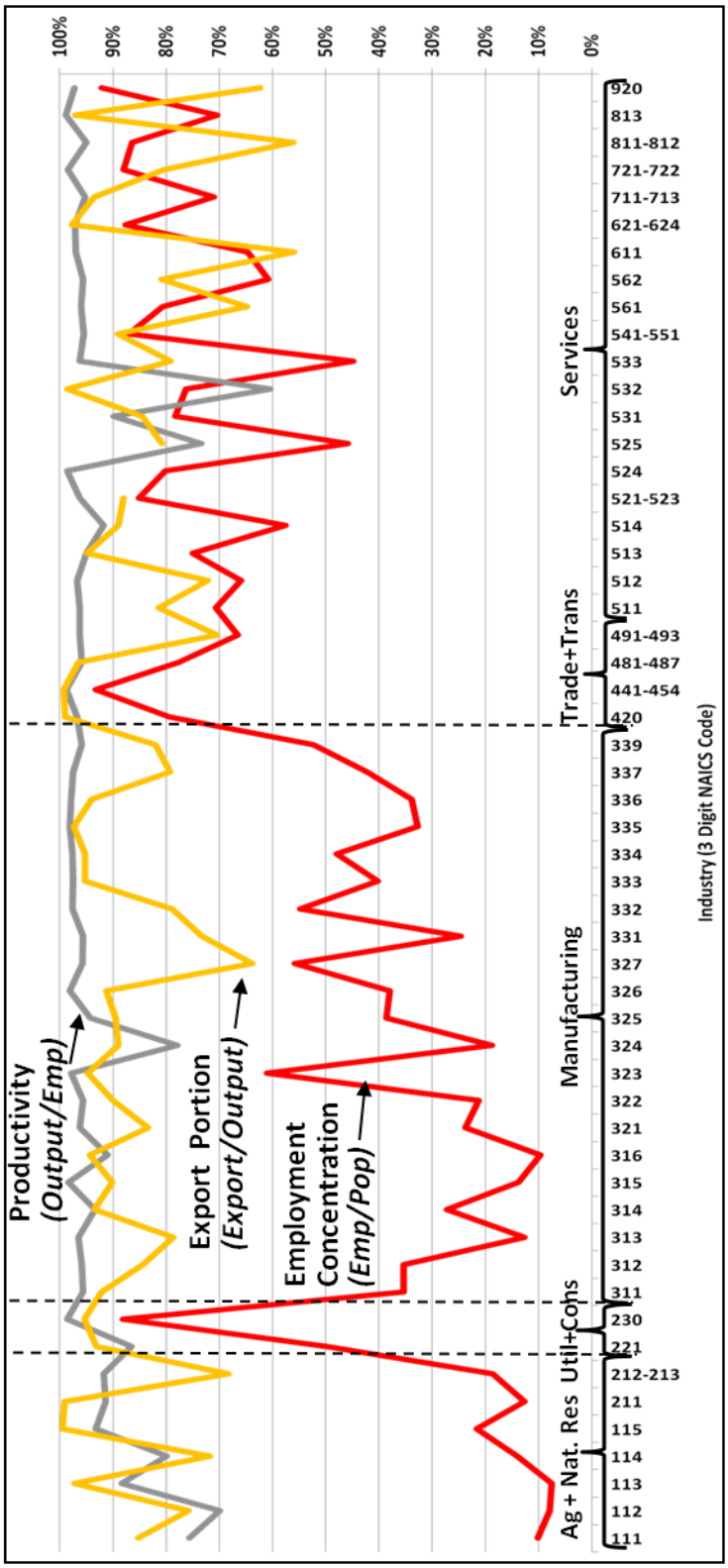

FIGURE 1. Overall Regression Fit (R^2), by Industry

TABLE 2 Overview of Industry Sensitivities to Access Measures (1 to 10 Scale)

NAICS	Sector Description	Sensitivity to Access Measure (1-10 scale)			
		40-min Market	3-hr Delivery Market	Commercial Airport	Rail Intermodal
111	Crop Production	3	5	0	3
112	Animal Production	0	5	0	3
113	Forestry & Logging	5	0	2	0
114	Fishing, Hunting & Trapping	0	3	0	3
115	Support for Agriculture & Forestry	3	0	0	0
211	Oil & Gas Extraction	0	0	0	0
212-213	Mining & Support Activities	3	0	4	5
221	Utilities	5	0	3	5
230	Construction	8	5	7	8
311	Food Products	3	0	0	0
312	Beverage & Tobacco Products	10	0	0	3
313	Textile Mills	5	5	2	3
314	Textile Product Mills	5	10	0	0
315	Apparel Manufacturing	5	5	0	0
316	Leather & Allied Products	5	3	2	5
321	Wood Products	0	5	0	5
322	Paper Manufacturing	0	5	0	5
323	Printing & Related Activities	10	10	7	0
324	Petroleum & Coal Products	6	0	0	0
325	Chemical Manufacturing	5	3	4	3
326	Plastics & Rubber Products	8	10	0	3
327	Nonmetallic Mineral Products	5	5	2	0
331	Primary Metal Manufacturing	3	5	4	0
332	Fabricated Metal Products	10	5	2	0
333	Machinery Manufacturing	0	5	2	0
334	Computer & Electronic Products	3	5	2	3
335	Elec Equipment, Appliances	0	10	3	0
336	Transportation Equipment	5	5	3	3
337	Furniture & Related Products	5	10	3	0
339	Miscellaneous Manufacturing	5	5	5	0
420	Wholesale Trade	10	0	3	0
441-454	Retail Trade	8	3	3	5
481-487	Transportation	5	0	3	0
491-493	Mail, package delivery & warehousing	10	0	2	3
511	Publishing Industries (except Internet)	10	0	10	0
512	Motion Picture & Sound Recording	10	3	9	0
513	Broadcasting	10	0	5	0
514	Internet & data process svcs	8	3	5	0
521-523	Monetary, Financial, & Credit Activity	10	0	3	0
524	Insurance Carriers	10	3	5	0
525	Funds, Trusts, Financial Vehicles	5	5	5	0
531	Real Estate	10	0	7	0
532	Rental & Leasing Services	10	0	5	0
541-551	Prof. Scientific, Technical, Services	10	3	10	0
561	Admin & Support Services	5	0	10	0
562	Waste Mgmt & Remediation Service	3	5	3	0
611	Educational Services	10	5	3	0
621-624	Health Care & Social Services	8	0	0	0
711-713	Recreation & Amusements	5	0	10	0
721-722	Accommodations, Eating & Drinking	5	0	7	0
811-812	Repair, Maint, & Personal Services	5	0	7	0

Examples for Selected Industries.

Another way to show overall model results is to focus on the estimated statistical relationships for specific industries. To demonstrate these results, we simulated the applied the model coefficients and formulas to show how a 1% change in each access variable would change the expected employment density, productivity and international exports for each of the 54 industries in all 3,141 counties in the US. The results, summed up over all counties, are shown for two illustrative industries: (1) transport equipment manufacturing and (2) recreation.

For *transport equipment manufacturing*, key findings are shown in Figure 2. They indicate that enhancing "rail access" and "regional 3-hour delivery market" ("emp180") have the greatest proportional impact on this industry's employment concentration. However, only the latter form of access also delivers significant productivity growth, particularly for counties with medium size populations (i.e., around 50-100 thousand). The figure also shows that access to labor markets and airports each have small but relatively constant productivity impacts.

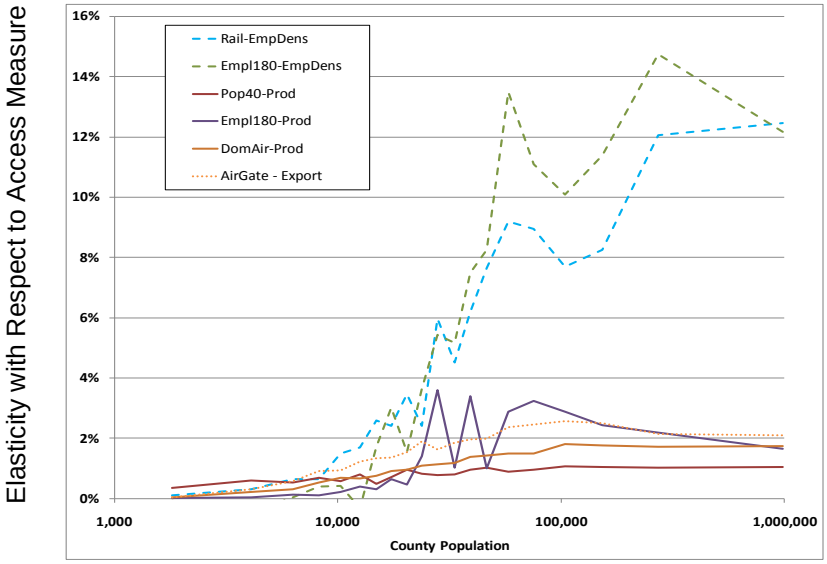

FIGURE 2 Results for NAICS 336: transportation equipment mfg.

For the *recreation sector*, key findings are shown in Figure 3. They indicate that enhancing the "local 40-minute labor market" ("pop40") has the greatest proportional impact on this industry's productivity, and the effect grows (i.e., increasing elasticity of response) with greater county population size. Increasing the "regional 3-hour delivery" also adds to productivity for this sector of the economy, though the elasticity grows to 5% for counties with a population about 50,000 and becomes smaller (though still positive) as population increases beyond that point. There are further impacts on recreation employment concentration associated with both local market size and airport access, which are most pronounced for counties with medium-size populations. Taken together, these two examples show the many ways in which different industries are affected by different forms of transportation access.

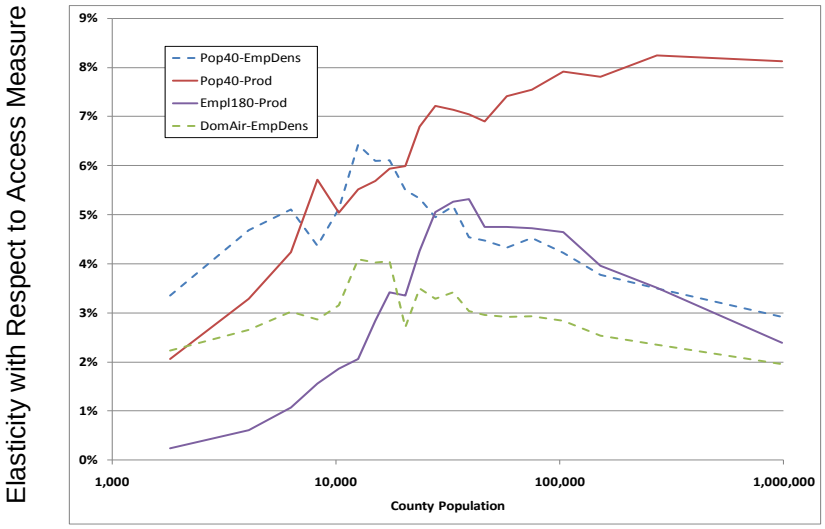

FIGURE 1 Results for NAICS 711-713: amusement and recreation.

CONCLUSIONS

Practical Use

The research reported in this paper shows that there are multiple dimensions of market access and connectivity that can be measured, and they occur at the differing scales of urban labor markets, broader same-day truck delivery markets and access to intermodal terminals. The research findings show that there is systematic variation around the US in the economic composition of local areas and in productivity levels within industries, and both appear to be related to differences in these various dimension of access. The results further demonstrate that it is possible to utilize non-linear regression methods in a series of simultaneous equations to distinguish the incremental impacts of various access dimensions.

The multiple dimensions of access, and their relationship to business patterns and productivity, can be relevant factors to consider in both economic impact analysis (EIA) and benefit-cost analysis (BCA) for transportation projects. Based on the results of this analysis study, the TREDIS economic analysis software suite has incorporated these business pattern impacts (employment concentration and export portion) into its EIA calculations, and it has incorporated the productivity impacts into its BCA modules for US and Canadian studies. That system has been applied to calculate effects of expanding same day delivery market effects for proposed rail and air freight terminal expansions in Georgia and British Columbia, and labor market enhancement effects of proposed rail transit and regional rail lines in Ontario and Massachusetts (8, 9).

Need for More Research

Methods for measuring market access and connectivity, as well as their economic impacts, are in their infancy. More research is particularly needed in the following five areas:

(a) Defining “markets” – There are other dimensions of market access enabled by transportation infrastructure that have not been addressed in this paper, such as visitor attraction (tourism and convention business) markets, and regional (multi-city) supply chain and

technology cluster markets. And besides enabling agglomeration economies such as production scale economies and knowledge spillovers, there may be other situations where highways can enable "dispersion economies" (such as the southern automotive manufacturing corridors in the US). Further research is needed to more systematically classify all of the various forms of market access and connectivity effects and their effects on business growth and productivity.

(b) Measuring "effective density" – There is general agreement that expanding market access can be thought of as an expansion of the "effective density" of an area. However, there are limitations associated with all known methods for measuring market access, including the defined boundary approach used in this study as well as alternatives incorporating predefined weights for distance or time discounting. Research to date indicates that there are systematic differences in breadth of commuting for different types of jobs and in delivery areas for different types of freight, but more work is needed to observe these patterns and examine alternative ways to reflect them when measuring transportation effects on market scale.

(c) Measuring "intermodal connectivity" – The measures of access intermodal terminals that were used in this research include average access time to the closest applicable type of terminal, and when available, a measure of the activity level occurring at that terminal. However, improved measures could reflect the breadth of spatial links enabled by various intermodal terminals, as well as the value of having other nearby choices.

(d) Behavioral "threshold" effects – It is widely accepted in the business community that the feasibility of locating and operating various types of business activity in a given area can be dependent on the existence of labor and delivery markets large enough to enable matching of supply and demand for specific worker skills and products. That leads to minimum market size thresholds for some types of business activity to occur, with diminishing value to further increasing scale. The logarithmic regression formulation used in this study was an attempt to recognize that non-linear effect, but further research could more accurately measure and reflect these threshold effects in transportation economic impact studies.

(e) Distinguishing scale of analysis – There is growing recognition that both transportation and economic changes can be viewed differently from micro-, meso- and macro-economic perspectives. And it is clear that different market effects and economic changes occur at these different scales. This study utilized data on county-level economic patterns, which is a broader scale studies of US "tract" or UK "ward" zones within cities. More research is needed to further sort out how different forms of access appear at these different spatial scales.

The overall conclusion, then, is that there is both statistical significance and practical uses of this line of research, yet also substantial need and opportunity for further refinement of analytic methods and their conclusions.

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