TREDIS®

TREDIS® v5 Technical Documentation:

Market Access Module

Update, May 2020

www.tredis.com

TREDIS Software
155 Federal Street, Suite 600, MA 02110 USA
Tel: +1 617 303 0424
E-mail: info@tredis.com

Table of Contents

1 Background: Accessibility in the TREDIS Context

TREDIS does not measure market accces. The TREDIS market acess module accepts a variety of measures of market access provided by users, and then calculates how they will affect productivity and other economic outcomes.

There are many types of access relevant for planning and policy. In the context of transportation economic evaluation addressed by TREDIS, some forms of access are of particular importance and relevance. This section provides an overview of these issues.

Definition: Concept of Access. Fundamentally, transportation systems exist to provide access to desired destinations for education, health care, employment, shopping, recreation and business activities. So it is natural for people to consider transportation adequacy in terms of how well they are able to access those destinations. State and local agencies often make plans and policies and also assess proposed projects on the basis of how they serve various access needs. A variety of scoring and rating systems exist to help decision-makers consider those types of factors.[1]

In the context of transportation economics, there is an important distinction to be made between (1) business access to markets and (2) population access to specific types of destinations:

- *Market Access.* The form of access that is most clearly developed in transportation economics is "market access'" for labor, supplier and customer markets. There is a strong body of research documenting how larger size markets can provide "economies of scale" for producers as well as "economies of specialization" for job skills and supplier/buyer markets. These benefits represent "productivity gains" that represent benefits in BCA and drivers of economic growth in EIA. It is also clear that better performing transportation systems can enhance access to workforce and business delivery markets, and thus enable those benefits to occur. TREDIS is designed to capture and reflect these types of access improvements.
- *Access to Destinations.* There can also be economic benefits and impacts associated with access to specific destinations to meet human needs for education and health care. There is a rich body of research showing that access to good education and good health care supports income growth and regional economic development. However, these benefits depend as much (or more) on the location siting and offerings of public and private institutions than they do on transportation investment. And there are not necessarily any further productivity gains (scale economies) from having access to multiple schools or multiple hospitals in a region. For these reasons, it is currently difficult to establish the incremental $ benefit of education and health care access when considering payoffs from transportation infrastructure and service investments. These factors have not been further developed in TREDIS to date, though they may be a topic appropriate for future TREDIS coverage.

Focus on Economics Analysis. The field of transportation economics, and specifically TREDIS – the Transportation Economic Development Impact System – can reflect evaluate how market access changes caused by transportation improvements povides either $ economic benefits or $ economic impacts. TREDIS coverage of access includes:

[1] See Weisbrod (2016), "Economiic Prosperity Impact Metrics for Transportation Project Scoring," Caltrans Scoring Workshop. http://innovativemobility.org/wp-content/uploads/Glen-Weisbord.pdf

- Benefit-Cost Analysis (BCA) – comparing the net present value of benefits and costs, where improved access to opportunities can be assigned a benefit $ valuation based on either stated preference or revealed preference, and
- Economic Impact Analysis (EIA) – showing impact over time on regional economic growth, where access to larger markets leads to revenue and income $ growth as a consequence of productivity gains from scale economies in operations.

The differences between these forms of economic analysis is discussed in a separate document, which explains their very different uses in transportation planning and decision-making processes. (See: *Application of Economic Analysis for Transportation Decision-making: A Guide to the Different Uses of Benefit-Cost Analysis, Economic Impact Analysis and Financial Impact Analysis*).

See the **Benefit-Cost Analysis** and **Dynamic Economic Model** Technical Documents for more on TREDIS use for BCA and EIA.

Transportation Modal Access. From a planning and decision evaluation viewpoint, access is usually measured in terms of specific transportation modes – e.g., walk access, bike access, transit access or car access. This is important because, while accessibility is typically widest for cars, many people do not have that option. Some people do not have access to a car. Others cannot, should not, or do not wish to drive a car. Yet others have a car in the household, but they have more drivers than cars which means that some people have to utilize other modes of travel or else not travel when and where they want to.

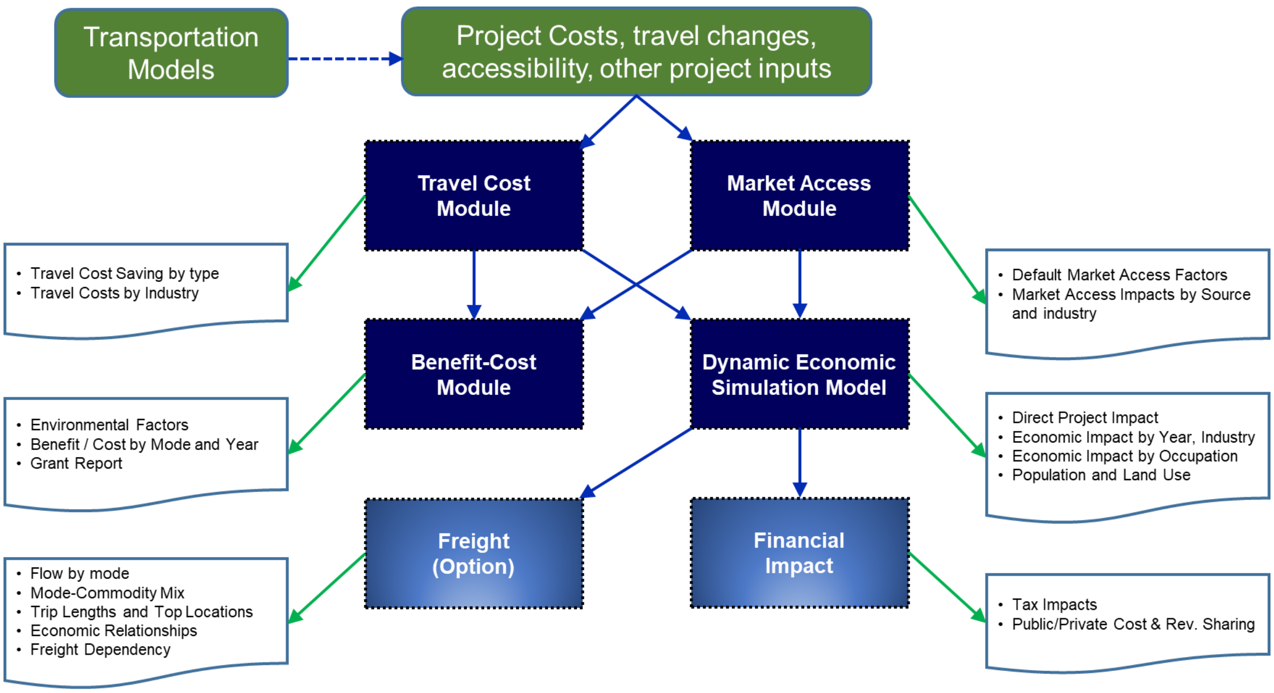
TREDIS enables the portrayal of *market access* by various modes, and then applies user data regarding the applicable and available modes so that it can calculate the extent to which transportation improvements lead to economic benefits and impacts. TREDIS also enables different measures of access for corridor improvements and for area-wide improvements.

1.1 The TREDIS Framework: A Modular Design

TREDIS is an integrated economic impact analysis system for transportation planning and project evaluation, designed to cover a wide range of applications including the assessment of benefits, costs, finance, and regional economic impacts of alternative projects, plans, and programs. It covers all passenger and freight modes, and it assesses costs, benefits, and impacts across a range of economic responses and societal perspectives. To accommodate this range of features, there is a TREDIS Framework that operates as a set of interconnected "core" modules as shown in the figure on the next page. The core modules are: travel cost, market access, benefit-cost analysis and regional economic model.

The modular design of TREDIS enabling users to either use or bypass specific modules depending on need. In general, the *travel cost module* and *market access module* translate changes in transportation performance into economic factors that drive both the benefit-cost module and regional economic impact model. However, many projects and programs are designed primarily to change the capacity, reliability, condition, safety or speed of existing facilities or services. In general, they trigger changes in factors handled in the TREDIS Travel Cost module, and do NOT trigger a need to fill in data for the Market Access module. The market access module is mainly applicable when a project or program is designed to extend corridors or services to: (a) expand the spatial area of job markets or truck distribution markets served or (b) provide new or significantly enhanced connectivity to/from intermodal terminals.

TREDIS Framework: Modular Design



1.2 Use for Assessing Wider Economic Impacts in BCA and EIA

Defining Wider Economic Impacts. As noted earlier in section 1.1, TREDIS focuses on economic analysis, and in that context “Wider Economic Impacts” (WEI) are commonly defined as external effects on economic productivity *beyond just the direct changes in travel time or cost factors*. Wider impacts typically occur when a project also significantly affects the breadth of the labor market area for attracting workers to jobs or the breadth of the market for same-day product or service delivery to customers. These wider impacts may also occur from changes in business access to intermodal facilities (such as airports, marine ports, or rail terminals) or other supporting activities.

Wider economic impacts and benefits have been identified in research literature going back over a long period of time, but the UK’s Eddington Transport Study (2008)[2] served to coalesce interest in this topic by highlighting six distinct drivers of WEI: (1) agglomeration economies, (2) business efficiency associated with transport reliability & logistics, (3) facilitating trade via intermodal gateways and terminals, (4) labor supply enhancement, (5) increased competition in imperfect markets, and (6) enabling innovation & technology adoption. TREDIS’s handling of drivers “1”, “3” and “4” is discussed in this document. The TREDIS approach to measuaring drivers “2”, “5” and “6” is discussed in the Dynamic Economic Simualtion Model technical documentation. A further discussion of U.S. approaches to productivity measurement is provided in NCHRP Report 456.[3]

---

[2] The Eddington Transport Study: The Case for Action: Sir Rod Eddington's Advice to Government, UK Department for Transport, 2008.

[3] Weisbrod, . et al. “Assessing Productivity Impacts of Transportation Investments,” NCHRP 786. Transportation Research Board, 2014. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_786.pdf

How Wider Market Access Effects Occur: A Simple Example. Consider two projects: one adds a lane to a congested urban highway; the other builds a bridge between two disconnected communities or regions.

- For the first project (congested urban highway), benefits arise from reduced transportation costs. In this case, reduced costs from travel time and reliability, combined with lower vehicle operating costs, translate to lower business operating expenses and household expenditures for existing patterns of trip-making activity. 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.
- For the second project (new bridge), which creates a new link between two economies, benefits (and ensuing economic impacts) arise in a totally different manner. . Rather than reduce costs for existing travelers, the facility most likely 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 current trip-making activity is small, despite the fact that the cost savings per trip could be quite large (perhaps hours of time and hundreds of vehicle-miles). Moreover, measuring benefits in this manner misses the point of the investment, which is to enable new economic linkages. With the bridge investment, firms find new consumers for their goods, they find an expanded pool of suppliers and potential business partners, and they find a new pool of potential employees. Similarly, households find new goods and services as well as more potential firms to work for. In all cases, the expanded market scope provides the opportunity for new economic connections and growth.

Following from the preceding example, we can see that market access is primarily relevant for projects or programs with spatial consequences for extending or connecting comunities or places.

General Advice: When Market Access is Applicable

As a general rule, the TREDIS market access module is applicable for projects or programs that provide new or extended routes or services to either (a) effectively extend the spatial area to be served by the given mode, or (b) provide new connectivity to/from intermodal terminals (that serve as gateways to spatially expanded markets via another mode).

Users do need not provide inputs to the market access module for projects and programs that are primarily intended to improve the capacity, reliability, pavement or structure condition, safety or speed of existing facilities or services. These changes in transportation system performance are handled in the TREDIS Travel Cost module.

2 Measurement of Market Access

There are different ways to measure market access and they can all be relevant for specific research studies or public policy discussions. However, for transportation investment evaluation, the type of transportation investment, project or program and its context will dictate what kind of measure is most appropriate. This section reviews the types of meassures and their applicabilty in TREDIS.

2.1 Scale of Measurement

Options. Market access occurs in several distinct ways, occuring at different spatial scales:[4]

- *Access to a Specific Location (Market Center)* - enabling the development of business clusters that are in close proximity to transportation access points, where they that can gain from the shared use of common resources. For instance, central business districts, high tech office centers and freight distribution centers all depend on transportation networks and services to reach worker and/or customer markets.
- *Local/Metro Market Scale* – a combination of physical density and transportation service quality in a metropolitan area, that together enables the metro area or region to offer businesses access a larger effective base of workers and customers. This also increases the ability of businesses to access workers with diverse and specialized skills, and achieve a better matching of workers skill to business need. Unlike the preceding category, this measure is based on zone-to-zone averages across a region, rather than access to a specific location.
- *Regional Market Scale* – a combination of regional economic patterns and regional highway network density and speed performance that together expands same-day delivery of products to customers. That enables scale economies for supply chains and delivery operations. It applies primarily to improvements in statewide corridors connecting supply chain delivery markets.
- *Corridor Access to a Gateway* – applicable for connectors to airports, marine ports or rail terminals, that effectively open up a region to longer-distance passenger or freight markets.

TREDIS Approach. TREDIS sorts out different aspects of market access benefits by enabling all of these spatial scales, while distinguishing passenger and freight market effects occurring at these various spatial scales. In this way, it allows for analysis of both “urbanization” (market size) effects and more specialized “localization” (connectivity to industry input factors) effects. A benefit of this disaggregated approach is that it makes it possible to focus on factors that are most directly affected by specific transport improvements. Thus, TREDIS is designed to address market access to a central business cluster, more generalized composite metro and regional access measures, and connectivity to an intermodal gateway.

4 The different spatial scales and forms of market access are further discussed in Weisbrod, G.(2016), “Productivity: The Connection Between Transportation Performance and the Economy, *Transportation Research News*, #301, Jan-Feb., http://edrgroup.com/pdf/TRN301_Weisbrod_pp_18-21.pdf

2.2 Forms of Measurement

Options. TREDIS can be configured to work with different forms of access measurement. This can include:

- *person-based or place-based approaches*, which depend on whether the primary beneficiary of improved access is the household sector (e.g., access to jobs) or a business activity center (access to workers or customers);
- *access time-based or opportunity count-based approaches*, which depend on whether the primary form of access improvement is connectivity time to a gateway or terminal, or measure of the scale of regional markets;
- *threshold-based opportunity count or generalized composite opportunity score*, which depend on whether minimum access sufficiency is to be recognized (e.g., population accessible within a 30 minute travel time) or generalized regionwide measures of access are desired (e.g., an "effective density" metric). This choice is discussed in section 2.3.

TREDIS Approach. In the benefit-cost module of TREDIS, the incremental economic benefits of improved market access (beyond direct user benefits) are business productivity gains that lead to income generation. For that reason, placed based access measures (based on business activity locations) are used, though they may be defined as either (a) the scale of market around a specific central business district or (b) zone-to-zone measures representing a metro or regional composite of activity centers. Either way, productivity is generally connected to scale economies that come from larger workforce or customer delivery markets – i.e., requiring an opportunity count approach. Even when considering connectivity to an intermodal terminal, both access time and the scale of destination opportunities at that terminal may be considered.

In the economic impact model of TREDIS, productivity gains associated with market access considered as in BCA. The analysis of impacts on a regional economy can also include inward flows of income to a region that from industrial site and tourism attraction. These additional impacts require use of the contingent development features in the regional economic simulation model since they depend on local area site features and other factors outside of the market access module coverage.

2.3 Threshold vs. Composite Measures of Market Scale

Options. Nearly all of the literature on productivity gains from market access (discussed in Section 3) relates to scale economies enabled by a larger market mass – specifically a larger available workforce or a larger available customer or delivery base. Both threshold and composite measures reflect market mass:

- A threshold-based metric captures the scale of cumulative opportunity within a defined travel time from a specified location, such as the workforce accessible within a predefined "reasonable commute" time or delivery market accessible within a predefined "same day" delivery time window.
- A composite metric involves some form of averaging among all zones in a region, usually via an impedance-weighted, gravity model approach that imposes a distance decay formula in place of a threshold cutoff. "Effective density" metric is the most common form of this latter approach, and despite the name, it is actually a measure of market mass rather than a density ratio.

TREDIS Approach. TREDIS now recognizes both threshold and composite decay approaches, based on two facts. First, both the threshold and decay approaches involve inexact approximations of time constraints. Second, neither approach can work across all situations. So we can map out when each approach is most applicable, based on the discussion below.

In the context of market access for local commuting and regional truck delivery markets, there different factors affecting the cutoff or decay for defining market size:[5]

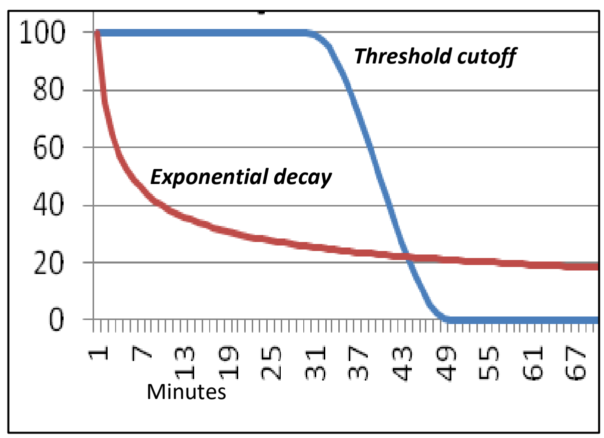
- *Regional truck delivery market.* Truck deliveries are subject to regulations limiting daily driving hours, and labor laws on hours of work and business hours of operation. These factors affect the distances that a truck driver can achieve for a same-day delivery in a just-in-time supply chain. That limits the scale of market from which a producer can receive materials or ship to customers for time-sensitive deliveries. It also limits the number of destinations that a truck driver can serve from a local distribution center in a given day, a factor particularly important for overnight shipments.

  A common rule of thumb is that the area that can be served with same day product and service deliveries is roughly 3 hours from the place of origin. This is based on a window of 8 hours of operation, with an allowance of 3 hours for each of the outbound and inbound trips, plus one hour at each end for pickup and delivery.

- *Local labor market.* Home location and workplace location choices are affected by worker preferences regarding commute travel time, and specfically preferences to avoid very long commutes. Most planning studies assume that this preference for travel times within a deflection point of approximately 40 minutes (or somewhere between 30 and 45 minutes). This interpretation is supported by the American Community Survey, which indicates that 2/3 of all commutes in the US are less than 30 minutes, 80% are less than 40 minutes and 90% are less than 55 minutes. Consequently, the mean commute time in the U.S. is 26 minutes and even in the largest metropolitan areas, the mean is below 40 minutes.

The graphic on the right illustrates two forms of decay functions:[6] (a) a fixed cutoff or gradual threshold that kicks in at a specific travel time, or (b) a more gradual decay function based on a gravity-based, exponential decay factor. The case for a threshold-based approach is strongest for same-day truck delivery markets, based on legal regulation affecting allowable daily truck driving hours. There is also a widely accepted rule of thumb in most developed countries that a 30 -60 minutes threshold is most applicable for representing reasonable commuting access. There is demonstrated by the wide range of 30-60 minute isochrone maps representing commute time ranges for cities.[7]

Comparison of Zonal Attraction Decay Factors



[5] This following text is drawn from Weisbrod, G. (2015), *Estimating Wider Economic Impacts in Transport Project Prioritisation using Ex-Post Analysis*, OECD Roundtable: Quantifying the Socio-Economic Benefits of Transport, Paris. https://www.itf-oecd.org/sites/default/files/docs/estimating-wider-economic-impacts.pdf

[6] This text is drawn from Weisbrod, et al. "Assessing Productivity Impacts of Transportation Investments," NCHRP 786. Transportation Research Board, 2014. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_786.pdf

[7] Examples include Sydney, Australia (https://www.pwc.com.au/publications/pdf/30-minute-cities-may17.pdf), Boston, MA, USA (https://boston.curbed.com/2019/4/25/18515568/boston-commute-times-to-from), Nashville, TN, USA (https://www.nashvillesmls.com/drive-time-map.php). global metropolitan areas (https://www.brookings.edu/wp-content/uploads/2017/08/measuring-performance-accessibility-metrics.pdf), and "Access Across America" (http://access.umn.edu/research/america/transit/2017/maps/index.html).

Fixed Threshold Measure: Single Location. To use a threshold function with travel demand models, one simply counts the cumulative population or employment contained in all zones that are within the designated time threshold of travel time to/from the selected employment location. The selected employment location is usually the Central Business District in the case of labor market access, or a regional industrial and distribution center in the case of "supply chain" freight access. Population is the most appropriate measure for labor force accessibility; employment may be used to represent economic activity for business-to-business (e.g., freight delivery) access. The relevant cutoff for threshold-based market size measurement and the relevant decay function for effective density measurement are discussed in Section 3.

The calculation of fixed threshold market size around selected zone j is:

$$MS_j = \sum_{z=1}^{k} (E_k * T_k)$$

where:
MS = Market Scale (size) surrounding zone j
z = all zones (1..k)
E_k *= Employment in k zones around and including zone j*
$T_{jkm,}$*= threshold status of zone (= 1 if* GC_{jkm} *<= threshold, e.g., 30 minutes; =0 if* GC_{jkm} *> threshold)*
GC_{jkm} *= trip weighted impedance (time or generalized cost) of travel from zone j to k for mode m*

Gravity-Based Measure: Single Location. A gravity-based measure of market size is often referred to as an "Effective Density"(ED) measure. To calculate an Effective Density measure around a single location, one uses the same travel model zonal data with a gravity decay function that discounts the value of more distant zones in lieu of using a threshold cutoff.

$$ED_j = \sum_{k,m} E_k \times GC_{jkm}^{-\alpha}$$

where:
α *= decay parameter.*

Gravity-Based Measure: Regional Composite. To calculate a region-wide composite measure of accessibility, one simply calculates the total effective density across all k zones.

$$ED_{Region} = \sum_{z=1}^{k} (ED_z)$$

where "EDz" denotes the effective density from any given zone (z)
and k denotes total number of zones

The magnitude of this measure depends on the number of different zones being summed, so it is sometimes useful to represent the weighted average across all zones:

$$ED_{average} = \sum_{1}^{k} (ED_k / E_k)$$

where ED_k *denotes effective density among k zones*
and E_k *denotes emplyment in each of k zones*

TREDIS is designed to accept both gravity-based (composite effective density) and threshold-based measures of market scale. The productivity equations (discussed in Section 3) were originally calibrated for threshold based measures -- most commonly based using a 3-hour threshold for one-way regional truck delivery and 40/45 minute threshold for commuting trips, though data is available for adjustment to other distance bands (such as 4 hours for truck delivery markets and 30 or 60 minutes for commuting). More recently, an algorithm was developed for normalizing effective density measures to also work with TREDIS. Since effective density values depend on the number of zones being analyzed in a region and the weighting scheme applied to those zones, their values have no intrinsic interpretation and hence need to be considered in terms percentage changes. However, one can also express threshold-based measures of market scale in terms of percentage changes and hence normalize both types of market scale measurement relative to the region's total employment or GRP. See TREDIS staff for further instructions on this conversion process.

Work is now underway to update and recallibrate TREDIS economic responses to a wider array of threshold and composite measures of market access. This may include zonal attraction "logsum" measures derived from discrete choice logit models of trip distribution.

2.4 Choosing the Right Measures of Market Access Impact

Context. The TREDIS framework is structured so users may select the form of access measure that is most appropriate for the situation. The table below summarizes the ways that TREDIS may be used to assess market access impact. Most projects or plans will fall into one category, depending on its spatial scale and setting. Other transportation projects may be intended to expand capacity, enhance speed or improve safety, in which case there may be no further impact on market access.

Selecting Market Access Measures to Match Different Types of Transportation Contexts

Type of Project or Program	Application Examples	Applicable Market Access Measure
Rural road link	Improves connectivity from small towns to a larger metro area for working or shopping, enlarging the market size reachable from the metro center	Threshold commute market
Regional or national highway or rail line	Provides supply chain route between major activity centers, expanding market reach for the dominant activity center	Threshold same-day truck market
connector to intermodal air/marine/ rail terminal	Provides local producers access to larger customer (buyer or visitor) markets via air, marine or rail service	Terminal access time/size measure
Urban highway or transit corridor	Reduces travel time between endpoints, expanding market reachable from the dominant activity center	Threshold commute or same day market
Long-range highway or rail system plan	Network improvements enhance generalized movement across many or all zones within the region	Composite inter-zonal improvement (e.g., effective density)

Correlation and Overlap. Another reason to avoid classifying a project into multiple access categories is the problem of correlation. The fact is that the more populated metro areas tend to simultaneously have larger labor markets, larger freight delivery markets and better access to rail and air terminals. As shown in the table that follows, this leads to a significant correlation between most of these impact factors. So a transit or road improvement that simultaneously improves multiple forms of access could lead to double-counting of benefits. TREDIS has built-in features to correct for this problem. That correction will tend to show that two forms of market access improvement lead to less impact than the sum of their individual effects.

Correlation between Measures of Market Access

US National Average	Local Pop Mkt	Same-Day Del Mkt	Air port	Rail Term	Marine Port	Border	Intl. Gateway
Local Pop Mkt	1						
Delivery Mkt	**0.63**	1					
Airport	**0.62**	0.39	1				
Rail Terminal	**-0.65**	**-0.52**	**-0.53**	1			
Marine Port	**-0.57**	**-0.59**	**-0.42**	**0.49**	1		
Border	-0.07	-0.02	-0.10	0.08	0.06	1	
Intl. Air Gateway	-0.50	**-0.57**	-0.36	0.41	**0.49**	0.09	1

Source: Alstadt, Weisbrod and Cutler (2013)."The Relationship of Transportation Access and Connectivity to Local Economic Outcomes: A Statistical Analysis," Transportation Reasearch Record 2297, pp.154-162.

Polycentric Metropolitan Areas. A further consideration is the case where a long-range regional transportation plan is proposed for an entire metropolitan area. There has been a number of recent research studies examining how today's large metropolitan areas have become polcycentric, with multiple market centers that are specialized (heterogeneous). This includes studies of Houston, TX (Craig S et al, 2016)[8], Los Angeles (Giuliano et al, 2019)[9] and Chicago (Yang et al, 2019)[10]. For evaluating regional transportation plans affecting polycenetric cities, the most applicable market access metric a composite measure of inter-zonal access improvement.

[8] Craig S, Kohlhase J, Perdue A (2016) Empirical polycentricity: the complex relationship between employment centers. J Reg Sci 56(1):25–52).

[9] Giuliano G, Hou Y, Kang S, Shin E-J (2019) Agglomeration economies and evolving urban form, The Annals of Regional Science, Vol. 63, 377–398

[10] Yang T, Pan H, Hewings G, Jin Y (2019) Understanding urban subcenters with heterogeneity in agglomeration economies: Where do emerging commercial establishments locate? Cities 86:25–364).

3 Connecting Market Access to Economic Productivity Gain

TREDIS builds on a body of research concerning how productivity is affected by enhanced market access. This chapter provides a synopsis of the research basis for this relationship and an overview of factors utilized by TREDIS in determining productivity impacts,

3.1 Theoretical Basis for Agglomeration Economies

The inclusion of transportation market access benefits in the context of regional economic competition is based on the work of Krugman (1991), [11] who showed that, with imperfect competition, regions 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 (i.e., lower cost).

This effect can reflect not only production scale economies (spreading fixed cost over a wider base to reduce unit cost), but also economies associated with greater access to differentiated inputs (i.e., cost and quality benefits associated with greater ability to acquire specialized labor & materials). The effect is driven by inter-industry linkages (which create demand for specialized suppliers that varies by industry) – a concept further developed by Krugman and Venables (1995).[12] These concepts are further explored and discussed in the Appendix (section 5).

Ultimately, a variety of behavioral mechanisms (including enhancement of specialized product/service sharing, specialized input requirement matching and specialized knowledge spillovers) can enable agglomerations to serve this demand for specialized inputs. The result -- greater worker productivity in larger and more diverse markets that drive industry agglomeration -- is ultimately reflected in higher GRP or worker income. Those impacts are recognized in both the benfit-cost and regional economic model impact elements of TREDIS.

3.2 Research Basis for Agglomeration Economies

The process for calculating market scale and productivity impact factors in TREDIS is supported by empirical studies that measured productivity impacts across a a wide set of market access elements, transportation modes and industries. This includeds five key aspects:

a) The theoretical and empirical modeling approach for measurement of ***industry response elasticities***, following the Krugman approach, was laid out in the 1998 article on productivity and accessibility by Weisbrod and Treyz, published by the Bureau of Transportation Statistics. [13]

---

[11] Krugman, P. (1991), "Increasing Returns and Economic Geography", *Journal of Political Economy*, 99, 483-499.

[12] Krugman, P. and A. Venables (1995), Globalization and the Inequality of Nations, *Quarterly Journal of Economics*, 110, 857-880.

[13] Weisbrod, G. and F. Treyz (1998), "Productivity and Accessibility: Bridging Project Specific and Macroeconomic Analyses of Transportation Investments," *Journal of Transportation and Statistics*, v1, n3, https://rosap.ntl.bts.gov/view/dot/4715 .

b) Research on productivity gains from ***access to broader labor markets with diverse worker skills*** was developed NCHRP Report 463 (2001),[5] Prudhomme (2001),[14] Graham et al (2007)[15] and studies of the effects of transport access and cost on wage gradients: Timothy & Wheaton (2001),[16] Carlson (2006),[17] Knaap (2006),[13] Partridge et al (2009)[18]

c) Research on productivity gains from ***new route connectivity***, enabling wider trade between market centers, was developed in reports of the Appalachian Regional Commission (2008),[19] ASTRA/TIPMUC study of Trans-European Networks (Cambridge Econometrics, 2003)[20] and studies of gains from intermodal connectivity by Targa et al (2005),[21] Lynch et al (2007),[22] and Appalachian Regional Commission (2008).[16]

d) Agglomeration impacts associated with ***labor market and truck delivery markets*** were statistically estimated in work by EDR Group jointly with MIT in 2007 and subsequently updated in an EDR Group research paper in 2009[23], and Transportation Research Record (2013).[24]

e) A ***best practice review*** of agglomeration benefit analysis was conducted in 2014 by EDR Group with two universities in the UK, as part of NCHRP 02-24.[25]

These five elements of empirical research form the basis for TREDIS to distinguish market access effects by spatial scale (distinguishing labor markets, freight delivery markets and terminal access corridors) and by industry sector.

---

[14] Prud'homme, R., 2001 "Size Sprawl, Speed and the Efficiency of Cities", *Urban Studies* http://usj.sagepub.com/content/36/11/1849.abstract

[15] Graham, Daniel (2007). "Agglomeration Economies and Transport Investment," Joint Transport Research Centre, Discussion Paper No. 2007-11, December 2007.

[16] Timothy, D. and W.C. Wheaton, 2001. "Intra-Urban Wage Variation, Employment Location and Commuting Times" *Journal of Urban Economics*, 50, 338-366. http://web.mit.edu/cre/students/faculty/pdf/commute-wage2.pdf

[17] Carlson, W. E., 2009 "The Spatial Variation of Wages in US Cities and States" working paper, Wesleyan Univ.,.http://www.wesleyan.edu/econ/seminar/2009f/Printable%20Polycentric%20Paper%20101909.pdf [13] Knaap, Thijs, 2006. "Trade, Location and Wages in the United States" Regional Science and Urban Economics, 36, 595-612. http://ideas.repec.org/a/eee/regeco/v36y2006i5p595-612.html

[18] Partridge, Mark D. et al., 2009. "Agglomeration Spillovers and Wage and Housing Cost Gradients Across the Urban Hierarchy", Journal of International Economics, 78, 126-140 http://www.sciencedirect.com/science/article/B6V6D-4VNKH0J-2/2/1092a7c421aa4223d73ca360fddf791c

[19] *Economic Impact Study of Completing the Appalachian Development Highway System*, June 2008..

[20] Cambridge Econometrics, 2003. *Transport Infrastructure and Policy Macroeconomic Analysis*, European Commission

[21] Targa, F., K. Clifton and H. Mahmassani, 2005. "Economic Activity and Transportation Access: An Econometric Analysis of Business Spatial Patterns", Transportation Research Record #1932. http://trb.metapress.com/content/f1335u277tv8247r/

[22] Lynch, T., T. Comings and G. Weisbrod (2007). "Population Base and Access to Airports," *Sources of Regional Growth in Non-Metro Appalachia: Vol. 3 Statistical Studies of Spatial Economic Relationships*, ARC.

[23] "Weisbrod, Glen and Tyler Comings (2009). "Relationship of Market Access and Business Composition: Implications for Economic Development and Transportation Planning," EDR Group., Working Paper, 2009

[24] Alstadt, B. G. Weisbrod and D. Cutler (2013)."The Relationship of Transportation Access and Connectivity to Local Economic Outcomes: A Statistical Analysis," Transportation Reasearch Record #2297, pp.154-162, 2013. www.edrgroup.com/pdf/Alstadt-et-al-TRR-2012.pdf

[25] Weisbrod, . et al. "Assessing Productivity Impacts of Transportation Investments," NCHRP 786. Transportation Research Board, 2014. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_786.pdf

3.3 TREDIS Response Factors

With TREDIS, the direct productivity impact of access to an enlarged market scale can be represented as:

$$P = \sum_k \left[\left(\frac{MS_{,s=2}}{MS_{,s=1}}\right)^{\mu} - 1\right] \times \, per\ workerGRP_k * \ E_k$$

where:
P = productivity impact
K = all zones
$MS_{s=1,} MS_{s=2}$ = market scale (or effective density measure) for (1) base and (2) project scenarios
μ = economic productivity response parameter
per worker GRP_i = the gross regional product in zone k, per worker in zone k
E_k = total employment in zone k

Empirical studies have examined the elasticity of GRP impact with respect to changes in market scale, and confirm that the industries requiring specialized workers in large market and wide regional freight delivery markets are also the ones that have the highest productivity gains from market access (agglomeration effects). The basis for TREDIS market access response factors are summarized below, with a table summarizing the key market response factors incororated into market access module.

- *Regional Freight Delivery Market Access.* Research by TREDIS staff on same day freight delilvery markets confirmed that scale economies in supply chains occur for industries with a high value/weight ratio in competitive export markets (Alstadt et al, 2012)[21].
- *Local Workforce Market Access.* Research by TREDIS staff also showed that professional service and banking/finance industries (which have the highest preference for central urban locations that maximize access to skilled workers) also tend to have a high elasticity of labor market impact on economic activity (in the range of .05 to.10). That study (Alstadt et al, 2012) [21] also showed that manufacturing activities (which are more likely to be found on the periphery of urban areas) have a lower elasticity of labor market impact (in the range of .01-.04) but a greater sensitivity to truck delivery market size. This followed research by Graham (2007) [12] that also found that the highest elasticities of impact are for banking, finance and business services (.22 to .24) whle the lowest elasticities occur for manufacturing and construction (.07 to .08). The two studies had different impact measurements and hence the elasticity numbers are not comparable, though they agree that banking/finance and professional business services have an economic impact elasticity for workforce access that is roughly triple that of manufacturing and construction.

Summary of TREDIS Industry Response to Expanded Market Access

	Form of Scale Economy from Expanded Market			
	Local Market Passenger Car/Bus Access	Regional Supply Chain Truck Access	Wider Market via Air Terminal (freight or pass)	Wider Market via Rail/Marine Freight Terminal
Agriculture - perishables		X	X	
Agriculture – bulk, non-perish,				X
Mining/Extraction				X
Low Value/Wt. Prod. Mfg (LV)		X		X
High Value/Wt. Prod. Mfg (HV)		X	X	
Construction, Utilities, Transport	X (c)			
Warehousing & Wholesale		X		
Retail Trade	X (c)			
Restaurants & Bars	X (c)			
Tourism: Lodging, Recreation			X	
Communications	X (w)		X	
Repair + Personal Services	X (c)			
Prof + Scientific Services	X (w)		X	
Professional Services	X (w)			
Banking, Finance, Insurance	X (w)			

(LV) =low value/wt. industries: textile, wood, paper, furniture, coal, minerals, metal products, transportation equipment
(HV) = high value/wt. industries: computer/electronics, pharmaceuticals
(c) = customer market: the scale economies are based on access to a larger customer market
(w) = workforce market: the scale economies are based on access to larger, more diverse workforce

4 Model Elements: Inputs and Outputs

4.1 Inputs

Since TREDIS has the goal of estimating the impacts of transportation investments *on a project or program scenario* basis, it uses access measures explicitly tied to transportation networks and connectivity among traffic zones. This means measures of market acces based on origin/destination opportunities and travel times among zones, by mode. This is in contrast to the approach used in more general economic models, which rely on the far more coarse metrics of county to county travel times or distances or even county population density.

Based on these considerations, TREDIS currently accepts any of four different types of measure of market access. Each is based on travel time and is used to proxy a distinct and different facet of accessibility:

- **Local population market.** This input measures local" customer and labor market potential, and should capture agglomeration effects related to labor market matching, final good (consumer market) matching, sharing, knowledge spillovers, and competition. It can be expressed in terms of the population within a specified threshold (such as 40 minutes) or as a composite measure of access based on zonal population weighted by a gravity model function of travel times (also referred to as an effective density measure). Both can work for specific corridor projects; the latter is necessary for evaluation of region-wide transportation improvement programs. Separate options are offered for car, public transportation or composite access measures.[26]
- **Regional industry market.** This input measures "regional" truck delivery market potential, and it should capture matching, sharing, knowledge spillover, and competition consequences of industry supplier/delivery markets. It is most commonly defined based a proxy measure of buyer/supplier market size, which is the employment base within a 3-hour threshold that represents the outer-limit within which a business can make same-day deliveries (based on industry surveys).
- **Access to a major airport.** This input serves as a proxy for inter-regional or international connectivity for time-sensitive freight deliveries and business trips. It can be an important component of innovation networks, knowledge spillovers, and high-value supply chains. Inputs are both average travel time to access the terminal and the scale of destination services based on annual aircraft operations.
- **Access to an intermodal rail or marine facility.** This input serves as a proxy for inter-regional or international freight delivery connectivity via rail. It applies to manufacturing sectors that are highly not time sensitive, for product delivery. It measures the regional average drive time to an intermodal yard with COFC/TOFC rail service, or to a marine port.

Users are not required to input any of these measures. They should do so only if the project involves new facilities or services that extend to serve a new area, or improvements in performance of existing facilities or services that will effectively serve a broader base of travelers than before. The market access measures must be provided for both the base case and the project/build case, enabling TREDIS to

[26] Best practice is to derive a composite access measure that counts road access for the portion of the population who have car availability, and add transit access only for the portion of the population who do not have car availability but are within walking distance (e.g., ¼ mile) of a bus or train stop.

calculate the incremental change in accessibility between the two. Normally, a project or program will change only one of the above four classes of market access.

Selected Mode: Car | Expanded Access: Linked to external areas | Define Linked Area | Terminals Selection | Save

Cancel Changes

Alternative	Mode	Local Market	Same-Day Market	Average Travel Time to Terminal (via local surface mode)				
				Rail Passenger Terminal	Airport Terminal	International Air Gateway	Marine Freight Terminal	Terminal Access Int Border
Base	Car	4,985,544	2,795,042	368	87	411		158
Project	Car	5,549,332	3,010,443	368	87	411		158

4.2 Outputs

The Market Access Module results are shown in two tables:

1) Market Access Impacts by Source, distinguishing among the employment density, productivity, and export effect, but summed across all industries.

2) Market Access Impacts by Industry , summed across all sources, but with full industry detail.

Note that impacts shown in both reports are gross local, before accounting for spatial relocation or contingent development effects. Net market access impacts, after adjusting for contingent development effects and spatial relocation, are provided in a separate report that is discusssed in the Dynamic Economic Simulation Model technical documentation .

Market Access Impacts for 2033 (Car) - by Source

	ACCESS CHARACTERISTICS SUMMARY							
	Labor/Consumer Market (population)	Same Day Delivery Market (employment)	Domestic Air (annual ops per drivetime access minute)	Rail Passenger (avg. access time - minutes)	Marine Intermodal (avg. access time - minutes)	Land Gateway (avg. access time - minutes)	Air Gateway (avg. access time - minutes)	
Base Scenario	4,985,540	2,795,040	4,947.8	368.0	411.0	158.0	411.0	
Project Scenario	5,549,330	3,010,440	4,947.8	368.0	411.0	158.0	411.0	
Change	563,788	215,401	0.0	0.0	0.0	0.0	0.0	
% Improvement	11.31	7.71	0.0	0.0	0.0	0.0	0.0	
Source of Impact	**GROSS BUSINESS ATTRACTION FROM MARKET ACCESS IMPROVEMENT ($M Output)**							**Row Totals**
From Business Migration	693.614	383.911	0.000	0.000	0.000	0.000	0.000	1,077.525
From Labor Productivity	657.651	119.819	0.000	0.000	0.000	0.000	0.000	777.470
From International Exports	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Change in Output	**1,351.265**	**503.730**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**1,854.995**
Source of Impact	**Percent Change in Output**							**Row Totals**
From Business Migration	0.138584	0.076706	0.000000	0.000000	0.000000	0.000000	0.000000	0.215290
From Labor Productivity	0.131399	0.023940	0.000000	0.000000	0.000000	0.000000	0.000000	0.155339
From International Exports	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Total % Change in Output	**0.269983**	**0.100646**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.000000**	**0.370629**
Source of Impact	**Implied Elasticity of Output with Respect to Market Access Change**							**Row Totals**
From Business Migration	0.012	0.010	0.000	0.000	0.000	0.000	0.000	0.022
From Labor Productivity	0.012	0.003	0.000	0.000	0.000	0.000	0.000	0.015
From International Exports	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Implied Elasticity	**0.024**	**0.013**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.037**

Market Access Impacts for 2033 (Car) - by Industry

Industry	GROSS BUSINESS ATTRACTION FROM MARKET ACCESS IMPROVEMENT ($M Value Added)							Total Impact
	Labor/Consumer Market (population)	Same Day Delivery Market (employment)	Domestic Air (annual ops per drivetime access minute)	Rail Passenger (avg. access time - minutes)	Marine Intermodal (avg. access time - minutes)	Land Gateway (avg. access time - minutes)	Air Gateway (avg. access time - minutes)	
Agriculture & Extraction	0.000	2.896	0.000	0.000	0.000	0.000	0.000	2.896
Utilities	78.760	17.261	0.000	0.000	0.000	0.000	0.000	96.021
Construction	5.193	30.501	0.000	0.000	0.000	0.000	0.000	35.694
Manufacturing	81.752	110.730	0.000	0.000	0.000	0.000	0.000	192.483
Wholesale Trade	54.255	11.548	0.000	0.000	0.000	0.000	0.000	65.803
Retail Trade	100.373	4.588	0.000	0.000	0.000	0.000	0.000	104.960
Transportation	19.585	4.815	0.000	0.000	0.000	0.000	0.000	24.399
Postal & Warehousing	52.965	14.296	0.000	0.000	0.000	0.000	0.000	67.261
Media and Information	18.187	5.812	0.000	0.000	0.000	0.000	0.000	23.998
Financial Activities	91.648	6.931	0.000	0.000	0.000	0.000	0.000	98.579
Professional & Business Services	145.798	9.290	0.000	0.000	0.000	0.000	0.000	155.088
Education & Health Services	48.083	3.944	0.000	0.000	0.000	0.000	0.000	52.027
Other Services	10.362	0.000	0.000	0.000	0.000	0.000	0.000	10.362
Government	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**706.960**	**222.612**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**929.572**

5 Appendix: Foundations of Market Access Literature

5.1 Theoretical Basis of Market Access Impacts

In a simple way, the bridge example illustrates how a transportation investment can increase accessibility, thereby expanding the size markets for both economies – that is, it increases the number of active participants in markets. That market size contributes to economic growth has been known at least since Adam Smith, but the specific mechanisms by which agglomeration benefits arise were (arguably) first proposed by Alfred Marshall in 1920[27]. He conceived of benefits arising from three separate consequences of higher economic density: *matching*, *sharing*, and *knowledge spillovers* (sometimes called *learning*). His pioneering work has since been built into a body of economic work called the "New Economic Geography" – a synthesis that emerged from the seed of Paul Krugman's 1991 paper *Increasing Returns and Economic Geography* (for which he won the Nobel Prize).[28]

Although Marshall's basic insights still serve as an important foundation of our understanding of agglomeration benefits, a more recent line of research considers it through the lens of firm dynamics, competition, and industry life-cycles. This approach, preliminarily labeled "Evolutionary Economic Geography[29]", has generally reinforced the importance of matching, sharing, and knowledge spillover effects. However, it focuses on an important fourth: *competition*.

Each of these four concepts is briefly discussed below. As a final issue of relevance, we also review the industrial scope of impacts – that is, whether firms simply value metropolitan scale, or if the type of industry nearby is also important.

Sharing. Sharing benefits are closely tied to economies of scale. Large pools of customers allow for economic activities that would otherwise be unprofitable. A simple example is a skating rink, which is poorly supported by one or two hockey teams, but becomes profitable for large numbers of teams (which require large populations)[30]. These are called "sharing" benefits precisely because demand can be shared, or spread, across a large number of people (or companies). A more subtle version of this effect involves the technology by which firms produce their goods. Large customer bases can support the investment necessary for more efficient production techniques. Said another way, a company with $100 million in annual sales has much more incentive to streamline production than a company with $100 thousand in annual sales. Thus, the sharing of resources facilitates industrial scale, which can enable economic new activity and make existing activity more productive.

---

[27] In his textbook *Principles of Economics* (1920), MacMillan, London.

[28] Krugman (http://www.princeton.edu/~pkrugman/aag.pdf) provides a summary of the emergence and evolution of the New Economic Geography. The Handbook of Urban and Regional Economics, Volume 4 (2004) also provides a comprehensive statement. Two chapters of particular relevance can be found online as working papers. The first, by Duranton and Puga, reviews "Micro-foundations of urban agglomeration economies" (http://diegopuga.org/papers/urbanagg.pdf). The second, by Rosenthal and Strange, reviews "Evidence on the nature and sources of agglomeration economies" (http://www.core.ucl.ac.be/staff/thisseHandbook/rosenthal%3Astrange.pdf)

[29] See Boschma, R. and Martin, R. (2010). The Aims and Scope of Evolutionary Economic Geography. *Papers in Evolutionary Economic Geography, No. 10.01*, Utrecht University Urban & Regional Research Centre (online: http://econ.geo.uu.nl/peeg/peeg1001.pdf).

[30] This example is taken from Duranton and Puga (2003) – see note 23

Matching. Matching benefits are closely tied to economic specialization. They capture the fact that "good economic fits" facilitate productivity. It is widely recognized that specialization is a key factor in economic growth. Indeed, this was one of Adam Smith's primary insights in *Wealth of Nations*. However, diversity and specialization are only part of the story. The true benefits of specialization arise from *matching* specialized products and services to specialized needs. The following three matching benefits are most commonly discussed:

- *Labor market* – urban areas create large and fluid pools of labor. As the pool of accessible labor grows, odds increase that a firm will find a good fit for their specialized skill needs.
- *Intermediate inputs* – urban areas bring firms and industries near one another. As this pool of firms grows, odds increase that a firm needing a specialized input (for example a manufacturer needing a specific metal alloy) will find it.
- *Final goods market* – cities offer large pools of customers shopping for goods. As this pool grows, odds increase that person seeking a unique good (say, an extra small widget in lime-green) will find a firm that produces or otherwise supplies it.

Ultimately, good matches lead to higher productivity because they are more efficient. In the labor market, one "perfect" employee might substitute for two "adequate" employees. In the intermediate input market, the correct metal alloy may allow a manufacturer to eliminate a downstream production cost. In the final goods market, the right match between product and consumer can trigger a sale that might otherwise never have happened.

Knowledge Spillovers. Cities bring people together. As people interact, they share ideas and knowledge (intentionally or not), and collaborate to create new knowledge. This has been understood at least since Marshall, who noted that information can diffuse quite easily, "as it were in the air"[31]. Recent research has looked at the specific ways that knowledge can accumulate, spread through networks, and be incorporated into the productive process – with a key focus on the relationship between knowledge and innovation[32]. A common thread from Marshall to the present is that proximity is a key to knowledge diffusion (although it has emerged that proximity can be measured in ways other than spatial distance). With economic density, the potential for interactions increases and can improve the pace and breadth of learning and knowledge accumulation. This knowledge, over time, gets embodied in worker skills and production techniques to improve firms' efficiency (productivity).

Competition. The ideas of competition as a driving force in economic change were championed perhaps most notably by Joseph Schumpeter[33]. His fundamental insight was that economic development is driven by firm behavior – primarily innovation – and that competition is an important (but not the only) driving force of innovation.

So how does market access affect competition? While it has already been discussed that proximity can drive innovation through knowledge spillovers (a kind of passive knowledge accumulation), other research has suggested that increased competition due to industrial clustering can speed "active"

---

[31] Principles of Economics (1920), p. 271.

[32] For a non-technical discussion, see Boschma, R. and Frenken, K. (2005). The Spatial evolution of Innovation Networks: a Proximity Perspective. Papers in Evolutionary Economic Geography, No. 09.05, Utrecht University Urban & Regional Research Centre (online: http://econ.geo.uu.nl/peeg/peeg0905.pdf).

[33] The Theory of Economic Development, Oxford University Press, 1934

knowledge growth by forcing firms to "innovate or fail"[34]. Simply put, expanding market access can increase the number of firms that directly compete with each other. As the number of market participants increases, two things happen: (1) poor performers are more likely to be driven out of business, and (2) remaining firms feel more pressured to innovate – to actively acquire knowledge. Both effects can lead to higher rates of innovation and productivity[35].

Urbanization, Localization, and Related Variety. The previous four sections discussed specific mechanisms by which economic accessibility can contribute to growth and productivity. An important question relevant to all of these is: "accessibility to what?" Do firms value being near other "similar" firms, or do they just value being in large cities, irrespective of proximity to their own industry? If the latter is true, is it the diversity, or merely the size of the city that matters? The New Economic Geography line of research has answered this question with the following distinction:

- *Urbanization Economies* – describes benefits from overall city size (scale) and also its level of economic diversity. These are sometimes called Jacob's externalities (after Jane Jacobs, who championed the importance of economic diversity in urban growth). Of the four types of benefits listed above, sharing and knowledge spillovers are frequently cited as emerging from urbanization economies.
- *Localization Economies* – describes benefits from the density of a specific type of economic activity, typically defined as a single industrial sector. Localization measures typically capture proximity to employment or number of firms in the same industry. Of the four benefits above, matching, knowledge spillovers, and competition are frequently cited as emerging from localization economies. As such, these are closely related to industrial "clustering".

In addition to these two, recent research has shown that a third type of proximity is important, particularly for innovation:

- *Related variety* – describes benefits from being close to activities related to (but distinct from) a firm's industry. These benefits arise through "innovation networks" which are typically cross-industry rather than own-industry. However, industries too dis-similar (for example, food processing and optics manufacturing) will gain little by being near each other because there is low potential to create something new and useful through collaboration.[36]

When considering these three distinctions, it is important to note that measurements of diversity or related variety depend critically on the level of industry detail that these measurements are being created from. For example, studying the effect of industry diversity at the two-digit NAICS level may yield different conclusions than if diversity were measured at the three-digit level. Similarly, what may appear to be a localization benefit at the two-digit NAICS level may end up looking like related variety or even urbanization benefits at the three-digit level. The main point is that the level of detail of analysis

---

[34] Michael Porter has written extensively on how to use strategy to compete successfully, and has been influential to this line of research.

[35] See Metcalfe, J., Ramlogan, R., and Uyarra, E. (2002) Economic Development and the Competitive Process, *Working Paper No. 36*, Centre on Regulation and Competition, University of Manchester (online: http://ageconsearch.umn.edu/bitstream/30612/1/cr020036.pdf).

[36] For further discussion of related variety, see Boschma, R., Minondo, A., and Navarro, M. (2010). "Related Variety and Regional Growth in Spain", *Papers in Evolutionary Economic Geography, No. 10.12*, Utrecht University Urban & Regional Research Centre (online: http://econ.geo.uu.nl/peeg/peeg1012.pdf). [38] Alternative measures are capital productivity and total factor productivity (which includes capital and labor).

matters to the results. This fact, discussed further in the next few sections, is important to understanding the TREDIS Market Access Module approach and results.

5.2 Estimates of Market Access Impacts

The previous section summarized a century of thought on how access to markets might contribute to economic efficiency and growth. In this section, we briefly review evidence of these effects. Namely, what is the *observed* relationship between market access and economic benefits? Answering this question will help provide context for TREDIS estimates. Along the way, it will also help clarify some measurement and design issues. The first step is to define how "benefits" are typically measured.

Productivity. Most empirical studies of agglomeration focus on labor productivity outcomes, defined as output per worker. This is a natural way to measure the benefits of agglomeration for two reasons. First, it captures the efficiency with which goods are produced, thereby suggesting the underlying firm-level processes of investment and innovation. Second, labor productivity is closely related to per-capita income, such that growth in one can translate to growth in the other. Thus, productivity is a good way to capture potential societal "benefits" of agglomeration.

One limitation to using productivity to measure agglomeration benefits is that it tends to mask the underlying mechanisms as described in Appendix B1. That is, productivity is the emergent result of all the underlying forces of agglomeration, and for a particular observation, it is very difficult to say, for example, that 50% of the productivity benefit is from knowledge spillovers. This is a required trade-off, as the data that would reveal the underlying processes would probably not be very good at revealing the combined and final effect. As Rosenthal and Strange[37] put it, "it is hard to imagine the ideal data ever being available, and so some sort of econometric compromise is necessary" (p. 24). Fortunately, they also show that "agglomeration economies whose sources are knowledge spillovers, labor market pooling, or input sharing all manifest themselves in pretty much the same way," (p. 25) and that productivity is a good measure of the combined effect.

Therefore, agglomeration research typically uses cross-sectional or panel data to estimate a relationship between productivity and one or more measures of agglomeration (market size, density, or potential). Results are presented in the form of an "elasticity":

$$e = \frac{\%\ Change\ in\ Productivity}{\%\ Change\ in\ Agglomeration\ Measure}$$

Thus, a study finding an elasticity of 0.1 suggests that increasing agglomeration (however it is measured) by 10% results in a productivity change of 1%.

Estimates and Methodological Issues. This short description oversimplifies what is actually a broad range of variations of data and methodology. In an effort to find some empirical robustness across this variety, the authors Melo, Graham, and Noland[38] conducted a meta-analysis of agglomeration research performed

[37] Rosenthal, S. and Strange, W. (2008). The attenuation of human capital spillovers. *Journal of Urban Economics, Vol. 64 (2)*, pp. 373-389. (available online as a working paper: http://www.aeaweb.org/assa/2006/0106_1430_1603.pdf).

[38] Patricia Melo, Daniel Graham, and Robert Noland (2009). A meta-analysis of estimates of urban agglomeration economies, *Regional Science and Urban Economics*, Vol. 39, pp. 332-342

over the past 40 years or so. Their effort compiled 34 different studies yielding over 700 separate estimates of agglomeration elasticities (184 of these were derived from U.S. data).

For the U.S. studies, the authors found an average economy-wide elasticity of 0.036, suggesting that increasing agglomeration by 10% increases productivity by 0.36%. This highly aggregated result again belies a wide variability in estimates, and how methodological differences can affect the results. Some of the authors' key observations of this variety are as follows.

- *Agglomeration Measures* – these typically fall into three categories: (1) measures of urban scale, such as total MSA population or employment, (2) measures of economic density, such as population or employment per square mile, and (3) market potential measures, which sum activity (such as population or employment) within a distance or time threshold. Most studies considered only a single access measure's influence on productivity, and these are typically of types (1) and (2). Only recent work has used market potential to measure agglomeration, or simultaneously consider different *types* of market access.
- *Industry Sectors* – elasticities were typically estimated at three levels of industry aggregation: (1) all industry sectors, (2) all manufacturing sectors, and (3) all service sectors. That is, these results paint a picture of highly aggregated outcomes that potentially mask a great deal of variation at more detailed views. As will be discussed, this is an important point of divergence from our approach, which focuses on more narrowly defined industry groups (roughly 3-digit NAICS – see Appendix A). Notwithstanding, the authors found strong evidence that agglomeration benefits to *the* service sector (as a *whole) are signifi*cantly higher than for manufacturing or for "all sectors". Average elasticities for the service sector are on the order of 0.1 to 0.15.
- *Worker Skills – the au*thors find strong evidence that controlling for "human capital" – that is, the level of education or skill in the workforce – significantly lowers the resulting elasticity measures. Put another way, *not* accounting for worker skill may lead to an upward bias in the resulting elasticity. This bias is on the order of about 0.05. This important result accounts for worker mobility – that higher skill workers are more likely to move to cities.
- *Publication Bias* – one of the authors' motivations was to test for "publication bias", which occurs when positive and s*ignifi*cant studies are mor*e likely to get f*avorable reviews and ultimately be published. Using several *te*chniques, they found "some evidence supporting the presence of positive repor*ting bias in* agglomeration estimates" (p. 341).

A final issue not explicitly covered by Melo et al. deals with how agglomeration affects differ by the size of the economy. This is an important issue for TREDIS, which has the goal of estimating impacts generally – from isolated rural counties to extremely dense metropolitan centers. Very few studies have considered this issue, and those that have typically focus on how agglomeration benefits of large metro areas diminish as you move further from the central core. Despite the limited research in this area[39], results consistently show that agglomeration benefits decline with distance from urban centers.

[39] See, for example, Graham, D. (footnote 17) or Rosenthal, S. and Strange, W. (see footnote 32)